Diversity of fields and farmers

Explaining yield variations in northern Cameroon

Promotor: dr. ir. L.O. Fresco
hoogleraar in de tropische plantenteelt,
met bijzondere aandacht voor de
plantaardige produktiesystemen

Bart de Steenhuijsen Piters

Diversity of fields and farmers

Explaining yield variations in northern Cameroon

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STELLINGEN

1 De vergelijking van gewasopbrengsten zonder specificatie van hun variatie in ruimte en tijd heeft slechts beperkte waarde.
Fresco, L.O., 1986. Cassava in Shifting Cultivation. A systems approach to agricultural technology development in Africa. Royal Tropical Institute, Amsterdam.

2 De brede toepassing van de variantie-analyse in het landbouwkundig onderzoek is zowel een stimulans als een belemmering voor het vergroten van inzichten in processen in de landbouw.
Dit proefschrift.

3 Het terugkerende debat omtrent kwantitatief versus kwalitatief landbouwkundig onderzoek is weinig zinvol omdat onderzoek onder realistische omstandigheden beide dient te omvatten.

4 Onderzoek naar regionale problemen zoals ontbossing, voedselschaarste en urbanisatie moet behalve verschillende disciplines ook verschillende schaalniveau's omvatten.
Dit proefschrift.

5 Het zonder voldoende voorkennis definiëren van doelgroepen in een gegeven regio kan net zo schadelijk zijn als een generaliserende ontwikkelingsbenadering waarbij geen onderscheid tussen doelgroepen wordt gemaakt.
Minister van Ontwikkelingssamenwerking, 1990. Nieuwe kaders voor ontwikkelingssamenwerking in de jaren negentig: een wereld van verschil. Ministerie van Ontwikkelingssamenwerking, Den Haag.

6 Het heeft geen enkele zin om hoogwaardige statistische technieken toe te passen als de kwaliteit van de data onbekend is.

7 Het gebrek aan betrouwbare landbouwstatistieken in Afrika kan beschouwd worden als één van de meest beperkende faktoren voor het verwerven van inzichten in de Afrikaanse landbouw.

8 In agroecosystemen met braak is subsidie op prikkeldraad een maatregel met een even groot of groter effect op duurzaam landgebruik dan subsidie op kunstmest.

9 Vanwege de omvang van de erosie in het Zuiden en de concentratie van materie in het Noorden is het aanbevelingswaardig om eenmaal per jaar te controleren of de aarde haar bijna ronde vorm van de afgelopen 4.5 miljard jaar nog wel heeft behouden.

10 Dankzij de grote individuele toegang tot computers en de vergaande democratisering van informatie en kennis is een nieuwe periode van Verlichting in de wetenschap waarschijnlijk.

11 Het feit dat het woord 'gen' tweemaal voorkomt in het woord 'Wageningen' doet vermoeden dat zelfs de stadsnaam gemanipuleerd is.

12 Een terugkeer naar de anonimiteit van de kunstenaar zoals die in de Middeleeuwen gewoon was, zou een welkome bijdrage zijn om tot een zuiver oordeel van kwaliteit in de hedendaagse kunst te komen.

13 Een beetje klasse kan geen kwaad.

Bart de Steenhuijsen Piters

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Wageningen, 14 februari 1995.

Contents

Acknowledgements

Almost five years ago, in January 1989, I arrived in northern Cameroon with the objective to discuss my research proposal with national researchers and authorities. Northern Cameroon was an option for my field work because the national agricultural research institute IRA had requested CIRAD to supply a systems agronomist to reorient their research program. The Département Systèmes Alimentaires et Ruraux (SAR) of CIRAD and the Department of Tropical Crop Science had just signed an agreement for collaboration, hence making it possible that a Dutch researcher could satisfy a Cameroonian demand to a French research department.

Back in the Netherlands, I was confronted with the withdrawal of the director of my department. Often, this results in a drastic change of status of the director's research-assistant who not seldomly becomes a scientific orphan without the comfort of a loving promotor. However, it did not take long before Prof. Dr Louise Fresco adopted me to become her first 'own' PhD-student. After some time, I became aware of the fact that despite my unfortunate start I might have had the Gods with me. During the years that followed, Prof. Fresco combined professional support with personal interest and I remember our numerous discussions on various topics, not always related to the topic of study, with great pleasure.

When in October 1990 I arrived at Garoua airport, Cameroon, I met a young man who worked there as a porter. This person impressed me so much that some time later I asked him to become my field assistant. Douryang Philippe proved to be my second gift from the Gods, providing me with a daily support a PhD-student can only dream of. During the three years of field work, he did not budge from my side, the reason for which we were given the foulfouldé nickname of *sioutoubè*, meaning twins. To complete my Dream Team, the village prince, Njoussa Haman, joined us as my interpretor. For the entire field period, we lived in his household where Fanta Haman took perfectly care of us.

Writing a PhD thesis is often considered a great individual achievement. I prefer to state the opposite: during the field work and the writing, I realised that my thesis would become the result of an enormous collective effort of many people. I owe a great debt to all these people, supporting me in so many ways at various stages of the study.

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Bart de Steenhuijsen Piters

Chapter 1

Agrodiversity: from experimental variation to agroecosystem diversity

1.1 Notions of variation in a historical context

The identification of variation

It is now over 150 years since experimental research on agricultural stations began: the first agricultural research station, which was set up in France in 1834 was followed by Rothamsted Experiment Station in the United Kingdom in 1843 (Salmon & Hanson, 1964). From the outset, variations in yield were observed, but although undesired, they were not viewed with concern. Experimental plots were laid out systematically in the field and treatment means were compared but not tested. Often, one of the treatments resulted in such better results that deviations from the mean were of minor importance, making the superiority of the treatment obvious. However, in less clear-cut situations, where experimental results were close and variations were important, incorrect conclusions could be drawn from the experiments. Hence, a particular treatment could yield an unexpected result when repeated.

It was not until the beginning of this century that researchers turned their attention specifically to undesired yield variation in field experiments. One of the first to do so, L.H. Smith, stated in reference to his variety experiments with corn: "The topic proposed embraces some vital questions, and it is one which should certainly be of great interest and importance to every agronomist who has to do with field experiments. The elimination or control of the variable factors, so essential in experimentation of any sort, becomes unusually difficult in field experiments where we have to deal with so many uncontrollable conditions" (Smith, 1909). The recognition of the importance of these 'uncontrollable conditions' was new. In the first decade of this century, agronomists openly expressed their concern about the perturbations in their experiments that made interpretation so difficult. The agronomist E.G. Montgomery reported after six years of experimentation with winter wheat that a great variation was found in the control rows, even when conditions appeared quite uniform (Montgomery, 1913). Besides this observation, he also underlined the problem of how to handle factors causing variations: "All things being equal, the yield of the 47 plots should have been the same. But all factors can never be equal, so in row-breeding work, owing to unequal environment, we must expect a wide degree of error. The only practical way so far suggested to overcome this error is to repeat the plots, according to some systematic method, enough times to equalise variations in soil or climatic effects" (Montgomery, 1913). Methods and techniques to deal with undesired variation, inherent to field experimentation were lacking and the single known solution was repetition. The existence of factors causing variations in yield was known, but that few writers on field experimentation sufficiently recognised it, and none adequately emphasised its importance (Harris, 1920).

The statistical solution

Meanwhile, mathematicians were investigating problems of probability, population distributions and testing errors of observation largely in relation to astronomy and biology (Fisher Box, 1978). Much of the debate was carried out in pages of the journal *Biometrika.* For example, in his article "The Probable Error of a Mean", Student (a pseudonym adopted by W.S. Gosset) aimed to determine the significance of the means of a series of experiments, especially when large repetitions were not feasible, as in agricultural experiments (Student, 1908). He underlined the importance of randomisation and introduced the assumption of normality for small sample sizes, which he based on empirical analysis of random sampling in a large population of finger measurements of 3000 criminals. Students major contribution to the evolution of agricultural research was probably the introduction of the *z-distribution* (z being a function of the mean and the standard deviation). However, it was Fisher who in 1915 provided the actual mathematical proof that led to the acceptance of the z-distribution (later called t-distribution) and the normality assumption. The tabulation and diffusion of the distribution made it possible to *test the significance of means* in field experimentation. Nevertheless, it took ten years before the use of tables, distributions and testing of significance was generally adopted in agricultural research. Fisher's "Statistical Methods for Research Workers" may be regarded as the major breakthrough which led to the general acceptance of testing in experimentation (Fisher, 1925). Fisher called this method 'analysis of variance' and Snedecor simplified and sophisticated the distribution, calling it the F-distribution, in honour of Fisher (Fisher Box, 1978). At the end of the twenties, analysis of variance and covariance were ready for distribution and use in experimental research.

The development of statistical methods provided agricultural researchers with immediate solutions to their problems of "uncontrollable conditions" and undesired variation. In the 1930s, testing based on distribution tables was widely adopted, giving an important impetus to agricultural research. The undesired variation could be eliminated from the results by following simple techniques. However, the uncritical way analysis of variance was applicated in experimental field work was questioned and concern about it was expressed: "Many observers, in such a case [of important variation in results] consult a manual offering them numerous prescriptions for calculation, often without a proof. They try to find out which case has the greatest affinity to their own, and then, fully relying on the error-doctor, meekly follow the given recipe. For such blindly submissive natures this book has not been written" (van Uven, 1935). Sceptics like van Uven could not prevent analysis of variance from becoming commonly adopted and applied in agricultural science to standardise procedures on the treatment of any deviations from the mean. For the moment, variation was no longer of concern to agriculural scientists and the debate on its treatment was adjourned.

The quest for farm homogeneity

The technology developed by on-station experimental research focused on the intensification of agricultural production. One of the underlying assumptions was that the optimum of the production function was similar for all farms within the same type in a region and that less intensive farms would follow the target farms, adopting the new technologies when proven superior. Persistent diversity of farms and variations in yields within a given region were explained by slowness of diffusion of the innovations, imperfections of the institutional environment, a certain degree of soil heterogeneity and differences in the individual capacities of the farmers. In other words, the causes of diversity and variation were considered residual factors to the model (Bolhuis & van der Ploeg, 1985). The effects were the desire to control and standardise the environment of production and to homogenise farm management as much as possible (Huxley, 1986).

Agricultural research in the colonies

Agricultural research in the colonies was not basically different from its temperate equivalent. During the colonial episode, close contacts between the plantation managers and the commodity research institutes were established, so that the research would be relevant to the development of commodity agriculture. Because these plantations were large and rather uniform in design and management, innovations from experimental research could easily be put into practice. Rubber and oil palm in Ivory Coast and Cameroon, tea in Kenya and sugarcane on Java, Indonesia, are good examples of the succesful introduction and extension of commodity crops through technology, developed on crop-specific research stations.

The success of commodity production was limited to plantation agriculture. In contrast, the introduction of cotton in semi-arid West Africa by the French was not an immediate success. Here, the colonizers made some attempts to establish cotton plantations, e.g. in Mali via the *Office de Niger*, but local resistance to working on these plantations was too great, preventing them from becoming profitable. Realising this, the French decided to introduce the cotton crop into local agriculture. This brought French agricultural research into a totally different perspective. It soon dawned upon the colonial administrators that cotton production could not be forced on local farmers without causing serious competition with food production, unbalancing local societies. This notion led to many research efforts to integrate cotton production into local agriculture by giving it a particular, supplementary role. Many of these efforts were station experiments, focused on variety selection, fertiliser use and land preparation. However, for French research and extension, it was also crucial to pay attention to local agriculture, resulting in many field studies *'pour connaître le milieu réel'*. Examples of these studies, called *'monographies'*, are numerous (Cournarie et al., 1937; Fourneau, 1938; Cabot & Dizain, 1955) and they typify the French observational attitude in agricultural research. Based on a long ethnographic tradition which was formalised by the foundation of the *Institut d'Ethnologie* in 1925 in Paris (Boekraad et al., 1983), the French studies described thoroughly many West African populations, economies and agricultural activities, implicitly accepting ethnologically based diversity in agriculture.

The need for another approach

During the post-colonial period, technology for food production became a more important research topic. The international agricultural research institutes, founded during the sixties, such as IRRI (1961, Philippines) and

IITA (1967, Nigeria) continued their agricultural research in the same scientific tradition as their colonial predecessors. Experimental research to obtain new technologies was considered the best strategy to increase food production. In terms of production increase, this approach became a success in the (mostly irrigated) areas of Asia. By analogy with plantation agriculture, the irrigated areas of Asia are relatively uniform environments, facilitating the diffusion of new technologies. However, in rainfed regions with great environmental heterogeneity and socio-economic diversity, this generalised modernization approach failed to have substantial impact. In her elaboration on the stagnation of agricultural development in Africa, Fresco (1986) states: "One thing which transcends from the mass of literature and official documents is that science based technology has had very little or no impact at all on food production in Africa, with the exception of hybrid maize".

In the late 1960s and early 1970s, it became evident that another approach to agricultural development was needed, particularly with respect to Sub-Saharan Africa. One way to deal with local diversity in agriculture was to define small entities which could serve as more uniform units of diffusion. In 1968, French researchers introduced the approach of these *'unités expérimentales'* in the Sine-Saloum of Senegal (Tourte, 1971 and 1977; Kleene, 1974 and 1975). It was assumed that the major problem of precedent approaches was the transfer of modern, general technology to a heterogenous environment, or as Richard & Faye (1975) state: *"un problème de transfert au monde rural d'une technologie de modernisation"*. This Francophone experiment may be regarded as the first institutionalised farming systems research (FSR) effort. Other researchers had already initiated comparable approaches on an individual basis, of which an important example is the work of de Schlippe (1957) in Zaire. During the seventies and early eighties, both in Francophone and Anglophone research, many experiments with FSR methods were conducted under different conditions and with different objectives (see: Hildebrand, 1981; Billaz, 1981; Conway, 1985). Others focused on problems of definition and conceptualisation, like Ruthenberg (1971), Byerlee & Collinson (1980), Jouve (1986) and Fresco (1986). The outcome was more a conglomerate of techniques and methods, labelled FSR, than a well defined and universally accepted approach. What the advocates of FSR had in common was their application of elements of a systems theory on agriculture and their efforts to take account of the farmers in the research. Thanks to the international research institutes, some FSR elements became disseminated more widely and were applied more or less universally, like the notions of **recommendation domain** (i.e. a group of roughly homogeneous farmers with similar cirumstances for whom we can make more or less the same recommendation (Byerlee et al., 1980)) and **agro-ecological zone** (i.e. an area of similar soil, vegetation and population density characteristics (Fresco, 1986)). Methods like **rapid rural appraisal** and **on-farm research** are nowadays generally accepted and integrated into research programmes.

However, FSR cannot be regarded as an analytical approach for understanding basic processes in agriculture. It is a *framework for ranking* the elements of the system, not an approach to elucidate relations between the different elements and between the different scales of interaction. In fact, systems theory, as it is known in ecology, is only partly applied in agriculture. It is essentially static, especially in the Anglophone tradition (Fresco, 1986), ignoring dynamic processes which take place in space and time. Many FSR advocates firmly believe in the primacy of technological development, pre-defining solutions, without sufficiant emphasis on non-technical constraints or solutions (Oasa, 1985). Although many efforts have been made, the methods and techniques are still lacking for defining basic FSR components, such as 'a group of homogeneous farmers'. Notions such as recommendation domain and agro-ecological zone assume the intrinsic homogeneity of the farming, cropping and livestock systems which is directly related to system output. Given the same agro-ecological and socio-economic conditions, no significant variation in systems output is expected. However, there is evidence, albeit poorly documented, that heterogeneity is more likely than homogeneity, even if the external conditions appear, on the surface, to be the same (de Steenhuijsen Piters & Fresco, 1994). Refering to the future of FSR Norman has already stated that "To develop and maintain credibility we need to take into account the complexity and heterogeneity of both the technical and human environment affecting crop production" (Norman, 1986).

The old debate reopened

In addition to the research being done on farming systems, experimental research is being done in the various disciplines of agricultural science. When analysing the literature in these fields, some remarkable similarities with the literature between 1910 and 1930 emerge. In common with many publications in that period, the existence of (undesired) variation is often mentioned, as well as the problems it imposes on the interpretation of results: "Marked spatial variability in crop growth over short distances in sandy Sahelian soils ... causes yield reductions within a farmer's field and complicates analysis of results from field experiments" (Chase et al., 1989). Proposed solutions are to adapt "the numbers of samples necessary to characterise the soil" (Burrough, 1981), to "select carefully the sites of experimentation" (van Arkel, 1982) or to perform the experiments "on sites that are 'sufficiently homogeneous' to facilitate statistical treatments of the results" (van Noordwijk et al., 1992). In fact, these solutions are similar to those applied between 1910 and 1930. The factors that cause undesired variation are still regarded as disturbances that "adversely affect the analysis of field experiments by inflating the estimate for experimental error. This in turn reduces the researcher's ability to detect treatment differences. If treatment effects are small, high field variability may not allow for the detection of differences" (van Es & van Es, 1993).

The above quoted authors, underlining the importance of variation, re-open the debate which was closed after the general acceptance of the analysis of variance during the thirties. Again, the treatment of variation is questioned. During the last seventy years of agricultural research, the only effective way to treat undesired variation was to reduce it by experimental design and eliminate it through analysis of variance. The finally isolated undesired variation is now called 'error', 'residue', 'random fluctuation' or, simply, 'noise'. It is hardly surprising that these names all have a negative connotation, being a major nuissance and source of frustration of the experimental results.

The recognition of variation

However, some authers re-interpret variation, giving it a totally new meaning and explicitly positive connotation. In their paper on soil and crop growth variability, Brouwer et al. (1993) presented data that suggest that in subsistence farming systems in the semi-arid tropics of West Africa, where nutrient and water availability alternate in limiting agricultural production, soil and crop growth micro-variability may be an asset to farmers. In that paper, soil variability and microtopography are identified as factors causing yield variation, but which are interpreted as risk-reducing factors when analysed over several years with different rainfall regimes. Huxley (1986) mentions that farmers in tropical agroforestry systems deliberately exploit environmental heterogeneity, both in space and time. For example, a small farmer will often arrange his crops to take advantage of the variation in soil fertility across his plot. Also he may use sequential plantings to optimise growth opportunities, or to minimise pest infestations. Van Noordwijk et al. (1992) introduced the term 'meaningful diversity' when referring to flexible farmers' practices under situations of climatic uncertainty and heterogeneous environmental conditions.

In the disciplines of biology and plant breeding, biodiversity has become an important topic because of the growing concern about environmental issues. Authors like Harlan (1975), Brush et al. (1980) and Zimmerer (1991a;

1991b; 1992) have shown, with special reference to maize and potato cultivars in the Andes, that genetic heterogeneity is an important element in the reproduction and survival of (traditional) farming systems. For a long time, the species richness in agroecosystems was underestimated (Paoletti & Pimentel, 1992). However, the criterion of biodiversity has recently been applied when assessing the value of certain agroecosystems, redefining their role (Brookfield and Padoch, 1994) as well as the function of their components (Rhoades & Bebbington, 1990; Lagerlof et al., 1992).

Variation as source of information

As the foregoing account has demonstrated, the notion of yield variation and its causes has often changed during the evolution of agricultural research. There have been periods of interest and awareness, as well as periods in which this notion has been ignored. The development of adequate methods and techniques to handle variation has played a major role, determining the importance accorded to the notion in the research agenda. Recent literature shows renewed interest in the causes of crop yield variation. This interest is due to the growing concern about the methods of eliminating these causes from the experimental results, as well as an awareness of their function and importance in agroecosystems. However, efforts to identify and define the factors that cause variation remain fragmented. Because of the focus on experimental research and of the inherent multidimensionality of the problem which therefore means that many disciplines are involved, an integrated approach for its analysis is lacking. Priority should be given to the development of such an approach and variation should be treated as an object of research, instead of as a statistical residue, in order to determine its objective importance and to derive essential information from it.

1.2 Sources of yield variation

The main sources of variation in yield, which are commonly discerned in the literature are climate, soils, cropping practice, damage due to biotic factors, land use and specific farmer characteristics.

Traditionally, climate has been regarded as an important source of crop yield variation. Many attempts have been made at regional and higher levels of aggregation to predict rainfall trends in order to forecast crop yields for semi-arid regions. These studies emphasise relatively simple statistical relationships between climate and agriculture. Only recently has attention shifted to the analysis of interactions between climate, environment and human activity (Parry et al., 1988). Although extreme climatic conditions tend to have a general impact on crop yield ('low yield' and 'high yield' years), there still is an important intra-annual variation to be observed because of interactions of climate with, e.g. soil type, topography, type of crop and cultivar, cropping calendar and insect pests (Le Houérou, 1992). Brouwer and Miller (1991) also found evidence that the impact of rainfall on yield is not constant because of interactions between rainfall and a heterogeneous environment. They showed that crop growth on fertile and unfertile fields responded differently to a particular rainfall regime, thus deviating from the mean response curve.

Another well documented source of variation is spatial variations in soil properties. According to Moormann and Kang (1978), soil variability in the tropics is comparable to that in the temperate regions, but its impact on crop growth and yield is more pronounced because of less favourable production conditions, such as uncertain rainfall distribution and low fertiliser applications. This is particularly valid for cropping systems in the semi-arid areas of Africa. Physical and chemical soil properties may vary over short distances, causing uneven crop stands (Burrough, 1981). Parent materials of soils may also vary irregularly over short distances. Rock and gravel layers may be present at shallow depth and contribute to soil microvariability. The lithological variability of the surface soil may be intensified by water and wind erosion and local deposition of products of erosion. Minute lateral changes in texture profiles, in depth and organic matter content of the top soil and in properties such as pH, base saturation, CEC, exchangeable Al, Ca etc., are strongly reflected in annual crop growth and productivity (Chase et al., 1989). According to Moormann and Kang (1978), biogenetic factors contribute most to soil microvariability in tropical areas. Known examples of factors that increase soil fertility locally are termite activity (Brouwer et al., 1991) and nitrogen fixing plant species, such as *Faidherbia albida* Del (Dancette & Poulain, 1969). Human activity may also change soil properties over short distances. Under shifting cultivation systems, the cleared forest or bush vegetation is often assembled in one or more places in the field and burned. In the farming systems of the Taï region in Ivory Coast, soil fertility is concentrated in heaps (de Rouw, 1991). Crops growing on heaps or on areas in which there is a locally high concentration of ash generally grow better than crops in the rest of the plot during the two or three years of cultivation before the land is abandoned. This is because of locally high concentrations of plant nutrients including P, Ca, Mg, K, and even N under conditions of slow burning (Sanchez, 1976).

Within a given farming system, farmer practices with respect to one particular crop may vary considerably (Bédu et al., 1987). Farmers in the tropics often grow more than one crop or crop variety on a field, thus deliberately introducing species diversity and affecting crop yields. Intercropping is often considered as a risk- reducing practice, but this has not been confirmed experimentally or theoretically (Vandermeer & Schultz, 1990). However, the reasons for intercropping vary according to agroecological zones, production goals, market outlets, labour constraints and resources (Rhoades & Bebbington, 1990). Good examples of high intra-field species diversity are the Andean potato agriculture (Zimmerer, 1991;

Brush & Taylor, 1992) and agroforestry systems, of which the tropical home garden system may be considered of greatest complexity and diversity (Gliessman, 1990; Hoogerbrugge & Fresco, 1993).

Biotic factors, induced from sources external to the field, may cause damage to the crop, resulting in site-specific loss of yield. Outbreaks of diseases and pests (insects, birds, rodents, game), cattle and even theft may cause important yield reductions. Without exception, farmers will attempt to minimise damage by applying available prevention, avoidance and control measures (Kellman, 1974). An example is the practice of intercropping, which impedes the movement of disease organisms or predators within the ecosystem, reducing the risk of total crop failure (Ewel, 1986).

Yields may be spatially distributed and may be a function of land use intensity. 'Concentric circles of varying land use intensity' are commonly identified in semi-arid Africa, e.g. in Tanzania (Friedrich, 1968), in northern Ghana (Benneh, 1971), in eastern Nigeria (Lagemann, 1977), and in Burkina Faso (Prudencio, 1993). Land use intensity may also vary between fields as a result of farmers' priorities: *"Pratiquement toutes les études citées ont montré que les rendements obtenus dépendent des choix des priorités faits par rapport aux activités non agricoles de la famille"* (Morlon, 1992). Van der Ploeg (1990) showed that yield variations in agricultural systems can be a function of different styles of farming, depending on the availability of resources and on farmers' rationales. Differences in age, gender, social status and access to power between groups or classes of producers have been emphasised in order to explain differences in production strategies and the subsequent variable yields (Yung & Zaslavsky, 1991). Although long neglected (Mosse, 1993), gender-related differences with respect to agricultural production are increasingly being made a topic of study (Boserup, 1970; Guyer, 1978, 1979 and 1981; Poats et al., 1988). Population density, and specific geographical characteristics, such as the presence of railways and the development of commercial coal mining may explain historical variation in regional agricultural patterns (Arcury, 1990).

The authors mentioned above all underline the importance of yield variations and mention some of its plausible causes. Few have systematically studied the problem without a pre-defined bias and focus on one particular scientific discipline. Recognition of the role and importance of interactions between the sources of variation is increasing, but these interactions have seldom been studied specifically. There has been a lack of sufficient integration, especially of the relations between sources at different levels of aggregation, such as the field and household levels. To date, the importance of the interaction between the different causes of variation in yield remains virtually unknown, and there is no comprehensive approach to analysis.

1.3 Concepts and methods of analysis

Although no integrated approach is available for the analysis of yield variations in agroecosystems, several relevant concepts and methods have been elaborated in related fields of science.

In ecology and evolutionary biology, problems of heterogeneity and diversity have long been of interest. However, until recently, despite their relevance, these subjects have not been analysed comprehensively: "Intuitively, the concept of heterogeneity is clear, but as we scrutinize it our initial impression fractures into complexity" (Kolasa & Rollo, 1991). When composing a glossary of heterogeneity, these authors noticed that a classification cannot be based on one single criterion. They applied important criteria of spatial and temporal scales of heterogeneity, but noted that environmental heterogenity may be due to random variation across scales, or that it follows chaotic and fractal patterns which are scale-independent. Besides this multi-criteria classification, they stressed the importance of *'grain'* which is relative to the resolution of the observer or the scope of perception. Grain refers to the phenomenon that heterogeneity (or variation) vanishes at higher levels of aggregation. Other criteria of classification were applied, such as function (measured versus functional heterogeneity) and behaviour (continuous, patchy, homogeneous heterogeneity).

Similar criteria of classification of environmental heterogeneity are applicable to agroecosystems. Yield variations within a system may depend on the spatial and temporal scales of measurement. Variations may follow random patterns, which is often the case when damage is caused by biotic factors external to the field. Yield is commonly expressed per field, whereas it is, in fact, the aggregate of the yields of individual plants of a field. Yield variations at lower levels may thus be obliterated or reinforced at higher levels. The common use of the term 'mean yield' at higher levels of aggregation (e.g. as a characteristic of households, villages or regions) conceals possible lower level variations. Yield variations may be continuous, but may also become 'patchy' when dependent on a particular environment or condition (Brouwer & Miller, 1991).

The ecological concept of heterogeneity is not applicable in all respects to agroecosystems. In ecology, it is assumed that communities result from species response to abiotic and biotic constraints (Milne, 1991). In contrast, in agroecosystems, abiotic and biotic constraints can be manipulated, controlled, avoided, thereby changing their impact, as well as their composition and importance. This *deliberate* manipulation of the environment, crucial in agroecosystems, cannot satisfactorily be explained by the ecological concept of environmental heterogeneity. A second particularity of agroecosystems is that variation can be obliterated or reinforced not only between levels of aggregation, but also between system components at one level. Mixtures of crop varieties may dilute the effect of soil heterogeneity on yield variation. Under semi-arid conditions, when spells of drought occur, fertiliser use may amplify yield variation.

Another concept which focuses explicitly on problems of variation and diversity has been elaborated by sociologists. The humanities have a long history of debate on the processes of cultural and social differentiation and theoretical concepts explaining it. Among the first who put explicit emphasis on the relation between social diversity and agricultural behavior were Bolhuis and van der Ploeg (1985). Elaborating on previous work from, amongst others, Hofstee (1946) and Lacroix (1981), they introduced the concept of *'styles of farming'*, applicable at micro-economic level and avoiding rigid deterministic economic views. In this approach, diversity of farms and variations in production are the object of extensive research and analysis. Based on household surveys and informal discussions, farm characteristics are combined with farmers' objectives and rationales, explaining the co-existence of different types of farms with variable productive results within one agroclimatological zone. Explicit attention is paid to the multidimensional character of the problem, using multivariate techniques of analysis. The result of this approach is a high 'goodness of fit' of the model, explaining much systematic variation which used to be dismissed as random.

One of the limitations of this approach is that farmers' practices are evaluated from the household level by questionnaires, and not by measurements at the field. This makes it difficult to analyse causal interactions between the two levels of aggregation with quantitative techniques. Moreover, environmental properties are not systematically assessed, depriving the analysis of the potential to draw any field-level conclusions on interactions between farmers' practices and the bio-physical environment of production.

Other scientific disciplines have emphasised the development of methods and techniques which focus on particular aspects of system diversity. As already mentioned in section 1.1, Farming Systems Research has introduced the concept of *recommendation domain*, which may be regarded as a step to discern different units within a given environment. In soil science, the technique of *kriging* has been developed to deal with spatial soil variation. Based on a statistical estimation procedure, results from sampling points are interpolated, covering the sampled space (Burrough, 1983; Mulla, 1987). In economics, *stochastic programming* techniques have been applied to understand farmers' sequential decision making under conditions of uncertainty (Adesina & Sanders, 1991). French agro-economists developed a method called *'typologie d'exploitations agricoles'* (Jouve, 1986) for the stratification of farms. Commonly used in vegetation science, and now applied in agriculture, *cluster analysis* is used to identify farm types (Hardiman et al., 1990).

Most of the above mentioned concepts and methods pay explicit attention to problems of diversity and heterogeneity, but focus generally on one level of analysis, or on one aspect of the problem. However, by defining diversity and heterogeneity as object of research, experience and knowledge has been obtained, thus making a major contribution to the development of a comprehensive concept of analysis.

1.4 Analysis of agroecosystem diversity: measures, magnitudes, terminology and framework

Measures of variation

Since the beginning of the debate on the treatment of variation in the early 1900s, many discussions have focused on defining appropriate measures of variation. Nowadays, numerous measures are known and applied. Examples are: *variance, covariance, standard deviation, coefficient of variance, Cuddy and Della Valle index, total and random variability index, percentage range, average percentage range, Gini coefficient, and moving average.* The first three are absolute measures to estimate variation, while the others are relative measures, independent of the unit of measurement. Most of these measures are employed under specific conditions. Their use is defined by the object of analysis and by characteristics of the data (time series data or spatial data, interference of trends in the data and distribution of the data). In the natural sciences, absolute measures are inappropriate because the variance tends to increase concomitantly with the values measured (Weiner & Thomas, 1986). A relative measure is needed to enable yield variations to be compared between fields, crops, households, agroecosystems etc., over years of mesurement. In situations where the standard deviation varies with the mean, the coefficient of variance, i.e. the standard deviation divided by the mean, is a useful measusure of variation (Day & Fisher, 1937). The coefficient of variance, which will herafter be refered to as CV, is commonly used and can be employed on both spatial and temporal scales (Anderson et al., 1987), as well as in non-normally distributed populations (Benjamin & Hardwick, 1986). However, there are some drawbacks when using it which have to be taken into account:

- a change in CV can be due to a change in the mean, or in the standard deviation, or in both; to find out which, they have to be examined in turn;
- a CV does not account for trend in mean, which may lead to overstatement of variation (Offutt & Blandford, 1981).

To compare yields in agroecosystems, the CV may be regarded as the most appropriate measure, but it is advisable not to use it without considering other variables, such as the distribution of the population.

Magnitudes of variation

At higher levels of aggregation, variations in yield are rather well documented. Using data from the agricultural administration, the crop yields of regions, provinces and countries are compared over long periods. In all the cases I studied, only the CV, or same other measure of variation, was mentioned, without considering other features, such as methods of measurement, standard error, distribution of the population, or differences in time frame.

At the farming system and lower levels of aggregation, there are ample examples of authors using yield and production means, without even mentioning their variation. At these levels, examples of well described yield variations under realistic conditions are rare, whilst good examples at the field level are virtually absent. The only source from which some indications of yield variations between fields can be derived, are data from on-farm trials (Matlon, 1983; Stoop, 1986; Mutsaers & Walker, 1990) which, however, do not represent undisturbed situations.

Yield variations seem to diminish at higher levels of aggregation and in time (see Table 1.1). This is due to the grain of observation through which lower level variations are obliterated. No general classification of yield variation in agroecosystems is possible, because variation is always relative to its specific context. Moreover, insufficient references of CVs of reliable and verifiable quality are available.

Terminology in the analysis of system diversity

By analogy with the use of numerous measures for variation, a multitude of names indicate that an object, entity or process varies from a mean or central tendency. Examples are: *deviation, differentiation, dispersion, diversity, heterogeneity, inconstancy, instability, multiformity, pluriformity, uncertainty, unsteadiness, variability, variance, variation, and versatility.* When considering literature on these topics, it appears that few authors define their terminology, and that many do not use it systematically. Often, some kind of value judgement is associated with a name, or an implicit negative connotation is suggested by it (McBratney, 1992).

***Table 1.1** Magnitudes of variation at decreasing levels of aggregation*

level of aggregation, country, time period		crop	CV of yield (%)	source of reference
world (excluding China), 1971-1982		all cereals	3	Hazell, 1989
		rice	4	
		maize	4	
		millets	8	
		sorghums	6	
country, United Kingdom, 1948-1984		wheat	5	Herdt, 1986
region, Jodphur and Indore, India, 1954-1970		rainfed sorghum	128 29	Parry et al., 1988
region, Ivory Coast, one year		rainfed cotton	37	Bolhuis & van der Ploeg, 1985
		food production	44	
village, India, 1975-1983		irrigated rice	31	Walker, 1989
		rainfed sorghum	68	
		rainfed cotton	44	
village, Philippines, 1974-1977		irrigated rice	37	Flinn & Garrity, 1989
		upland rainfed rice	44	
trial field, Nigeria, one year		maize	30	Mutsaers & Walker, 1990
trial field, Swaziland, one year		maize	>40	Seubert et al., 1989
trial field, Burkina Faso, 1981		sorghum	40-120[1]	Matlon, 1983
trial field, Burkina Faso	1981	sorghum	9	Stoop, 1986
	1981	maize	22	
	1983	millet	110	
	1983	sorghum	33	
plant, Sumatra, Indonesia, one year		cassava	59	Nugroho et al., 1992

[1] These CVs were calculated from Matlon, 1983:22, Table 4, by dividing the standard deviation by the mean for the class of 'low management'.

Based on literature review (Shachak & Brand, 1993; McBratney, 1992; Kolasa & Rollo, 1991), the following definitions are proposed, which will be used hereafter:

variation: the actual fluctuation in the value of an object or entity.
variability: the tendency or ability of an object or entity to vary.
variance: the average of the squares of deviations from the mean.
heterogeneity: the condition of being composed of parts of different kinds.
diversity: the condition of a population being composed of parts of one kind (state of being multiform).

The term heterogeneity is most often applied to indicate differences in the abiotic factors of an environment (Shachak & Brand, 1993), such as landscape units or soil types. Diversity most often refers to a population, such as species diversity, ethnic diversity or (farm) household diversity. Environmental heterogeneity and population diversity interact in agroecosystems and the result may be defined as ***agrodiversity***. These interactions are presented in a schematic form in Figure 1.1.

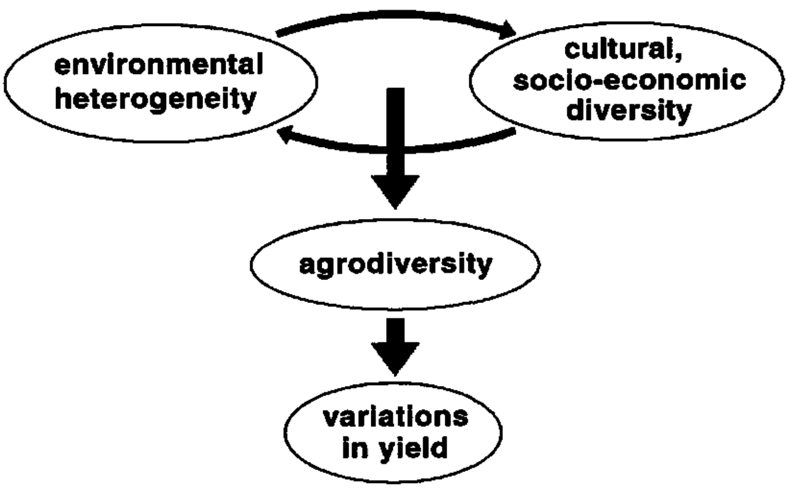


Figure 1.1 *Schematic presentation of agroecosystem diversity*

A framework for the analysis of agroecosystem diversity

Agrodiversity is expressed at different levels of aggregation. A region may comprise several agroecological zones and a village may include several agroecosystems. An agroecosystem may be composed of several cropping and livestock systems, while a cropping system may comprise several field types. A field type may be composed of several crop species and several landraces within each crop population. Basically, agrodiversity refers to diverse land use at different spatial and temporal scales.

Elaborating on the definition of agrodiversity, the following schematic presentation of its components and interactions at field level can be composed:

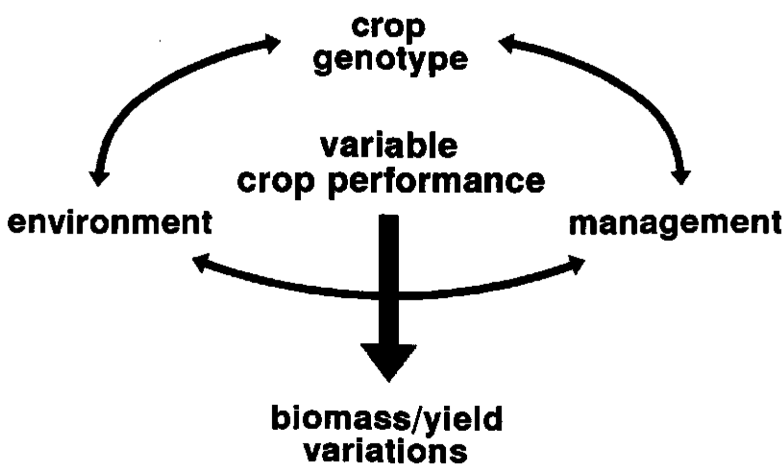


***Figure 1.2** Composition of agrodiversity at field level*

Agrodiversity is a function of the interaction between **environment, crop genotypes and management**. The object of this interaction is **crop performance,** which results in **biomass and yield**. In agroecosystems, the three interacting components are not homogeneous or uniformly distributed, resulting in variable crop performance and, finally, in some degree of variation in biomass and yield. In some agroecosystems, e.g. in irrigated, high-input rice cropping, environmental heterogeneity is controlled and reduced as far as possible by management, and with a uniform improved rice variety, it results in relatively low yield variation. In other agroecosystems, e.g. in many rainfed cropping systems of semi-arid West Africa, environmental heterogeneity is less controlled. Here, management and crop genotypes are more tuned to exploiting the given environment without too much risk of total crop failure. Yield variations at field level may be relatively great in space, but at the household level, and in time, they may be less variable than expected, thus assuring household production and survival.

The three components of agrodiversity are composite variables. When applied at field level, a sub-division according to the origin of the variables, as presented in Table 1.2, can be made.

In addition to interactions between components, interactions between variables of one component may occur. Some examples of plausible interactions are: soil texture x hydrology x rainfall, slope x geography x radiation, crop husbandry x biocide application. Interactions between and within components can be classified as **(1) natural deterministic, (2) deliberate and (3) random.** The first class reflects the given situation at a certain moment, the second reflects human response or action and the third reflects casual events.

It is possible to have interactions between levels as well as at one level of aggregation. It has already been stated that agrodiversity is a product of higher level environmental heterogeneity and cultural and socio-economic diversity. Various factors may affect the components of agrodiversity at the household level, such as unequal distribution of means of production, differences in production goals and the presence of income-generating opportunities outside agriculture. An example is the unequal distribution of soils of the village land between the farmers of a community, inducing differences in management and resulting in variable input-output ratios and variations in crop yield.

***Table 1.2** Agrodiversity components and examples of field variables*

environment	crop genotype	management
abiotic environment:	**genetic properties:**	**practices and techniques:**
soil properties	plant architecture	soil preparation
* soil texture	length of growing cycle	sowing/planting
* chemical composition	mechanism of reproduction	crop husbandry
* soil depth	multiplication factor	cropping calendar
hydrology	quantity of seed	
slope	mechanism of seed dispersion	
geography		
climate:		**inputs:**
rainfall		seed
temperature		labour
radiation		fertilisers
wind		biocides
		mechanised or animal power
biotic environment:		
soil (micro and meso) fauna		
weeds		
vegetative parasites		
insects and diseases		
pathogens		
macro fauna		

In summary, agroecosystem diversity is characterised by the interaction between an heterogeneous environment and cultural and socio-economic diversity at different levels of aggregation and spatial and temporal scales. The result is agrodiversity, i.e. specific combinations of environment, crop genotypes and management in space and time. The multidimensional interactions between and within these components may be natural deterministic, deliberate or random. Agrodiversity is ultimately expressed by yield variations. The most appropriate measure for it is the coefficient of variance which, however, should not be used without other features, such as the distribution of the population.

1.5 Topic, objectives and delimitation of research

Research topic

As demonstrated in the previous sections, agrodiversity and yield variations are frequently identified, but have rarely been investigated systematically. In experimental studies, especially those done under realistic conditions on farmers' fields, undesired yield variation still poses problems of interpretation. There is ample evidence that existing concepts of analysis and research approaches are too generalistic to cope appropriately with agricultural problems when agrodiversity is considerable. For long, agricultural research has disregarded even obvious variations in experimental results. As a result of this, these approaches have resulted in general solutions to problems of variation and diversity, thereby reducing the effectiveness of agricultural interventions.

I wish to state that yield variations are not random side-effects in agroecosystems, but are largely the result of deliberate and structural human response to a heterogeneous environment within a particular cultural and socio-economic context.

At present, there is no comprehensive approach with an appropriate methodology for the analysis of agrodiversity. Some elements of such an approach are, however, elaborated in other scientific disciplines, but have not been combined, improved and tested on agroecosystems.

Research objectives

The aim of the study described in this thesis was to assess the magnitude of importance of yield variations within one agroecosystem. The methods of measurement and analysis were tested and applied to explain these variations as much as possible by an analysis at two levels of aggregation, i.e. the field and the household. Particular emphasis was put on the links between yield-explaining variables at field level, and on the links between the two levels of aggregation. The relevance of variations and agrodiversity, as realistic phenomena and as sources of information, was evaluated and their importance for agricultural policy, research and development will be discussed.

Delimitation of research

Sub-Saharan West Africa is an appropriate region in which to study diversity in agroecosystems. Great environmental heterogeneity, in climate and natural resources, is one of the region's most striking characteristics. Moreover, this heterogeneity coincides with great ethnic diversity and their interaction has led to great diversity in agroecosystems. Many of these agroecosystems are focused on food production, using local resources as much as possible. Measures to control environmental heterogeneity are usually not available, thus making heterogeneity a given factor for the farmer, affecting people's daily food security, as well as their opportunities for development.

Northern Cameroon, especially the Far North Province, may be considered a good example of West Africa's agroecosystem diversity. Mountainous areas alternate with wetlands and plains which are occupied by a population which is rich in ethnic and cultural diversity. The region has a long history of human occupation which has been very dynamic through the ages. In the semi-arid climate, rainfall is highly variable, thus imposing a major risk on agriculture.

The study presented here was emphasised on agroecosystem diversity at field and household level. It comprised three years of measurement (1991-1993) and was limited to one village, thus keeping constant all factors at higher levels of aggregation, such as changes in climate, demography, economy and politics.

Photo 1 *Weighing of rainfed sorghum biomass sample in the field.*

Photo 2 *Yield samples of mouskouari sorghum fields.*

Chapter 2

Materials and methods

In this chapter, the organisation of the study is presented. The study can be divided broadly into a period of field work, lasting three years, and one year of data analysis and thesis writing. Methods of measurement and analysis will be presented and, where necessary, discussed. The geography, demography and farming systems of the village chosen for the case study are described in chapter 3.

2.1 Field work

Data collection was organised according to the following sequence of activities:

1. Choice of the region, discussions with authorities and informants and survey of the region for village selection.
2. Rapid rural appraisal for primary understanding of the organisation of the village, the farming system, the cropping and livestock systems and of output levels. Inventory of secondary information on the region.
3. Selection of households and fields, first year of data collection, analysis for testing techniques and finetuning of hypotheses.
4. Selection of households and fields, second year of data collection for testing hypotheses. Tentative analysis of data and discussions with farmers about results of first year.
5. Third year of data collection for final verification of specific hypotheses and second year results. Testing of hypotheses and statistical techniques.

Site selection

The site was selected in consultation with local authorities. The selected region satisfied the requirements of IRA. The region had to represent to a certain extent semi-arid conditions for agriculture, and particularities, such as mountainous areas or flood plains, were avoided. It was decided to focus on one village, which had to meet criteria of:

1. demographic stability: having a considerable history *in situ* and not being subject to particular perturbations of community and village structure, such as large scale migration,
2. agricultural evolution: having been subjected to external, colonial and post-colonial, interventions and having adopted considerable imported technology,
3. size: for reasons of statistical analysis, 200 to 500 households was considered as a target village size.

During a field visit, five potential villages were visited. One of these villages was finally selected, largely because of the enthusiasm shown by the village population. This village, Gaban, satisfied the three criteria well (see chapter 3). Moreover, the village had the advantage that the population belongs to two etnic groups, the autochthonous Moundang, who founded the village about 200 years ago and the Toupouri, who settled recently.

Sample size and selection procedure

In the first year, five Toupouri and ten Moundang households were selected at random and all their fields (n=89) of the three major crops (rainfed sorghum, cotton and dry season 'mouskouari' sorghum) were included in the analysis. Other crops of minor importance, such as peanuts and cowpea, were not included. The fifteen households were selected from a list of tax paying households. In the second year, the household sample was increased with ten randomly chosen Toupouri and twenty-one randomly chosen

Moundang households and all their fields (n = 262) of the major three crops were included into the study. In the third year, the rainfed sorghum fields (n = 40) of fifteen Moundang households from previous years of observation were included.

***Table 2.1** Sample size of fields and households*

year	# of households	rainfed sorghum # of fields	cotton # of fields	mouskouari sorghum # of fields
1991/1992	15	44	22	23
1992/1993	46	137	52	73
1993/1994	15	40	0	0

Data collection

Data can be categorised according to their origin, nature and level of analysis. The categories of data collected in this study are presented in Figure 2.1. In Annex 1, a summary is given of the variables and the methods and techniques of measurement. The data collection can broadly be divided into (1) measurements and observations of field variables, (2) formal surveys, interviews and discussions with with farmers and (3) active farmer participation through daily recording of all agricultural activities. This participative method, which was tested and used by the DRSPR (Division de la Recherche sur les Systèmes de Production Ruraux) in southern Mali in order to motivate farmers to use their recent literacy (Kleene et al., 1989) is especially useful for collecting precise data on labour. Moreover, the notebooks the farmers used to record the information form a concrete object of discussion. It is nevertheless essential to check the notebooks and to regularly visit the participants in the field and at home. In this study, each household was visited every day or every other day, and various household members were informally interviewed to discuss and verify the data in the notebooks. The results are not only precise data about labour times, but also insights into the timing, organisation and reason for the activities and techniques applied by the farmers.

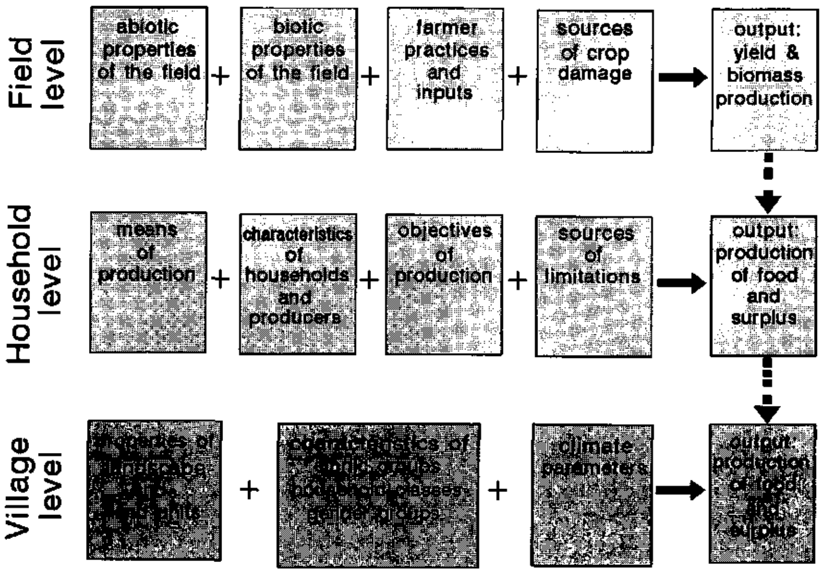


***Figure 2.1** Categories of data collected*

The team, which was basically composed of one assistant of research, one interpretor from the village and myself, resided in the village for most time of the year.

2.2 Data analysis

A broad spectrum of methods and techniques of statistical analysis and presentation are required to analyse agrodiversity. In this study, the following procedure was followed:

1. Formulation of working hypotheses and definition of dependent variables and proxies.
2. Determination of the magnitude of variation of the dependent variables, expressed by: standard deviation, coefficient of variation, extremes, frequency tables and distributions.
3. Exploration of data by methods, such as: correlation coefficients, two-dimensional plots, and principal component analysis.
4. Adjustment of hypotheses in the light of preliminary findings.
5. Testing of hypotheses by: multiple regression with path analysis and model testing, two-dimensional plots, testing of significant group differences (T-test and analysis of variance).
6. Composition of synthesis by principal component analysis.

In this procedure, particular attention was paid to understanding the 'behaviour' of the data and to the formulation and refinement of hypotheses. Both are essential when dealing with large databases and multi-dimensional problems. Statistical techniques were used as tools to explore the dimensions and nature of the problem and to provide first insights to refine its definition. It must be realised that multi-dimensional problems are not easily definable in orthodox two-dimensional hypotheses of the form: *if....then.....* Therefore, other forms that present the multi-dimensionality are sometimes needed.

Principal component analysis (PCA) was used in two ways. First, it was applied in an explorative way, to group all included variables and to formulate a tentative idea about their multidimensional relationships. At the end of the statistical procedure, it was used to synthesise the results from the preceding, mostly two-dimensional techniques. In order to examine the relationships among a set of p correlated variables, it may be useful to transform the original set of variables to a new set of uncorrelated variables called *principal components*. These new variables are linear combinations of the original variables and are derived in decreasing order of importance so that, for example, the first principal component accounts for as much as possible of the variation in the original data set. The transformation is in fact an *orthogonal rotation in p-space* (Chatfield & Collins, 1980). In general, the main objective of principal component analysis (PCA) is to reduce the dimensionality of the data and to simplify later analyses. It is performed after calculation of the correlation coefficients. If the correlations are generally low, components will be difficult to compose and PCA will provide little extra information. Chatfield and Collins (1980) prefer PCA over factor analysis, which they do not recommend for use in most practical situations. The authors note that there are many drawbacks to factor analysis, which make its application risky and difficult to interpret. For my procedure, I also preferred PCA because of its wider applicability. Yet, PCA also has some drawbacks, which must be borne in mind:

1. It is sometimes difficult or subjective to read 'meaning' in the components.
2. There is no underlying statistical model and error terms are difficult to exclude from the analysis.
3. There is no objective rule which defines the number of eigenvalues to be extracted.
4. The matrix of variables can be rotated, which changes the components, thus making it difficult to decide which best represent the original variables.

It must be realised that PCA is not a test and that the results cannot be considered as proof.

Multiple regression with path analysis is a reductionistic technique which selects explanatory variables. A path coefficient (ß or beta weight) is a standardisation of the partial regression coefficient (b) which allows the selected variables to be ranked in importance. The objectives of this technique are (1) to increase the explained variation of a dependent variable ('a high R^2'), (2) to reduce the number of explanatory (independent) variables and variables and (3) to increase the contribution of each independent variable to the explanation of the variation (high path coefficients). Multiple regression is often used in combination with stratification of the data in order to (4) reduce the within-stratum variation (homogeneous groups with small within-stratum variation and large between-strata variation). The output of this technique is a *'best fitting combination of variables'* which best explains the variation of the dependent variable. Comparing the beta weights reveals the importance of each individual contribution and its direction, i.e. positive or negative. If a path analysis on every variable in the combination is performed (so, the independent variable becomes the dependent variable), a model with direct and indirect effects can be composed. Indirect effects can be calculated by multiplying the beta weights and the total effect can be calculated by totalling the direct and indirect effects.

Hierarchy of explanatory variables of
dependent variable Y with
arbitrary path values:
variable B = .562
variable A = .451
variable C = .435 = .279 + (.345 * .451)
variable D = .388 = .891 * .435

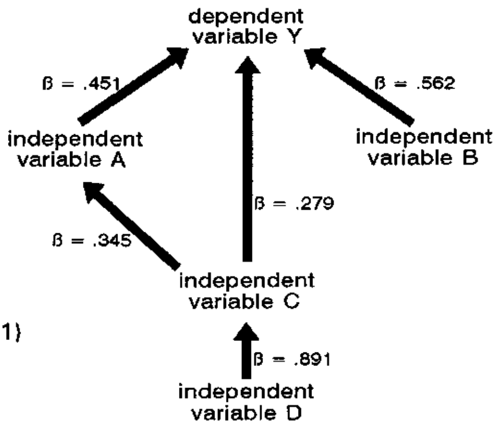


***Figure 2.2** Example of a regression model with arbitrary path coefficients*

For the application of multiple regression with path analysis, several assumptions have to be respected. Checking that these assumptions are not violated is a way of testing if the (limited) model describes reality correctly (for the purposes intended). It is primarily done by analysing the residuals. The principal assumptions are:

1. Normality of the model. If the relationship is linear and if the dependent variable in the population is normally distributed for each value of the independent variable, then the distribution of the residuals should also be approximately normal (Norusis, 1987). A residual is the difference between the observed value and the predicted value.
2. Linearity of every individual equation of which the model is composed.
3. Homoscedasticity, which means that all distributions must have the same (constant) variance.
4. Absence of autocorrelation of the observations.

These assumptions imply that the quality of input data must be relatively high. Serious violations of these assumptions will result in incorrect and unrealistic statements about relationships which in reality are spurious. Moreover, it must be realised that the model itself is not causal *per se*. Causality is an interpretation of significant relationships, based on hypotheses and arguments. In the following chapters, all assumptions are tested against the results obtained. If an assumption is violated, this is mentioned.

Chapter 3

Natural resources, population and agriculture of the village of Gaban

3.1 Geography and natural resources of the village

The village of Gaban is located in the Far North Province of Cameroon at $10^0$10' N latitude and $14^0$30' E longitude (see maps, Annex 2). It is part of the *arrondisement* of Lara and of the *département* of Mayo Kani. The distance to the nearest town and commercial centre, Kaélé, is 16 km of which about 10 km is metalled road. Several tracks and a laterite road lead to the town of Mindif, another important commercial centre at a distance of approximately 25 km (see Annex 2). The village's accessibility may be considered as good during the greater part of the year.

The climate of the region is of the type Aw/Bs in the Köppen classification (tropical humid with dry winter/semi-arid) (Times, 1992), and is known as *soudano-sahélien*. It is characterised by an unimodal distribution of the rainfall and a long dry season. The rainy season lasts four months, from June to September, with two intermediate months of uncertain rainfall, May and October. The average yearly temperature is 28^0 Celsius. The relative humidity attains near saturation (90%) during the rainy season, and is only 25% during the dry season (Vaillant, 1956). The dry and cold desert wind, *the harmattan*, blows from October until April, chilling the night temperature to 12^0 to 15^0 Celsius. From April to October, the hot and humid wind from the Gulf of Guinea blows, raising daily temperatures up to maxima between 40^0 and 45^0 Celsius.

Before 1970, the average yearly rainfall, based on records dating back to 1950, was around 800 mm/year. However, since 1970 annual rainfall has declined to between 600 and 700 mm/year (Vallée & Essang, 1991). In 1991 and 1992 the annual rainfall in the village of Gaban exceeded 800 mm/year.

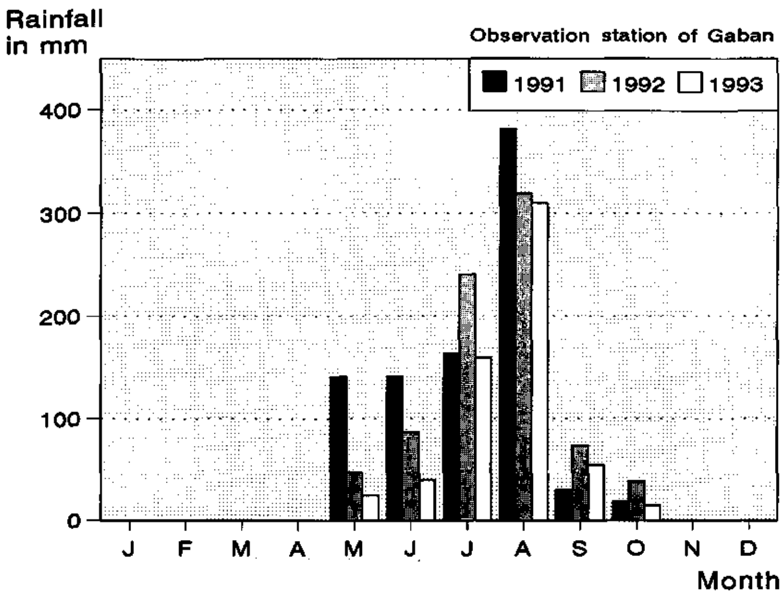


Figure 3.1 *Monthly average rainfall in 1991, 1992 and 1993 in the village of Gaban*

The village of Gaban is situated at 400 m above sea level. Geomorphologically it is part of the larger *Plaine du Diamaré* which is, in turn, part of the Lake Chad Basin. This landscape is characterised by slightly indulating plains with occasional granite inselbergs and rock outcrops and ephemeral streams ultimately discharging eastwards into the Logone river. The natural vegetation is a savanna of shrubs and trees, dominated by several species of the Acacia family, such as *Acacia senegalensis* Willd. and *Faidherbia albida* Del, and by species, such as *Anogeissus Schimperi* Hochst. and *Tamarindus indica* L.

The geology is a basement of volcanic, metamorphic rock, gneiss or granite, of Pliocene age, overlain by Quaternary deposits of irregular thickness. During the period in which Lake Chad reached its maximum extent (between 7000 and 5000 BC: Beauvilain, 1989), lacrustine sediments were deposited, in which Vertisols developed. During the following periods, the inselbergs and rock outcrops were eroded and colluvium was deposited on top of the Vertisols. The seasonal, meandering streams in this landscape deposited alluvium along their banks.

Over time, the various processes of soil formation have given rise to important pedological heterogeneity in the village land. Based on the field surveys and on a 1:100 000 soil map from ORSTOM (1963), four major soil types may be distinguished (see Figure 3.2, p. 54). Combined with field observations and translated to the FAO classification, these are:

1. Vertisols or vertic Cambisols. Vertisols have three characteristic properties: more than 30% clay, wide and deep cracks at some time of the year and a specific morphology characterised by one or more of the following three criteria: gilgai microrelief, intersecting slickensides, and wedge-shaped structural aggregates (Blokhuis, 1989). Although all properties used in the definition were recognised in the field, it is not certain that they were present at each site. Henceforth, the term Vertisol will be used to indicate that the soil has explicit vertic properties. Vertisols are difficult to till and have very poor drainage characteristics. However, they have a high cation exchange capacity and a high base saturation and their water-holding capacity may be considered good.

2. Eutric and Chromic Cambisols. ORSTOM (1963) defines two soil types, which may both be considered Cambisols: *'sols ferrugineux tropicaux, non lessivés, à texture sableux à sablo argileux'* and *'sols peu evolués, jeunes ou alluvions anciennes, sur granito gneiss, à texture sablo argileux à argilo sableux'.* Cambisols are difficult to describe because it is a grouping of soils that "just missed out on one or more requirements for other soil groupings" (Driessen & Dudal, 1989). The presence of a 'minimum B-horizon' demonstrates that Cambisols are in an early stage of soil formation. On the whole, Cambisols make good agricultural land (Driessen & Dudal, 1989). Chromic Cambisols may become **Chromic Luvisols** in later stages of genesis. A dominant characteristic of the former is the presence a brown or red argic B-horizon, formed by the translocation of clay from the surface soil to the depth of illuviation.

3. Planosols. Poels (Driessen & Dudal, 1989) defines Planosols as "Soils having an E-horizon showing stagnic properties at least in part of the horizon, and abruptly overlying a slowly permeable horizon within 125 cm of the surface, exclusive of a natric or spodic B-horizon". According to Brabant and Gavaud (1985) all the soils in Gaban village, excluding the Vertisols, are Planosols. However, the qualitative assessment during field work and the ORSTOM 1:100 000 map cast doubt on this. A large majority of the soil samples showed no evidence of stagnic properties to a depth of 100 cm. However, in some cases, an abrupt impervious clayey horizon was found at a depth between 40 and 80 cm. In these cases, the soil has a Planosol-like hydrology, although strictly speaking it is not a Planosol. The characteristic problems of such soils for agriculture are poor drainage, shallow root development of the crop and crop sensitivity to spells of drought.

4. Fluvisols. This class refers to young alluvial soils which have 'fluvic soil properties' which means that they are subject to regular flooding, through which they receive new sediments and still show stratification and/or an organic matter profile (Driessen & Dudal, 1989). Fluvisols are normally situated alongside rivers and streams. Their texture can vary from coarse sand to clay, depending on the position with respect to the current.

At field level, at a scale of less than 1:10 000, an important pedological heterogeneity is to be observed. During the field work, the soil types were assessed with the population of the village to verify and translate local soil taxanomy. It appeared that the people of Gaban, especially the autochthonous Moundang, have a good understanding of the soil types that prevail in the region and that a precise definition, which is commonly accepted in the village, exists. A crucial step in the understanding of local soil nomenclature is to define commonly accepted criteria of classification, and to separate these from personal terminology. Dvorak (1988) gives examples of criteria, which prove to be very culture and location specific, ranging from colour, degree of salinity, taste, location on the catena, age, firmness, vegetation etc.

The Moundang classification of soils (see Table 3.1) combines characteristics of appearance (colour, stoniness, texture) with qualitative evaluation (fertility, hydrology, porosity). The Moundang nomenclature of soils is influenced by the Foulbé nomenclature, with which it has some soil names in common. The Foulbé have occupied and culturally dominated the region in the past (section 3.2), explaining the similarities in nomenclature of soils. Results from numerous discussions and field visits can be compared to information from Vaillant (1956), who studied the Foulbé classification in the same region extensively.

The *mbouri* soil is the soil most appreciated for rainfed agriculture. It originates from the alluvial deposits by ephemeral rivers and streams. The *mbouri* soil corresponds with the soil class called *boulouwoul* in the Foulbé classification. According to Vaillant (1956), its composition is 9-26% clay, 16-18% loam, 40-60% fine sand and 4-6% coarse sand. Its fertility and porosity are good. Under dry circumstances, the soil is difficult to till and drainage may become a problem during periods of heavy rain. The soil is liable to crust because of the relatively high proportion of fine sand.

The *doudoudi* soil is less appreciated than the *mbouri* soil, but is still suitable for all rainfed crops. It corresponds to the Foulbé terms *dande mayo* and

***Table 3.1** Moundang soil classification*

Name	origin	colour	texture	fertility	prefered crop and land use
Mbouri	alluvial	dark grey/ brown	sandy-clay, not sticky	fertile	rainfed sorghum, cotton, cowpea
Doudoudi	alluvial	grey/red	clayey-sand	moderately fertile	all rainfed crops
Drammé	alluvial, by submergence	black/grey/ brown	heavy clay with vertic properties	very fertile	mouskouari sorghum
Mbèdèkè	colluvial	grey/red	fine sand with silt	unfertile	groundnuts, fallow
Zaïn	colluvial	red	coarse sand with gravel	unfertile	fallow
Pili	anthropogenic	red/grey	clayey-sand or sandy-clay, very compact	fertile to moderately fertile	unsuitable for agriculture
Mpolé	alluvial	brown/white	sticky clay	-	construction material

yoldé which both refer to light soils with a large fraction of fine sand (approximately 70%) and a clay or silt fraction of 15 to 20%. Often, this soil overlies a more clayey soil. The doudoudi soils are formed by ancient and recent alluviations. Porosity and drainage are good and the soil is easily tilled. However its intrinsic fertility and cation exchange capacity are moderate to low which makes the soil liable to loss of fertility.

The soil class named *drammé* refers to a Vertisol, which is known as *lopé* in the Foulbé classification. It is a heavy clay soil with a clay fraction of about 50%, it is very compact and has a low porosity. During dehydration, prismatic structures with large cracks are formed. The soil is very fertile, but is usually inundated during the rainy season and is very difficult to till. Its use is limited to fallow land and, in the dry season, to the cultivation of the transplanted mouskouari sorghum crop (*'le sorgho repiqué'*).

The *mbèdèkè* and *zaïn* soils only occur irregularly in the landscape. Both soil classes are colluvial in nature and their origin can be traced back to the Lara inselberg, 10 km from the centre of the village of Gaban. These soils are considered infertile and are only used as fallow land and, occasionally, for groundnut cultivation.

The soil class *pili* is known in Foulfouldé under the term *hardé*, and refers to a soil which has become 'sterile' through superficial crust formation and poor hydrological properties (Bruneau de Mire, 1975). It refers to the surface characteristics of the soil, and not to its chemical composition or to its physical structure beneath the crust. The cause is anthropogenic, i.e. over-exploitation through continuous grazing by livestock, leading to a decline in the organic matter content of the soil, loss of structure and alkalisation. The soil is usually almost bare, except for some rainy season Graminea. The *hardé* state is not irreversible and soils can be rehabilitated for agricultural purposes. The farmers' technique is to apply large amounts of manure (between 5 and 10 tons/ha), combined with ploughing.

Table 3.2 *Estimated distribution of soil classes over village land*

soil class	proportion of total area (%)	total area[1] (ha)	total cultivated 1992 area[2] (ha)
sandy-clay soil *'mbouri'*	5	250	200
clayey-sand soil *'doudoudi'*	60	3300	600
Vertisol or vertic soil *'dramme'*	25	1400	900
other soil classes	10	550	100

[1] Estimates based on transect walking and 1:100 000 map (ORSTOM, 1963)
[2] *Estimates based on 1992 field surveys, excluding fallow land*

The total village area is estimated at 5500 ha of which 1800 ha (i.e. 33%) was cultivated in 1992. The remaining area, available for crop production and animal husbandry, can be estimated at 3700 ha. However, the quality of this land is not comparable with the cultivated area. Almost all sandy-clay soil (80%) and the best Vertisols (65%) are permanently cultivated. An estimated 85% of the remaining area belongs to the soil class clayey-sand or to one of the less suitable soil classes. Large areas are fallow land and some sites show signs of over-exploitation because of continuous cattle grazing (see section 3.4 and Figure 3.3, p. 55).

The most important soil types for rainfed agriculture are the sandy-clay and clayey-sand soils. In Table 3.3, their acidity and composition are presented. The sandy-clay soil is slightly, but statistically significantly less acid and contains more nitrogen and potassium than the clayey-sand soil (t-test, $\alpha < 0.05$). The sandy-clay soil may be considered as more favourable for agricultural production than the clayey-sand soil. Both soil types contain a very small amount of phosporus and have a low organic matter content.

***Table 3.3** Mean acidity and chemical composition of sandy-clay and clayey-sand soils (CaCl$_2$ method in mg/kg, 1991 data, 60 fields).*

property	sandy-clay soil	clayey-sand soil
pH	5.8	5.3
N-total	8.8	5.7
N-NO3	4.1	1.5
P	0.0	0.2
Na	13.3	9.1
K	87.8	59.6
% C	0.6	0.6

3.2 Population and historical context

The village of Gaban has approximately 3000 inhabitants, distributed over 350 households. These people belong to two ethnic groups, the Moundang

(2200 inhabitants) and the Toupouri (800 inhabitants). A few Chadian migrants seeking work have settled temporarily in the village. There are eight Moundang settlements, established close to each other around the bridge over the ephemeral river and about four kilometers away there are six Toupouri settlements, which are more dispersed. Each Moundang and Toupouri settlement originally corresponded to a clan.

According to oral history, the village of Gaban was founded at the end of the 18th century by a Moundang clan called *Laré,* which came originally from the Kingdom of Léré in Chad. These first settlers were hunters and gatherers. The second Moundang clan that arrived, the *Bonggaban*, were agriculturists. In due course, they took over power and expanded the village, finding good land for agriculture. During the subsequent decades, other Moundang clans settled down in Gaban, submitting themselves to the power of the *Bonggaban.* Moreover, individual families from other ethnic groups (possibly Toupouri and Guiziga) were assimilated into the Moundang community. These were turbulent times of frequent wars and slave and cattle raids, of which Beauvilain (1989) cites numerous exemples dating back to the beginning of the 19th century. During the first half of the 19th century, the Foulbé (also called Fulani or Peulh) armies invaded northern Cameroon from the Nigerian side and during the second half of that century, they waged a *Jihad,* the holy war to convert the animistic populations to Islam. Some ethnic groups fled into the Mandara mountains and others, such as the Moundang, surrendered or were defeated and put under Foulbé rule. Only a few ethnic groups resisted, of which the Toupouri and the Massa are well known examples.

In 1901, after many battles with the armies of the Foulbé and other ethnic groups, the Germans annexed the northern part of Cameroon. Until its retreat in 1915, the German army was in continuous struggle with local resistance, and did not bring peace to the region. The French, who took over rule from the Germans, sought to pacify the region so that they would be able to install a colonial administration and collect taxes. Agreements of a form of formalisation of Foulbé rule under French authority were made with the local sultans. However, the non-Islamised ethnic groups refused to recognise these agreements. Beauvilain (1989) cites a report from a French army commander in 1920, who describes the situation with respect to the Toupouri and the Massa (named *Kirdi,* meaning animist): *"Traqués comme des bêtes fauves pendant cent ans par les Foulbé qui avait fait de leur pays un terrain de chasse aux captifs, ils ont pu conserver leur indépendance en s'enfuyant devant les razzieurs sur la rive droite du Logone et dans les marais du Mayo Kébi. Ils ont une haine profonde des Foulbé et ne veulent pas aller à Maroua parce que le commandant de circonscription fut trop souvent circonvenu par les Foulbé. Ceux-ci ne pouvant plus faire des incursions chez eux, ce sont les Kirdis qui font des < <reprises> >. Ils vont par bandes enlever les troupeaux dans la brousse. En outre, ils ne veulent pas payer l'impôt et quoi que j'ai constaté qu'ils possèdent deux fois plus de bovins que les Foulbé, ils n'ont jamais été mis dans l'obligation de payer la taxe de pacage".*

These historical facts explain some striking differences between the ethnic groups, which still persist today. The Moundang in Gaban have never left their village. They have stayed at this site for about 200 years and have developed a close relation with, and knowledge of their environment. They had to sacrifice some of their independence through partial and temporal submission to the Foulbé, but were able to conserve stability of the community and to develop economic activities. It is not accidental that commercial cotton cultivation and the use of animal traction in northern Cameroon were adopted rapidly and successfully by the Moundang (Pontie, in: Boutrais et al., 1984). The Moundang culture may be considered 'open' to innovations coming from outside the community. Hallaire (in: Boutrais et al., 1984) calls the Moundang modernist, and considers the Toupouri as their adversaries: *"Les groupes humains en présence montrent plus ou moins d'aptitude à accepter les nouvelles techniques imposées par la culture du coton. Ainsi les Moundangs, réputés pour leur modernisme, les ont adoptées* *beaucoup plus rapidement que des populations plus conservatrices comme les Toupouri".*

In contrast to the Moundang, the Toupouri have always been mobile. Through the ages, they have preserved their specific cultural identity, refusing any form of submission. Their culture may be considered 'closed' to imposed change, and may be regarded as stable under different environmental conditions. They do not have a profound relationship with a particular site, which is reflected in their mobile attitude. At moments of hardship, the Toupouri tend to move, in search of better opportunities. The older Toupouri families, who started to settle in the village of Gaban in 1970, have already migrated at least twice during one generation. The reason they give for these migrations, are degrading soil fertility and insufficient rainfall.

3.3 Religion, rule and social organisation

In the Moundang community, various religions exist: 32% of all households are Muslim, 32% Catholic, 19% Protestant and 17% are animist. The Toupouri community is far more uniform in this respect, 90% of the households being animist, practising traditional Toupouri religious customs, initiation rites and sacrifices.

In Gaban, the Toupouri are subject to Moundang rule, which is based on the hierarchical Foulbé power structure. Highest in the hierarchy is the *Lamido* or sultan, who has command over a *Lamidat* which corresponds to an *arrondissement* in contemporary Cameroon. Second highest in the hierarchy is the *Lawan ('chef de village')*, who commands a village with his *Kaigama's ('conseillers')*. Each settlement of the village, which corresponds to a clan, is commanded by a *Djaoro ('chef de quartier')*. In contemporary Cameroon, this power structure has been preserved where it was already implemented by the Foulbé, but its importance varies between the regions. Co-existing with this traditional structure is a formal structure based on French legislation. In the situation of the village of Gaban, daily problems and land disputes are solved by the *Lawan*. In the case of major crimes or problems involving other villages or people from outside the village, the *Lawan* refers to the formal legislation in Kaélé.

Land use rights are obtained by clearing a field, which is only allowed after consulting the *Lawan*. He remains the final owner of the land, but only uses his right to withhold land on rare occasions. The right to use the once cleared land continues when a field is put under fallow, and includes the exploitation of its wood. However, this restriction to other users does not engage cattle owners, who are allowed to pasture their herds on all fallow land. Even Arab Choua nomads and neighbouring Foulbé are allowed to use the grazing land of Gaban after authorisation by the *Lawan*. During the months of July, August and September, they settle on the village land, introducing approximately 1200 head of cattle. Conflicts with the Moundang and Toupouri farmers occur, but not on a regular basis and any damage to crops is settled by paying compensation for the estimated loss of yield. In contrast, more serious conflicts occur when cattle are stolen from the Arab Choua who suspect someone in the village. In those cases, the *Lawan* needs all his diplomacy to pacify the nomads.

Moundang female farmers may obtain land use rights by clearing fields. Toupouri female farmers do not have this right, which is forbidden by the Toupouri *Djaoro*, although allowed by the Moundang *Lawan*. According to Pontie (in: Boutrais et al., 1984), the Moundang are exceptional in northern Cameroon because they allow women access to land and accept that women have land in property.

In recent years, new forms of organisation have emerged in the village. Examples are the *'Association Villageoise'*, introduced by the cotton organisation SODECOTON (Société de Développement du Coton), the *'Codegab'* (Comité de Développement de Gaban), the village development comittee composed of all (Moundang) members living elsewhere, and the *'Association Féminine'*, the womens' organisation. In all these new organisations, the Toupouri are under-represented. Moreover, organisation along religious lines seem to be becoming more important in the Moundang community.

There are numerous regional markets in the neigbourhood of Gaban and local products are easily marketed within reasonable distances. Besides these markets, each *'quartier'* of Gaban has its market on a fixed day of the week; these are often more important as meeting places where local beer is available than as commercial events.

3.4 Agriculture

Numerous definitions of farming system exist. Fresco (1986) defines a farming system as "A decision making and land-use unit, consisting of the farm household, cropping and livestock systems, that produces crop and animal products for consumption and sale". In this definition, decision making refers to the allocation of the available resources and the distribution of the production. Note that non-agricultural activities that generate income are considered as activities that take place within the farming system.

Unit of decision and consumption

The Moundang and Toupouri **farm households** are patrilinear; female-headed households and extended families are rare exceptions. A new household is created by marriage and construction of a new compound. In the case of Muslim and animist households, polygamy is a frequent phenomenon,

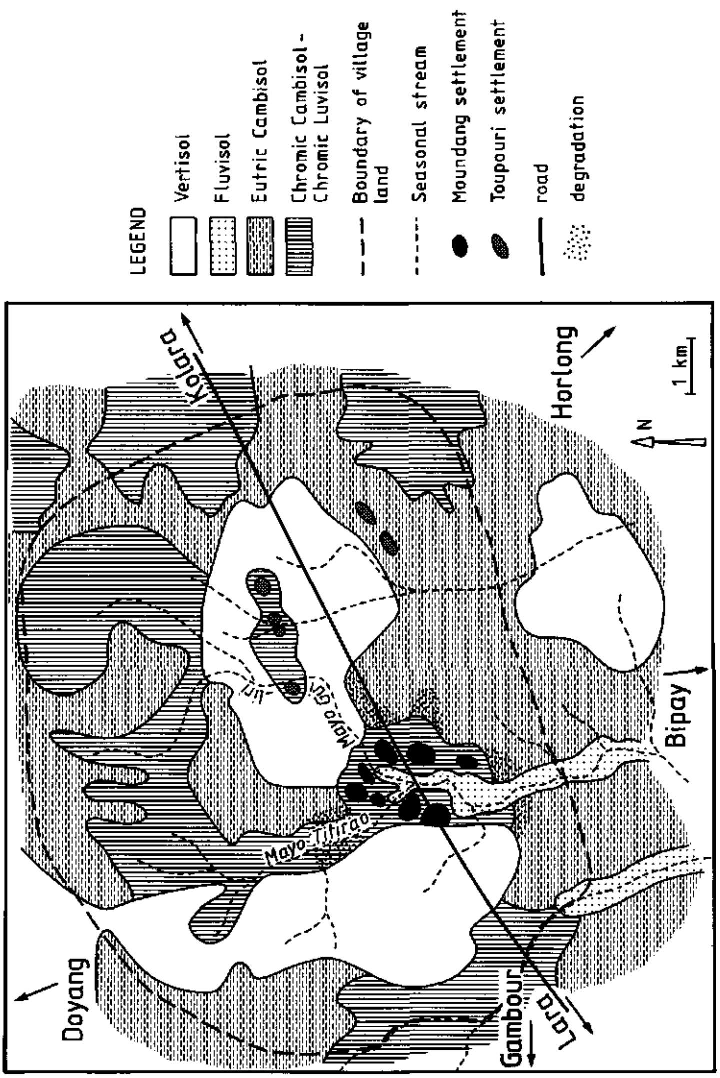


Figure 3.2 Soil map of the village of Gaban (source: field surveys and after ORSTOM, 1963)

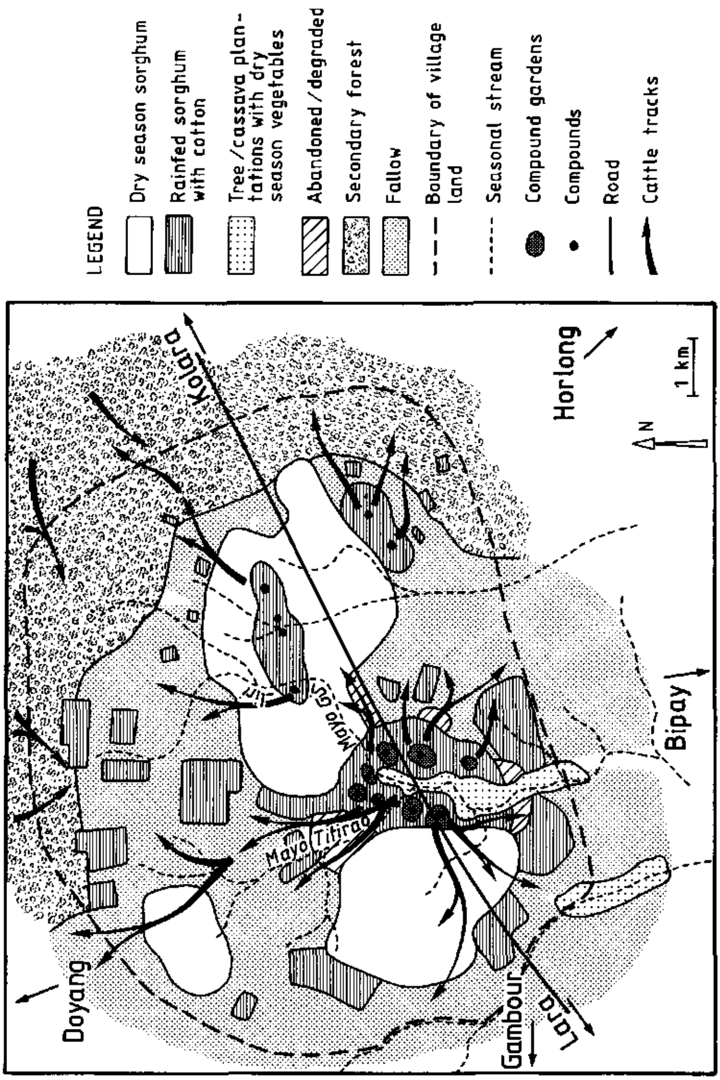


***Figure 3.3** Land use map of the village of Gaban (source: field surveys)*

explaining the uneven female:male ratio's of 1.2 for the Moundang and 1.9 for the Toupouri. Toupouri households (average 11.8 members) are larger than Moundang households (average 9.3 members).

Moundang and Toupouri women farmers cultivate fields of their own. Toupouri women farmers are obliged to feed the family for six months of the year. The Toupouri head of the family is obliged to help his wife or wives to fulfill her/their obligation to the family and will provide her/them with the necessary means of production. In addition, she/they will help him to produce the additional food. Toupouri women do not own the resources and the use of their production seems to be fixed to family consumption. In contrast, Moundang women do not have the obligation to feed the family. A Moundang woman is owner of the land and can choose what to do with what she produces.

The average **land** area per Moundang household is about six hectares, of which an estimated two hectares is fallow. Probably, most households have more long-term fallow land, which was not identified in this study. An average Toupouri household has about five hectares, of which only a very small portion (half a hectare) is fallow land.

The available family **labour force** is similar between the two ethnic groups: five workers per household. Besides family labour, other sources of labour can be employed to satisfy labour demands. Toupouri households make frequent use of labour from working parties. The number of workers attending the party seems to be a function of the amount of sorghum beer available. Moundang households organise similar parties, but those who are Muslim or Protestant serve a dish of meat instead of sorghum beer. Moreover, Moundang households engage workers who are paid in cash (e.g. 2500 CFA francs for ploughing a quarter of a hectare) or in kind (e.g. one cow for herding the cattle during six months). Some workers stay in the household on a permanent basis, whilst others are only engaged for well-defined activities, such as ploughing or clearing the fields.

The available **capital** in the household is difficult to assess. In the case of the Toupouri, it may be presumed that most capital is represented by livestock. In the case of the Moundang, livestock is only one source of available money. They often have hard cash at their disposal and own luxury goods, like radios, stereos and even televisions, which might be sold when necessary. Moreover, the Moundang have started to invest in brick houses, which cannot easily be sold. However, for both ethnic groups it is reasonable to assume that livestock are easily sold or exchanged, which means that ownership of livestock is highly variable and time bound.

The available **animal-drawn equipment**, which is also capital goods, consists of single ploughs and two-wheeled carts. Other equipment, such as harrows, cultivators or ridgers, is virtually absent. The draught animals are most often oxen, and in some cases donkeys. The quality of the available equipment is poor because it is old, well-used, lacks maintenance, and spare parts are unavailable. Moundang households own one plough and one pair of oxen more often than Toupouri households (45% versus 30% of the households). Moreover, the average number of ox-drawn ploughs per household is much higher for the Moundang than for the Toupouri (0.8 versus 0.3 per household). Donkey-drawn ploughs are almost equally distributed between the two ethnic groups: 0.3 per household.

Cropping and livestock systems and other income generating activities

Four **cropping systems** can be distinguished within the farming system (Figure 3.3, p. 55).

1. Directly around the habitation, **small compound gardens** are situated, characterised by a high diversity of crops. Local vegetables (usually grown for their leaves) are combined with more commonly known vegetables, such

as okra (*Abelmoschus* spp.), Guinea sorrel (*Hibiscus sabdariffa* L.), jute (*Corchorus olitorius* L.), and local garden egg (*Solanum aethiopicum* L.) (Stefels, 1990). Sometimes, if the garden is large enough, maize (*Zea mays* L.) is grown; its cobs are harvested and consumed when still fresh. In a few cases, certain cultivars (e.g. cv. Djigari and cv. Babouri) and sub-cultivars of sorghum (*Sorghum bicolor* (L.) Moench race caudatum) are cultivated to multiply seed.

Soils of the gardens are often clayey in texture and are enriched with domestic waste, ash and livestock and poultry manure. Although they may appear to be disorganised at first sight, the gardens are important for daily food supply and species conservation.

2. On the Cambisols and Planosols, **rainfed sorghum and cotton cultivation** are grown. Sorghum (*Sorghum bicolor* (L.) Moench race caudatum) is grown in monoculture on the nearby fields, or in rotation with cotton (*Gossipium hirsutum* L.) and with fallow on the fields further away. The most dominant sorghum cultivar is *'Djigari'*, of which numerous sub-cultivars are grown, such as *'Massimili'*, *'Gling'*, *'Mabasi'*, and *'Panari'*. Each of these sub-cultivars has particular characteristics and is distinguished by its colour (red or white), its architecture (long and open or short and robust), the form of its panicles (open or compact), the length of its growing cycle (between 90 and 140 days from germination to seed maturity) and culinary properties (e.g. taste and suitability for beer brewing). In most cases, more than one sub-cultivar is grown on one field (on average, 2.2 per field) and different sub-cultivars may occupy a particular spot or may be sown in mixtures. Fields are often ploughed and plant densities vary between 30 000 and 110 000 plants/ha. Most of the fields at short distance from the compound receive heavy manure applications every year (on average, 1500 kg/ha). Compared to other cases (Quilfen & Milleville, 1983; Pichot et al., 1981) this manure is of good quality, containing 1.74% nitrogen, 0.23% phosphorus and 2.08% potassium per kg dry manure. An average manure application of

1500 kg/ha contains, corrected for its moisture content, about 23 kg nitrogen, 3 kg phosphorus and 28 kg potassium. No fertiliser is applied on these fields.

Cotton fields are ploughed and the crop is cultivated at variable plant densities, between 25 000 and 60 000 plants/ha. The average fertiliser gift is 75 kg/ha of N:P:K:S:B (22:10:15:5:1) and fields are treated with biocides three times a year on average. Cotton is often intercropped with cowpea (*Vigna unguiculata* (L.) Walp.), although SODECOTON does not condone this. In every cotton-growing village, SODECOTON has contracted an agent to encourage farmers to apply prescribed cropping techniques and input applications. Yet, in reality, few farmers respect these prescriptions.

Cucurbitaceae species are frequently sown into the sorghum and cotton crops. Small fields of other crops, like groundnuts (*Arachis hypogaea* L.) and Bambara groundnuts (*Voandzeia subterranea* (L.) Thou.) appear at low frequency. These crops used to be more important, but nowadays their extent is reduced to small areas because of abundant and uncontrolled insect damage.

3. On the Vertisols, a **transplanted dry season sorghum** crop is grown. It is a cropping system of sorghum (*Sorghum bicolor* (L.) Moench race dura cv. Mouskouari) in monoculture. In a few cases, the cultivar Babouri is grown. Two Mouskouari sub-cultivars are known: *'Sauchei'* and *'Forlami'*. In August, at the end of the rainy season, sorghum is sown in nurseries to obtain seedlings. When the dry season has started, large fields (between 1.0 and 3.5 ha.) are cleared from the annual grasses which have emerged during the rainy season. Using an iron stick about 1.5 m long (*'baramine'*) holes are dibbled into the soil to a variable depth between 10 and 30 cm. The roots of the seedlings are removed and the seedlings are planted in the holes and watered once. The function of the holes is to bring the seedlings into the heavy clay which is underneath the surface and where evaporation is

reduced. During the whole cycle, the crop grows on residual soil moisture, which is replenished by capillary rise. Plant densities are generally low (between 10 000 and 15 000 plants/ha), but mouskouari sorghum is known to compensate with large panicles (Carsky, 1993a). No fertiliser is applied and regrowth of weeds is very limited, considerably reducing weeding efforts. The crop cycle is about 175 days, from the beginning of October until the end of February (Barrault et al., 1972). Recent research attempts to increase yields have only shown significant results in the case of multiple irrigation events; fertiliser applications and plant density increase did not have significant positive effects (Carsky, 1993; Carsky & Ndikawa, 1993a). The strong indication that water availability is the most important yield reducing factor is underscored by the farmers' practice of constructing numerous small dikes on the field to obtain soil water saturation at the end of the rainy season.

4. Flanking the ephemeral streams, on the Fluvisols, **fruit tree and cassava plantations** are found and **vegetable cultivation with irrigation** is practised. The plantations are small and are situated just above the river-banks on the recent alluvial deposits. Fruit trees, such as mango (*Mangifera indica* L.), lime (*Citrus aurantifolia* (Christm.) Swing.) and guava (*Psidium guajava* L.) are planted. Sometimes, a part of the plantation is planted with several local cultivars of cassava (*Manihot esculenta* Crantz). Between the fruit trees, or on a particular spot in the plantation, vegetables are grown with tubewell irrigation. These are most often marketable crops, such as onion (*Allium cepa* L.), tomato (*Lycopersicon esculentum* Mill.) and local garden egg (*Solanum aethiopicum* L.).

Whereas all four cropping systems are present in the Moundang farming system, the Toupouri farming system is less diversified and is mainly focused on rainfed sorghum and Mouskouari sorghum cultivation. Few Toupouri farmers grow cotton. Moreover, they do not have tree or cassava plantations, nor do they grow vegetables and legumes. However, they grow pearl millet (*Pennisetum americanum* (L.) K. Schum.) which is hardly grown by the Moundang. For their daily food they also collect leaves and tubers from the secondary savanna forest.

In addition to these cropping systems, four **livestock systems** can be distinguished based on composition and management.

1. **Large livestock** (*Bos indicus* race White Fulani, which is a West-African lyre-horned Zebu). Every morning, the animals are herded into groups of between 50 and 100 head. These large herds are pastured on the fallow land, on the seasonally uncultivated Vertisols, on the distant fields after harvest and in the forest. During the day, an appointed herdsman is responsible for the herd. At night, the cattle return to the compound or to the corral, where the individual owner resumes responsibility for the animals. During the dry season, the animals obtain additional feed from crop residues which are collected vigorously up to a distance of about 3 km from the homestead (depending on the household's available means of transport). Dry season mouskouari sorghum is particularly appreciated for its qualities as fodder. Rainfed sorghum is often cut after harvest, a practice which initiates the regrowth of tillers. These are of good fodder quality and are fed to the animals at the start of the dry season. At the end of the dry season, water availability may become a serious problem. The village has several wells and in 1992, the construction of a dam in the seasonal stream was financed, reducing the period of water scarcity.

For local cattle, the village and surrounding villages have no fixed boundaries. After receiving permission from the *Lawan* in charge, the nomads may also use the village grazing land. They settle from July to September. The total number of large livestock of the village is estimated at 2000 head, of which 1400 are owned by the Moundang and 600 by the Toupouri. The Toupouri own more large livestock per household than the Moundang (7.2 versus 5.2 head per household). Based on the estimated fallow and forest area of 3700 ha, large livestock pressure on the land is estimated at 54 head/km^2 and at 92 head/km^2 including nomad cattle. As Leloup (1994) states with respect to southern Mali, these high cattle pressures on the land can only be maintained by intensive use of the crop residues.

2. Small livestock (sheep, *Ovis aries* race Fulani and goats, *Capra hircus* race Maradi or Red Sokoto). Most often, herds of small livestock are pastured separately from the herds of large livestock by one or several young children, who are yet not old enough to work in the field. Herds of small livestock do not go far from the village and remain on the nearby fallow land, uncultivated Vertisols and fields after harvest. Because the herders are young, these herds often cause damage to the crops. During the dry season, the animals obtain a supplementary feeding from stored crop residues, of which cowpea, groundnut and Bambara groundnut residues are highly appreciated. These crop residues are occasionally sold in the market.

In the village of Gaban, there is an estimated number of 4000 head of small livestock, of which 2400 head are owned by the Moundang (8.8 head per household) and 1600 head by the Toupouri (18.9 head per household). Based on the estimated fallow and forest area of 3700 ha, the pressure of small livestock on the land is estimated at 108 head/km^2.

3. Horses and donkeys. Where donkeys are frequently used for transport and traction purposes, horses are only kept for sport and pleasure (races) or for ceremonial occasions. Often, horses roam freely, but donkeys are tethered to a tree for grazing.

4. Poultry. Chicken, ducks and Guinea fowls are kept in and around the compound. Little care is taken of their management. Chicken are particularly prone to diseases which occasionally wipe out most of the village flock.

In the village, many activities, that are not directly related to agriculture, can be performed to obtain income. In some cases, these are quasi full-time professions such as blacksmith, carpenter, butcher and teacher. However, in most cases, these activities are minor and complementary to agricultural activities. They procure an additional income for the family and are performed after working on the fields or in times when the demand for labour in agriculture is low. Examples of these activities are brewing and selling of beer, trade, wood cutting and selling of timber and weaving of mats.

3.5 Synthesis

The village of Gaban has a long history of agricultural development. The autochthonous Moundang founded the village about two hundred years ago, whereas the Toupouri settled there only recently. The Moundang society is known as open to influences from outside, thus easily adopting innovations such as cotton growing and animal traction. The Toupouri are more cautious in this respect, but are characterised by a high mobility.

Land use in the village of Gaban shows spatial pattern which largely reflects the distribution of soils (see Figures 3.2 and 3.3). Dry season mouskouari sorghum occurs only on the Vertisols, and the tree and cassava plantations are restricted to the Fluvisols. The Moundang village apears to be on the higher-lying, fertile clayey soils, where nowadays intensive cropping systems are found. Further away, sorghum and cotton production competes with grazing land. There are several uncultivated areas around the village where the soil is very degraded.

Although two thirds of the village land is not cultivated in any given year, the pressure on the land may be regarded as high. The most appropriate soils for agriculture are permanently cultivated. Most of the uncultivated land is fallow and only a small portion is secondary forest. Fallow land has to meet the conflicting goals of feeding the livestock and allowing soil fertility to recover. Livestock pressure is high, slowing down regrowth of the natural vegetation, making the recovery of soil fertility difficult.

At village level an important diversity in land use is observed in spite of the relatively homogeneous environment. This village level diversity finds its origin in the presence of different user-groups (e.g. sedentary farmers versus nomads) and in the different suitability for agricultural production of the land.

***Photo 3** Moundang female farmers ploughing a field with animal traction.*

***Photo 4** Cotton field and rainfed sorghum field, 5th of August 1991*

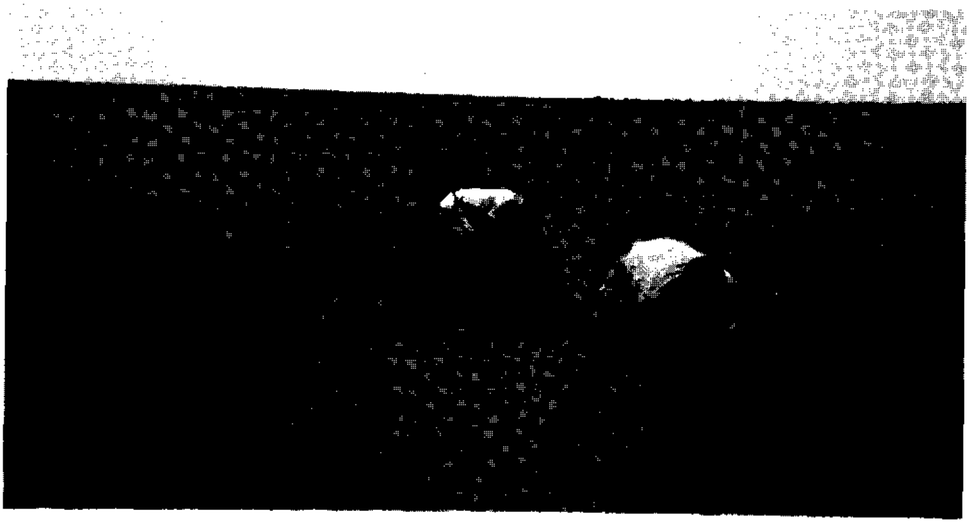


Photo 5 *Hired workers clearing a mouskouari field*

Photo 6 *Moundang farmer dibbling holes with a 'baramine' to prepare for transplanting of mouskouari sorghum.*

Chapter 4

Yield variation as a function of agrodiversity

With reference to the central problem statement in section 1.5, the null hypothesis can be formulated that, within one cropping system, there will be a high degree of homogeneity in yields.

In this chapter magnitudes of variation will be assessed for three major crops **at field level** in the village of Gaban. If for a crop the null hypothesis is rejected, further analysis will be done on agrodiversity components and field variables (see Table 1.2, section 1.4) in order to explain the identified yield variation.

4.1 Rainfed sorghum

4.1.1 Variation in yield

In Table 4.1 yield and yield characteristics of the three years of observation are presented.

Table 4.1 *Variations in rainfed sorghum yield*

year	no. of fields	mean yield (kg/ha)	CV (%)	min. yield (kg/ha)	max. yield (kg/ha)
1991	44	1900	52	500	4300
1992	137	2500	51	200	5500
1993	40	1600	47	300	3200

Results in Table 4.1 show a high variation of sorghum yield which was more or less uniform for the three years of observation. Yields were distributed over a wide range.

In 1992 mean sorghum yields were higher and extremer than those in 1991 and 1993 (oneway analysis of variance of group differences and Tuckey-B procedure at $\alpha < 0.050$ with SPSS statistical package).

From these results, it can be concluded that the null hypothesis is not confirmed and has to be rejected. Within the agroecosystem of the village of Gaban, there is an important variation in rainfed sorghum yield.

4.1.2 Agrodiversity in rainfed sorghum cultivation

A multiple regression analysis (method 'backward') of the dependent variable yield was performed on all 1992 sorghum fields. Results show (see Annex 3) that from the initial thirty-six variables included in the analysis, eight meet the criteria of selection and the coefficient of determination is 61%. At this stage of analysis, indirect variables, such as field distance from homestead, field age, and producer related variables, were excluded from the analysis. These variables can have no direct effect on yield but may have an indirect effect through interaction with other, direct yield-related variables.

Amongst the eight selected variables, plant density was the only variable which distinguished itself by a relative high path-coefficient (.408). This was in conformity with the 1991 results, where plant density had a path-coefficient of .343 (Annex 3). The sorghum sub-cultivar *'Gling'* had the second highest path-coefficient (.297). Besides plant density, four other cropping practices were selected. Ploughing, frequent weeding and high labour input in weeding had a positive effect on yield, whilst late sowing had a negative effect. Of the fertility related variables only manure application (.186) was selected as a yield explaining variable. This was conform the

1991 results, although its 1991 path-coefficient (.407) was higher. In 1992 Striga (witchweed, *Striga hermonthica* (Del.) Benth) incidence was also included and showed a negative effect on yield (-.198).

Evaluating the results of the multiple regression analysis, it must be concluded that the goals to perform a multiple regression analysis (see section 2.2) were not met. For causal interpretation and practical use, the number of included variables was too high and the path-coefficients were too low (or too 'plane'). In order to achieve the goals, the analysis was continued by a stratification of the fields.

Based on literature, interviews and field observations the hypothesis was formulated that ethnic origin of the producer was a major cause of yield variation *through* strong and unequal interaction with direct yield determining variables. Table 4.2 shows the results of a comparison of the characteristics between fields of the two ethic groups. 1992 yields were significantly higher on the Toupouri fields than on the Moundang fields. Moreover, of the eight yield explaining variables, five differed significantly between the two ethnic classes. Besides these differences, there were two significantly different indirect variables. The results show that between the two field classes, there was no uniformity of management, crop genotype, input levels, cropping practices, and yields. If a cropping system is defined by "when on two separate plots of a single farm the same crops are grown on a similar soil type with the same type of management, resulting in similar weed, pest and disease incidence, these plots may be considered as belonging to the same cropping system" (Fresco, 1986), it must be concluded that within the agroecosystem of the village, there are two different rainfed sorghum cropping systems.

***Table 4.2** Rainfed sorghum field characteristics per ethnic producer class (1992)*

yield and field characteristics		Toupouri fields (n=48)	Moundang fields (n=90)	2-tailed signific.
yield	kg/ha	3100	2100	< 0.001
CV	%	36	56	
direct yield explaining variables				
plant density	plants/ha	49600	60400	< 0.001
sub-cultivar *'Gling'*	% of plants	75	11	< 0.050
ploughing	% of field	63	68	-
sowing date	days > 1st of May	29	29	-
number of weedings		1.9	1.6	< 0.001
total weeding time	hours/ha	750	340	< 0.001
amount of manure	kg/ha	600	1000	< 0.150
Striga incidence	parasites/ha	32000	34000	-
indirect yield explaining variables				
distance from homestead	km	0.3	2.1	< 0.001
duration of cultivation	years	10	33	< 0.001

When the fields were stratified according to the ethnic origin criteria, multiple regression with path-analysis gave satisfactory results in the case of the Toupouri fields (see Annex 3):

- yield variation decreased significantly,
- a high portion of variation was explained (69%),
- a reduced number of explaining variables was selected (5),
- a clear dominance of one variable, i.e. plant density (path-coefficient .605), over the other variables was observed.

Yield variation on the Moundang fields was explained for 71% by eight variables of which only one paremeter, i.e. plant density, distinguished itself by a relatively high path-coefficient (.449, see Annex 3). The variable 'sub-cultivar' was not selected, but now soil type 'sandy-clay' and first weeding date were included in the set of yield explaining variables. However, this approach showed an increasing yield variation for the Moundang fields and although the degree of explanation was somewhat higher, the selected variables were also high in number and plane in distribution. Consequently, a second stratification was needed. Based on literature, interviews and observations, the hypotheses was formulated that there was an important influence of the variables 'distance of field from habitat' and 'field age' on yield through strong and unequal interference with the eight variables in the Moundang fields equation. In Table 4.3, the Pearson correlation coefficients (r) for these variables are presented.

Table 4.3 *Correlation coefficients between 1992 Moundang field characteristics*

	field distance	field age
yield	-.393 **	.556 **
field age	-.757 **	1.000
plant density	-.379 **	.497 **
ploughing	-.190	.169
sowing date	.241	-.339 *
1st weeding date	.203	-.200
total weeding time	-.161	.119
soil 'sandy clay'	-.287 *	.431 **
amount manure	-.356 **	.375 **
Striga incidence	-.201	.149

2-tailed siginificance: * $\alpha < 0.01$; ** $\alpha < 0.001$

Results in Table 4.3 show linear correlations between the two indirect variables and the eight yield explaining variables, which implies that Moundang rainfed sorghum cropping has spatial and temporal dimensions. These two dimensions are interrelated, because field distance and field age show a high significant correlation (r = -.757**).

In Figure 4.1 the Moundang sorghum yields are plotted as a function of field distance from homestead. The figure shows a remarkable pattern in the relation between sorghum yields and field distance from homestead. At a distance of less than 1.0 km, yield variation was high and yields were uniformly distributed over a wide range. At distances greater than 1.0 km, yields and their variation were low, although yields showed a tendancy to increase beyond 4.0 km from the homestead.

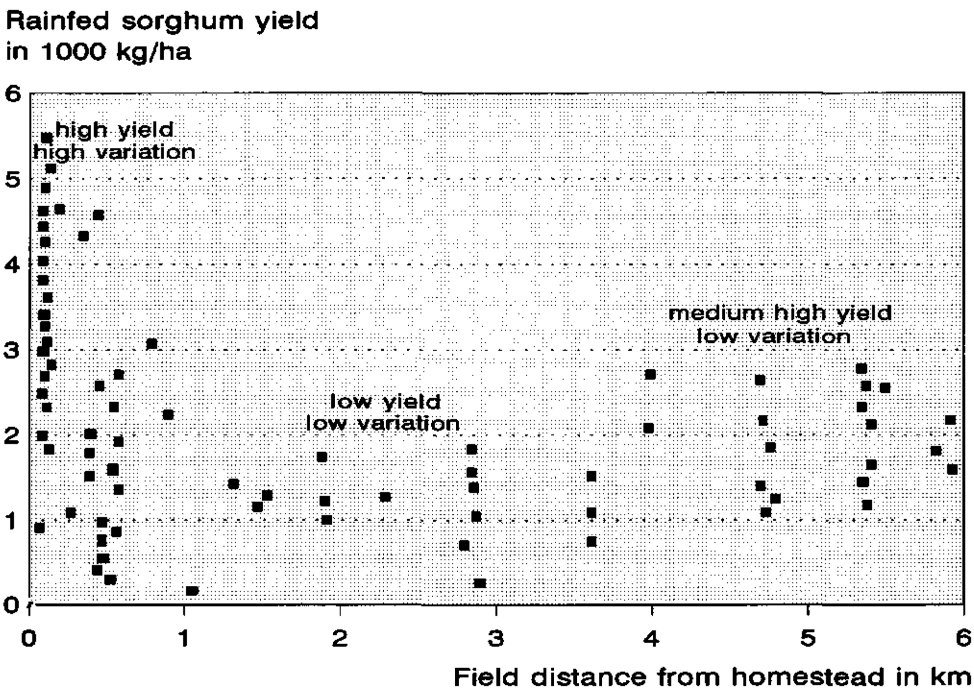


***Figure 4.1** Plot of Moundang rainfed sorghum yield by field distance from homestead (1992, 90 fields)*

Based on Figure 4.1 and on the high correlation between field distance and field age, an interactive, combined *space-time variable* was used as stratification-criterion for the Moundang rainfed sorghum fields. The boundaries of resulting strata are not static. The best stratification which can be proposed for the Moundang rainfed sorghum fields is: (1) less than 0.1 km, (2) from 0.1 to 0.6 km and (3) from 1.5 to 6.0 km. Between 0.6 km and 1.5 km, inondation during the rainy season is common and the soil type Vertisols dominates. Generally speaking, rainfed sorghum is not cultivated here.

An analysis of variance ('oneway') showed that yields from the first stratum differed significantly from the two other strata (at $\alpha < 0.01$). In the first class, i.e. up to 0.1 km from the homestead, yield variation decreased considerably (from 56% to 32%, Annex 3). The coefficient of determination also decreased, but only three well accentuated variables were needed to explain 54% of yield variation in this stratum. In the second class, from 0.1 to 0.6 km from the habitat, yield variation remained high, but so did the coefficient of determination which was obtained by only two variables (Annex 3). In the third class, yield variation decreased, the coefficient of determination was high, but the number of selected variables (6) was high too, although fairly accentuated on some variables (Annex 3).

Based on a space-time stratification of the Moundang fields, it must be concluded that each stratum has its specific yield and variation level. The absolute and relative importance (the path-coefficients) of the explaining variables differs between the strata. Therefore, we consider each stratum as a *specific rainfed sorghum field type.*

According to the above argumentation, a Toupouri and a Moundang rainfed sorghum cropping system can be distinguished. Within the Moundang cropping system, fields can be classified according to a combined space-time criterion, which leads to the definition of three field types. Hereafter, each of these cropping systems and field types will be described and compared by a number of characteristics, as presented in Table 4.4.

The Toupouri rainfed sorghum cropping system

In 1992, the Toupouri fields were characterised by relatively high and homogeneous yields. These fields are large in area and located close to the homestead. The average field age is relatively low with a maximum of 20 years, corresponding to the arrival of the first Toupouri immigrants. The fields have been cultivated continuously without fallow. The predominant soil texture class is 'clayey-sand'.

Almost all Toupouri fields were ploughed and sown early. Plant densities were uniformly low. Manure and urea applications were moderate and variable. Labour input in weeding was extremely large, well timed and very variable. On average, Striga incidence was moderate but very variable between the fields, with extremes between 0 and 200 000 parasites/ha. On most fields, rainfed sorghum is grown year after year and on few fields, cotton was grown in the previous year.

The different interactions can be summarised by the model presented in Figure 4.2. This model explained 69% of the variation in the 1992 Toupouri sorghum yields.

***Table 4.4** Rainfed sorghum field characteristics (1992)*

field characteristic			all fields (n=137)	Toupouri (n=47)	Moundang ≤ 0.1km (n=25)	Moundang 0.1-0.6 km (n=20)	Moundang ≥ 1.0 km (n=45)
sorghum	Mean	kg/ha	2500	3100	3400	1800	1500
yield	CV	%	51	36	32	65	38
plant	Mean	plants/ha	56700	49600	75000	56800	53600
density	CV	%	29	26	18	34	21
field age	Mean	year	25	10	70	51	4
	CV	%	116	67	20	50	133
field area	Mean	ha	0.5	0.6	0.3	0.4	0.6
	CV	%	74	72	72	70	73
soil texture	Mean	% of field	32	24	68	35	20
sandy-clay	CV	%	125	42	31	36	45
amount of	Mean	kg/ha	900	600	2200	1500	0
manure	CV	%	236	210	140	193	*
amount of	Mean	kg/ha	14	8	0	16	34
urea	CV	CV	189	219	*	190	129
ploughing	Mean	% of field	66	62	76	80	58
	CV	%	71	79	58	51	81
sowing	Mean	days[1]	29	29	21	29	33
date	CV	%	46	46	29	41	45
1st weeding	Mean	days[2]	30	27	28	28	34
date	CV	%	35	29	36	38	34
weeding	Mean	hours/ha	620	890	580	440	420
time	CV	%	105	107	53	53	57
association	Mean	%[3]	35	10	24	40	66
cowpea	CV	%	137	310	179	125	73
Striga	Mean	paras./ha	34000	32000	51000	51000	18000
incidence	CV	%	169	150	189	112	137
previous crop cotton		% of fields	29	12	17	45	88
labour	Mean	kg/hour[4]	4	4	5	4	4
productivity	CV	%	54	51	43	59	58

* variance = 0, CV is not defined

1) mean sowing date of field in days after 1st of May

2) mean 1st weeding date of field in days after mean sowing date

3) % of fields with cowpea

4) Labour productivity in kg of produced sorghum per hour of labour

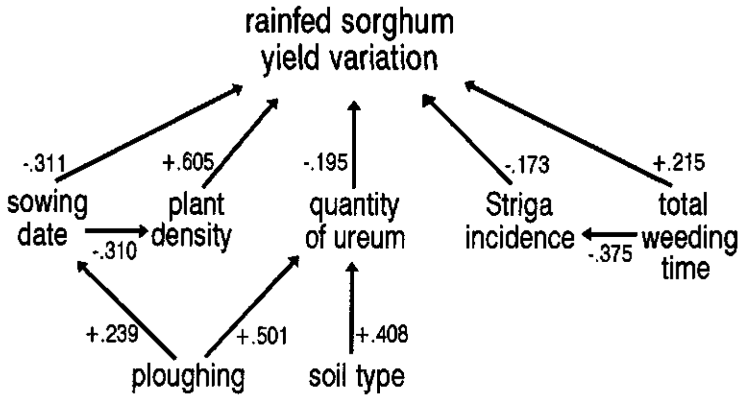


Figure 4.2 *Explanatory model with path-coefficients for 1992 Toupouri rainfed sorghum yield variation*

Plant density explained most of the variation in sorghum yield. This important relation (r = .658**) is plotted in Figure 4.3. Variation in plant density was explained by sowing date. The later a field was sown, the lower the plant density and, as a result, the lower its yield. However, sowing date also had a direct negative effect on yield (-.311). Late sowing implies a shorter growing season and therefore a lower yield potential. The combined effect of sowing date on 1992 rainfed sorghum yield was -.499 (-.311 + (-.310 * .605)).

Ploughing did not affect yield directly, but had an indirect effect on yield. The combined effect ((.239 * -.311) + (.239 * -.310 * .605) + (.501 * -.195) = -.217) was small and negative. Ploughing postponed the sowing date with six days, which affected plant density negatively. However, the start of the first weeding was postponed with four days (t-test, $\alpha < 0.10$). In this way, the negative effect of a later sowing date was compensated by a positive effect of a postponed weeding date. Postponing the moment of weeding is important with respect to the sowing of other fields. So, there are two

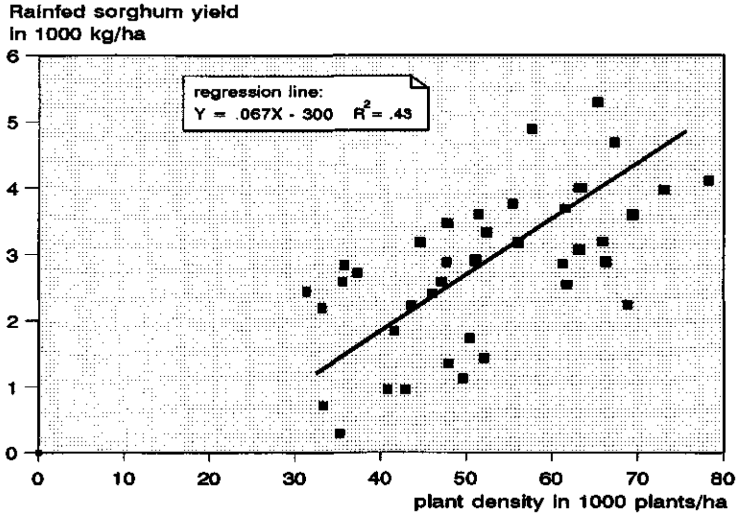


***Figure 4.3** Plot of Toupouri rainfed sorghum yield by plant density (1992, 48 fields)*

structural combinations of variables which appeared frequently:

(1) ploughing + late sowing + late weeding

(2) not ploughing + early sowing + early weeding

Moreover, ploughing and field age were correlated (r = .673 **). The structural combinations and correlation imply that ploughing cannot be considered as a single, independent variable.

Urea appeared to affect yield negatively (Figure 4.2). However, one has to be careful with the interpretation of models because of misleading causalities. The reason of the negative effect is that urea application is strongly related to one soil type, clayey-sand (analysis of variance, at a significance level of $\alpha < 0.05$) and cannot therefore be considered as a single, independent variable. Not one sandy-clay field received urea, and all clayey-sand fields received some, be it variable amount. So, what can be concluded from the model is that on fields with a soil type clayey-sand fertilised with urea lower yields were obtained than on fields with a soil type sandy-clay without urea application.

Striga incidence had a small, negative effect on yield (Figure 4.2). Weeding negatively affected Striga incidence: the more time was spent on weeding, the less important was the Striga incidence and the higher the yield. Weeding may be regarded as a Striga control measure. This stands to reason if it is assumed that Striga also parasites on weeds that surround the sorghum crop (see also Fortier, 1992).

The sorghum yield showed a significantly positive correlation with the indirect variable field age (r = .452 *). This relation is plotted in Figure 4.4:

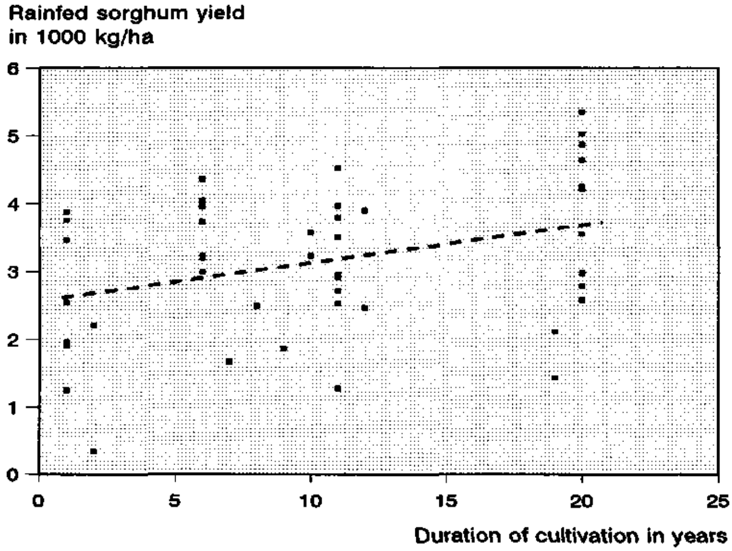


***Figure 4.4** Plot of Toupouri rainfed sorghum yield by field age (1992, 48 fields)*

Figure 4.4 shows a tendency of yields to increase with field age. However, the Toupouri migrants have settled down in three 'waves' which is reflected in the age-distribution of the fields. Fields of different waves are cultivated by farmers with different characteristics, such as access to the means of production and knowledge of the (new) environment. Accordingly, field age is not an independent variable and it must be concluded that the Toupouri yields result from three different sample populations. Each sample population reflects a class of age and the Toupouri fields can be characterised accordingly.

***Table 4.5** Rainfed sorghum Toupouri field characteristics per age class (1992)*

characteristic		1 - 3 years (n = 10)	6 - 12 years (n = 26)	18 - 20 years (n = 12)
mean yield	kg/ha	2300	3200	3600
minimum yield	kg/ha	200	1200	1600
maximum yield	kg/ha	3900	4500	5300
plant density	plants/ha	45200	48100	56600
ploughing	% of fields	50	50	85
sowing date	days[1]	41	26	25
1st weeding date	days[2]	25	27	30
labour time	hrs/ha	420	600	1350
amount of manure	kg/ha	100	800	500
amount of urea	kg/ha	10	7	6
Striga incidence	parasites/ha	4000	33000	52000
productivity	kg/hour	5	5	3

[1] mean sowing date of field in days after 1st of May
[2] mean 1st weeding date of field in days after mean sowing date

When the fields were stratified into three age classes, the 6 to 12 and the 18 to 20 years old fields showed significantly higher mean, minimum and maximum yields than 1 to 3 years old fields (oneway analysis of variance, at $\alpha < 0.050$). Because Toupouri fields are permanent, it is preferable to speak of a time trend towards higher yields, rather than of fixed field classes. The

18 to 20 year fields corresponded with ploughing, early sowing, a very large labour input and an important Striga incidence. The youngest fields were ploughed less frequently, sown later, received less labour and had a very weak Striga incidence. The amounts of applied manure were smaller on these fields, but the mean amounts of urea were not significantly different between the three field classes.

It can be concluded that, within the Toupouri cropping system, there is a trend towards yield increase in time. Despite an important Striga incidence, the highest yields were obtained on the oldest fields because of large input of labour and manure and because of good timing of cropping practices.

The Moundang rainfed sorghum cropping system

Field type 1 (0 - 0.1 km)

The Moundang fields at a distance of up to 0.1 km from the homestead have been continuously cultivated, on average, for 70 years (Table 4.4). These fields are rather small and soils are predominantly of the texture class 'sandy-clay'.

Results in Table 4.4 show that the 1992 rainfed sorghum yields were high and that their variation was moderate (CV = 32%). The average amount of applied manure was large, but variable with extremes between 0 and 10 000 kg/ha. The fields were frequently ploughed (76%), sown early and labour input was large. The Striga incidence was high. On a small number of fields (17%), the previous year another crop than rainfed sorghum had been grown.

Yield variation was explained for 54% (Annex 3) by three variables, which is shown in Figure 4.5. Ploughing affected yield positively. The few fields that had not been ploughed, were sown early but produced less than the fields that had been ploughed (t-test, $\alpha < 0.100$). Within field type 1, sowing date did not affect yield, being rather uniformly distributed (CV = 29%); all fields, except one, were sown between the 16th and the 30th of May.

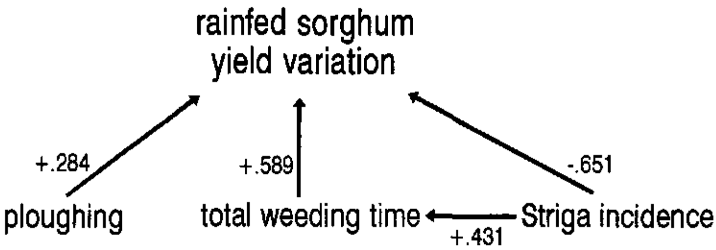


Figure 4.5 *Explanatory model with path-coefficients for 1992 Moundang field type 1 rainfed sorghum yield variation*

Striga incidence had a direct, negative effect (-.651) on yield and total weeding time had a direct positive effect (.589). In the fields with an important Striga incidence more time was spent on weeding than in fields with a low Striga incidence (.431). The indirect effect of Striga on yield was positive (.431 * .589 = .245), which compensated the negative, direct effect. The total Striga effect was therefore reduced to -.406 (= -.651 + .245). Within field type 1, weeding can be regarded as the major control measure of Striga.

The use of manure is an important variable in the distinction between field types, but seems not to play a role within field type 1. The problem of analysis is that its effect is disturbed by the residual effects of former manure applications. So, a low application in 1992 may be preceded by a high application in 1991, which has a strong residual effect on 1992 yield. In the 1993 data analysis, 1992 manure application was introduced as a variable (see Annex 3) and selected as an explanatory variable in the 1993 regression equation.

From the results it can be concluded that high rainfed sorghum yields in field type 1, up to 0.1 km from the homestead, were the result of a high intrinsic soil fertility, a high manure application, frequent ploughing, early sowing and a relatively high labour input. These variables compensated for the high field age and the important Striga incidence. Yield variation was explained by variation in ploughing frequency, weeding intensity and Striga incidence.

Field type 2 (0.1 - 0.6 km)

Moundang fields at 0.1 to 0.6 km from the homestead have been cultivated with short fallow periods on average since 50 years (Table 4.4). These fields are somewhat larger than the fields of type 1 and their soils are predominantly of the texture class 'clayey-sand'. On several fields, micro-relief is undulating (slope of field between 2 and 5%) and important soil erosion is observed.

The yields were significantly lower and more variable (CV=65%) than the yields on the fields of type 1 (Annex 3). The plant densities were lower, the amounts of manure were smaller and the sowing dates were later and more variable (between the 15th of May and the 23th of June). The majority of the fields was ploughed and Striga incidence was as important as on fields of type 1. On 45% of the fields, cotton had been grown in the previous year.

Yield variation was explained for 64% (Annex 3) by only two variables, which is shown in Figure 4.6. Sowing date affected yield negatively and plant density had a strong positive effect. Variation in sowing date could not be explained by other field variables. Variation in plant density was explained for 31% by the amount of manure. Its indirect effect on yield was positive (.485 * .635 = .308). The Striga incidence explained 36% of the variation in manure application. The indirect effect of Striga incidence on yield was positive, which was because of an over-compensation through large amounts of manure on fields with important Striga incidence. Farmers confirmed in interviews that manure is used on fields that are infected seriously by Striga.

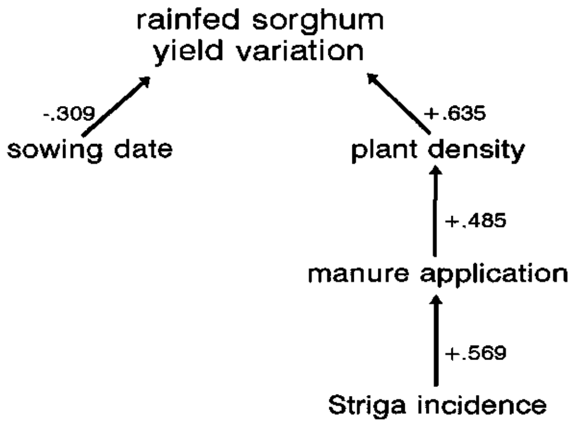


Figure 4.6 *Explanatory model with path-coefficients for 1992 Moundang field type 2 rainfed sorghum yield variation*

The total weeding time on the 'clayey-sand' fields was two times as great as on the 'sandy-clay' fields, but this extra labour input was not reflected in a higher yield. Weeding intensity may be regarded as a compensation factor for low soil fertility. So, two structural combinations of variables with similar yield levels were observed:

(1) clayey-sand texture with high weeding intensity
(2) sandy-clay texture with low weeding intensity.

It must be concluded that sorghum yield variation in field type 2, between 0.1 and 0.6 km from the homestead, can be explained by sowing date and plant density. Sowing date is determined by farm household characteristics. On the contrary, the variation in plant density is partly explained by the variation in manure application, and indirectly by the variation in Striga incidence. Low soil fertility is compensated by high weeding intensity.

Field type 3 (beyond 1.0 km)

Moundang fields at more than 1.0 km from the homestead have been cultivated for an average period of only four years with extremes of one and ten years. After the period of cultivation, fields are abandoned and become fallow and grazing land. The fields are larger than the fields of the previous two types and soils are predominantly of the texture class 'clayey-sand'.

The yields were significantly lower than the yields on the fields of type 1, but yield variation was comparable (CV = 38%). Plant densities were significantly lower and sowing dates were very variable (between the 15th of May and the 2nd of July). Only half of the fields was ploughed and first weeding dates were significantly later compared with the previous two field types. No manure was applied, amounts of urea were relatively large and variable and Striga incidence was low, but very variable. The percentage of fields with cowpea was higher compared with the fields of type 1 (66% versus 24%, see Table 4.4). On almost all fields, cotton had been grown in the previous year.

Yield variation was explained for 70% by six variables (Annex 3) presented in Figure 4.7. The relative large number of explanatory variables suggests a relative important agrodiversity. Many (theoretical) combinations are plausible with these six variables. However, the model in Figure 4.7 shows that most of this agrodiversity was associated with ploughing, timing of cropping practices and Striga incidence. The variables plant density and field area were uncorrelated with other variables.

To test the effect of ploughing, field characteristics were compared between ploughed and unploughed fields (Table 4.6).

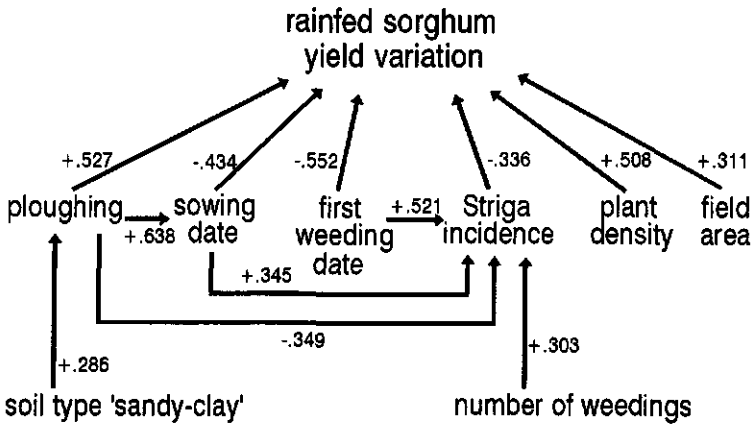


***Figure 4.7** Explanatory model with path-coefficients for 1992 Moundang field type 3 rainfed sorghum yield variation*

***Table 4.6** Comparison between unploughed and ploughed fields of the Moundang field type 3 (1992, n=40[1])*

characteristic		unploughed fields (n=16)	ploughed fields (n=24)	2-tailed significance
yield	kg/ha	1500	1500	-
plant density	plants/ha	56100	52100	-
sowing date	days[2]	21	42	< 0.001
1st weeding date	days[3]	32	35	-
number of weedings		1.7	1.3	< 0.05
total weeding time	hours/ha	410	230	< 0.02
Striga incidence	parasites/ha	22000	15000	-
field age	years	4.7	2.8	-
soil type 'sandy-clay'	% of fields	8	29	< 0.05
field sowing rank number		1.3	2.3	< 0.001

[1] five fields were not included because they were only partly ploughed
[2] mean sowing date of field in days after the 1st of May
[3] mean 1st weeding date of field in days after mean sowing date

Results in Table 4.6 show no significant difference in yield, nor in plant density between unploughed and ploughed fields. However, there were important differences in field characteristics: sowing dates were very late on the ploughed fields, total weeding time was very high on the unploughed fields and soils of the ploughed fields were more often of the texture class 'sandy-clay'. No causality *between* these relations should be sought (e.g. ploughing does not *cause* a mean delay of sowing of 21 days). In contrast, the causal factor here is the field sowing ranking number, explaining that, within the farm, unploughed fields were sown first, while ploughed fields were the last fields in the sowing sequence. Late sowing is a consequence of priority of other fields and other activities. Because weeds have the opportunity to germinate, ploughing has become a necessity for establishment of the crop.

With respect to Striga incidence, four relations were found:
- ploughing was related to low Striga incidence;
- late sowing was related to important Striga incidence;
- late first weeding time was related to important Striga incidence;
- frequent weeding was related to important Striga incidence.

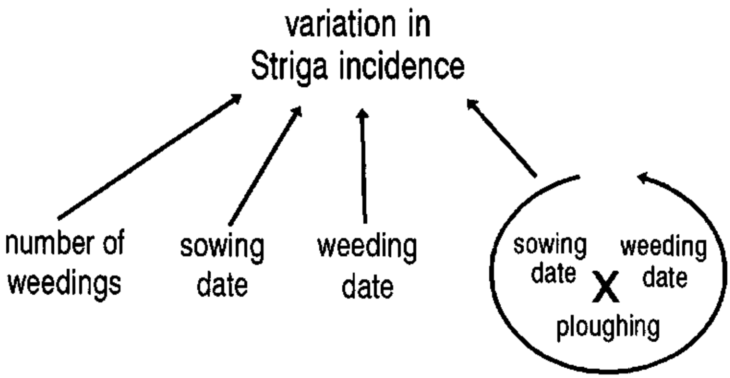


***Figure 4.8** Explanatory model with path-coefficients for 1992 Striga incidence variation on Moundang field type 3*

Figure 4.8 shows the variables that explained variation in the incidence of Striga for 69%. The interpretation of the different effects related to Striga incidence was complicated by the fact that Striga not only parasites on the sorghum crop, but also on weeds. Moreover, Striga incidence is often related to poor soil fertility (Naredra & Shinde, 1985; Cairns & Lea, 1990) which complicates extra the interpretation. However, within field type 3, no relation was found between Striga incidence, field age, urea application or soil type. All interactions refered to cropping practices and, more particularly, to the establishment of the crop. Ploughing, sowing date and first weeding date were interrelated and, therefore, could not be treated as independent variables. Figure 4.8 shows that variation in Striga incidence was explained by single variables, such as sowing and weeding date, but that a combined, interactive variable had the highest path-coefficient with a negative (i.e. reducing) effect. Late sowing and late weeding affected Striga incidence positively, but the combined effect of these two with ploughing was negative. The effects were not unequivocal, but relative and multi-dimensional.

It must be concluded that sorghum yield variation in field type 3 (beyond 1.0 km from the homestead) was explained by six variables of which four were highly related. Some of these variables were present as fixed combinations that were a function of the sowing order within the whole farm. Other interactions were less unequivocal and depended on the dominance of a single variable, or on the combined effect of several variables.

4.1.3 Synthesis and discussion

Variation in rainfed sorghum yields was great over the three years of observation. Intra-annual variation could be reduced effectively by stratification of the fields. Within each stratum, different sets of a reduced number of variables explained the yield variation.

Two cropping systems were distinguished. Although the environmental conditions were comparable, and although the same crop was grown, the Toupouri rainfed sorghum cropping system differed significantly from the Moundang rainfed sorghum cropping system.

Highest yields were obtained in the Toupouri cropping system. Results indicate that Toupouri farmers make rational use of their ploughs and decide to use them in combination with rainfall distribution and field characteristics. In this way, a farmer can decide to sow one field immediately after the first rains without ploughing to make full use of the growing season, whereas another field is prepared later, using the plough to oppress weeds. The results are an increase in flexibility and adaptability to external and internal influences. This flexibility reflects itself also in other variables, such as urea application and total weeding time. Urea is only applied on soils of the texture class 'clayey-sandy' and may be regarded as a compensation for poor soil fertility. Weeding reduces the incidence of Striga and may be considered as its main control measure.

The trend towards higher yields corresponds with a trend towards labour intensification. Total labour input and its effectiveness (ploughing, timing of sowing) were significantly greater on the older fields. Also Striga incidence increased with time, which is related to continuous sorghum cropping and which is often regarded as a reflection of declining soil fertility. However, labour productivity did not increase with time, which suggests strongly that additional labour input compensates for fertility decline. This evolution is a major characteristic of the dynamics which take place within the Toupouri cropping system.

Moundang rainfed sorghum fields varied significantly in yield and in the relative importance of the variables that explained this variation. Fields of type 1 (up to 0.1 km from the homestead) are cultivated in a land and labour intensive way, resulting in high yields ànd in high labour productivity. Yield reducing effects, such as declining soil fertility and increasing Striga incidence, are compensated by relatively large amounts of manure. Striga is controlled by high, effective labour input.

Fields of type 2 (between 0.1 and 0.6 km from the homestead) are cultivated in a less land and labour intensive way. Their soils are more sandy, which implies poorer intrinsic soil fertility. This results in lower yields and lower labour productivity. Where Striga incidence is important, nutrient loss is compensated by selective manure application, thus showing no measurable negative effect on yield. Low soil fertility is compensated by high labour input, especially in weeding.

Fields of type 3 (beyond 1.0 km from the homestead) are cultivated in a land and labour extensive way. Ploughing and sowing dates reflect the priority given to these fields. Striga incidence is controlled by several practices which are effective through their mutual interference. Low soil fertility is not compensated and fields are abandoned when soil fertility becomes too limited for a reasonable labour return. Rotation with cotton may be regarded as a measure to postpone the moment the field has to be left fallow.

This strongly differentiated rainfed sorghum cultivation is characteristic for the Moundang cropping system. In this way, intensive land use is combined with extensive land use which result from flexible use of the natural resources and the available means of production. A key element is the variable management of soil fertility through the production and use of manure, the flexible use of urea and the regeneration of soil fertility through fallow. This fallow land is also essential as grazing land for large cattle, thus being the source of manure for the fields in type 1.

It can be concluded that great variations in yield are explained by significant differences between cropping systems and between field types within the same cropping system. This agrodiversity is composed of specific variables, but also of specific interactions between similar variables. It appears that not only the absolute importance of the variable, but also its relative value plays a role in the explanation of yield variation. Within the cropping system, these selective interactions are because of interventions of the farmer confronted with a specific bio-physical characteristic of the field. However, within the agroecosystem, such interventions may also be caused by higher level farmer and household characteristics.

4.2 Cotton

In contrast to rainfed sorghum, cotton is a crop which is cultivated exclusively for the market. It was introduced in the village of Gaban during the fifties and was incorporated successfully into the rainfed sorghum system. Cotton is a *'culture encadrée'*, i.e. a crop with cropping practices that are largely dictated by the extension service of the SODECOTON. Their prescriptions involve:

- complete cleaning from cotton crop residues,
- cultivation in collective blocks of (rectangular) fields,
- use of one cotton variety,
- ploughing and early sowing in rows,
- no intercropping,
- application of 100 kg/ha of compound fertiliser,
- application of 4 to 5 biocide applications
- collective marketing.

This important market incorporation and external 'streamlining' of cotton cultivation leads to the null hypothesis of limited variation in cropping techniques, compared to a multiple purpose and indigenous crop such as rainfed sorghum. Consequently, a relatively small intra-annual yield variation between cotton fields is expected.

4.2.1 Variation in yield

In Table 4.7, yields and yield characteristics are presented for two years of observation.

***Table 4.7** Cotton yield variations*

year	no. of fields	mean yield (kg/ha)	CV (%)	min. yield (kg/ha)	max. yield (kg/ha)
1991	22	1000	62	240	2530
1992	52	520	75	40	2120

Results in Table 4.7 show a great variation in the yield of cotton. This variation was somewhat greater in 1992 than in 1991, whereas its mean yield was lower. Yields were distributed over a wide range from extremely low to very high.

It can be concluded that within the rainfed cropping systems there was an important variation in cotton yield. The null hypothesis of uniform yields is not confirmed and has to be rejected.

4.2.2 Agrodiversity in cotton cultivation

A multiple regression analysis (method 'backward') of the dependent variable yield was performed for all 52 cotton fields of 1992. 32 measured variables were included of which four contributed significantly to the model, explaining 56% of the variation in cotton yield (Table 4.8). One variable was the interaction between soil type and number of biocide applications. With the exception of the number of weedings, the variables in the 1992 equation were the same as the variables in the 1991 equation. However, path-coefficients of the 1991 variables were more pronounced than those of 1992 variables, suggesting greater importance of single variables.

Table 4.8 *Yield variation and explaining variables with path-coefficients (multiple regression analysis, 1991 and 1992)*

cotton 1991 (n=22)		cotton 1992 (n=52)	
Mean yield: 1000 kg/ha, CV=62%		Mean yield: 520 kg/ha, CV=75%	
R^2= .70		R^2= .56	
Variables:		**Variables:**	
soil 'sandy-clay' x no. of treatments	.519	sowing date	-.324
sowing date	-.437	no. of weedings	.306
no. of non-active termite mounds	.273	soil 'sandy-clay' x no. of treatments	.397
		no. of non-active termite mounds	.298

x = interaction-effect

In Figure 4.9, the variables in the equation and the model are presented.

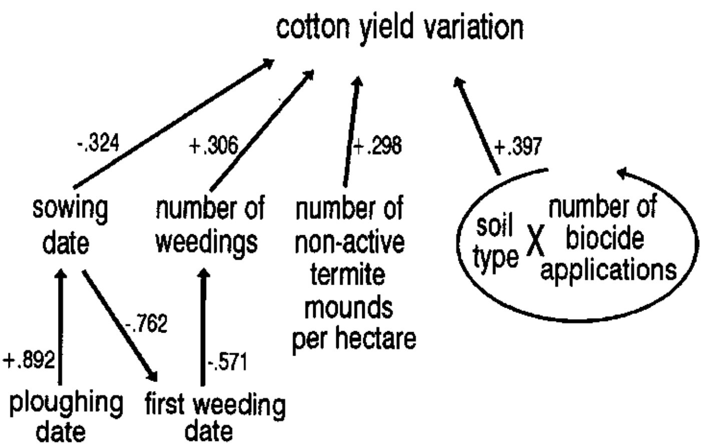


Figure 4.9 *Explanatory model with path-coefficients for 1992 cotton yield variation*

The model shows that the sowing date had a direct, negative effect on the cotton yield (the later sown, the lower the yield). The sowing date was highly determined by the date of ploughing (r = .892**). The number of weedings had a direct, positive effect on the yield and was negatively related to the date of the first weeding: weeding short after sowing corresponded with a high weeding frequency. Non-active termite mounds may contribute to the fertility of the soil (Brouwer et al., 1992), hence influencing the cotton yield in a positive way. The soil type and the number of biocide applications were correlated (r = .571**) and only had a positive effect on cotton yield as a composed variable.

In order to examine the effect of sowing date on yield, these variables are plotted against each other in Figure 4.10.

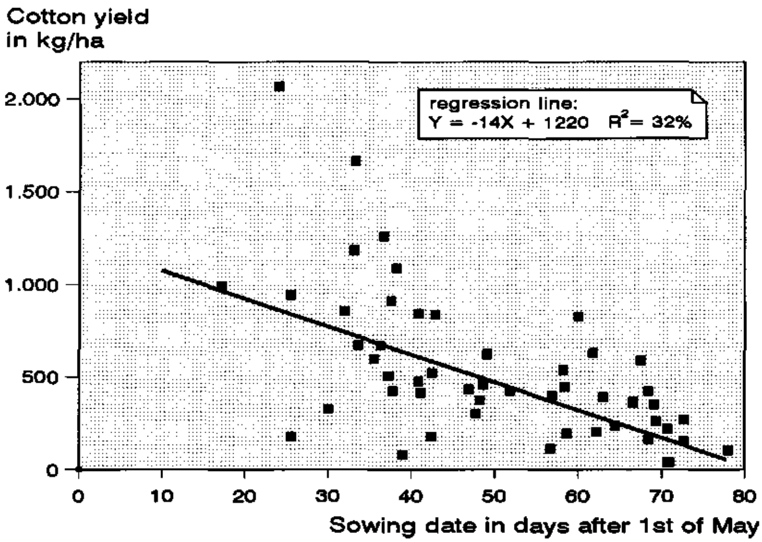


***Figure 4.10** Cotton yield as a function of sowing date (1992, 52 fields)*

The cotton yields were negatively correlated with the sowing date (r = -.566**); on average they decreased 14 kg/ha per day. This was because later sowing causes a shorter growing season, which has a negative effect on cotton yield (Audebert, 1993). However, the results (Figure 4.10) suggest that the effect of sowing date became more pronounced after the 45th day. Moreover, before the 45th day, no linear declining regression equation was found, even if two high-yield outliers were excluded from the analysis. Within this range, variation remained great (CV = 66%) and high yields, as well as low yields were observed. A relatively early sowing date seems to be a necessary condition, but not a garantee for high cotton yields.

The effects of the number of biocide applications, weedings, termite mounds and soil type are best analysed by means of an analysis of variance ('oneway') on group differences. Each group in Table 4.9 represents a specific value or range of the independent variable.

***Table 4.9** Cotton yield variation per regression variable (1992, 52 fields)*

number of biocide treatments

0 (n=9)	2 (n=7)	3 (n=18)	4 (n=12)	5 (n=6)
360	420	460	550	970*

number of weedings

1 (n=8)	2 (n=35)	3 (n=9)
300	470	890*

number of non-active termite hills

0 (n=20)	2 (n=17)	4 (n=8)	6 (n=5)	8 (n=3)
460	480	510	500	760*

% of field 'sandy-clay'

0 (n=33)	50 (n=9)	100 (n=10)
440	540	790*

* significant at $\alpha < 0.050$

Remark: each rectangle represents a value of the explanatory variable. In each rectangle, the mean yield for that specific value is printed.

What strikes one in Table 4.9 is that for each variable only the extreme high values of the variable had significantly higher yields:

- The mean yield of '5 biocide applications' differed from the mean yields of '2 and 3 biocide applications'.
- The mean yield of '3 weedings' differed from the mean yields of '1 and 2 weedings'.
- The mean yield of '8 non-active termite mounds per hectare' differed from the mean yields of '0 and 2 non-active termite mounds per hectare'; all other mean yields did not differ from each other.
- The mean yield of '100% sandy-clay' differed from the mean yields of '0% and 50% sandy-clay'.

These relative differences imply that the statistical effect on yield variation of an independent variable (see Table 4.8 and Figure 4.9) was, in fact, only the result of one extreme high value of the variable, and not of its whole range.

The sowing date, the number of non-active termite mounds and the interaction of soil type x number of biocide applications were not correlated. No fixed combinations of extreme values of these variables were found. In practice, many combinations may lead to the same result. Examples of combinations that resulted in a high cotton yield, are:

- sowing before the 10th of June and '8 non-active termite mounds per hectare',
- sowing before the 10th of June and '3 weedings',
- sowing before the 10th of June, '100% sandy-clay' and '5 biocide application'.

The two high yield 'outliers' (2120 and 1750 kg/ha) in Figure 4.10 resulted from a combination of: sowing before the 10th of June, '3 weedings', '100% sandy-clay' and '5 treatments'. In other words, to obtain these high yields, one conditional variable (sowing date) and three extreme high values of relative, yield determining variables had to be combined.

Ploughing and plant density did not have any measurable effect on cotton yield. All fields were ploughed and sown at a density of 40 000 to 50 000 plants per hectare. This is because of a general agreement amongst farmers, probably inspired by SODECOTON, that ploughing is essential for cotton cultivation and that 40 000 to 50 000 plants per hectare is the optimal density for this crop.

Yields did not depend on the field distance from the homestead, nor on the duration of cultivation of the field. These two variables were not lineary related to one of the variables in the regression equation. Distance from the homestead was very variable which confirms the observation that fields were not grouped in collective blocks, as prescribed by SODECOTON. With a mean distance of 2.4 km (Annex 4), most cotton fields were located in what corresponds to the rainfed sorghum field type 3. Here, cotton forms part of the annual rotation with rainfed sorghum, being a means to manage soil fertility.

On half of the number of cotton fields (see Annex 4), cowpea was sown as an intercrop between the plants in the row. The cowpea plant densities were low (estimated at 1000 to 5000 plants per hectare. No effect was observed of these low cowpea densities on cotton yield.

4.2.3 Synthesis and discussion

Within the rainfed cropping systems, cotton yields were very variable over the two years of observation. The null hypothesis of low yield variation was rejected. The observed variation in yield was partially explained by only four variables. These four yield determining variables did not have a similar effect. The effect depended on the nature of the variable's variation and on its interactions with other variables. The variables were classified according to their effect on cotton yield:

- Absolute variables, such as ploughing and plant density. If not respected, the cotton crop will fail. All cotton growers respected these variables, thus having no effect on yield variation.
- Conditional variables, such as early sowing. If not respected, production will be low. These variables have considerable effect on yield variation.
- Relative variables, such as number of biocide applications and number of weedings. These variables have only significant effect on yield at high values.
- Variables that have no measurable effect on yield, such as intercropping with cowpea.

Despite high market incorporation and efforts of the extension agency to control cotton production, agrodiversity in cotton cultivation remains important. Some prescriptions of the SODECOTON are not respected by farmers. Farmers prefer not to group their cotton fields, they sow their fields over a long period, they apply variable amounts of fertilisers and biocides and they intercrop cotton with cowpea. In the other hand, they agree about the necessity to plough and to sow in rows at a fixed density. Farmers are also confronted with certain bio-physical sources of variation, such as soil type and number of non-active termite mounds. These sources of variation, often considered fixed characteristics of the field, appear to be part of the management decisions of the farmer. This explains also farmers disagreement with the cotton block system of SODECOTON; every farmer wants to have active control over his/her fields in order to manage soil fertility within the perspective of the whole farm. Good soil being a limited resource, the farmer may reserve it for cotton or for rainfed sorghum. In the previous section (4.1), it was discussed that this flexible land use is essential to the fertility management of the cropping system. Moreover, farmers' objectives for cotton growing are not always in agreement with the objectives of SODECOTON. Variable input levels, variable sowing dates and intercropping suggest that there are other objectives besides optimalisation of cotton production. Apparently, cotton cultivation is also determined by characteristics of the farmer. This aspect will be discussed in more detail in chapter 5.

4.3 Mouskouari sorghum

Mouskouari sorghum is a crop that is cultivated during the dry season on the Vertisols and heavy clayey river banks. Grown under harsh climatic conditions, and being completely dependent on residual soil moisture, the crop is likely to be very sensitive to site specific characteristics, such as soil texture, water holding capacity, duration of cultivation, and to the date of transplanting. As a consequence, a relatively great variation in yield is expected.

4.3.1 Variation in mouskouari sorghum yield

In Table 4.10, yields and yield characteristics are presented for two years of observation.

***Table 4.10** Mouskouari sorghum yield variations*

year	no. of fields	mean yield (kg/ha)	CV (%)	min. yield (kg/ha)	max. yield (kg/ha)
1991/1992	24	1000	31	500	1800
1992/1993	72	800	34	200	1700

Results in Table 4.10 show a moderate variation in the yield of mouskouari sorghum. This variation was more or less similar for the two years of observation, but yields were higher in the 1991/1992 than in the 1992/1993 season.

4.3.2 Agrodiversity in mouskouari sorghum cultivation

A multiple regression analysis (method 'backward') of the dependent variable yield was performed for all 72 mouskouari fields of 1992/1993. 22 measured variables were included of which three contributed significantly to the model, explaining 34% of the variation in yield (Table 4.11).

***Table 4.11** Mouskouari sorghum yield variation, explaining variables and path-coefficients (multiple regression analysis, 1991/1992 and 1992/1993)*

Mouskouari sorghum 1991/1992 (n=24) Mean yield: 1000 kg/ha, CV=31%		**Mouskouari sorghum 1992/1993** (n=72) Mean yield: 800 kg/ha, CV=34%	
R^2= .36		R^2= .32	
Variables:		**Variables:**	
plant density	.363	plant density	.409
mean planting date	-.358	sub-cultivar *'Sauchei'*	.619
		sub-cultivar *'Forlami'*	.818

The three selected variables were directly related to the crop, i.e. to plant density and crop genotype. However, the two sorghum sub-cultivars were not uniformly distributed over the fields, but were site-specific (Figure 4.11). On the clayey river banks and on the fields that are divided into compartments by numerous small dikes, the yellow sub-cultivar *'Sauchei'* was transplanted, while on the flat vertisols the white sub-cultivar *'Forlami'* was transplanted. This important interaction between crop genotype and site characteristics was confirmed by the 1991/1992 data, which showed strong correlation between the sub-cultivar *'Sauchei'* and the river bank site (r = .784**).

Every interviewed farmer, both Toupouri and Moundang, confirmed the need to distinguish between field sites and stressed the need to adjust the choice

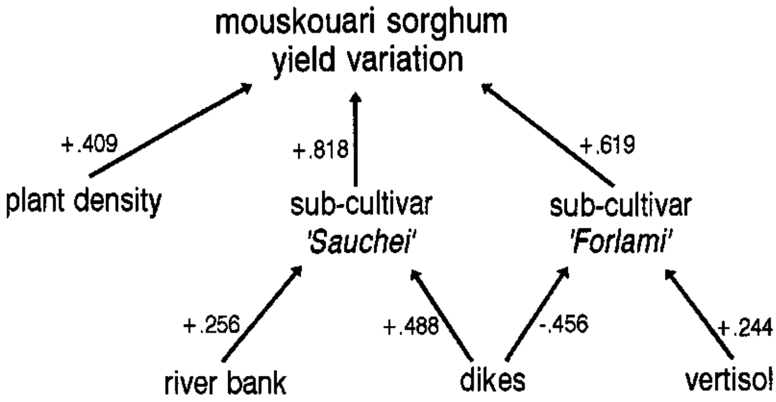


Figure 4.11 *Explanatory model with path-coefficients for mouskouari sorghum variation (1992/1993)*

of the sub-cultivar to the site. The site characteristics that are considered important are related to the water holding capacity of the field. This was confirmed by extensive IRA research on improvement of mouskouari sorghum cultivation showing a significant effect of supplemental irrigation, and no effect of N and P fertiliser application (Carsky & Ndikawa, 1993b).

During the 1992/1993 season, sorghum plant density had a marked effect on yield, which is shown in Figure 4.12. Although the effect of plant density on yield was pronounced (r = .480**), the deviation from the regression line was important and increased with increasing plant density. From the results (Figure 4.12), it can be concluded that the plant density effect was in fact only effective between 6000 and about 12 000 plants per hectare. In this range, yield variation declined to 27% and was explained for 47% by plant density. This was confirmed on a more indicative basis by the 1991/1992 results. For the range between 12 000 and 19 000 plants per hectare, yield variation was more or less constant (36%) and could be explained for only 16% by plant density.

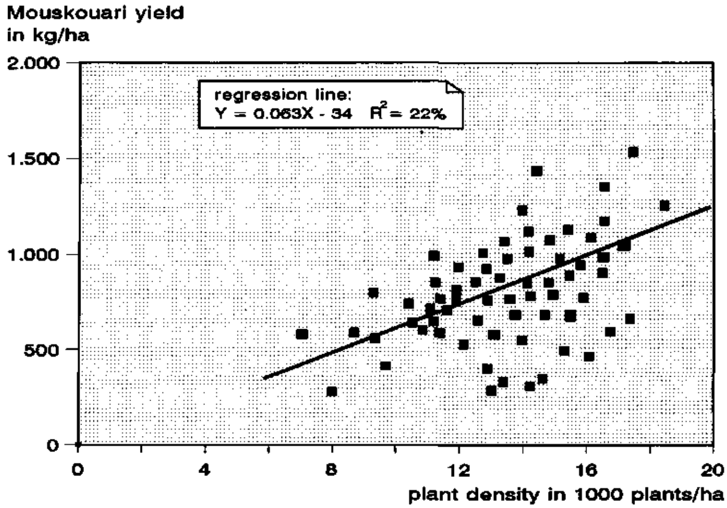


***Figure 4.12** Plot of mouskouari sorghum yield by plant density (1992/1993, 72 fields)*

Results from IRA research on mouskouari sorghum (Carsky & Ndikawa, 1993a) show that optimum plant density is around 10 000 plants per hectare. Between 10 000 and 50 000 plants per hectare, panicle weight decreases with increasing density, resulting in increases in grain yield, which are too small to be economically viable. This confirms the observation of high plant density effect at plant densities lower than 12 000 plants per hectare.

A principal component analysis (PCA, with SPSS procedure) was performed on mouskouari sorghum fields (1992/1993) and four components explained 74% of the matrix variation (Table 4.12). These components included the interactions between site and sub-cultivar, and between plant density and yield. Moreover, the results suggest an interaction between sowing date of the nurseries, plant density and yield.

Table 4.12 Principal component analysis on mouskouari sorghum fields with cumulation of explained variation in percentages (1992/1993, 72 fields)

characteristic	component 1 24.2%	component 2 43.5%	component 3 61.4%	component 4 74.2%
yield	+.464	-.439		+.525
plant density		-.432		+.543
sowing date nursery		+.625		-.478
field preparation date		+.832		
transplanting date		+.801		
sub-cultivar *'Forlami'*	-.765		-.479	
sub-cultivar *'Sauchei'*	+.797		+.408	
vertisol	-.671		+.707	
river bank	+.671		-.707	
presence of dikes			+.670	

all component loadings > +.400 and < -.400 are printed

A regression analysis on yield as a function of sowing date in the nursery was performed and no linear relation was found. In Figure 4.13 this relation is plotted. Yields did not exceed the 800 kg/ha level if sown later than the 10th of August. However, before this date, 30% of the fields yielded 800 kg/ha or more. In other words, the chance for a high yield increased with early sowing. An early sowing date was not a garantee because yield variation did not decline, but remained 33%.

No interactions were observed between yield and duration of cultivation, or between yield and field distance from the homestead. However, older fields were more frequently surrounded and divided in compartments by small dikes than younger fields (r = .677**). This was confirmed by informal interviews with farmers who considered the construction of dikes as a necessary technique to avoid yield reduction on fields with a long history of cultivation.

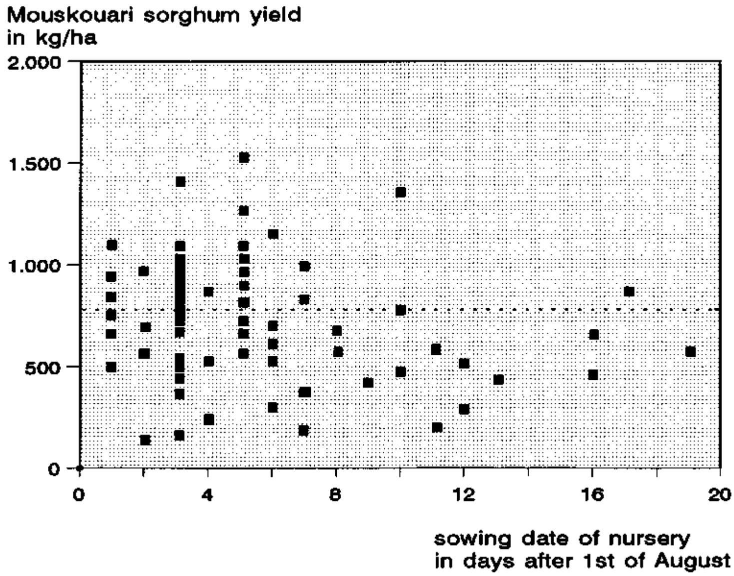


***Figure 4.13** Plot of mouskouari sorghum yield by sowing date of the nursery (1992/1993, 72 fields)*

Field observations and informal surveys with farmers suggested that farmers adjust the depth of transplanting to soil differences at micro-level, such as texture and moisture content. Depth of transplanting is subject of constant debate between farmers; they consider it as an important source of yield variation. Because it is an intra-field variation, within the context of this study it was not possible to include it as a variable in the quantitative analyses.

4.3.3 Synthesis and discussion

The 1991/1992 and 1992/1993 mouskouari yield variations were moderate, which did not correspond with the initial expectations of great variation. This moderate variation was explained by crop genotype and management adjustments to the water holding capacity of the field. A field characteristic, such as water availability, is not always a given fact, but proves to be adjustable through the construction of small dikes. So, the undivided vertisol with sub-cultivar *'Forlami'* may become an improved vertisol with sub-cultivar *'Sauchei'*, when considered advantegeous by the farmer. These fixed combinations occur on the fields of both Moundang and Toupouri farmers.

High 1992/1993 yields were only obtained if two conditions were met with: sowing in the nursery before the 10th of August and transplanting at 12 000 plants per hectare or more. However, these two conditions were no garantee for high yields, but only increased the chance for a high yield.

From the moderate yield variation, the fixed combinations between water holding capacity of the field and the management characteristics, and the uniformity of farmers' response to the interviews, it can be concluded that there is a common sense, or a general agreement, amongst the farmers of the village of 'how to grow mouskouari sorghum', resulting in moderate agrodiversity and moderate yield variation.

4.4 Conclusions

The results presented in the previous sections show that the magnitude of intra-annual yield variation was not constant for the three crops. Cotton showed greatest variation, followed by rainfed sorghum and mouskouari sorghum. It must be concluded that the magnitude of variation is crop-specific.

Yield variation in **rainfed sorghum** was effectively reduced and explained by stratifying the cropping systems and field types on the basis of the ethnic origin of the producer and the location of the field. Variables which explained yield variation differed significantly between the cropping systems and between the field types. Variables explaining **cotton** yield variation did not show these ethnic and spatial dimensions, but appeared to be effective in combinations of high positive values of a reduced number of variables. The latter can be grouped into (1) availability of labour and equipment (ploughs, animal traction, biocide sprayers), and (2) intrinsic soil fertility. Both groups of factors refer to the general distribution of means of production between the households. Yield variation in **mouskouari sorghum** was explained by site characteristics related to the water holding capacity of the field, and by the modification of cropping techniques. The interaction between water availability and cropping techniques was not explained by the ethnic or socio-economic characteristics of the farmers.

Annex 4 shows.the spatial distribution of interpolated yields of the three crops. The spatial differentiation of the Moundang rainfed sorghum fields is clearly visible, as well as the concentration of the rainfed sorghum fields, with very high yields, around the Toupouri homesteads. Annex 4 shows also that the cotton fields are almost absent in the Toupouri cropping system. The distribution of mouskouari sorghum fields shows a pattern that corresponds with the distribution of Vertisols and the presence of ephemeral streams.

Crop-specific differences in the explanation of intra-annual yield variations can be classified according to three basic phenomena at field level:

- **Spatial differentiation of fields.** The process of differentiation in space is clear for the rainfed fields of the autochthonous Moundang. Rainfed fields of the Toupouri have not yet differentiated spatially. The quest for soil fertility is a major cause of spatial field differentiation, resulting in intensively cultivated fields near the homestead, and extensively cultivated fields and fallow at a distance from the homestead.
- **Mechanisation of cultivation.** Mechanisation occurs on Moundang rainfed fields, and to a lesser extent on Toupouri rainfed fields. Mechanised land preparation is essential for cotton cultivation, and advantageous for rainfed

sorghum cultivation. Mouskouari sorghum cultivation cannot be mechanised; this crop is essentially cultivated by manual labour.
- **Environmental adaptation of cultivation.** All crops are to some extent adapted to certain bio-physical characteristics of the environment. Mouskouari sorghum is cultivated under extremely harsh climatic conditions, increasing the necessity to adapt cropping techniques to the specific bio-physical properties of the field.

The three phenomena at field level are related to phenomena of diversity at higher levels of aggregation:

- **Ethnic diversity.** Rainfed sorghum and cotton cultivation greatly depend on the ethnic origin of the household, while mouskouari sorghum cultivation is not significantly different between the two ethnic groups.
- **Household diversity.** Unequal distribution of means of production between and within households affects the cultivation of rainfed sorghum and cotton. Manual cultivation of mouskouari sorghum is not determined by the ethnic or socio-economic diversity of households.

It must be concluded that important variations in yield are observed within a single agroecosystem. The agrodiversity explaining these variations is crop-specific and may express itself in different forms and composition. The characteristic phenomena underlying the observed agrodiversity may be highly related to phenomena of diversity at higher levels of aggregation.

Chapter 5

Agrodiversity as a function of household diversity

While chapter 4 emphasised the explanation of yield variations at field level, in this chapter the relation between field and farmer will be highlighted. The agrodiversity, as identified in the previous chapter, is considered a function of the diversity of households. In the case of the village of Gaban, diversity of households may include ethnic groups (5.1), classes of household (5.2) and gender categories (5.3).

5.1 Ethnic diversity

Based on the central problem statement (section 1.5), the null hypothesis was formulated that, under similar environmental conditions, there will be a large degree of homogeneity in yields at field level and in production at household level. This hypothesis will be tested for the two ethnic groups in the village of Gaban.

In chapter 4 important variations in yield were observed. Rainfed sorghum yields could be partly explained by making a distinction between a Toupouri and a Moundang cropping system. Apparently, the conditions, under which agricultural production takes place, are not similar between the two ethnic groups. This leads to the definition of the alternative hypotheses:

(1) Yields and production are not uniformly distributed between the two ethnic groups in the village.

(2) The two ethnic groups differ in their access to the means of production.
(3) The two ethnic groups differ in their production goals and in their use of the means of production.

5.1.1 Distribution of means of production

The Toupouri and Moundang households can be compared with respect to the family composition and the available means of production:

***Table 5.1** Family size and means of production of the households per ethnic group (1992)*

family size and means of production	Moundang households (n=31)	Toupouri households (n=15)	2-tailed significance
number of consumers	7.9	10.1	-
number of workers	4.8	5.0	-
number of consumers per worker	1.7	2.0	-
number of ox-drawn ploughs	0.8	0.3	< 0.05
number of donkey-drawn ploughs	0.4	0.3	-
number of ox-drawn carts	0.2	0.1	-
number of oxen	1.5	0.9	-
number of cows	3.7	6.3	-
number of donkeys	0.4	0.7	-
number of sheep and goats	8.6	18.9	< 0.05
estimated available amount of manure (kg)	2300	3000	-
total area (including fallow) (ha)	6.2	5.3	-
total cultivated rainfed area (ha)	2.1	2.1	-
total area under fallow (ha)	1.8	0.3	< 0.01
total area per worker (ha)	1.3	1.1	-
total cultived rainfed area per worker (ha)	0.4	0.4	-

Consumption and labour. In 1992, in spite of their different background, the Moundang and Toupouri households did not differ in their family composition. The two ethnic groups had a comparable consumers-per-worker ratio, which was about two consumers on one worker.

Capital and equipment. The two ethnic groups differed significantly in the ownership of ox-drawn ploughs and small livestock. Moundang households owned almost three times more ploughs than Toupouri households, who owned more sheep and goats. Although there was a tendency towards more large livestock for the Toupouri households, this was not statistically significant. The general impression that livestock is of particular importance to the Toupouri was in this case only confirmed with respect to small livestock. However, it has to be mentioned that the composition and ownership of livestock is very dynamic in time and that any measurement of its importance reflects only its state at one moment. Moreover, the Toupouri people in the study are migrants who do not represent the entire Toupouri society in all respect.

Land and land quality. On average, Moundang and Toupouri households cultivated a similar total area. Because there was no difference in the average number of workers, the land-per-labour ratio was comparable between the two. The only difference was the area under fallow, which was larger for the Moundang households.

Besides the absolute land distribution, the quality of the land should also be taken into account. A proxy for land quality is the texture class of the soil (see section 3.1). Table 5.2 presents the distribution of soil types for the rainfed cultivated land (i.e. all rainfed sorghum and cotton fields). Results in Table 5.2 show that the quality of the rainfed cultivated land, expressed in texture class, was nearly identical between the two ethnic groups. In both cases, almost two third of the land was of the texture class 'clayey-sand'.

Elaborating on the distinction between field types discussed in chapter 4 the ethnic groups can also be compared according to the distribution of their land over these strata (Table 5.3).

Table 5.2 *Distribution of household rainfed cultivated land over soil types per ethnic group (1992, excluding fallow land)*

soil type		Moundang households (n=31)	Toupouri households (n=15)	2-tailed significance
sandy-clay	area (ha/household)	0.57	0.58	-
	% of total household area (%)	28	27	-
clayey-sand	area (ha/household)	1.39	1.44	-
	% of total household area (%)	67	68	-
other	area (ha/household)	0.10	0.10	-
	% of total household area (%)	5	5	-

Table 5.3 *Distribution of household cultivated land over field distance strata per ethnic group (1992, excluding fallow land)*

field type		Moundang households (n=31)	Toupouri households (n=15)	2-tailed significance
0 to 0.1 km	mean area/household (ha)	0.29	0.90	< 0.001
	% of total area/household	14	43	< 0.01
0.1 to 0.6 km	mean area/household (ha)	0.36	0.73	< 0.01
	% of total area/household	18	35	< 0.05
0.6 to 7.0 km	mean area/household (ha)	1.37	0.48	< 0.05
	% of total area/household	68	22	< 0.01

Both the absolute and the proportional distributions of the land over the three field distance strata were significantly different between the two ethnic groups. Only a small portion of the land of the Moundang households was located at a short distance from the homestead. In contrast, three quarters of the land of the Toupouri households was located within a distance of 0.6 km from the homestead.

It must be concluded that, with respect to the distribution of the means of production, there are few differences between the two ethnic groups. The differences which are relevant for agricultural production, are discussed below:

- The Toupouri cultivate more land at short distance from the homestead than the Moundang. This can be explained by the fact that (1) there are more Moundang households than Toupouri households and (2) the Moundang quarters are more concentrated than the Toupouri quarters, which are more dispersed over a larger area (see Figure 3.3, p. 55). Consequently, there is more land available at short distance for the Toupouri households.
- The Toupouri households arrived only recently. This implies that the land has not been used longtime for agriculture, which explains the relative small portion of land under fallow. The Moundang households put large portions of their land in the third field type under fallow as a way to manage soil fertility.
- In northern Cameroon, the Moundang were one of the first ethnic groups who succesfully adopted mechanised cotton production (see section 3.2). Ploughs and oxen were obtained on credit provided on the basis of a minimum cotton area. This explains the relative large number of ploughs and oxen in the Moundang community. Nevertheless, this has not led to extension of the cultivated land: the land per labour ratio is the same for the two ethnic groups. The Toupouri of Gaban have only occasionally grown small portions of cotton, thus having been excluded from credit facilities and purchase of ploughs and oxen.
- In the traditions of the Toupouri people, great value is attached to livestock. For example, it plays an important role in the arrangement of marriages. A guiding principle is that a man has to give ten head of large livestock to the father of the woman he wants to marry. The Moundang pay their bride-price in cash and those who are Muslim, pay an additional dowry. In theory, this should lead to more livestock in the Toupouri

community than in the Moundang community. However, because the Toupouri do not marry the Moundang and because this particular Toupouri community is very small, many marriages are arranged with other Toupouri communities. Men stay in the community, but look for a (first, second, third etc.) wife in other communities. Accordingly, there is a net export of large livestock leaving the Toupouri community of Gaban.

Based on the criteria of ethnicity, it must be concluded that the access to most means of production is almost similar for the households of Gaban. Two important exceptions are the better availability of ox-drawn ploughs in the Moundang community, and the larger rainfed area at short distance from the homestead of the Toupouri households.

5.1.2 Variations in yield

The null hypothesis is that there are no statistically significant differences in yield of the three major crops between the two ethnic groups. Because each household often cultivates more than one field per crop, the mean and maximum yields will be compared and tested.

Table 5.4 *Mean and maximum yields of three major crops per ethnic group (1992/1993)*

yield	Moundang households	n	Toupouri households	n	2-tailed significance
mean rainfed sorghum yield (kg/ha)	2100	31	2900	15	< 0.005
maximum rainfed sorghum yield (kg/ha)	3100	31	3700	15	< 0.05
mean cotton yield (kg/ha)	550	28	330	7	< 0.05
maximum cotton yield (kg/ha)	650	28	360	7	< 0.005
mean mouskouari sorghum yield (kg/ha)	800	31	800	15	-
maximum mouskouari sorghum yield (kg/ha)	900	31	900	15	-

Remark: the mean and maximum yield per ethnic group do not include households which do not grow cotton.

The results in Table 5.4 show an inverse relation between rainfed sorghum and cotton yields. In 1992, the Toupouri households obtained higher mean and maximum yields of rainfed sorghum than the Moundang households, which obtained higher mean and maximum yields of cotton. As a matter of fact, this difference in cotton production was even more pronounced, because only half of the Toupouri households grew cotton, whilst this was ninety percent for the Moundang households. The mouskouari sorghum yields were not different between the two ethnic groups.

It must be concluded that the two ethnic groups differed significantly in their yields of the rainfed cropping system.

5.1.3 Variations in production

In Table 5.5 the annual household productions of the three crops per ethnic group are presented. In 1992, a Toupouri household produced, on the average, twice as much rainfed sorghum as a Moundang household. In contrast, the latter had a five times higher cotton production than the former (including only the cotton growing households). Mouskouari sorghum production was not statistically significantly different between the two ethnic groups. The same contrast between rainfed sorghum and cotton was observable for the production per worker, which showed higher rainfed sorghum and lower cotton production per worker for the Toupouri households. But the production of mouskouari sorghum per worker was also higher for the Toupouri households than for the Moundang households. The production per working hour was only different with respect to cotton. Where the Moundang households had an average return to labour of one kilo per hour, it was negligible (near zero) for the Toupouri households. The fact that the rainfed sorghum production per worker was higher, but that per working hour it was equal to that of the Moundang households, may be interpreted as a greater labour investment of the Toupouri households in this crop.

***Table 5.5** Household production per ethnic group (1992/1993)*

production	Moundang households (n=31)	Toupouri households (n=15)	2-tailed significance
production of rainfed sorghum (kg)[1]	2800	5100	< 0.01
production of cotton (kg)[2]	305	55	< 0.01
production of mouskouari sorghum (kg)[1]	1900	2500	-
production of rainfed sorghum/worker (kg)	500	1100	< 0.001
production of cotton/worker (kg)	64	11	< 0.001
production of mouskouari sorghum/worker (kg)	400	600	< 0.1
production of rainfed sorghum/hour (kg)	4	4	-
production of cotton/hour (kg)	1	0	< 0.001
production of mouskouari sorghum/hour (kg)	2	2	-
surplus of total sorghum (kg)[3]	2700	5100	< 0.01
surplus of rainfed sorghum (kg)[4]	1800	3900	< 0.005
surplus of mouskouari sorghum (kg)[4]	900	1200	-

[1] These production estimates include 10% losses due to transport and stockage, but exclude reduction of the available production due to gifts, reimbursements and payments to others.
[2] Weighed by village agents and confirmed by the SODECOTON.
[3] Based on the FAO standard for yearly food consumption of 250 kg/consumer/year.
[4] Based on a consumption period of 6 months of rainfed sorghum and 6 months of mouskouari sorghum, i.e. 125 kg/consumer/6 months.

The total net 1992 sorghum surplus of both ethnic groups was very high. On the average, a Toupouri household produced two times more sorghum surplus than a Moundang household. This difference was because of a difference in rainfed sorghum surplus. At village level, based on the 1992 distribution of households over the two ethnic groups, total sorghum surplus could be estimated at 1.2 million kg. This estimate did not include processing sorghum into beer, which may have been considerable, especially in the Toupouri community.

Figure 5.1 shows the distribution of sorghum surplus of the sampled households. The figure shows that for both ethnic groups, total annual

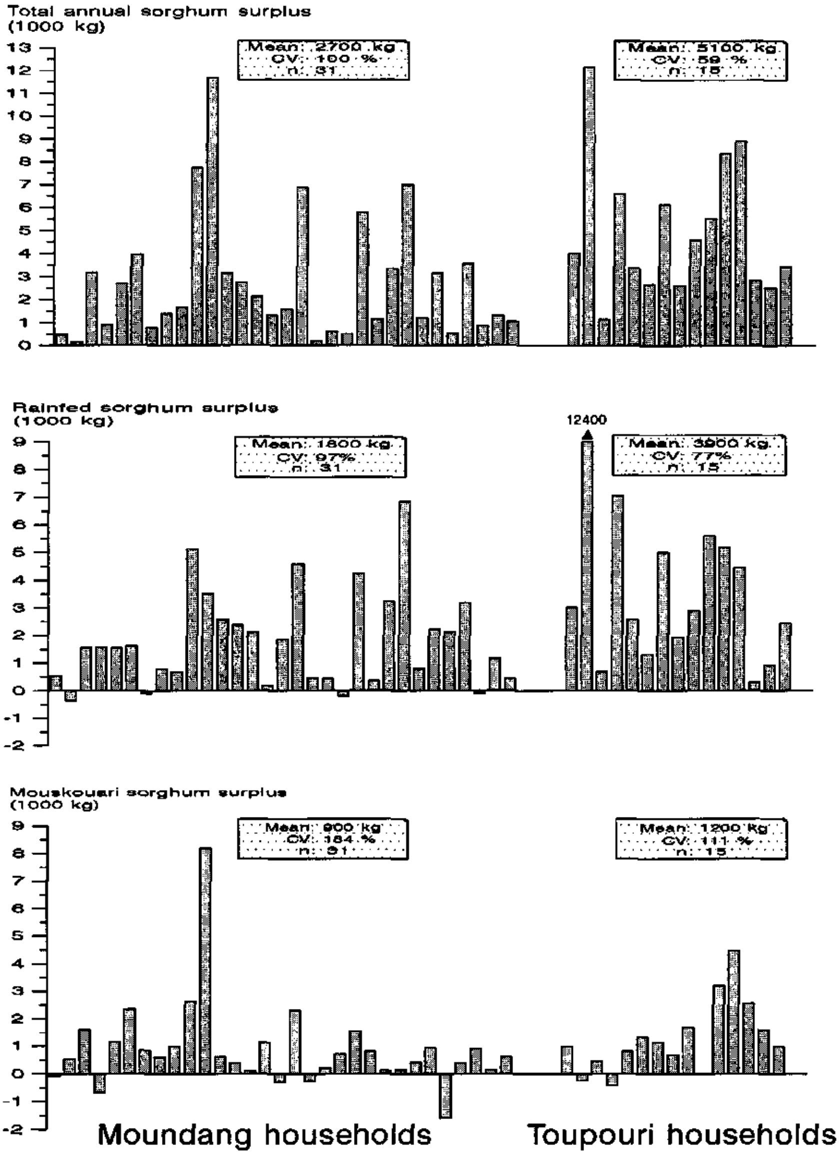


Figure 5.1 *Total annual sorghum, rainfed sorghum and mouskouari sorghum surplus distribution of sampled households per ethnic group (1992/1993)*

sorghum production was, in theory, sufficient to satisfy family consumption. However, some Moundang households obtained such a small sorghum surplus that they were close to food shortage. In practice, sorghum is often used to reimburse debts or is sold to finance basic expenditure. What was considered as a small surplus, might have been a shortage in reality. Moreover, temporary shortages may have occured during the year, which were not reflected in the total annual distribution. In 1992, it was observed that in five out of thirty one cases, rainfed sorghum production did not satisfy Moundang family consumption demands until the next mouskouari harvest in February. With respect to this crop, all Toupouri households were self-sufficient. However, in both sample populations, there were households with a mouskouari sorghum shortage. Because the total annual sorghum production was, in theory, sufficient in all cases, temporary shortages in one sorghum production were stabilised by surplus of the other sorghum production. This can also be concluded by the fact that intra-group variation in rainfed and mouskouari sorghum surplus did not lead to higher, but to equal intra-group variation in total annual surplus (Moundang households: CV = 100%) or to even lower variation (Toupouri households: CV = 59%).

Variation of sorghum production was large in both ethnic groups. This stresses the need to compare not only the production *mean*, but also its *range* and its *distribution*. Figure 5.2 shows that 55% of the Moundang households obtained less than 2000 kg of sorghum surplus, compared to only 7% of the Toupouri households (one case). In contrast, the Toupouri households were concentrated in the 2000 to 4000 kg class, and their frequency is higher for all subsequent classes than the Moundang households. So, sorghum surplus of the Toupouri not only exceeded that of the Moundang in absolute sense, but it was also less variable and showed another distribution which a tendency to larger values.

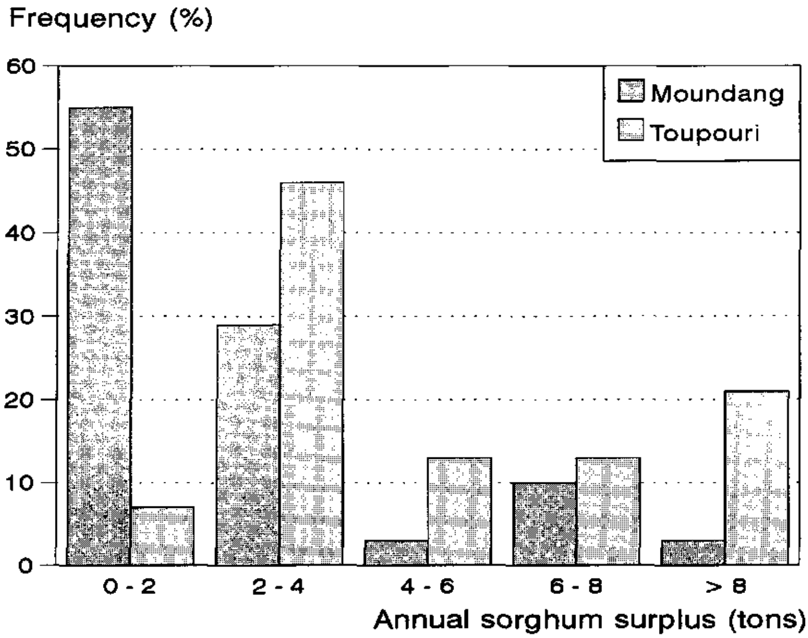


Figure 5.2 *Frequency distribution of total sorghum surplus per ethnic group (1992/1993)*

5.1.4 Variations in sources of capital

The importance of agricultural production as a source of capital can only be assessed when other sources are evaluated as well. Table 5.6 shows all sources of capital with their value. For both ethnic groups, total sorghum surplus was by far the prime source of capital. For the Moundang, second best were the non-agricultural sources of capital, of which trade was very important. Capital from cotton production and from animal husbandry were almost equally important. Second best for the Toupouri was also non-agricultural capital, with beer brewing as the most important activity. Cotton production only played a marginal role as source of capital.

***Table 5.6** Sources of capital and value per ethnic group (1992/1993, in CFA francs)*

source of capital and value in CFA francs	Moundang households (n = 31)	Toupouri households (n = 15)	2-tailed significance
total sorghum surplus value	135000	255000	< 0.01
net cotton production value	25900	4700	< 0.05
total animal husbandry	24000	31000	-
sale of small livestock	20000	24000	-
sale of large livestock	3000	8000	-
total non-agricultural activities	58000	46000	-
beer brewing[1)]	4000	27000	< 0.005
weaving of mats	1000	6000	< 0.01
wood cutting	8000	0	< 0.001
trade[2)]	39000	7000	< 0.05
other activities	6000	6000	-

[1)] Capital produced with beer brewing is not independent from the estimated total sorghum surplus value. The two sources of capital cannot be cumulated without checking on overlap.
[2)] Excluding one Toupouri household of which the male head of the household is a semi-full time trader with an annual income of 225 000 CFA francs.

It must realised that expression in CFA francs of sorghum surplus remains theoretical. Especially the Toupouri produce large amounts of beer, which are distributed free of charge to anyone who passes by. Moreover, Toupouri women may also sell their beer on market days in the village of Gaban or in neighbouring villages. The Moundang do not know the custom of 'free beer for everyone'. Moundang women only sell their beer, at fixed volumetric units with variable prices, depending on the market price of sorghum. With the exception of the Muslim and Protestant Moundang, both ethnic groups organise working parties during which the available amount of beer determines directly the number of participants (workers). Consequently, sorghum surplus is not only an important source of income or of social status, it has also direct productive value, comparable to the production factor capital, and has to be considered as a commodity.

It must be concluded that, although access to the means of production is largely similar, there are important production differences between the Moundang and the Toupouri. Sorghum yields and production of the Toupouri are high and sorghum surplus is their prime source of capital. Moreover, rainfed sorghum plays an important social role. Cotton production is only of minor importance to the Toupouri. For the Moundang, although yields are lower compared to the Toupouri, sorghum is also the prime source of capital. Cotton production is superior to that of the Toupouri, but as a source of capital, it comes after trade.

Under similar envrionmental circumstances, households with largely similar access to the means of production, but with different ethnic origin, obtain significantly different yields and production. The origin of these differences must be sought in a different use of the means of production.

5.1.5 Production strategies

A production strategy is defined by the deliberate allocation of the available resources over the different agricultural and non-agricultural activities in order to produce goods and/or capital. A production strategy is the producer's way to fullfill his or her short and long term objectives. Production and income, as presented in the previous section, are the direct result of household production strategies. As a consequence, variations in production and income may find their origin in (a) the available means of production and (b) their allocation over (c) the different economic activities.

Allocation of land

***Table 5.7** Allocation of land of households per ethnic group (1992/1993)*

cultivated area	Moundang households (n=31)	Toupouri households (n=15)	2-tailed significance
total cultivated area (ha)	4.4	5.1	-
rainfed sorghum area (ha)	1.4	1.8	-
cotton area (ha)	0.8	0.3	< 0.005
mouskouari sorghum area (ha)	2.2	3.0	< 0.1
total cultivated area/worker (ha)	1.0	1.1	-
rainfed sorghum area/worker (ha)	0.3	0.4	< 0.05
cotton area/worker (ha)	0.2	0.1	< 0.001
mouskouari sorghum area/worker (ha)	0.5	0.7	< 0.05
percentage rainfed sorghum area of total area (%)	32	36	-
percentage cotton area of total area (%)	18	6	< 0.001
perc. mouskouari sorghum area of total area (%)	50	58	< 0.05
percent. rainfed sorghum area of rainfed area (%)	65	85	< 0.001

The results in Table 5.7 show that the total cultivated and rainfed sorghum areas were comparable between the two ethnic groups. Moreover, the Moundang cultivated a significantly larger cotton area, while the Toupouri cultivated a larger mouskouari sorghum area. The cultivated land per labour ratio shows the same pattern, but now, it appears that the Toupouri cultivated more rainfed sorghum area per worker than the Moundang. The proportional distributions show the importance of cotton to the Moundang and of mouskouari and rainfed sorghum to the Toupouri.

Allocation of labour

***Table 5.8** Allocation of labour in agriculture of households per ethnic group (1992/1993)*

labour input	Moundang households (n = 31)	Toupouri households (n = 15)	2-tailed significance
total labour input (hours)	2630	3220	-
labour input in rainfed sorghum (hours)	790	1380	< 0.01
labour input in cotton (hours)	810	340	< 0.01
labour input in mouskouari sorghum (hours)	1030	1500	< 0.1
total labour input per worker (hours)	580	650	-
labour input per worker in rainfed sorghum (hours)	170	270	< 0.001
labour input per worker in cotton (hours)	170	50	< 0.001
labour input per worker in mouskouari sorghum (hours)	240	330	< 0.001
percentage rainfed sorghum labour input of total labour input (%)	31	42	< 0.001
percentage cotton labour input of total labour input (%)	28	7	< 0.001
percentage mouskouskouari sorghum labour input of total labour input (%)	41	51	< 0.005
percentage rainfed sorghum labour input of total rainfed labour input (%)	54	85	< 0.05

Remark: It was not feasable to measure labour input in animal husbandry and in non-family labour (e.g. trade, handicrafts, beer brewing, wood cutting) at a satisfying level of accuracy.

Overall labour input and total labour input per worker were not significantly different between the two ethnic groups although there was a tendency to larger values for the Toupouri households. All other labour input values differed significantly. In combination with the results in Table 5.7, it appears that the Moundang households spent significantly more labour time on cotton production, whilst the Toupouri households spent significantly more labour time on rainfed and mouskouari sorghum production.

Labour can originate from the family or from sources outside the family. Non-family labour can be obtained through hiring of seasonal- or contract-workers, through organising working parties or through exchanging ploughs and oxen for manual labour. The next table shows the proportional importance of non-family labour.

***Table 5.9** Non-family labour input of households per ethnic group (1992/1993)*

non-family labour input	Moundang households (n=31)	Toupouri households (n=15)	2-tailed significance
total non-family labour input (hours)	300	190	< 0.05
percentage of total labour input (%)	12	6	< 0.05
non-family labour input in rainfed sorghum	30	0	*
percent. of total rainfed sorghum labour input (%)	4	0	*
non-family labour input in cotton (hours)	140	10	< 0.001
percentage of total cotton labour input (%)	17	3	< 0.001
non-family labour input in mousk. sorghum (hours)	130	180	< 0.05
percentage of total mouskouari labour input (%)	13	12	-

* variance = 0, CV is not defined.

In absolute and relative sense, the Moundang households engaged more non-family labour than the Toupouri households. This difference was especially caused by the high non-family labour input in cotton production. Both ethnic groups engaged a substantial amount of non-family labour for the mouskouari sorghum production (i.e. for land clearing activities), whilst it was negligible in the case of rainfed sorghum production.

The origin of the non-family labour is difficult to quantify, especially when it concerns hired labour and equipment-for-labour exchanges. In contrast, working parties are easily to be measured. Estimation based on these data, shows that 90% of all non-family labour of the Toupouri originated from working parties and (free) neigbour and family support. For the Moundang, these sources did not exceed 40%, which implies that about 60% originated from hired or exchanged labour. This contrast between the two ethnic groups confirms the idea that in the Toupouri community the social relations are very important, affecting directly household labour availability. This results in more or less equal labour exchanges, although there are differences due to hierarchy and access to sorghum for beer production. In this way, all individual households have access to a large labour pool which exceeds by far the available family labour. Occasional high labour demands in agriculture can be satisfied quickly, leading to effective field management and a relatively favourable 'labour input-sorghum output ratio' of all households.

The Moundang households prefered to engage non-family labour on a more indiviual and one way basis. The majority of it originated from hired workers from outside the village, or, for those who own ploughs and oxen, from non-equiped households who are in need of equipment. On average the exchange ratio is three to four days of manual labour to one day of equipment use. Both sources of non-family labour are, directly or indirectly, based on capital or capital goods. In some cases, households which have borrowed cereals during periods of shortage, reimburse their loans in labour. A consequence is that extra labour is not available to all households, but only to those who have sources of surplus accumulation and ownership of equipment.

Allocation of capital

The allocation of capital can be understood through assessing expenditures on inputs and use of ploughs and oxen for crop production. Table 5.10 shows that on all input items, the Moundang spent about twice as much as the Toupouri. However, the proportional distribution over the items was similar for the two ethnic groups. They both spent the majority of their expenditures on extra labour.

Ploughs and oxen may be considered as capital goods that are employed for productive purposes. Results in Table 5.11 show that the ploughed areas did

***Table 5.10** Household expenditure on inputs per ethnic group (1992/1993)*

expenditure on inputs	Moundang households (n=31)	Toupouri households (n=15)	2-tailed significance
expenditure on labour (francs)	20900	12200	< 0.05
expenditure on fertilisers (francs)	9700	5600	< 0.1
expenditure on biocides (francs)	4800	2200	< 0.01
total expenditure on inputs (francs)	35400	20000	< 0.01
total expenditure on inputs per worker (francs)	7400	4000	< 0.01
total expenditure on inputs per hectare (francs)	8000	4000	< 0.01
percent. labour expenditure of total expend. (%)	59	61	-
percent. fertiliser expenditure of total expend. (%)	27	28	-
percent. biocide expenditure of total expend. (%)	14	11	-

Remark: in the case of beer for working party's, the price of sorghum is estimated at 50 francs per kilo.

***Table 5.11** Employment of ploughs and oxen of households per ethnic group (1992/1993)*

proportion ploughed area	Moundang households (n=31)	Toupouri households (n=15)	2-tailed significance
percentage of rainfed sorghum area ploughed (%)	68	62	-
percentage of cotton area ploughed (%)	100	91	-

not differ between the two ethnic groups in spite of the higher availability of ox-drawn ploughs in the Moundang community (0.8 versus 0.3, Table 5.1). This can only be explained by the collective use of the available ploughs in the Toupouri community. In this way, the non-equiped majority of the households had access to ploughs and oxen, without submission to the equiped households with subsequent unequal reimbursement in manual labour. This collective use is often based on lines of kinship and is especially effective within each clan. The available equipment is almost a collective good and is used at its optimum during the periods of ploughing.

On the contrast, an equiped Moundang farmer will, *grosso modo,* only rent his plough and oxen *after* the receiving household has provided for three to four days of manual labour. These unequal exchanges are very common in the Moundang community and take even place within direct lines of kinship. Equipment is a very individual good and hiring it to other households is considered an adequate way to obtain extra labour.

5.1.6 Synthesis and discussion

In chapter 4 it was concluded that within the village of Gaban two cropping systems for rainfed sorghum and cotton have to be distinguished on the basis of ethnicity of the farmers. The Toupouri rainfed cropping system appeared to be more uniform than the Moundang rainfed cropping system, which had to be subdivided into three specific field types with characteristic yield levels.

Access to the means of production is similar for the two ethnic groups. The Moundang households own more ploughs and oxen and have more fallow land than the Toupouri. The latter cultivate more rainfed area at a short distance from the homestead.

Important differences were observed in the yields and production achieved by both ethnic groups. The Toupouri obtained higher yields of rainfed sorghum and the Moundang higher yields of cotton. Yields of mouskouari sorghum were similar between the two groups. The same contrast was observed for the production per household. The final result was a larger annual sorghum surplus in the Toupouri households, because of the larger surplus of rainfed sorghum and higher net cotton production in the Moundang households. Notwithstanding these differences, sorghum production is the prime source of capital for both ethnic groups. Non-agricultural activities are the second source, of which trade is of importance to the Moundang, and beer brewing to the Toupouri.

The production strategies explaining these differences in yields and production can be deduced from certain historical and socio-economic characteristics of each community that have an important impact on the production process. **The Toupouri community** in the village of Gaban is composed of migrants, who have arrived only recently. The members of the community have a mutual background and are organised in coherent clans along lines of kinship. A strong feeling of collectivity leads to collective use of the available labour force and equipment in the community. The generally large sorghum surplus that results from it, is partly used for the community in the form of beer, and partly to buy livestock, which are used as bride-price for marriages or as savings which can be used in times of hardship.

The collective use and organisation of the available labour force and equipment and the important role of sorghum explain the particular focus on the production of (red) rainfed sorghum. The beer produced with it is regarded as 'the gift' to the community, assuring future support. It forms the basis of the reproduction of *the community as a whole*. Mouskouari sorghum cannot be used for beer production and is particularly important for the establishment and reproduction of *the individual household*. In this system, there is little room for cotton production. The Toupouri still grow some cotton because this gives them access to fertilisers for the rainfed sorghum crop, and also because they need cash for new forms of monetary expenditure, such as health care and education. However, capital accumulation is almost impossible in the Toupouri system and important investments in equipment, housing or even public works (i.e. a school or a health center) are almost absent. Capital accumulation in the form of livestock is not an object in itself, but a way to secure family reproduction. The ownership of livestock is highly dynamic and is therefore not a factor of social differentiation. The driving forces of the more or less uniform production strategy are internal to the system and the system itself may be regarded as 'closed' to externally induced influences (see also section 3.2).

The Moundang community has evolved within its present environment for at least 200 years. The colonial administration recognised Moundang interest in innovations from outside the community and the first mechanised cotton production in Cameroon was introduced successfully here. This might be an indication that Moundang society was originally organised on an individual and hierarchical basis. However, it might also have been a result of the co-existence with the Foulbé society and the adoption of Muslim power structure (see also section 3.2). Nowadays, the Moundang society is highly differentiated which affects the production process to a large extent. An important socio-economic diversity is to be observed. Moreover, the long lasting exploitation of the environment has led to a diverse land use with specific field types described in chapter 4. The internal diversity of the system is therefore important, which implies that the ethnic group cannot be the final unit of analysis. Nevertheless, it is useful to summarise some characteristics which are relevant at this level of analysis:

- Compared to the area cultivated by the Toupouri, the relatively high degree of mechanisation of the Moundang community has not led to the extension of the cultivated area often mentioned in literature (Pingali et al., 1987). Moundang households have more land under fallow than Toupouri households. Putting distant land under fallow is a common practice for regeneration of soil fertility. Land near the homestead has been cultivated continuously for at least 50 years and heavy applications of manure are essential for soil fertility management. Most manure is produced by livestock grazing on the fallow land.
- Cotton cultivation with rotation is a way of diversifying fertility management and is therefore a functional element in the cropping system. Although sorghum production is the prime source of capital, cotton

production is important in the production strategies of the Moundang households.
- Non-family labour is important for cotton and mouskouari production, but it is only available if the household has capital or capital goods, such as equipment, at its disposal.
- The Moundang community may be regarded as 'open' to externally induced influences and is characterised by its internal diversity.

When two ethnic groups with contrasting historical background and community structure exploit a similar environment, yield and production variations due to variable use of land, labour and capital may occur. This ethnic diversity largely determines the present agricultural and non-agricultural production, as well as opportunities and constraints for future development.

5.2 Socio-economic diversity

In the previous section, ethnic diversity has been recognised as an important source of variation of yield and production. Now, the null hypothesis can be formulated that under similar environmental conditions and within one ethnic group there will be a high degree of homogeneity in yields and production. In this section, this hypothesis will be tested for **the Moundang community.**

Results from 1991/1992 suggested that, within the Moundang community, unequal access to the means of production land, labour and capital may cause variable land use with subsequent variations in yields and production. More precisely, in that year of observation it seemed as if the ownership of at least one plough and one pair of oxen and the access to manure, as well as the distribution of the land over the three identified field types influences potential yield and production levels of the Moundang households. These assumptions lead to the following alternative hypotheses:

(1) Yields and production are not unifomly distributed amongst the Moundang households.
(2) Means of production are not equally distributed amongst the Moundang households.
(3) Resource-rich households obtain higher yields and production than resource-poor households.

5.2.1 Distribution of means of production

In the second year of field research, households were classified on the basis of the ownership of ploughs, oxen and livestock. This corresponded to results from the first year which showed the importance of ploughing and application of manure in the rainfed cropping system. The terms 'resource-poor households' and 'resource-rich households' are employed to stress that the classification includes more than equipment for mechanisation only. If 'resource-rich' is defined as 'the ownership of at least one plough, two oxen and a herd' 44% of all Moundang households fall into this class and 56% in the class of 'resource-poor households'. The composition of the herd may be four cows or oxen or twenty sheep and goats, or any combination in between. Because of difficulties of assesment and of the composition of the herd in time, the criterion of ownership of a herd is not employed as a very strict criterion of classification.

Consumption and labour. Results show (Table 5.12) that in 1992, resource-rich households were larger in family size and disposed of a larger number of family workers than resource-poor households. However, the ratio between consumers and workers was not significantly different between the two household classes. Every worker had to support almost two consumers.

***Table 5.12** Family size and distribution of means of production per Moundang household class (1992)*

family size and means of production	resource-poor households (n=14)	resource-rich households (n=17)	2-tailed significance
number of consumers	5.5	9.7	< 0.01
number of workers	3.4	5.8	< 0.01
number of consumers per worker	1.8	1.7	-
number of ox-drawn plows	0.0	1.3	< 0.001
number of donkey-drawn plows	0.2	0.6	-
number of ox-drawn carts	0.0	0.4	< 0.005
number of oxen	0.1	2.7	< 0.001
number of cows	0.0	6.4	< 0.001
number of donkeys	0.3	0.5	-
number of sheep and goats	2.8	12.9	< 0.001
estimated available amount of manure (kg)	300	3700	< 0.001
total acreage (including fallow) (ha)	3.9	7.5	< 0.005
total rainfed acreage (including fallow) (ha)	2.3	5.0	< 0.005
total acreage per worker (ha)	1.3	1.3	-
total rainfed acreage per worker (ha)	0.8	0.9	-

Capital and equipment. Resource-rich households had at least one plough and one pair of oxen at their disposal. Moreover, these households owned all the large livestock and the majority of the small livestock. As a result, they had twelve times more manure at their disposal than the resource-poor households.

Land and land quality. Resource-rich households cultivated almost two times the area of the resource-poor households, but the total and rainfed area per worker ratios were not significantly different between the two classes of household.

Besides the absolute area per household, it is also important to compare the quality of the land. A criterion of land quality is the texture class of the soil (see section 3.1).

***Table 5.13** Distribution of rainfed cultivated land over soil types per Moundang household class (1992, excluding fallow land)*

soil type		resource-poor households (n = 14)	resource-rich households (n = 17)	2-tailed significance
sandy-clay	area (ha/household)	0.25	0.89	< 0.01
	% of total household area (%)	21	31	-
clayey-sand	area (ha/household)	0.89	1.86	< 0.05
	% of total household area (%)	67	64	-
other	area (ha/household)	0.14	0.14	-
	% of total household area (%)	12	5	-

The sandy-clay soil type may be considered as advantageous for agricultural production because of its relatively high intrinsic soil fertility (see section 3.1). Table 5.13 shows that the resource-rich households cultivated three times more sandy-clay area than the resource-poor households. However, the ratio between sandy-clay soil and clayey-sand soil was practically similar in the two classes of household. The resource-rich households (44%) own 71% of totally available sandy-clay soil, which leaves only 29% for the resource-poor households (56%).

Elaborating on the stratification of the rainfed cropping system discussed in chapter 4, classes of household can also be compared according to the distribution of their land over the three rainfed field types. The first field type is most advantageous for agricultural production (chapter 4). The results in Table 5.14 show the same pattern as the results in Table 5.13: there is no significant difference in the proportional distribution of the three field types within each household class. However, calculated for the actual distribution of land over the two classes of household, the resource-rich households own

70% of the land in the first field type.

***Table 5.14** Distribution of land over rainfed field types per Moundang household class (1992, excluding fallow)*

field type		resource-poor households	resource-rich households	2-tailed significance
field type 1	mean acreage/household (ha)	0.14	0.43	< 0.001
(0 to 0.1 km)	% of total acreage/household	13	15	-
field type 2	mean acreage/household (ha)	0.19	0.63	< 0.001
(0.1 to 0.6 km)	% of total acreage/household	17	22	-
field type 3	mean acreage/household (ha)	0.77	1.83	< 0.001
(1.0 to 7.0 km)	% of total acreage/household	70	63	-

It must be concluded that the proposed classification on the basis of ownership of equipment and cattle is useful in the sense that it represents a set of interrelated household characteristics. The resource-rich households, with at least one plough, two oxen and a herd, have more workers and larger amounts of manure at their disposal than the resource-poor households. The former cultivate more land, but the land per worker ratio is similar between the two classes of household. Apparently, the ownership of ploughs and oxen does not lead to expansion of the cultivated land. The resource-rich households dominate in the sandy-clay soil type and in the first field type, which are both beneficial for agricultural production. Their initial situation at the beginning of the rainy season is better than that of the resource-poor households, because they own more equipment, more means for the management of soil fertility and better situated fields with superior intrinsic fertility.

5.2.2 Variations in yield

Yields can be compared per class of Moundang household. Because a household cultivates often more than one field of every crop, the mean yield and the maximum yield per household are compared (Table 5.15). Based on the null hypothesis, no significant differences in yield of the three major crops between the two classes of household are expected.

Table 5.15 *Mean and maximum yield of three major crops per class of Moundang household (1992/1993)*

	resource-poor households	resource-rich households	2-tailed significance
mean rainfed sorghum yield (kg/ha)	1700	2500	< 0.01
maximum rainfed sorghum yield (kg/ha)	2800	3200	-
mean cotton yield (kg/ha)	380	550	-
maximum cotton yield (kg/ha)	400	690	< 0.1
mean mouskouari sorghum yield (kg/ha)	800	800	-
maximum mouskouari sorghum yield (kg/ha)	800	900	-

The results in Table 5.15 show that the resource-rich households obtained higher mean rainfed sorghum and higher maximum cotton yields than the resource-poor households. The mouskouari yields were not significantly different between the two classes of household, neither were the maximum rainfed sorghum yields and the mean cotton yields. It must be concluded that the null hypothesis was not confirmed: there were significant variations in yield between the two classes of household. However, it may also be stated that yields of the resource-poor households differed specifically on two aspects and not on all aspects in spite of their generally disadvantaged situation.

Within the household, the available means of production are divided over the different crops and fields. This implies that there are structural relationships between the crops and the fields of a household. A consequence is that a comparison of yields between households should not only be one-dimensional (Table 5.15), but should also include these inter-crop relationships.

In order to verify the inter-crop-at-household-level-relationships, the correlation coefficients are computed in the next table:

***Table 5.16** Correlation coefficients between mean yields of three major crops (1992/1993)*

	mean rainfed sorghum yield	mean cotton yield	mean mouskouari sorghum yield
mean rainfed sorghum yield	1.000		
mean cotton yield	0.222	1.000	
mean mouskouari sorghum yield	0.059	0.259	1.000

Remark: Mean yields are calculated for all fields of a crop within the household

The results in Table 5.16 show that there was no linear relationship between the 1992/1993 mean yields of the three considered crops. In other words, a household with a high mean rainfed sorghum yield did not obtain *automatically* proportional high yields of all crops. This does not imply that there was no relationship at all between the considered crops. One method to analyse non-linear relations is to subdivise each population into groups and to perform an analysis on the frequency distribution (crosstabs with chi-square analysis). If the criterion is 'lower or higher than average yield', each population can be subdivided into two groups. Four groups with an expected frequency of 25% per group are thus defined when subgroups of cotton and rainfed sorghum are combined ('crossed'). The results in Table 5.17 show that the actual frequency distribution differed significantly from the expected distribution. This is because of an unequal distribution in the first collumn, in which the values of the residuals (i.e. expected frequency minus actual frequency) are important. However, the two cells compensate for each other, which results in a distribution as expected between the two collumns and between the two rows. The only significant difference is therefore because of an over-presentation of the combination of a lower than average cotton yield with a lower than average sorghum yield and an under-presentation of the combination of a higher than average cotton yield with a lower than average sorghum yield.

***Table 5.17** Crosstabs with chi-square analysis for cotton versus rainfed sorghum yields (31 Moundang households, 1992)*

	lower than average sorghum yield	higher than average sorghum yield	
lower than average cotton yield	11 (35%)	7 (23%)	18 (58%)
higher than average cotton yield	4 (13%)	9 (29%)	13 (42%)
	15 (48%)	16 (52%)	31 (100%)

Chi-square: 2.78 at a level of significance < 0.100

In the following figure, the mean cotton and rainfed sorghum yields are plotted against each other. The median lines serve as a reference and the four quadrants that result from it, correspond to the four cells in Table 5.17. The figure represents the deviations from the median, as well as the relative distribution in each quadrant. Because each household often cultivates more than one field of every crop, a presentation of the maximum yields is included.

The four quadrants in Figure 5.3 signify specific combinations of cotton and rainfed sorghum yield levels. An over-presentation in the quadrants one and four is expected on the basis of the second alternative hypotheses. In accordance with the results in Table 5.17 over-presentation is only observed for the first quadrant. Moreover, quadrant three is almost empty for the mean yields. The deviation from the medians, or the contrast, is more pronounced for the maximum yields, compared to the mean yields. This contrast is especially due to the maximum rainfed sorghum yields, which seem to 'flatten and stretch out' the cloud of points (an accentuated dispersion along the x-axis).

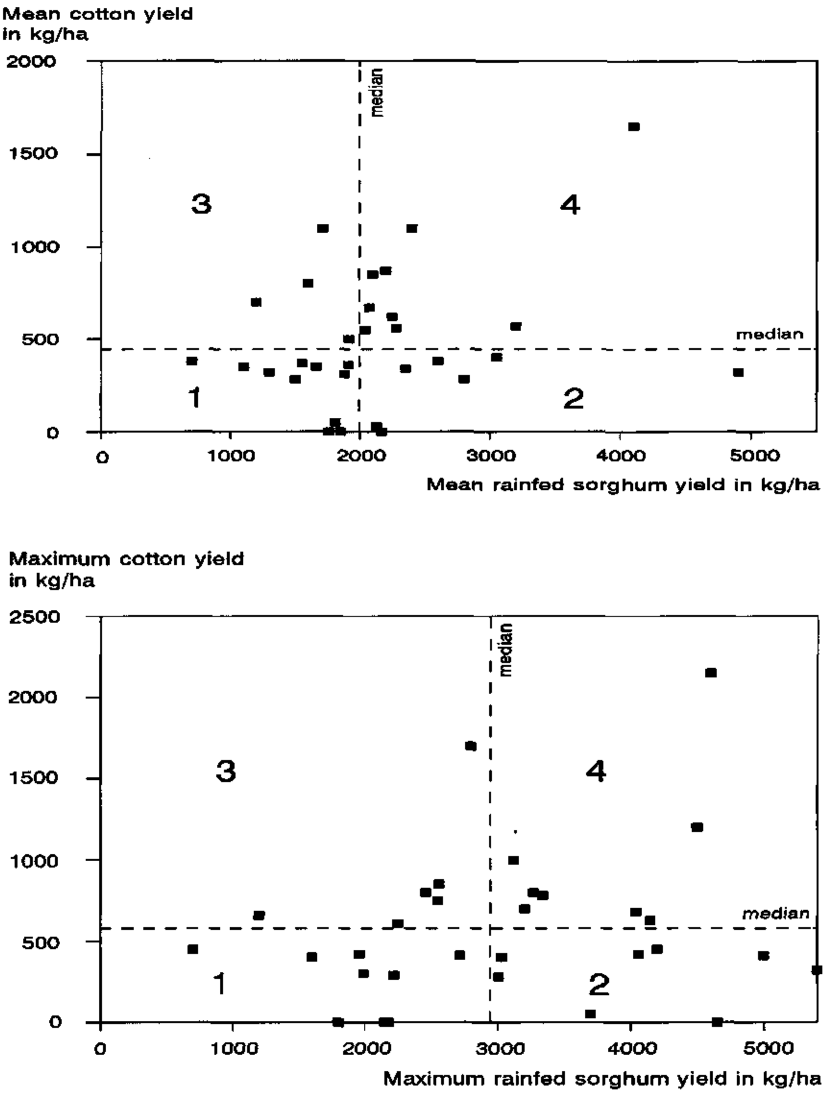


***Figure 5.3** Presentation in quadrants of mean and maximum cotton yield versus mean and maximum rainfed sorghum yield of Moundang households (1992)*

Based on the third alternative hypothesis on interrelation of yields and household resource endowment, a domination of the resource-poor households in the first yield quadrant and a domination of the resource-rich households in the fourth and/or third yield quadrant is expected. This is tested in Table 5.18.

***Table 5.18** Distribution of Moundang households over mean and maximum cotton and rainfed sorghum yield quadrants (1992)*

quadrant	mean cotton and rainfed sorghum yields			maximum cotton and rainfed sorghum yields		
	number (exp: 7.8)	resource-poor households (exp: 3.3)	resource-rich households (exp: 4.5)	number (exp: 7.8)	resource-poor households (exp: 3.3)	resource-rich households (exp: 4.5)
1	11	8	3	9	6	3
2	7	1	6	8	3	5
3	4	1	3	6	1	5
4	9	3	6	8	3	5

Remark: exp = expected number of households per quadrant

Figure 5.3 and Table 5.18 lead to the following observations and conclusions:

- For the mean yields, quadrant one is over-presented (n = 11), while quadrant three is under-presented (n = 4) compared to the expected number of households (n = 7.8). This tendency is not observed for the maximum yields.
- The first quadrant of the mean yields is dominated by the resource-poor households, while the other three quadrants are dominated by the resource-rich households. In other words, in 1992, most of the resource-poor households (62%) obtained lower than average mean cotton ànd lower than average mean rainfed sorghum yields.
- For the mean yields, three out of nine households in the fourth quadrant have a resource-poor endowment, which proves that it is not impossible to

obtain high mean rainfed sorghum yields ànd high mean cotton yields for these households. This tendency is also observed for the maximum yields.
- The resource-rich households are represented in all four quadrants. This suggests that there are more ways of allocating the available means of production with consequent variable yields. Yet, most resource-rich households (66%) obtained mean yields which are located in the quadrants two and four.

It must be concluded that there was a structural relationship between cotton and sorghum yields, which found its origin in the socio-economic diversity of households. Yields of the major crops were not lineary inter-related, so the 'simple' hypothesis that high cotton yields are related to high rainfed sorghum yields was not confirmed. The relation was more complex than assumed, but could be understood through a non-linear analysis.

The majority of the resource-poor households obtained lower than average yields for cotton and rainfed sorghum. The resource-rich households showed a lower than expected frequency of this combination. This contrast proves that there is a determinism in the relation between resource endownment and crop yields. However, this does not imply that there are no ways to escape this determinism. It does not explain intra-class variations, nor does it highlight a non-determined situation, as was the case for the resource-rich households. This can be analysed by focusing on the production per household and on the allocation of the available resources over the economic activities. Moreover, insight in the intra-household relations is needed (see section 5.3).

5.2.3 Variation in household production

With respect to rainfed sorghum and cotton production, the resource-rich households produced about four times more than the resource-poor households. Because the former had twice as many workers in the family as

***Table 5.19** Production per class of Moundang household (1992/1993)*

production	resource-poor households (n=14)	resource-rich households (n=17)	2-tailed significance
production of rainfed sorghum (kg)[1]	1000	3600	< 0.001
net production of cotton (francs)[2]	9600	36300	< 0.1
production of mouskouari sorghum (kg)[1]	1100	2100	< 0.1
production of rainfed sorghum/worker (kg)	300	600	< 0.001
net production of cotton/worker (francs)	3200	5600	< 0.1
production of mouskouari sorghum/worker (kg)	400	400	-
production of rainfed sorghum/hour (kg)	2	4	< 0.001
net production of cotton/hour (francs)	15	29	< 0.1
production of mouskouari sorghum/hour (kg)	2	2	-
surplus of total sorghum (kg)[3]	700	3300	< 0.001
surplus of rainfed sorghum (kg)[4]	300	2400	< 0.001
surplus of mouskouari sorghum (kg)[4]	400	900	-
mean value of total sorghum surplus (francs)[5]	35000	165000	< 0.001

1) These production estimates include 10% losses due to transport and stockage, but exclude reduction of the available production due to gifts, reimbursements and payments to others.
2) Total production, as weighed by village agents and confirmed by the SODECOTON, expressed in CFA francs, minus the costs for seed, fertilisers and biocides.
3) Based on the FAO standard for yearly food consumption of 250 kg/consumer/year.
4) Based on a consumption period of 6 months of rainfed sorghum and 6 months of mouskouari sorghum, i.e. 125 kg/consumer/6 months.
5) Mean value of sorghum surplus is estimated at a mean price of 50 CFA francs/kg.

the latter, this is only because of the higher number of workers. From the results in Table 5.19 it can be concluded that also the production per worker and the production per working hour of the resource-rich households were two times more than of the resource-poor households. So, there was also a clear difference in labour return between the two classes of household.

With respect to mouskouari sorghum, the resource-rich households produced about two times more than the resource-poor households, corresponding to the difference in family labour. The production per worker and the production per hour were not significantly different between the two classes of household and it cannot be concluded that there was a difference in labour return.

47% of the total sorghum production of the resource-poor households was rainfed sorghum, while this was 66% for the resource-rich households. This implies that in the former, mouskouari sorghum production was more or less equally important as rainfed sorghum production. In the resource-rich households, rainfed sorghum production was more important than mouskouari sorghum production.

Animal husbandry and non-agricultural activities are sources of capital which have to be considered too. Results in Table 5.20 show that resource-rich households obtained six times more capital from animal husbandry than the resource-poor households. This was achieved through the trade of large livestock. Resource-rich households produced four times more capital with non-agricultural activities than the resource-poor households. Trade (78%) was the prime source of capital for the resource-rich households from these activities. Wood cutting (45%) and beer brewing (25%) were the prime source of capital for the resource-poor households from non-agricultural activities. From these results, it must be concluded that the resource-rich households dominate trade, while handicrafts, such as weaving of mats and beer brewing, are particular activities of the resource-poor households.

Results in Table 5.21 show that the resource-rich households produced four times more net capital than the resource-poor households. What strikes is that the proportional importance of the different sources of capital was similar for the two classes of household. For both classes, the sorghum surplus production in monetary terms contributed for about fifty percent to the total net capital production and was five times larger than capital from cotton production. Cotton production contributed for only about ten percent to the total net capital production, while non-agricultural activities contributed for more than twenty-five percent to it.

***Table 5.20** Sources of capital and value per class of Moundang household (1992/ 1993, in CFA francs)*

source of capital	resource-poor households (n=14)	resource-rich households (n=17)	2-tailed significance
total animal husbandry	6000	38000	< 0.05
sale of small livestock	4000	3000	-
sale of large livestock	2000	35000	< 0.01
total non-agricultural activities	20000	85000	< 0.05
beer brewing	5000	2000	< 0.05
weaving of mats	3000	0	< 0.001
wood cutting	9000	7000	-
trade	1000	67000	< 0.01
other activities	2000	10000	< 0.05

Remark: Capital produced with beer brewing is not independent from the estimated total sorghum surplus value. The two sources of capital cannot be aggregated without checking on overlap.

***Table 5.21** Proportional importance of different sources of capital per class of Moundang household (1992/1993, in CFA francs)*

	resource-poor households (n=14)		resource-rich households (n=17)	
source of capital	francs	%	francs	%
cotton production	9600	13	36300	11
sorghum surplus production	35000	50	165000	50
animal husbandry	6000	9	38000	12
non-agricultural activities	20000	28	87000	27
total net capital production	70600	100	326300	100

In 1992, sorghum surplus, i.e. the amount of sorghum available after family consumption, was the prime source of capital in both classes of household. However, before any conclusions can be drawn, the variation in sorghum surplus within each household class has to be considered.

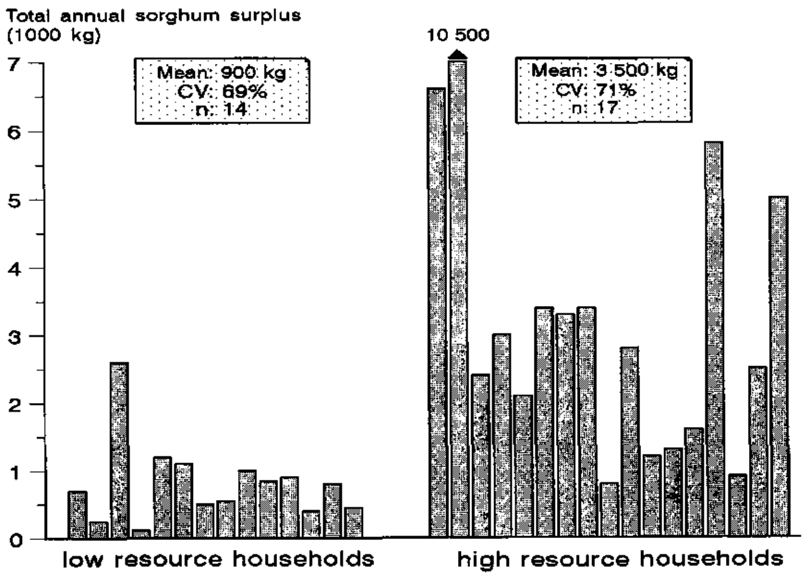
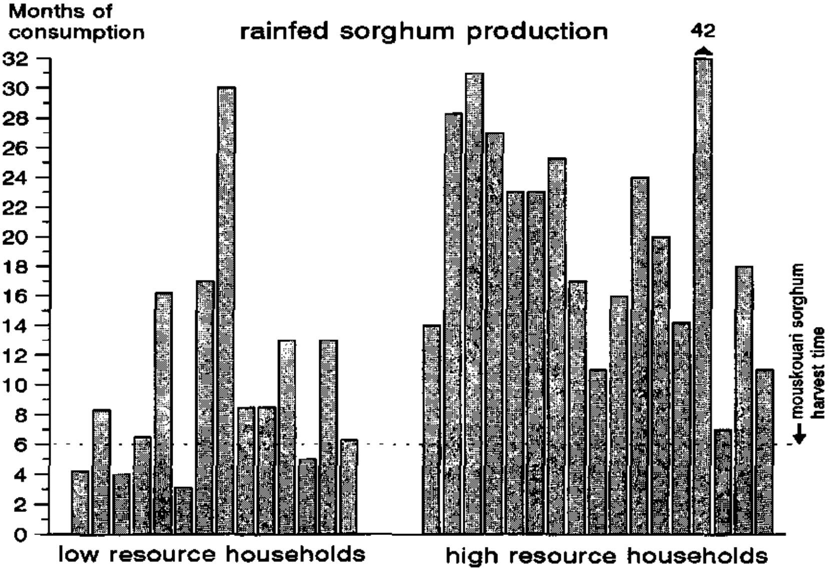


Figure 5.4 *Sorghum surplus distribution per class of Moundang household (1992/1993)*

The difference in sorghum surplus between the two classes was a difference of its *mean* and of its *range*. The surplus of resource-poor households ranged from 200 to 2 800 kg, while the surplus of resource-rich households ranged from 800 to 10 500 kg. This difference was because of a difference in rainfed sorghum surplus, and not because of a difference in mouskouari surplus (Table 5.19).

Figure 5.5 presents the potential number of months of consumption based on rainfed sorghum and mouskouari sorghum production.



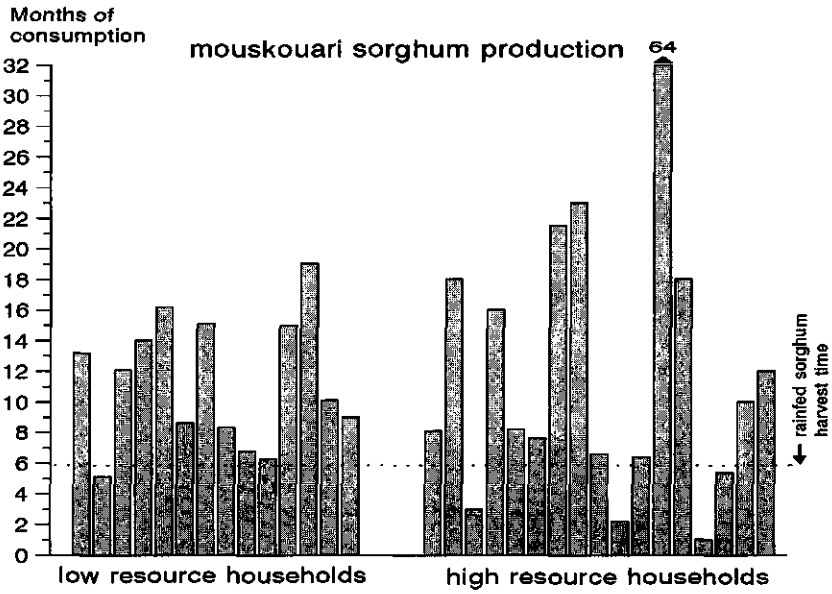


***Figure 5.5** Potential number of months of consumption based on rainfed sorghum and mouskouari sorghum production per class of Moundang household (1992/1993, in months)*

Figure 5.5 shows that rainfed sorghum production did not satisfy family consumption needs of the resource-poor households in four out of fourteen cases. In reality, this number was higher (i.e. seven out of fourteen, based on an end-of-campaign interview with the head of family). The available production was reduced considerably because of reimbursements of debts and selling of sorghum to raise cash for direct financial expenditure. All resource-rich households but one were self-sufficient by large, and some households would be able to feed the family for three years with their 1992 rainfed sorghum production.

Mouskouari sorghum production showed almost the opposite pattern: resource-poor households (but one) were self-sufficient for the next six months until the new season's rainfed sorghum harvest, and at least four resource-rich households having a deficit in mouskouari sorghum. In both classes of household, there were households which produced an important surplus of mouskouari sorghum.

It must be concluded that there were important differences in production between the classes of Moundang household. Mouskouari sorghum production was relatively more important in the resource-poor households than in the resource-rich households. Resource-poor households compensated a rainfed sorghum shortage with a mouskouari sorghum surplus, while the resource-rich households did the inverse. In both classes of household, sorghum surplus is the prime source of capital, followed by trade in the resource-rich households, and by wood cutting and beer brewing in the resource-poor households. Cotton only played a marginal role as a source of capital.

5.2.4 Production strategies

Allocation of land

In Table 5.22 the allocation of land per household class is preseneted.

Table 5.22 *Allocation of land per Moundang household class (1992/1993)*

cultivated area	resource-poor households (n = 14)	resource-rich households (n = 17)	2-tailed significance
total cultivated area (ha)	2.8	5.4	< 0.005
rainfed sorghum area (ha)	0.8	1.8	< 0.005
cotton area (ha)	0.4	1.1	< 0.001
mouskouari sorghum area (ha)	1.6	2.5	< 0.1
total cultivated area/worker (ha)	1.0	1.0	-
rainfed sorghum area/worker (ha)	0.3	0.3	-
cotton area/worker (ha)	0.1	0.2	< 0.1
mouskouari sorghum area/worker (ha)	0.6	0.5	-
percentage rainfed sorghum on total area (%)	30	34	-
percentage cotton on total area (%)	12	21	< 0.05
percent. mouskouari sorghum on total area(%)	58	45	< 0.05
percent. rainfed sorghum on rainfed area (%)	74	62	-

In absolute sense, the resource-rich households cultivated more land of each crop than the resource-poor households. However, the culivated land per worker ratio only differed between the two classes of household with respect to cotton. The proportional distribution of the land over the three considered crops within each household class shows the relatively great importance of mouskouari sorghum in the resource-poor households and of cotton in the resource-rich households. This may be considered as a difference of importance of the unmechanised versus the mechanised crop. The proportional distribution of land over the two rainfed crops shows that the resource-poor households did not allocate more rainfed cultivated land to sorghum than the resource-rich households.

The following table shows the proportional distribution over field types of the production of rainfed sorghum:

***Table 5.23** Proportional distribution of rainfed sorghum production over field types per Moundang household class (1992)*

percentage of total production	resource-poor households (n = 14)	resource-rich households (n = 17)	2-tailed significance
production in first field type (0 - 0.1 km) (%)	28	35	-
production in second field type (0.1 - 0.6 km) (%)	9	21	< 0.1
production in third field type (1.0 - 6.0 km) (%)	63	44	< 0.05

The resource-poor households produced most rainfed sorghum production in the third field type. In contrast, the resource-rich households produced most rainfed sorghum production in the first and second field types. Production on these fields was suffcient to feed the family for more than six months. As a consequence, all production in the third field type was surplus. This cannot be argued for the resource-poor households, for which production in the first and second field types was largely insufficient to satisfy family consumption demands. The third field type is essential for basic food production in the households of this class.

Allocation of labour

The total labour input per worker and the labour input per worker in rainfed sorghum were not significantly different between the two classes (Table 5.24). However, the resource-rich households spent significantly more labour time per worker on cotton production than the resource-poor households. On the contrary, the resource-poor households spent significantly more labour time per worker on mouskouari production. The same pattern is shown by the proportional distribution of labour time (Table 5.25). In accordance with the allocation of land, this contrast may be considered as a difference of importance of the unmechanised crop versus the mechanised crop. However,

***Table 5.24** Allocation of labour in agriculture per class of Moundang household (1992/1993)*

labour input	resource-poor households (n = 14)	resource-rich households (n = 17)	2-tailed significance
total labour input (hours)	1760	2970	< 0.01
labour input in rainfed sorghum (hours)	500	860	< 0.01
labour input in cotton (hours)	480	1080	< 0.05
labour input in mouskouari sorghum (hours)	780	1030	< 0.1
total labour input per worker (hours)	520	510	-
labour input per worker in rainfed sorghum (hours)	150	170	-
labour input per worker in cotton (hours)	140	190	< 0.05
labour input per worker in mouskouari sorghum (hours)	230	180	< 0.05
percentage rainfed sorghum labour input on total (%)	28	29	-
percentage cotton labour input on total (%)	27	36	< 0.05
percent. mousk. sorghum labour input on total (%)	45	35	< 0.05
percentage rainfed sorghum labour input on total rainfed labour input (%)	51	44	-

Remark: It was not feasable to measure labour input in animal husbandry and in non-agricultural activities at a satisfying level of accuracy.

***Table 5.25** Proportional importance of non-family labour per Moundang houshold class (1992/1993)*

percentage non-family labour	resource-poor households (n = 14)	resource-rich households (n = 17)	2-tailed significance
percentage non-family labour of total labour input (%)	5	15	< 0.05
percentage non-family labour of rainfed sorghum labour input (%)	0	3	-
percentage non-family labour of cotton labour input (%)	11	23	< 0.05
percentage non-family labour of mouskouari sorghum labour input (%)	5	17	< 0.05

the proportional distribution of labour over the two rainfed crops was not significantly different between the two classes of household.

With the exception of rainfed sorghum, the resource-rich households employed more non-family labour than the resource-poor households. Because of non-family labour, resource-rich households had fifteen percent more labour force than could be expected on the basis of their family composition. Almost one quarter of total labour input in cotton production in these households originated from sources outside the family. The *labour intensive cotton production* of the resource-rich households appears to be in the first place a *capital intensive production*. Moreover, the lower labour input in mouskouari production of these households is accentuated by the relatively high proportion of non-family labour. Their mouskouari sorghum production is not only relatively *labour extensive*, but also *capital intensive* because of the investment in non-family labour. Although rainfed sorghum production generates an important marketable surplus, it remains a *capital extensive production* for both classes of household. This is because of the fact that (a) this production is *partially land intensive* (i.e. in the first field type) and that (b) there is another important household level effect, i.e. gender differences, that interfers with the household strategy (see section 5.3).

Allocation of capital

The allocation of capital can be understood by means of measurement of the expenditure on inputs and of the employment of ploughs and oxen for crop production.

Table 5.26 shows that during the 1992/1993 campaign, resource-rich households invested more than 50 000 CFA francs in inputs, which is about five times more than the resource-poor households. The proportional expenditures (per worker, per hectare) were also significantly higher in the resource-rich households, which spend the greater part on labour. It can be argued that family labour was substituted by capital, because total labour input per worker was not significantly larger for this class of households. The consequence was that family members had more time for other activities, which may be income-generating, such as trade. Another consequence was that on moments of important labour demand (such as periods of ploughing and sowing), the household had a very important pool of workers at its disposal. This resulted in correct timing and fast execution of important cropping practices.

***Table 5.26** Expenditure on inputs per class of Moundang household (1992/1993, in CFA francs)*

expenditure on inputs	resource-poor households (n=14)	resource-rich households (n=17)	2-tailed significance
expenditure on labour (francs)	4100	33100	< 0.001
hired labour (francs)	400	20200	< 0.001
working parties (francs)	3700	6400	-
labour versus equipment exchange[1] (francs)	0	6500	< 0.005
expenditure on fertilisers (francs)	5400	15200	< 0.01
expenditure on biocides (francs)	1200	3100	< 0.05
total expenditure on inputs (francs)	10700	51400	< 0.005
total expenditure on inputs per worker (francs)	3100	8900	< 0.01
total expenditure on inputs per hectare (francs)	3800	9500	< 0.01
percentage of labour expenditure on total exp. (%)	38	64	< 0.01
percentage of fertiliser expenditure on total exp. (%)	51	30	< 0.01
percentage of biocide expenditure on total exp. (%)	11	6	-

[1] Expressed in monetary value equivalent to hired labor (i.e. 3 000 francs per quarter hectare)

The resource-poor households spent half of their expenditure on fertilisers. This is in accordance with the importance of the third field type in these households. Especially in this field type, fertiliser use plays an important role in postponing the moment the field has to be put fallow and a new field has to be cleared, which is labour intensive. This confirms the impression that these households tend to replace their most scarce resource, i.e. labour, by a less scarce resource, i.e. fertilisers on credit.

Ploughs and oxen can be considered as capital goods which can be employed for productive purposes. Their use is mostly limited to ploughing of fields in the rainfed cropping system.

Table 5.27 *Employment of ploughs and oxen per crop per class of Moundang household (1991/1992)*

	resource-poor households	resource-rich households	2-tailed significance
percentage of rainfed sorghum area ploughed (%)	55	75	< 0.05
percentage of cotton area ploughed (%)	100	100	-

The resource-poor households employed ploughs and oxen on half of the rainfed sorghum area and on all cotton area, despite that they did not own them. The way to obtain these resources is submission to a system of 'patronising'. In this system, ploughs and oxen of a resource-rich household are exchanged for manual labour of a resource-poor household. In most cases, the terms of exchange are defined by the resource-rich household which obtains extra labour input at moments of relative scarcity. Because the farmers in these households dictate the terms and moments of exchange, farmers of the resource-poor households often refer to them as their boss (*'patron'*).

5.2.5 Synthesis and discussion

With respect to rainfed sorghum production, the resource-rich households have higher mean yields and higher return to labour than resource-poor households. The reason for this difference is the unequal access to the means of production: land (i.e. quality of the land) and capital (i.e. equipment and cattle). The resource-rich households dominate in the fertile sandy-clay soils, as well as in the class of nearby fields and they have almost all available manure at their disposal. In this semi-mechanised rainfed cropping system, where fallow plays a minor role in two out of three field types, productivity per worker is higher when access to soil fertility and equipment is better. It is therefore the high intensity of land use, equivalent to the first field type, that results in high labour return. Accordingly, the resource-rich households are able to produce a rainfed sorghum surplus that is six times more than that of the resource-poor households, although the cultivated area per worker is similar for the two classes.

With respect to cotton production, the resource-rich households do not obtain higher mean yields than the resource-poor households. However, the former have four times the income from cotton and a higher return to labour (per worker and per hour) than the latter. This is because of a larger area of cotton per worker and to the good access to the means of production labour and capital (equipment and non-family labour). Through optimal timing of cropping practices, the same yield level as in the resource-poor households is obtained with less labour input.

The two classes of household do not differ in yield or labour return with respect to mouskouari sorghum production. This is basically because the cropping system is not mechanised. The result is that the two classes of household have a comparable surplus per worker, but that its relative importance in the total production of sorghum is greater for the resource-poor households than for the resource-rich households.

With respect to its relative importance, it can now be argued that rainfed sorghum and cotton are crops specific to resource-rich households and that mouskouari sorghum is specific to resource-poor households. Cotton is not a major source of income in either class of household. However, it is important because its cultivation is functional to the rainfed cropping system as a whole: through the acquisition and use of fertilisers and through the possibility of crop rotation, which is of special relevance to the distant field type. In the short term and from the farmers' perspective, it benefits the management of the soil fertility. Because this field type is relatively more important for the resource-poor households, it may be stated that these indirect effects of cotton production are even more essential to them than to the resource-rich households.

Within the Moundang farming system, the different crops and income-generating activities are related by flows of goods, cash and production. These relations are presented in Figure 5.6.

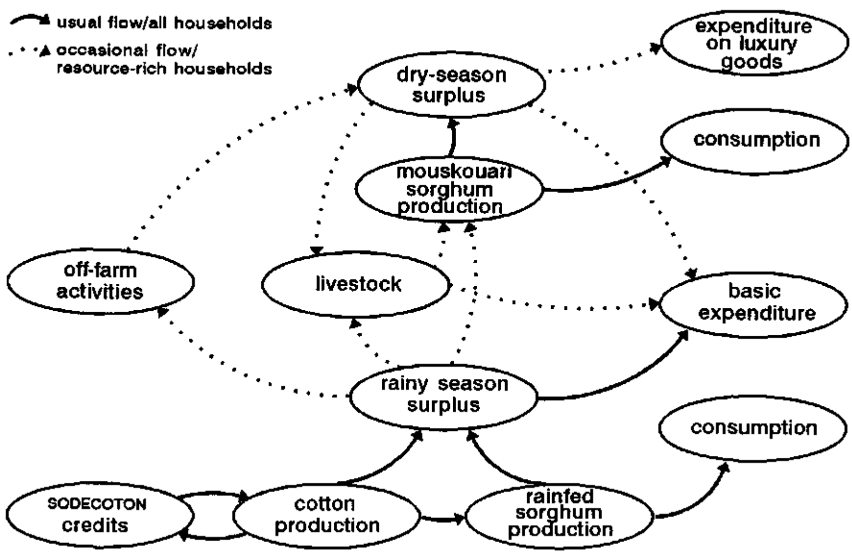


Figure 5.6 *Basic model for goods, cash and production flows in the Moundang farming system*

SODECOTON gives credit for fertilisers and biocides, based on the area under cotton cultivation. Any farmer wishing to use fertilisers for rainfed sorghum production, has to grow cotton. This credit is reimbursed after the cotton production has been sold. If the production of rainfed sorghum is more than the household expects to consume until the mouskouari harvest, it joins the net cotton income in contributing to the surplus produced by the rainfed cropping system. The resource-poor households use this rainfed season surplus for basic expenditure, such as reimbursements of debts and payment of taxes, school fees and clothes. It can also be used for investments in small livestock or for less productive purposes, such as drinking beer and travelling. If this surplus is not sufficient, small livestock are sold to raise cash for basic expenditure.

Resource-rich households use their surplus for investments in large livestock or in trade. Moreover, it becomes the productive capital for mouskouari production. Using money raised by selling the surplus of the rainy season, or indirectly by selling livestock obtained with the surplus from earlier years, labour is hired to clear and plant the mouskouari fields. The mouskouari sorghum produced enables family consumption to be satisfied for the next six months, until the new season's harvest of rainfed sorghum. If a dry season surplus remains, it is used for basic expenditure or, as is often the case for the resource-rich households, for investment in cattle or in luxury goods, such as the constructing of a brick house.

Small livestock and non-agricultural activities (such as handicrafts and beer brewing) are important as a source of surplus production for the resource-poor households. In times of hardship, these sources provide the family with capital to buy food. It may be stated that they make the household less dependent on agriculture and therefore less vulnerable to climatic influences and external sources of crop damage.

The interactions between the different elements of the farming system are functional, but not constant and identical for both classes of household. Whereas the surplus production of the resource-poor households is basically *reproductive,* it constitutes the *productive* capital for the resource-rich households. Within this class, great flexibility and individuality can to be observed in how the available means of production are allocated over the different productive activities. Some prefer trade to livestock, others focus on rainfed sorghum production or prefer to cultivate cotton rather than mouskouari. These preferences may even change from year to year. Within the main strategy of *capital generation through capital investment,* it is essential that many activities are possible. This intra-class diversity is characteristic ofr the strategy of the resource-rich households. In contrast, the strategy of the resource-poor households is mainly focused on *survival through flexible use of the available family labour.* In agriculture of this class of household, only family labour is used. At home, the family members continue with activities such as handicrafts and beer brewing. In the final resort, if food is really short and the small livestock have been sold, the people borrow food and repay in the form of labour, or sell their labour directly to the resource-rich households. This also explains the relative importance of the mouskouari sorghum, the unmechanised crop. Because of the absence of productive capital, these households hardly evolve to a higher level of production and remain in a situation of economic insecurity. If a resource-poor household evolves to the class of resource-rich households, this is always due to a primary capital investment from an *external source,* such as a family member who is working in town, a development project or the Catholic or Protestant mission.

When two socio-economic classes with unequal access to the means of production exploit a similar environment, yield and production variations because of variable use of land, labour and capital may occur. This socio-economic diversity largely determines present agricultural and non-agricultural production, as well as the prospects and constraints for future development.

5.3 Gender differences

In the previous sections, ethnic and socio-economic diversity have been identified as important sources of agrodiversity and subsequent variations in yield and production. Now, the null hypothesis can be formulated that under similar environmental conditions, within one ethnic group, and within one socio-economic class, there will be a high degree of homogeneity in yields and production. In this chapter, this hypothesis will be tested for the male and female farmers in the village of Gaban.

In agricultural research and extension, as well as in many rural development projects, differences between male and female farmers are often ignored, or generalised (Poats et al. 1988). Ignorance implies that the household is considered as a homogeneous unit of production and consumption in which the different members strive to realise the goals of the family through collective efforts. In contrast, generalisation of gender differences means that all male and female farmers are considered as uniform groups with opposing goals and competitive demands on the available means of production. In this chapter, gender differences with respect to fields, yields and means of production will be analysed and described with the objective to be able to make statements about the role of gender differences and their effects on yield and production in a single agroecosystem. The following alternative hypotheses were formulated:

(1) Yields and production are not uniformly distributed between the gender categories.
(2) Means of production are not equally distributed between the gender categories.
(3) Differences in access to the means of production results in variations in yield and production between the gender categories.

Based on sections 5.1 and 5.2, where structural differences in production and in the availablity of means of production were found between ethnic groups and between household classes, these hypotheses had to be tested for six gender categories: Toupouri male and female farmers, resource-poor Moundang male and female farmers and resource-rich Moundang male and female farmers.

Comparing gender categories with respect to their access to the means of production at household level is only feasible if all activities of all participants are measured. If only certain activities are recorded, as in this study only agricultural activities, absolute statements about the distribution of the means at household level will be difficult to make. A consequence is that a comparison between gender categories cannot be made in analogy with a comparison of ethnic groups or socio-economic household classes. Therefore, other, relative criteria are needed that give information about the actual use of and access to the means of production of the different gender categories. If the goal is to understand intra-household diversity, one has to focus on the *competitive demands on the same limited means of production at the same time*. This is the case at field level, where precise measurements of the use of the means of production took place. The actual use of these means at field level is considered as a function of the access to the necessary means of production of the individual male and female farmers at household level. Accordingly, specific field variables were treated as proxies of specific gender characteristics. In Table 5.28, the field variables with their 'translation' to the higher level of analysis, are presented.

5.3.1 Distribution of fields and yields

The results in Table 5.29 show that a large majority of all female farmers (80%), both Moundang and Toupouri, cultivated at least one field of rainfed sorghum. Toupouri female farmers did not cultivate cotton. A minority of them (30%) cultivated mouskouari sorghum, but these female farmers were

Table 5.28 *Field variables as proxies of farmer characteristics*

field variable	farmer characteristic
yield	production volume and labour productivity
number and area of fields distance from the homestead soil texture in percentage 'sandy-clay' of total area	access to land (quantity and quality)
manure application per hectare fertiliser application per hectare	access to fertility and capital inputs
percentage ploughed of total area	access to mechanisation and capital goods
mean date of sowing mean date of first weeding total number of weedings mean daily number of workers labour input per hectare	access to labour

from only three, polygamic households. A minority of the Moundang female farmers (25%) cultivated cotton and only a few of them cultivated mouskouari sorghum. Within the categories of Moundang female farmers, all resource-rich female farmers cultivated a field of rainfed sorghum, versus only one half of the resource-poor female farmers. 40% of the resource-rich female farmers produced cotton, compared to not one resource-poor woman farmer. These absolute differences imply that a comparison of field characteristics between the six farmer categories can only be made with respect to rainfed sorghum.

Table 5.30 shows the mean rainfed sorghum yields of the six gender categories in 1992. A oneway analysis of variance (with multiple range test and SPSS Tukey-B procedure for testing of group differences at $\alpha < 0.05$) on gender differences in yield showed that all mean yields per category

Table 5.29 *Field distribution per gender category (1992)*

		Toupouri		resource-poor Moundang		resource-rich Moundang	
	total no. of fields in sample	female farmers (n = 24)	male farmers (n = 15)	female farmers (n = 13)	male farmers (n = 13)	female farmers (n = 23)	male farmers (n = 18)
rainfed sorghum fields	137	20	27	6	24	22	38
cotton fields	52	0	9	0	12	9	22
mouskouari sorghum fields	72	8	16	2	16	3	27

Table 5.30 *Rainfed sorghum yields per gender category (1992)*

	Toupouri		resource-poor Moundang		resource-rich Moundang	
	female farmer fields (n = 20)	male farmer fields (n = 27)	female farmer fields (n = 6)	male farmer fields (n = 24)	female farmer fields (n = 22)	male farmer fields (n = 38)
rainfed sorghum mean yield (kg/ha)	3700	2700	1800	1800	1600	2700
rainfed sorghum minimum yield (kg/ha)	2200	1100	700	200	700	700
rainfed sorghum maximum yield (kg/ha)	5300	4400	5000	4700	4500	5500

differed significantly, except for the difference between the Toupouri and Moundang resource-rich farmer categories. In other words: highest rainfed sorghum yields were obtained on the fields of Toupouri female farmers and lowest yields on the fields of Moundang female farmers. T-tests on the significance of gender category differences (see also Tables 5.31, 5.32, and 5.33) showed that:

- Toupouri female farmers had higher yields than Toupouri male farmers;
- Resource-poor Moundang male and female farmers did not differ in yield;
- Resource-rich Moundang female farmers had lower yields than resource-rich Moundang male farmers.

Figure 5.7 (page 172) shows the distribution of yields of the sample fields per gender category. These results show that not only the mean, but also the lower and higher limits of the 90% yield-interval were considerably higher on the fields of the Toupouri female farmers compared to the fields of the other gender categories. The limits of the 90% yield-interval of the resource-rich Moundang female farmer fields were at one and two tons per hectare, and their yields may be considered as uniformly low.

It must be concluded that fields of the three major crops and yields of rainfed sorghum were not uniformly distributed among the different gender categories. Stratification of the fields on the basis of the origin of the male and female farmers showed significant differences in rainfed sorghum yields among the six categories identified. This variation in yield included differences between male and female farmers, as well as differences between female farmers of different ethnic and household origin.

5.3.2 Distribution of means of production

A comparison of field characteristics was made with respect to the rainfed sorghum fields of the six gender categories. Differences between fields of male and female farmers were tested on their significance with a t-test within each ethnic group and class of household .

Toupouri gender categories

The results in Table 5.31 show that in 1992 the yields were higher on the Toupouri female farmer fields than on the Toupouri male farmer fields. This could be explained by a better land quality, by an earlier sowing date and by a higher labour input of the women's fields. Fields of the male farmers were better fertilised and the daily number of workers was higher on these fields. These differences were not reflected in the production per working hour, which was about similar between the fields of the two Toupouri gender categories.

Translating these field characteristics to farmer characteristics, it may be concluded from the results in Table 5.31 that female farmers have access to land of good quality and that male and female farmers have almost similar access to fertility and capital inputs. They have also similar access to mechanisation, but the access to labour differs between the two gender categories. Female farmers had fewer family workers at their disposal, but the total labour input on their fields was twice as high as on the male farmers' fields. This was because Toupouri women are not obliged to work on their husbands' rainfed fields. During the rainy season, a Toupouri woman almost only works on her own field, assisted incidently by her husband for particular cropping practices, such as ploughing. Because she has no other fields, her single field obtains extremely high labour inputs, which is reflected in very high yields, but also in relatively low production-to-labour return. This apparent equality between Toupouri male and female farmers must be interpreted within the context of the household and the specific roles of the sexes. In the Toupouri community, women are obliged to feed the family for six months until the mouskouari harvest. Men provide food for the following

***Table 5.31** Rainfed sorghum field characteristics per Toupouri gender category (1992)*

	Toupouri households		
field characteristic	fields of female farmers (n=20)	fields of male farmers (n=27)	2-tailed significance
yield	3700	2700	< 0.001
distance from homestead (km)	0.1	0.4	< 0.05
average field area (ha)	0.53	0.56	-
% 'sandy-clay' soil of total field area	38	13	< 0.001
amount of manure (kg/ha)	800	400	-
amount of urea (kg/ha)	3	11	< 0.1
% ploughed of total area	65	61	-
mean date of sowing[1)]	25	31	< 0.05
mean date of first weeding[2)]	27	27	-
number of weedings	2.0	1.8	-
mean daily number of workers	1.8	2.5	< 0.01
labour input (hours/ha)	1450	740	< 0.01
production per working hour (kg/hour)	3.9	4.2	-

[1)] days after 1st of May
[2)] days after mean sowing date

six months until the harvest of rainfed sorghum. This implies that Toupouri female farmers cannot use their own sorghum production freely. The obligation to feed the family is well visualised when one visits a Toupouri family during dinner time: the head of the family is offered as many dishes as the number of women he has married. Consequently, female farmers can only use freely the (eventual) sorghum surplus after family consumption while, in contrast, their husbands can do what they want with their rainfed sorghum production. However, the husbands have the obligation to provide their wives with the necessary means, so that they are able to meet their responabilities. This explains why the distribution of the means of production during the rainy season is more or less equal between the sexes. It also explains why the labour input on the fields of female farmers was so extremely high.

Resource-poor Moundang gender categories

The results in Table 5.32 show that only half of the resource-poor Moundang female farmers cultivated a rainfed sorghum field of their own. These fields were smaller in area than the fields of their husbands. This was the only difference between the fields of the two gender categories. All other input levels and practices were equal, which resulted in a similar low production-to-labour return.

Table 5.32 *Rainfed sorghum field characteristics per resource-poor Moundang gender category (1992)*

	resource-poor Moundang households		
field characteristic	fields of female farmers (n = 6)	fields of male farmers (n = 24)	2-tailed significance
yield	1800	1800	-
distance from homestead (km)	1.4	2.2	-
average field area (ha)	0.22	0.38	< 0.01
% 'sandy-clay' soil of total field area	29	38	-
amount of manure (kg/ha)	300	200	-
amount of urea (kg/ha)	3	9	-
% ploughed of total area	50	56	-
mean date of sowing[1]	34	28	-
mean date of first weeding[2]	33	33	-
number of weedings	1.5	1.6	-
mean daily number of workers	2.3	2.2	-
labour input (hours/ha)	850	670	-
production per working hour (kg/hour)	2.2	3.1	-

[1] *days after* 1^{st} *of May* [2] *days after mean sowing date*

All agricultural production in the resource-poor households obtained on the fields of male and female farmers is used for family consumption and for basic family expenses. In fact, with respect to this collective use of the production for family survival, a classification of the fields according to the gender criteria, seems not to be relevant. Male farmers nor female farmers have any choice how to use the produced sorghum. The main objective of production, i.e. family survival, is determined by the often critical economic situation, and not by individual freedom of choice. This was confirmed by the fact that female farmers in resource-poor households did not cultivate cotton and hardly any mouskouari sorghum. It must be concluded that all available means of production, such as family labour, are employed for the benefit of the day-to-day survival of the family. However, in most cases, it is the male farmer who decides about their use for agricultural production.

Resource-rich Moundang gender categories

In contrast to the resource-poor male and female farmers, field characteristics of resource-rich male and female farmers differed considerably (Table 5.33). Female farmers' fields were smaller in area than male farmers' fields but the proportion of the relatively fertile 'sandy-clay' soil of the total field area was similar between the two sexes. Nevertheless, only two out of twenty-two female farmers' fields (i.e. 9%) was located in the first field type, compared to fourteen out of thirty-eight male farmers' fields (i.e. 38%). The majority (68%) of the female farmers' fields was located far away, in the thirth field type, compared to only 34% of their husbands' fields. The fields from female farmers were less fertilised with manure, were less frequently ploughed and were sown later than the fields of male farmers. Moreover, the female farmers had fewer workers at their disposal than their husbands, which was not reflected in the total labour input. The amounts of urea applied were similar between the fields of the two gender categories.

Table 5.33 *Rainfed sorghum field characteristics per resource-rich Moundang gender category (1992)*

	resource-rich Moundang households		
field characteristic	fields of female farmers (n=22)	fields of male farmers (n=38)	2-tailed significance
yield	1600	2700	< 0.001
distance from homestead (km)	3.1	1.6	< 0.01
average field area (ha)	0.37	0.63	< 0.01
% 'sandy-clay' soil of total field area	35	37	-
amount of manure (kg/ha)	700	1900	< 0.1
amount of urea (kg/ha)	21	23	-
% ploughed of total area	64	81	< 0.1
mean date of sowing	34	27	< 0.05
mean date of first weeding	32	29	-
number of weedings	1.6	1.6	-
mean daily number of workers	2.5	3.4	< 0.01
labour input (hours/ha)	530	560	-
production per working hour (kg/hour)	3.7	5.2	< 0.01

1) days after 1st of May
2) days after mean sowing date

It must be concluded that the resource-rich Moundang male farmers dominate the land, which is reflected by larger and more numerous fields in the best field type. They dominate also the use of the available manure and they use more frequently mechanisation than the female farmers. However, Moundang female farmers use similar quantities of urea, a capital input. They have access to it because they cultivate cotton or have other sources of monetary income. Female farmers obtain less labour from the family than their husbands, but they control their own labour.

In contrast to the Toupouri women, Moundang women do not have the obligation to feed the family. They may use their own production autonomously, as long as the economic situation of the household is not critical, as is the case in most resource-poor households. Often, resource-rich Moundang women sell their sorghum or stock it to sell it later during the year, when prices are higher. Moundang women are also not obliged to work on the fields of their husbands. The husband is formally obliged to ask her and often, labour is equally exchanged between the two sexes. There are examples of husbands paying their wifes for their labour. The husbands' responsability to feed their families explains at least partially why the farmers dominate over most means of production.

Male dominance over the means of production is not only limited to the cultivation of food crops. All Moundang farmers cultivated at least one cotton and one mouskouari field. These crop productions make it possible for male farmers to obtain surplus from agriculture. Male dominance over the means of production is not only a way to satisfy the needs of the family, but is also a way to achieve individual surplus accumulation.

5.3.3 Variations in production

Besides field characteristics and yield levels, a criterion of gender differences in the agroecosystem is variation in annual production and in the importance of the different sources of capital. Table 5.34 shows the annual capital production per source and per gender category. Based on the results in this table, the gender differences in economic activities and production can be summarised as follows:

The Toupouri gender categories. Toupouri male farmers produced most capital of all six gender categories if all sorghum surplus is expressed in monetary terms. In real, their income will be considerably lower because of the tradition of free beer drinking after the harvest. Although female farmers must feed the family for six months, they still had a considerable income from sorghum. However, it must be assumed that the amount of their

Table 5.34 Sources of capital and their mean value per gender category (1992)

annual capital production in CFA francs	Toupouri female farmers (n=24)	Toupouri male farmers (n=15)	resource-poor Moundang female farmers (n=13)	resource-poor Moundang male farmers (n=13)	resource-rich Moundang female farmers (n=23)	resource-rich Moundang male farmers (n=18)
sorghum surplus production value	55000	200000	45000		35000	100000
net cotton production	0	4700	9600		7000	29600
sale of small livestock	0	8000	1000	3000	1000	1000
sale of large livestock	0	24000	0	2000	5000	30000
total non-agricultural activities	21000	14000	16000	4000	34000	36000
beer brewing	17000	0	5000	0	2000	0
weaving of mats	0	6000	0	3000	0	0
wood cutting and timber selling	0	0	9000	0	7000	0
trade	1000	6000	1000	0	23000	38000
other activities	3000	2000	1000	1000	2000	8000

Remarks and assumptions:

- Every household needs (250 * number of consumers) kilograms of sorghum to feed the family.
- Every Toupouri female farmer supplies the family with (125 * number of consumers/number of wifes) kilograms of sorghum. Every Toupouri male farmer feeds his family during the following six months.
- The price of one kilo of sorghum is estimated at 50 CFA francs.
- Resource-poor Moundang male and female farmers use their production for the benefit of the family and do not have systematic individual surplus from agriculture.
- Resource-rich Moundang female farmers do not have the obligation to supply food to the family. All agricultural production is considered as surplus.
- Capital from beer brewing may partly overlap with the value of sorghum surplus.
- Capital from livestock sale may be used as productive capital for agricultural production.

sorghum surplus is highly variable over the years, depending on the climatic conditions. Beer brewing was the most important non-agricultural activity of female farmers and animal husbandry was a uniquely male activity. Capital from cotton production was of marginal importance to both gender categories.

The resource-poor Moundang gender categories. On a yearly basis, male and female farmers produce together enough food and capital for family survival under favourable climatic conditions, such as in 1992. However, basic family needs may not be satisfied under less favourable conditions, or in situations of high monetary expense (such as hospitalisation) or indebtness. Women's capital from non-agricultural sources was much higher than from men. Especially timber selling was of considerable importance. Animal husbandry and trade were of marginal importance to both gender categories. Male farmers had few other capital-generating activities outside agriculture.

The resource-rich Moundang gender categories. Male farmers obtained a high surplus from crop production, in spite of their responsability to satisfy basic family needs. Both sorghum and cotton production provided the male farmers with a considerable amount of capital. Trade was the second, and sale of large livestock was the third source of capital for male farmers. Capital from non-agricultural activities was of equal importance to both gender categories. Female farmers obtained most capital from sorghum surplus production and from trade.

5.3.4 Synthesis and conclusions

Table 5.35 presents a synthesis of previous results and interpretations. It must be concluded that the access to the means of production is very variable between the gender categories. Women's access largely depends on their ethnic origin and class of household. However, women's control over the means of production is rare irrespective of their category. In both ethnic

***Table 5.35** Access to and control over means of production per gender category*

	Toupouri		**resource-poor Moundang**		**resource-rich Moundang**	
	female farmers	male farmers	female farmers	male farmers	female farmers	male farmers
access to good land	yes	yes	no	no	no	yes
control over land	no	yes	no	yes	no	yes
access to labour	yes	yes	no	yes	yes	yes
control over labour	partially	yes	partially	yes	partially	yes
access to mechanisation	yes	yes	no	yes	yes	yes
control over mechanisation	no	yes	no	no	no	yes
access to capital	yes	yes	yes	marginal	yes	yes
control over capital	yes	yes	yes	no	yes	yes
responsability for food production	6 months	6 months	collective	collective	no	yes
surplus from crop production	under favourable conditions	yes	no	under favourable conditions	yes	yes
surplus from animal husbandry	no	yes	no	no	marginal	yes
surplus from non-agricultural activities	yes	yes	yes	little	yes	yes

groups and household classes, men decide how available means of production should be distributed, except in the case of women's own labour and capital. The main income-generating activities of women are in women's domains of the economy, such as beer brewing and timber selling, and only in the case of resource-rich Moundang households are they in a general domain such as trade. Animal husbandry is a uniquely male domain. In short, the basic elements of the female farmers' strategies can be synthesised as presented in *Figure* 5.8.

Toupouri female farmers must produce sorghum for the family. Their husband gives them the necessary means of production for that particular purpose. To obtain some private income, female farmers invest extra labour time in sorghum production to obtain a surplus. This sorghum is processed into beer to make some more profit from it. The two sources of capital are closely related: if there is no sorghum surplus, there will be no beer brewing and selling and no income.

Resource-poor Moundang female farmers have no individual interest in agriculture. All family members work collectively to feed the family. Female farmers obtain some income from a diverse set of non-agricultural activities, which are often the major source of capital for the total household.

Resource-rich Moundang female farmers own and control fewer means of production than their husbands. However, because these women have no obligation to feed the family, all agricultural production is surplus. They may freely employ their own labour force and have access to capital and capital inputs because they have their own revenue from non-agricultural activities. They are often engaged in very lucrative trade. Many of the female farmers invest capital in order to generate capital.

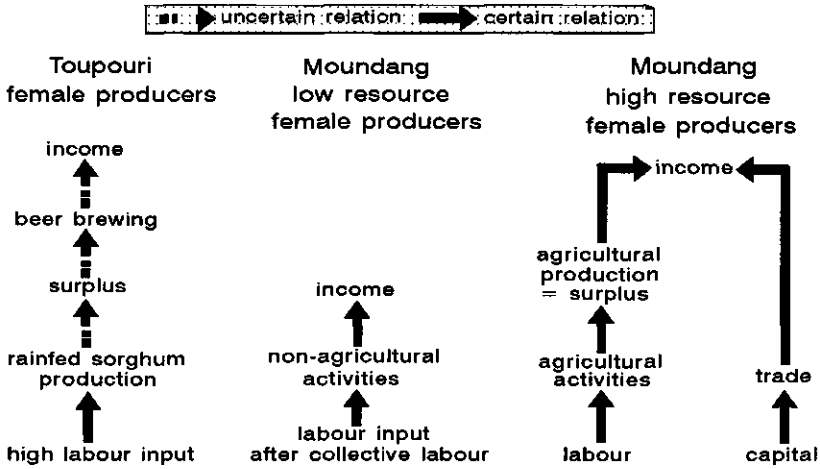


***Figure 5.8** Presentation of basic production strategies of female farmers*

Own labour is the major means of Toupouri female farmers to generate a surplus. Besides own labour, own capital is also extremely important to the resource-rich Moundang female farmers. This contrast implies that the rationality of production strategies differs radically between the two categories. Toupouri female farmers are very dependent on the climatic conditions and only produce surplus, and income from beer brewing, under favourable circumstances. Commercial activities depend on other factors, related to the market, and seem to be more flexible, providing the resource-rich Moundang female farmers with a more or less stable income. Resource-poor Moundang female farmers use the only means of production they control, i.e. their own labour *after working on the collective fields*, for activities that generate extra value from labour investment, such as wood cutting and beer brewing.

An important consideration arising from these differences in access to the means of production and subsequent contrasting production strategies, is that the gender criteria cannot be applied without other criteria of stratification, such as resource endownment or ethnic origin of the household. The female farmers of the village of Gaban cannot be considered as belonging to one uniform category. Moreover, the prospects for development of each particular category differs considerably. Anyone who has the objective to support 'rural women' has to analyse their particular situations and prospects within the context of their diversity. If gender categories are not distinguished on the basis of mutuality with respect to their socio-economic situation, their goals and their perspectives, any intervention in the sphere of income-generating activities is doomed to failure.

Within a similar environment, gender differences may cause important variations in yield and production. However, if ethnic and/or socio-economic diversity is important, gender differences cannot be regarded as an independent phenomenon, but may be specific for an ethnic group or a household class.

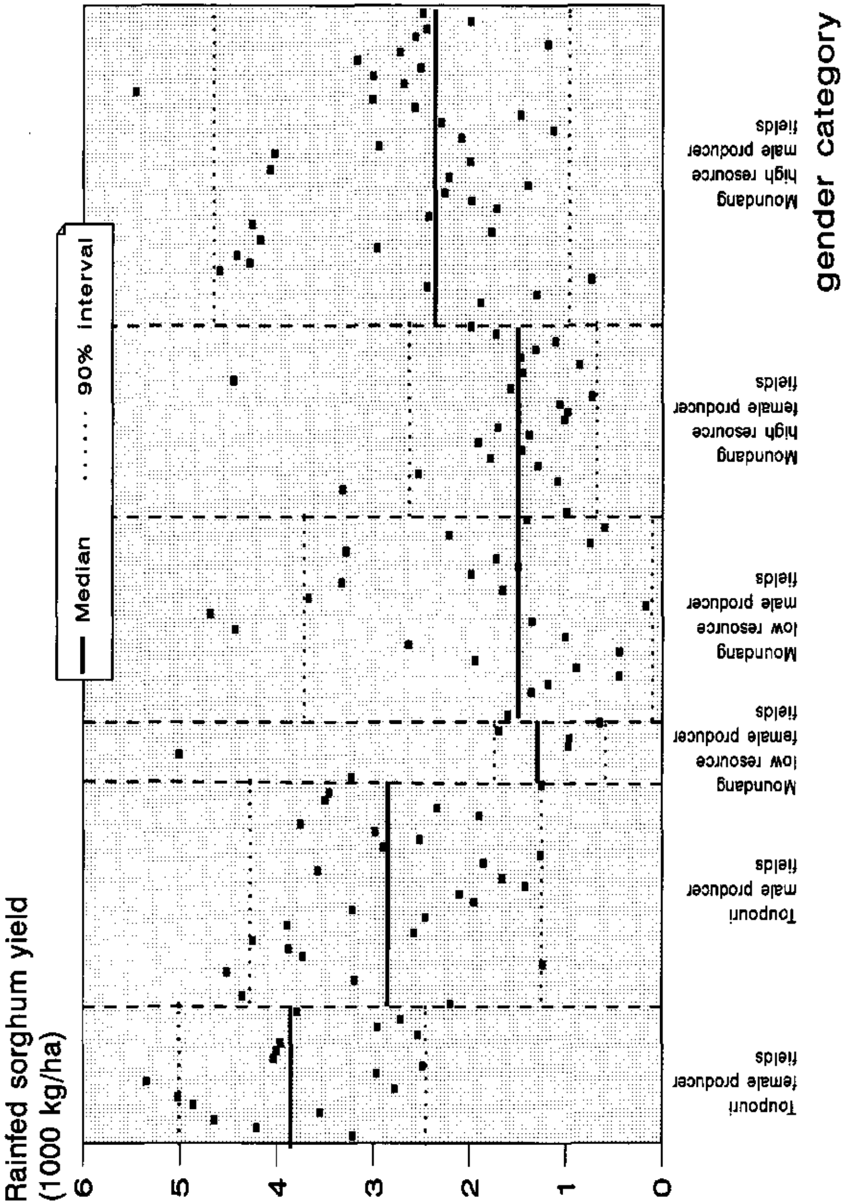


***Figure 5.7** Variations in 1992 rainfed sorghum yield per gender category*

Chapter 6

General conclusions and discussion

Variations in crop yield have long been observed in experimental research. These variations used to be considered a problem because they complicated the interpretation of the experimental results. Current research shows that variations in yield are real phenomena that are commonly present in agroecosystems (Paoletti & Pimentel, 1990). Notwithstanding this recent attention, a comprehensive approach in agricultural science to analyse problems of variation is lacking.

In the central hypothesis investigated in this thesis I stated that yield variations are not random side-effects in agroecosystems, but are largely the result of deliberate and structural human response to a given environment within a particular cultural and socio-economic context. This central hypothesis was tested in one village in northern Cameroon. From 1991 to 1993 I measured yields and field characteristics and interviewed the farmers growing these fields. During 1994 I analysed the data to explain yield variations at field and household level. I will elaborate on some drawbacks of the approach and discuss the nature of diversity, as well as its implications for agricultural research and development policies.

6.1 The methodology

To study agrodiversity in its entire complexity demands an interdisciplinary research effort which is constant in quality and which encompasses several years of observation. The approach and its execution presented in this thesis display certain drawbacks that lead to limitations to the conclusions that can be drawn.

The first drawback is that all research efforts were focused on one village. The argument for this geographical delimitation was that all higher level sources of diversity could be kept constant. Moreover it guarantees a constant quality of data because the researcher is thus able to personally execute or supervise all data collection, and that the farmers feel confident with the research team resident in the village for most of the year. A direct limitation is that results cannot be validated at another site, and that no conclusions can be drawn at higher levels of aggregation, such as at the regional level. Fortunately, some validation of results could be done at field level between the years of observation; these revealed both constancy (e.g. constant magnitude of inter-annual variation) and discrepancy (e.g. different variables explaining the variation of two years of observation) in the short term.

A second drawback is that the period of repeated measurements (two or three years) is too short to be able to draw conclusions on the temporal dynamics of agrodiversity. This study only explains a portion of the ongoing agro-biological and socio-economic processes. When the monitoring period is only a few years, there is a clear risk of measuring a specific, and not a generally valid situation. An example is the measurement under atypical rainfall conditions. Although the typicality of the years of observation can be estimated by using secondary data, it cannot be verified. Typicality in time is not a foregone certainty but is a chance which depends on variable conditions such as rainfall and market prices. Moreover, specific interactions between agrodiversity components under varying conditions are inherently part of agrodiversity. When measured over a short period, agrodiversity can only be described and analysed in quantitative terms with respect to the period of observation.

The study focused on a reduction of the number of explanatory variables and on their interactions. In some cases, the multidimensional interactions limited the possibility of interpretation in terms of simple two-dimensional causalities. When such information is wanted, it is most logical to opt for experimental research. Once information on farmers' conditions is available from previous research on agrodiversity, experimental research on two-dimensional relations is preferably done under controlled conditions.

The quantitative, statistical approach of the study makes high demands on the quality of data. Moreover, such measurements prove to be extremely time- consuming and demand constant presence of field workers and observers. Extension of the team and of the research to other sites will introduce variation because of variable measurement and measurement errors. In cases of unreliable measurements, systematic variation in yield and agrodiversity components will be difficult to isolate from 'measurement induced' variation. As a result, sensitive statistical techniques are of no use; they should be avoided when data quality is unknown.

Another drawback was that the study did not include livestock systems, fallow land and minor crops and cropping systems, to which the concept of agrodiversity is probably also applicable.

Any data base has limitations of size and one can never be certain that all relevant variables have been included. All statements on the importance of variables refer to the data base on which the analysis is performed. Moreover, a unique focus on agrodiversity will not reveal yield-determining variables or socio-economic problems that are uniformly distributed over all fields and all farmers, such as a generally low phosphorus content of the soil or a generally low level of education.

A final drawback to consider is that, because of its complexity, agrodiversity requires a diverse set of statistical techniques. In the past, variation and its causes were ignored because of standard application of statistics, such as analysis of variance. The results presented in chapters 4 and 5 showed that no standard recipe can be applied to analyse and describe agrodiversity. However, most techniques applied in this study are relatively simple and already known in experimental research.

6.2 The nature of agrodiversity

Notwithstanding its shortcomings, the study presented in this thesis has shown that agroecosystems may be less uniform than is generally expected. The 1992/1993 yield variations in the crops, expressed by the coefficient of variation, ranged from 75% (cotton) to 34% (mouskouari sorghum). Rainfed sorghum showed a large intermediate variation of 51%. These important yield variations could be explained by focusing on agrodiversity, i.e. the interaction between environment, crop genotype and management. These three components represent the abiotic and biotic properties of the field, and the characteristics of the crop, the farmer practices and the input levels. When analysed by including all variables that were considered of possible relevance, agrodiversity proved to be crop-specific.

Variation in the yield of rainfed sorghum could be explained effectively after a distinction had been made between cropping systems and between field types within one cropping system. In this way, yield variation within each stratum, as well as the number of explaining variables, decreased and the contrast between field types was enhanced. In fact, a field type reflects a certain land use and labour intensity. A field type may be considered as a unit of production with a specific yield potential, and specific constraints and limitations.

Variation in the yield of cotton was large, in spite of the many and protracted efforts of the cotton organisation SODECOTON to standardise cotton production for all farmers in the region. The agrodiversity explaining this variation was composed of a limited number of variables. The variables that play a distinct role in cotton cultivation proved to differ in their importance: some practices, such as ploughing, are applied by all farmers because they are considered to be indispensable for cotton cultivation. Such variables that are generally present do not cause yield variation. However, some practices are conditional for above- average yields, such as early sowing. These practices are not applied by all farmers and therefore cause important variation in yield. Other variables appear only to have a statistically significant effect on yield variation when present at high values, such as number of weedings and number of non-active termite mounds. Finally, there are variables that occur frequently, but have no effect on yield variation, such as intercropping in low cowpea plant densities. Cotton cultivation plays a role within the perspective of the whole farm and may serve other goals besides optimisation of yield, such as soil fertility management through fertiliser use and rotation with rainfed sorghum, or be restricted by limitations within the household, such as the availablity of labour and equipment for ploughing.

The moderate **yield variation of dry season mouskouari sorghum** was explained by the smaller number of crop-related variables, i.e. plant density and sub-cultivar choice. These were strongly related to site characteristics determining the water holding capacity of the field, such as soil type, the location (i.e. on the river bank or on the plain) and the presence of small dikes. The combination of crop genotype and site characteristics is not constant in space and time, because the water holding capacity of the field and the crop genotype are subject to interventions from the farmer. If a field is divided into compartments by the construction of small dikes, the farmer's choice of sub-cultivar is modified, in line with the new water holding capacity of the field. All farmers, irrespective of ethnic origin or household situation, agree with the need to adapt adjust their selection of sub-cultivars, and in principle, each farmer is able to construct the dikes to change the water availability. The agrodiversity in mouskouari cultivation does not result from ethnic or socio-economic diversity of households. Yield variation and agrodiversity remain moderate and it can be concluded that it is a relatively uniform cropping system.

The underlying phenomena causing crop specific agrodiversity can be summarised by (1) spatial differentiation of fields, (2) mechanisation of labour and (3) adjusting of cultivation to environmental conditions. The first two phenomena are distinctly related to the ethnic and socio-economic diversity of households. When the necessary knowledge is present, adjusting cultivation to environmental conditions is practicable, irrespective of the situation and origin of the household.

Ethnic diversity of households is reflected in agrodiversity of rainfed sorghum and cotton cultivation. In contrast to Moundang households, Toupouri households grow hardly any cotton. This can be explained by the high priority the latter give to the production of rainfed sorghum. Because this crop plays an important role in social relations and in the exchange of labour and equipment, little room is left for cotton cultivation. In contrast, the Toupouri farmers excel in cultivating rainfed sorghum and obtain superior results. As a consequence, the survival and reproduction of the individual households and of the community as a whole are guaranteed, but the options for the economic development of households and community are very restricted. In fact, the relatively uniform rainfed sorghum cropping system reflects this absence of socio-economic diversity amongst the households.

In contrast to the Toupouri community, a continuous process of differentiation takes place in the Moundang community, resulting in a distinct **socio-economic diversity of households**. This is reflected by the unequal distribution of the means of production over the households, directly affecting crop production. Most resource-poor households obtained below-average yields for cotton and rainfed sorghum. This contrast was not observed for mouskouari sorghum, which is essentially a crop that is cultivated manually and that is dominated by one environmental condition, i.e. water holding capacity of the soil.

The spatial distribution of rainfed sorghum fields has a significant socio-economic dimension. Resource-rich households dominate in the first, intensive field type close to the homestead, whilst the fields of the resource-poor households are more concentrated in the third, extensive field type far from the homestead. Therefore, the resource-rich households have a different rainfed sorghum yield potential than the resource-poor households. Moreover, constraints and limitations of production are not similar between the two classes of households. The transport of manure from the fallow land to the first field type is typical to the resource-rich households. The production obtained on these nearby fields is sufficient to satisfy family sorghum consumption for at least six months, until the mouskouari sorghum harvest. In contrast, the rainfed sorghum production of the resource-poor households is limited by the soil fertility in the third field type. Soil fertility is managed through putting land under fallow, rotating with cotton and using fertiliser. However, their fallow land is also used for grazing cattle by the resource-rich households and by incidental nomads. In other words, the resource-rich households exploit the vegetation which is essential for the regeneration of soil fertility of the fields of the resource-poor households. Because these distant fields produce most of the rainfed sorghum of the resource-poor households, the dual function of fallow land threatens their food production. Resource-poor households tend to clear fields in the secondary forest further and further away from the homestead. Hence more time is needed for clearing and transportation and there is a greater risk of crop damage from cattle and elephants. Marginalisation of these households to the periphery of the village land is a process which will reach its limits in due course. Expulsion from primary agricultural production may occur eventually. Non-agricultural sources of income are already important in the village and it is conceivable that marginalised Moundang households will focus more on these. Because trade is already dominated by resource-rich households, only handicrafts, timber cutting and beer brewing seem to be plausible options. However, it is more realistic to assume that most of the impoverished households will go to the towns in search for employment.

Gender differences affect crop production to various degrees. Whereas mouskouari sorghum is hardly grown by women farmers, cotton is frequently grown by resource-rich Moundang women farmers, and rainfed sorghum is grown by all women farmers, except for the most resource-poor Moundang women farmers. The example of rainfed sorghum shows that cultivation differs not only between gender groups, but also between women farmer sub-groups. The cultivation by Toupouri women farmers is characterised by high yields and very high labour input. This is explained by the obligation of Toupouri women to produce food for family consumption and by the absence of other opportunities for income generation. On the single field cultivated, the Toupouri woman farmer tries to produce more than the family needs. The resulting surplus is hers and to obtain some capital, she will transform it into beer and sell it, preferably, at a Moundang market. The very high labour input in rainfed sorghum may not be economically or agronomically logical, but makes good sense to the Toupouri women farmer.

Only half of the resource-poor Moundang women farmers cultivated a field of their own. The only difference with their husbands' fields was that womens' fields were smaller. All production is used for family consumption. Individual objectives are dominated by the main objective of the household, i.e. day-to-day survival. The lack of means of production and the often critical economic situation of these households means there is little room for the generation of individual income. Within these narrow margins wood cutting and beer brewing may provide resource-poor women farmers with some extra income which is used for the family.

In contrast, the rainfed sorghum fields of man and women farmers from Moundang resource-rich households differed statistically significantly in properties and management. The fields belonging to women farmers were almost all of the third field type. Besides her own labour and capital, these women farmers have little access to the means of production of the household. However, all Moundang women farmers produce is surplus, because they have no obligation to feed the family. Moreover, they are not obliged to work on their husbands' fields and thus have ample time to invest in other income-generating activities, such as trade.

I conclude that the agrodiversity which explains yield variations in agroecosystems results from adaptations of management and crop genotype to environmental conditions and from differentiation between households and farmers. These processes are deterministic for agricultural production when they limit the access of the household to the necessary means of production. If not, other dynamics will prevail, such as the social organisation of the community or gender relations between the farmers.

Household diversity, environmental heterogeneity, agrodiversity and variations in yield are not only interrelated phenomena, but may also affect higher level processes, such as regional deforestation, the emergence of a class of proletarised people and massive migration to towns. The social and environmental problems that result from these processes, although operational at regional scale, amplify the need to focus on the origin of the problems at the level of fields and farmers.

6.3 Considerations for the future

Efforts to standardise crop cultivation, such as in the case of cotton which is cultivated in a heterogeneous environment that is managed by a diversity of farmers, are neither realistic, nor advisable. Standardisation demands a great deal of control over environmental conditions and uniform management. In reality, cotton growing has to meet divergent household goals, which leads to different crop functions according to location and class of farmer. Standardising cultivation regardless of this diversity will reduce the overall productivity of the agroecosystem and may destabilise it.

Large variations in yield may reflect important agrodiversity. Accordingly, yield variation seems to be a good, and relatively easy, criterion to use when deciding whether research on agrodiversity is needed. Reliable assessment of yields is essential. However, in many cases, governemental statistical offices do not provide yield data that are sufficiently meticulous for variation analysis. This is especially true for food crops. I conclude that regular monitoring of farmers and assessment of yields is essential for agricultural research and policy.

Diversity in agroecosystems is scale-dependent. Understanding diversity cannot be based on an analysis at a single scale. Fields and farmers are inextricably related. Moreover, within a single agroecosystem, crops are no independent entities, but are interrelated by factors defining their management. This interdepency of crops and the scale-dependent nature of agrodiversity must be reflected by agricultural research. The importance of cropping systems and field types must be evaluated within the context of the entire agroecosystem. If crop cultivation is differentiated in space and time, the constraints and limitations of crop production cannot be defined in general terms. Because field level agrodiversity may be a reflection of higher level diversity of households, the development of technology for crop production cannot disregard the presence of specific user groups. If the goal is to eliminate the constraints and limitations of production, technical solutions, as well as solutions in the socio-economic sphere have to be sought.

Although it was not emphasised in this study, there are indications that at least some of the lower level diversity will express itself also at regional levels. To understand the topics and problems related to diversity at these levels, it is advisable to include the lower levels of aggregation in the analysis.

In cases of interaction of ethnic or socio-economic diversity with gender, there is no such group as 'the women farmers'. Any intervention focused on a target group defined in comparable terms is bound to fail. I wish to state that the first step of any rural development policy should be to clearly define target groups on the basis of realistic correspondence and contrast in available resources, production and objectives. An effective approach for separating relevant from irrelevant differences is to focus on the farmers' actual behaviour. Their active participation and consultation during the analysis is a condition for success. Pre-definition of target groups may be as harmful as generalisation.

Differences between fields and farmers will occur in any given situation and may express themselves at variable magnitudes of variation. The goal is to separate systematic and deliberate variation from random variation in order to be able to define the **meaningful diversity** of the system. Criteria for meaningful diversity cannot be defined beforehand, but must reflect the values and priorities of the people involved.

For a long time, agricultural research and development policies were focused on the generation and diffusion of widely adoptable technology. The dominant image of agriculture in African rural societies was one of inherent homogeneity. 'Naive' or 'indigenous' systems were not thought capable of effective and adapted exploitation of the environment (Richards, 1985), and socio-economic differentiation was not expected within ethnic groups. The failure of most agricultural research to make a significant impact on African agricultural development led to new approaches to elucidate what was wrong with these 'stagnating systems'. Development of technology remained basically generalistic, despite many research efforts often labelled Farming Systems Research (Oasa, 1985). Many policy makers still consider demography as the major dynamic variable in African societies, ascribing uncontrolled population growth, food shortages, unemployment and evironmental degradation to it (Hansen & McMillan, 1986).

Not until recently did it dawn upon researchers and policy makers that African systems and societies might be less homogeneous and more dynamic than believed. Examples of studies stressing the importance of variation and diversity in their topic of research are increasing in number (Brookfield & Padoch, 1994; Brouwer et al., 1993; Rhoades & Bebbington, 1990). Some disciplines, such as ecology and rural sociology, have acquired experience in topics that are related to diversity and heterogeneity. Agricultural research must accept that diversity and heterogeneity are part of reality and that they demand explicit attention if their complexe nature is to be understood. Policy makers must be convinced that demographic growth is not the only factor in African societies, but that evolution is determined by many dimensions. There are examples of studies that link environmental degradation to phenomena other than population pressure, introducing new solutions (Blaikie & Brookfield, 1987; Tiffins et al., 1994). In this thesis, I have tried to bring together recent experiences with diversity in order to contribute to a new approach in agronomy. The problems in African agriculture and their impact on societies require a good understanding of the diversity of fields and farmers. In order to achieve this understanding, agricultural research and extension must abandon their generalistic, conventional approach, and adopt a flexibility in methods and topics of research that responds better to the real problems of specific farmers. This may be the greatest challenge facing *agricultural research since the recognition of variation* at the *beginning* of this century.

Annex

Annex 1 Variables included and methods and techniques of measurement

Field level

abiotic properties of the field

soil texture	qualitative assessment of soil texture of all sample fields in combination with indigenous classification. On all 1991/1992 fields, five random augerings were taken to a depth of 100 cm.
soil depth	depth to 100 cm. On all 1991/1992 fields, five random augerings were taken to check for underlying impenetrable layers.
chemical composition and acidity of the soil	pH, organic carbon, N-total, $N\text{-}NH_4$, $N\text{-}NO_3$, P, Na and K. On all fields in the 1991/1992 sample (n=89), five random samples from the 0 to 20 cm layer were taken and mixed. The samples were dried at 70 degrees Celsius for 24 hours and sealed in plastic. In the laboratory of the Department of Soil Science of the Wageningen Agricultural University, the samples were analysed on the properties mentioned above by using the $CaCl_2$ method. The latter method was applied because it gives a reliable assessment of relative differences between the samples.
field area and field form	in m^2. Measurement of the field perimeter at intervals of 30 m maximum with a measuring tape, and measurement of the angles between intervals with a compass. Field area was calculated with geometry.
field distance from	in 100 m from the homestead. The odometer on a motor cycle was used to measure the distance walked between the homestead and the field. Topographic distance was measured by drawing a map and measuring the distances with a ruler.
slope of the field	in degrees. Measurement by clinometer.

biotic properties of the field

Striga incidence	infection rate in number of Striga parasites/ha and in number of seeds/ha. In the first year: counting at harvest of all emerged

	parasites within a radius of 25 cm around the rainfed sorghum plant holes in the yield estimate sample (see below). In the second year: as in the first year, plus: on each of all rainfed sorghum fields, five random samples were taken at a depth of 20 cm, and mixed. Striga parasite seeds were counted in 50 g of soil per sample in the IRA-Garoua laboratory.
trees	numbers per field and per ha. Counted in the field, whereas a tree is defined by a non-crop plant which height is at least 2 m.
active and inactive termite mounds	numbers per field and per ha. Counted in the field.
farmer practices and inputs	
soil preparation	hoe, donkey ploughing or ox ploughing. Determined in the field, while soil was being prepared.
depth of ploughing	depth of ploughing in cm. Measurement with a ruler at fixed intervals of 10 m perpendicular to the ploughing direction.
cropping calendar	dates, duration and intervals of execution. All dates (first and last day, number of days) of execution of all practices, recorded by the head of the family. These were discussed with individual producers and checked through daily field visits.
weeding intensity	frequency in number and days of weedings. Recorded by the head of the family, discussed with individual farmers (male and female) and checked through daily field visits.
labour input	in hours per field and per hectare. Of all practices and on all fields of the three major crops, daily working times (excluding breaks) and number of workers were recorded by the head of the family, who was given a watch, a pen and a notebook. At the end of the day or early the following morning, all households were visited to specify and evaluate the previous day's work (if necessary, separately with male and female farmers).
plant density	in number of plants per hectare. Approximately one month before harvest, each field was divided into three parallel sections. In each section, one row was selected at random, excluding the border rows (at random: by numbering the rows and using a die). In each row, at a random distance from the border, all emerged plants were counted over a continuous distance of 30 m.
cultivars and sub-cultivars	relative importance (in %) of sorghum cultivars and sub-cultivars. In the yield estimate sample (see below), ears of different sorghum cultivars and sub-cultivars were scored.
previous crop	determined in the field with the farmer.

application of manure	estimated in 100 kg/ha. On all fields to which manure was applied, three to five squares of 10 by 10 m, depending on the field size, were laid at fixed intervals along the diagonal of the field. All manure in the squares was collected and weighed on the spot with a suspended spring balance (5 kg x 10 g).
composition of manure	in % and mmol/kg N, P and K. Analysis of eight samples of cattle manure (four random samples of dry manure, four of moist manure) for N, P and K in the laboratory of the Department of Agronomy, WAU
application of fertiliser	frequency of application and quantity in kg/ha. Evaluated with the farmer.
biocide application	frequency of treatments, evaluated with the farmer.
field age and length of last cropping period	years, based on farmer interview.

crop damage

insect and disease damage	in the yield estimate sample of sorghum (see below), infected ears were scored.
elephant damage	recorded in the field.
livestock damage	recorded in the field.
bird damage	in the yield estimate sample (see below), ears without grains were scored.

yield and biomass production

sorghum yield	grains at 12 % moisture in kg/ha. Each field was divided into three sections. In each section, one row was selected at random, excluding the border rows (at random: by numbering the rows and using a die). In each row, at fixed intervals, five plant holes were selected and all plants were harvested. Ears were collected, counted, determined (varieties) and weighed on the spot with a suspended spring balance (5 kg x 10 g). In the first year, all ears were dried in an oven at 100 degrees Celsius for 24 hours and were weighed with an electronic balance (500 g x 0.1 g). In the second year, a sample of 30 ears was treated in the same way to estimate mean moisture content. Yield was calculated on the basis of plant density.
sorghum biomass	dry matter in kg/ha. In the first year, all plants in the yield sample were severed at root level and weighed on the spot with a suspended spring balance (5 kg x 10 g). To estimate the mean moisture content, a sample of 30 plants was dried in an oven at

	100 degrees Celsius for 24 hours.
cotton yield	in kg/ha. Production data based on marketing procedure: all cotton is weighed per farmer and per field by a village team before it is collected and transported to the factory.

Household level

means of production

amount of land	cultivated and fallow land in ha/household and ha/farmer. Aggregation of all field areas and estimation of fallow land with the farmer.
quality of land	proportional distribution of soil texture classes (in %) over cultivated land per household and per farmer.
labour force	number of family workers and non-family workers. Household surveys and cumulative labour input at field level. Each man, woman or child older than 12 years was considered. Each schoolgoing child over 12 years was considered half a worker.
capital goods	number of mechanised items of equipment, oxen and large and small livestock. Counted on several occasions in the homestead and in the corral. Investments in labour and chemical inputs were calculated on the basis of field data.

household and producer characteristics

ethnic group, clan, religion, age, sex, number of wives, number of children, number of school going children, age of household, education and training, professional skills, number of relatives in the city, memberships of associations	yearly formal household surveys and frequent informal discussions
objectives of production	informal discussions with all male and female farmers and group discussions

externally induced limitations

diseases and illness, death of family members	observations

reimbursement claims of debts in labour	observations and totalled labour input of fields
land conflicts	*observations*

production of food and surplus

production of sorghum	total of sorghum field production
production of sorghum surplus	in CFA francs per year and in sorghum surplus per year. Household surveys, including non-agricultural activities and income, aggregated field data on production and calculation of surplus production. Yearly food consumption was estimated based on the FAO standard of 250 kg of cereals per consumer per year. Each man, woman and child older than 12 years was considered as one consumer, each child younger than 12 years, half a consumer. School-going children and older people, living in the household, were also considered as full consumers and were included in the calculation.
production of cotton	in kg and in CFA francs per year. Based on marketing procedure and data from the cotton organisation.

Village level

properties of landscape units	aggregated field data, participatory mapping with groups of informants and key persons, transect walking.

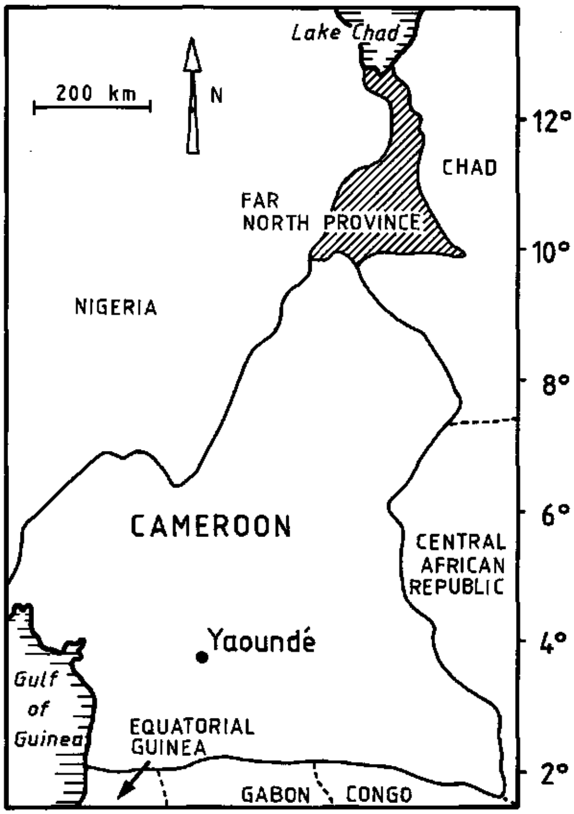
characteristics of ethnic groups, household classes and gender groups

values and traditions, power structure, legislation and land rights, prohibitions, gender relations, community and clan history	informal surveys, life histories, discussions with informants, secondary literature.
proportional importance of groups and classes	number of households and farmers and % of total households and farmers. Based on list of tax-paying households and 1992 household sample.

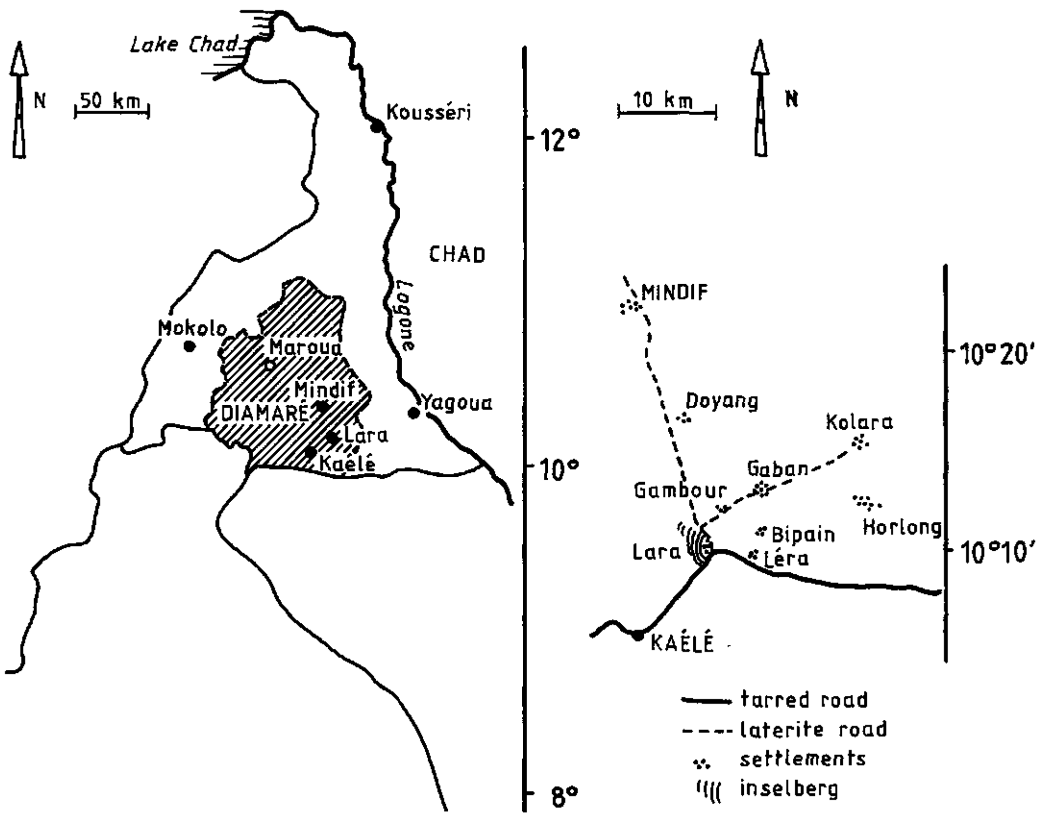
climate variables

rainfall	absolute amount in mm/year and distribution in mm/day. Daily measurement at 6 a.m. with rain gauge at two sites.
temperature, relative humidity, insolation, evapotranspiration	secondary data sources, if available.

production volume of sorghum and cotton	aggregated production data of sampled households aggregated to village level.



Annex 2 [A] *Map of Cameroon and location of the Far North Province*



Annex 2 ***B*** *Map of Far North Province and location of the village of Gaban*

***Annex 3** Rainfed sorghum field types: yield variations, explaining variables and path-coefficients (multiple regression analysis, 1991, 1992, and 1993)*

1991 Results

All fields (n=44)
Mean yield: 1950 kg/ha, CV=52%

R^2= .66
Variables:
ploughing .266 sowing date -.248
plant density .343 amount of manure .407
Striga incidence -.258

All Moundang fields
(n=32)
Mean yield: 2050 kg/ha
CV=51%

R^2= .68
Variables:

amount of manure	.384
soil type	.137
ploughing	.247
sowing date	-.239
plant density	.324
Striga incidence	-.221

Distance class < 1.0 km
(n=15)
Mean yield: 2490 kg/ha
CV=47%

R^2= .56
Variables:

amount of manure	.374
1st weeding date	.352
Striga incidence	-.577

Distance class > 1.0 km
(n=17)
Mean yield: 1670 kg/ha
CV=46%

R^2= .64
Variables:

ploughing	.948
sowing date	-.692
Striga incidence	-.398

All Toupouri fields
(n=12)
Mean yield: 1650 kg/ha
CV=52%

R^2= .81
Variables:

plant density	.856
Striga incidence	-.583

All fields (n=137) **1992 Results**
Mean yield: 2500 kg/ha, CV=51%

R^2= .63
Variables:
distance -.170 amount of manure .140
ploughing .154 sowing date -.216
number of weedings .184 total weeding time .191
sub-cultivar *'Gling'* .237 plant density .386
Striga incidence -.211

All Moundang fields
(n=90)
Mean yield: 2130 kg/ha
CV=56%

R^2= .71
Variables:

soil type 'sandy-clay'	.144
amount of manure	.184
ploughing	.272
sowing date	-.259
1st weeding date	-.178
total weeding time	.187
plant density	.449
Striga incidence	-.220

Distance class
≤ 0.1 km
(n=25)
Mean yield:
3400 kg/ha
CV=32%

R^2= .54
Variables:

ploughing	.284
weeding time	.589
Striga incid.	-.651

Distance class
0.1 ≤ dist ≤ 0.5
(n=20)
Mean yield:
1760 kg/ha
CV=65%

R^2= .64
Variables:

sowing date	-.309
plant density	.635

Distance class
≥ 1.0 km
(n=45)
Mean yield:
1580 kg/ha
CV=38%

R^2= .70
Variables:

ploughing	.527
sowing date	-.434
weeding date	-.552
plant density	.508
Striga incid.	-.336
field area	.311

All Toupouri fields
(n=47)
Mean yield: 3110 kg/ha
CV=36%

R^2= .69
Variables:

sowing date	-.311
plant density	.605
amount of urea	-.195
Striga incidence	-.173
total weeding time	.215

All Moundang fields (n=40) **1993 Results**
Mean yield: 1610 kg/ha, CV=47%

R^2= .60
Variables:
ploughing .255 plant density .224
1992 amount of manure .253 1st weeding date .281
number of weedings .269 Striga incidence -.191

Distance class < 1.0 km		Distance class > 1.0 km	
(n=20)		(n=20)	
Mean yield: 1970 kg/ha		Mean yield: 1250 kg/ha	
CV=35%		CV=50%	
R^2= .82		R^2= .58	
Variables:		**Variables:**	
ploughing	.325	ploughing	.579
no. of re-sowings	.435	sowing date	-.582
plant density	.503	soil type 'sandy clay'	-.625
1st weeding date	.305	weed incidence	.369
no. of weedings	.305		

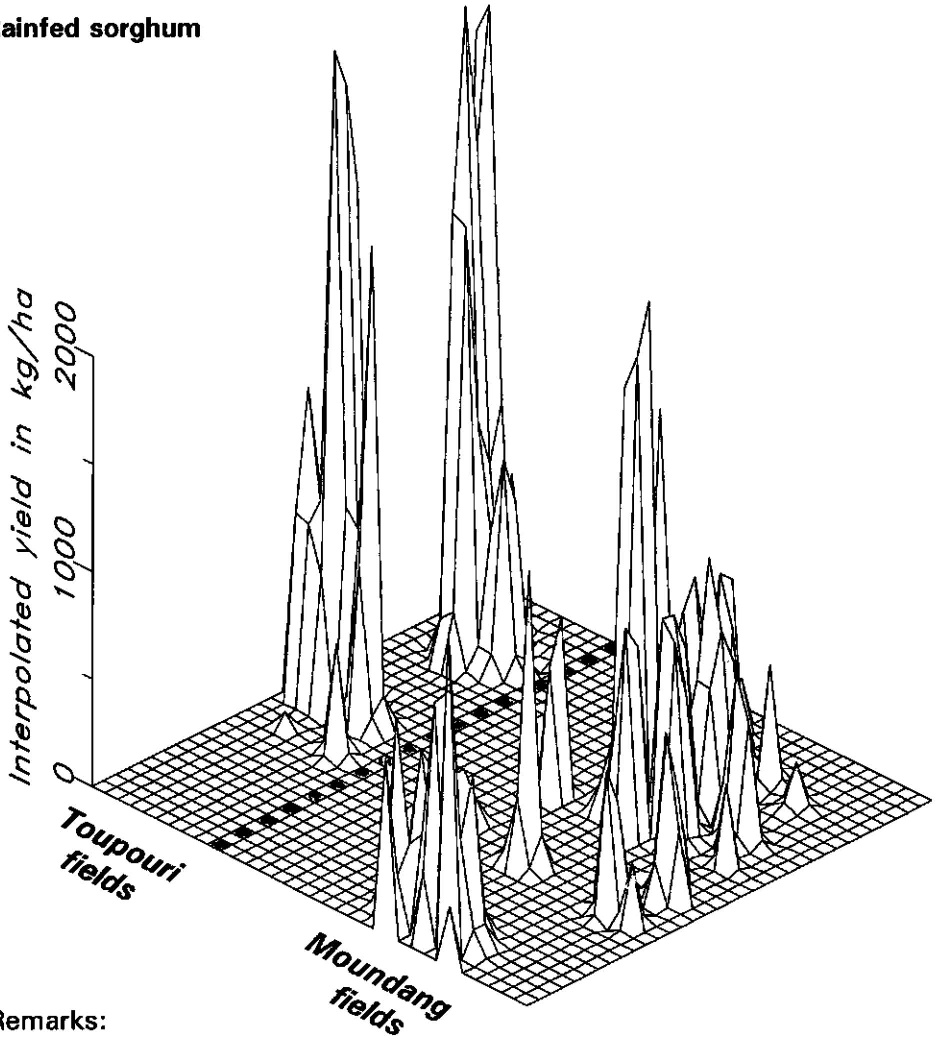
***Annex 4** Characteristics of cotton fields (1992, 52 fields)*

characteristic		mean	CV (%)
yield	kg/ha	520	75
field distance	km	2.4	87
duration of cultivation of field	years	20	136
field area	ha	0.6	59
soil type 'sandy-clay'	% of field	27	148
plant density	plants/ha	42500	20
sowing date	days > 1st of May	50	29
first weeding date	days > mean sowing date	32	26
number of weedings		2	29
total weeding time	hours/ha	590	56
cowpea intercropping	% of fields	50	*
number of biocide treatments		2.9	52
fertiliser application	kg/ha	74	51
number of non-active termite mounds	number/ha	2.2	130
labour productivity	kg/hour	0.5	71
profitability	CFA francs/ha	29500	108

* variance = 0, CV is not defined

***Annex 5** Spatial distribution of interpolated yields of rainfed sorghum, cotton and mouskouari sorghum (1992/1993, calculation with Surfer software package)*

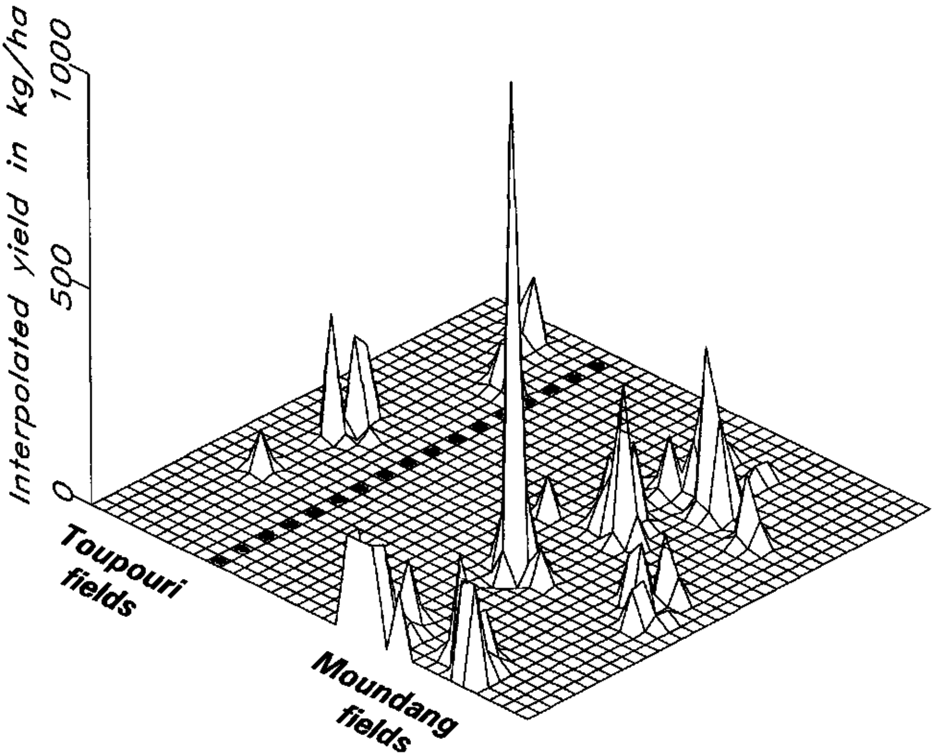
Rainfed sorghum



Remarks:

The Toupouri fields are concentrated around the homesteads in the two settlements. The interpolated yields are high.
The Moundang fields are distributed in space along one axis. The interpolated yields are highest around the homesteads.

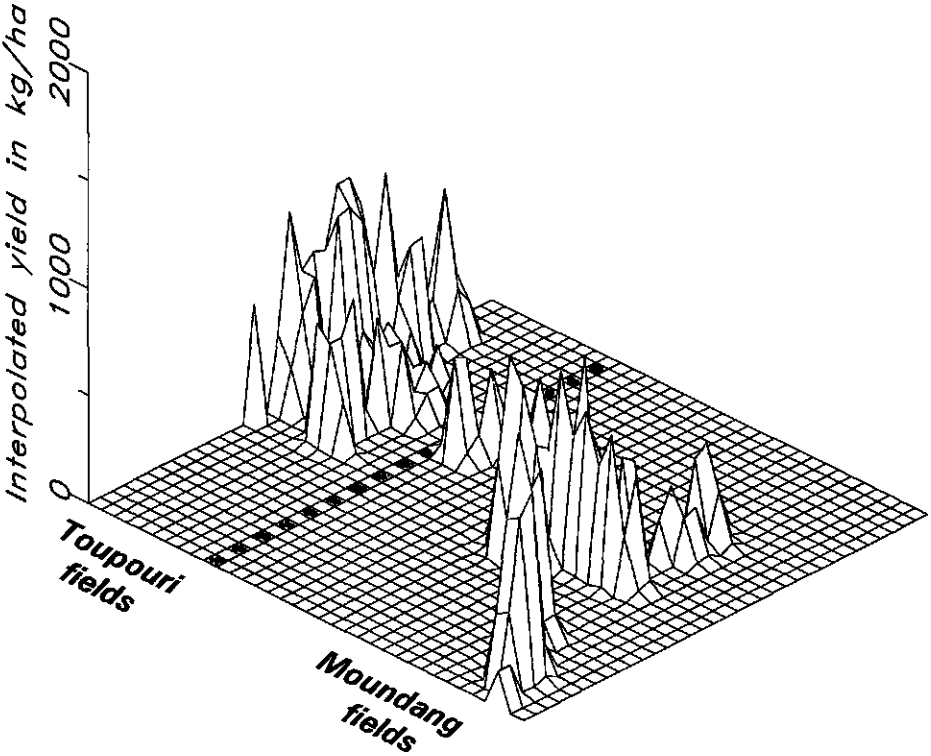
Cotton



Remarks:

Almost all cotton fields are cultivated by the Moundang. Their fields are distributed in the same area as the rainfed sorghum fields, but the interpolated yields do not show a clear spatial trend.

Mouskouari sorghum



Remarks:

The mouskouari fields show a spatial distribution which is similar to the distribution of Vertisols and ephemeral streams. The direction of the axis along which the fields are distributed is perpendicular on the direction of the axis of the Moundang rainfed sorghum fields. The interpolated yields do not show a spatial distribution and yield levels are about similar for the two ethnic groups.

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Summary

This research was inspired by the inability of agricultural research to deal adequately with phenomena of variation, diversity and heterogeneity in agriculture. Although these phenomena were observed as long ago as the beginning of this century, they are still causing concern. Until recently, analysis of variance was applied to any form of undesired variation in the experimental results. The statistical elimination of variation from the research coincided with attempts to uniformise agriculture in order to optimise production. For a long time, deviations from the standardised average were regarded as undesirable random effects.

Recent research has shown that variations in yield are very common in agroecosystems. They may be large, especially under difficult climatic conditions, and may even be considered as an asset to farmers. There is evidence that variations are not random, but are the result of systematic interaction between environment, crop genotype and management. This agrodiversity has important relations with the higher-level heterogeneity of the environment and diversity of farm households. At present, no comprehensive approach to its analysis is available, largely because agrodiversity is basically multidimensional in nature and may comprise several levels of aggregation.

The objective of this study was to contribute to the understanding of diversity in agroecosystems by focusing explicitly on variations of yield and their explanation at field and household level. Between 1991 and 1993, field work was done in one village in northern Cameroon. Yield variations of three crops, field properties, crop and management characteristics and household characteristics were assessed systematically. Various techniques for statistical analysis were employed to determine the magnitude of variation and to define the agrodiversity of

the system.

Within the agroecosystem of the selected village, variations in yield were observed for rainfed sorghum, cotton and dry season sorghum. The magnitude of variation was more or less constant over the years of observation, but varied between the crops. Two rainfed sorghum cropping systems were distinguished and within one cropping system, three field types were defined according to their distance from the homestead. Thus stratified it was possible to reduce overall yield variation and to explain it within each stratum by a reduced number of variables. It was concluded that *the composition of agrodiversity was not uniform over the strata.* Yield levels, limitations and constraints of rainfed sorghum production were specific to each cropping system and field type.

Of the three crops, yield variation was greatest in cotton, despite many efforts of the cotton agency to standardise its cultivation. This variation was explained by distinguishing between types of variables, each explaining cotton yield variation to a different degree and in a particular way. Dry season sorghum showed least variation in yield, although it is subject to great environmental stress. Crop genotype and management proved to be adapted to one dominant field property, i.e. the water holding capacity of the soil. All farmers, irrespective of ethnic or socio-economic origin, agreed about the need to adjust mouskouari sorghum cultivation to field characteristics that define the water availability. Processes at field level leading to agrodiversity could be summarised by (1) spatial differentiation of the fields, (2) mechanisation of labour and (3) adaptation of cultivation to the environment.

Ethnic diversity explained the absolute difference in cotton production, and the distinction between rainfed sorghum cropping systems within the agroecosystem. Socio-economic diversity explained the relative differences in cotton yield, and the distinction between rainfed sorghum field types.

Finally, gender differences highlighted variations in rainfed sorghum yields and in non-agricultural income. Gender differences and ethnic and socio-economic diversity proved to be interrelated, resulting in at least three classes of women farmers.

It must be concluded that within one agroecosystem, crop yields may vary considerably. The agrodiversity explaining these variations proves to be crop-specific. One agroecosystem may comprise several cropping systems and field types of the same crop. Agrodiversity is also spatially specific and is largely determined by ethnic and socio-economic diversity and gender differences at household level. The potentials and problems of crops and fields also prove to be specific to the farmer. Within the context of rural development, it is essential to distinguish between well defined target groups in order to prevent interventions from uneffective generalisation. To do so, variation, heterogeneity and diversity must be accepted as realistic phenomena in agroecosystems and considered as an important source of information.

Résumé

Le cadre de cette étude est constitué par l'incapacité de la recherche agricole de bien traiter les phénomènes de variation, de diversité et d'hétérogénéité dans le domaine de l'agriculture. Bien que ces phénomènes soient observés depuis le début de ce siècle, à l'heure actuelle les problèmes liés à leur interprétation ne sont toujours pas résolus. Il y a peu de temps encore, l'analyse de variance était appliquée pour éliminer la variation non-désirée des résultats expérimentals. Cette élimination statistique de la variation de la recherche coïncidait avec des efforts pour uniformiser l'agriculture dans le but d'optimiser la production. Pendant longtemps, les déviations de la moyenne standard étaient considérées comme des effets d'hasard n'étant pas désirables.

Des efforts de recherche récents ont montré que les variations du rendement sont très générales dans les systèmes agro-écologiques. Surtout sous des conditions climatiques difficiles, les variations du rendement peuvent être considérables et de plus peuvent être avantageuses pour les producteurs. Il y a des preuves que les variations dans le domaine de l'agriculture ne sont pas les effets d'hasard, mais qu'elles résultent d'une interaction systématique entre l'environnement, le génotype de culture et la gestion humaine. Cette agrodiversité est étroitement liée à l'hétérogénéité environnementale et à la diversité des exploitations à des niveaux supérieurs d'agrégation. A présent, il n'existe pas une approche intégrale pour leur analyse. Principalement, cette absence est causée par la nature complexe, multidimensionnelle, de l'agrodiversité, comprenant plusieurs niveaux d'agrégation.

L'objectif de cette étude était de contribuer à la compréhension de la diversité des systèmes agro-écologiques par ciblage des actions de recherche explicitement sur les variations du rendement et sur leurs explications au

niveau de la parcelle et de l'exploitation. Entre 1991 et 1993, une étude de terrain a été effectuée dans un seul village au Nord-Cameroun. Les variations du rendement de trois cultures, ainsi que les caractéristiques parcellaires et gestionnaires et les caractéristiques des exploitations, ont été mesurées systématiquement. Plusieurs techniques statistiques ont été utilisées pour déterminer l'étendue des variations et pour définir l'agrodiversité du système.

Dans le système agro-écologique du village sélectionné, des variations importantes du rendement des trois cultures suivies ont été observées. L'étendue de la variation était plus ou moins constante pendant les années d'observation, mais elle variait considérablement entre les trois cultures. Le cotonnier montrait la variation la plus élevée, suivie par le sorgho pluvial et par le sorgho repiqué de saison sèche. Après une analyse statistique des caractéristiques de la culture de sorgho pluvial, deux systèmes de culture devaient être définis. Dans l'un des deux systèmes, trois types de parcelle étaient distingués à base de leur distance de l'habitat. Ainsi stratifié, il était possible de réduire la variation totale du rendement et de l'interpréter dans chaque strate par un nombre limité de variables. Il était conclu que la composition de l'agrodiversité n'était pas uniforme parmi les strates. Les niveaux du rendement, aussi bien que ses limitations et contraintes de la production de sorgho pluvial, étaient spécifiques pour chaque système de culture et pour chaque type de parcelle.

La variation du rendement de coton était supérieure malgré les efforts de la Société de Développement du Coton de standardiser sa cultivation. Cette variation s'explique par une distinction en types de variables, expliquant la variation du rendement de coton d'un degré et d'une façon différents. Le sorgho de la saison sèche montrait la variation la plus faible du rendement malgré le fait que la culture subisse un stress environnemental important. Les résultats d'analyse démontraient que la gestion de la parcelle, ainsi que le choix des sub-cultivars, étaient adaptés à une charactéristique parcellaire: la capacité de rétention d'eau de la parcelle. Tous les producteurs, indépendants de leur origine ethnique ou socio-économique, confirmaient la nécessité d'adapter la gestion à cette caractéristique parcellaire dominante. Les processus au niveau parcellaire, résultant en agrodiversité, pouvaient être résumés par (1) une différentiation spatiale des parcelles, (2) la mécanisation du travail et (3) l'adaptation culturale à l'environnement.

La diversité ethnique des exploitations explique la différence absolue dans la production cotonnière et la distinction parmi les systèmes de culture de sorgho pluvial. La diversité socio-économique explique les différences relatives de rendements de coton et la distinction parmi les types de parcelle de la culture de sorgho pluvial. Finalement, la différence entre les sexes accentue les différences intra-familiales concernant la culture et les rendements de sorgho pluvial et les revenus non-agricoles. Il est ressorti que la diversité ethnique et socio-économique et la différence entre les sexes sont inter-relatées résultant, entre autres, au moins à la définition de trois types de productrices différentes.

Il est conclu que dans un seul système agro-écologique, les rendements des cultures peuvent varier considérablement. L'agrodiversité, expliquant ces variations, se trouve être spécifique par culture. Un seul système agro-écologique peut comprendre plusieurs systèmes de culture et types de parcelle de la même culture. L'agrodiversité est aussi spatialement spécifique et elle est déterminée à un niveau supérieur par la diversité ethnique et socio-économique et par la différence entre les sexes. Les potentiels et les problèmes liés aux cultures et aux parcelles se révèlent être spécifiques par rapport au producteur également. Dans le cadre du développement rural, il est essentiel de distinguer des groupes cibles bien définis pour priver les actions d'intervention d'une généralisation non-effective. Pour y arriver, la variation, l'hétérogénéité et la diversité doivent être acceptées comme phénomènes réels dans les systèmes agro-écologiques et doivent être considérées comme sources d'information importantes.

Samenvatting

De achtergrond van deze studie vormt het onvermogen van het landbouwkundig onderzoek om variatie, diversiteit en heterogeniteit in de landbouw adequaat te behandelen. Hoewel deze phenomenen al rond het begin van deze eeuw geïdentificeerd zijn, worden ze nog steeds beschouwd als een bron van verstoring van de resultaten in het experimentele onderzoek. Tot voor kort werd variantie-analyse toegepast om elke vorm van variatie uit de resultaten te verwijderen. Deze statistische eliminatie van variatie van het onderzoek ging samen met pogingen om de landbouw te uniformiseren met het doel van produktie maximalisatie. Lange tijd werden afwijkingen van het gestandaardiseerde gemiddelde beschouwd als het resultaat van toeval dat niet gewenst was.

Recent onderzoek toont aan dat opbrengst variaties zeer algemeen zijn in agro-ecosystemen. Met name onder ongunstige klimatologische omstandigheden kunnen opbrengstvariaties groot zijn en voor de boer een voordeel betekenen in de vorm van risicospreiding. Er zijn aanwijzingen dat opbrengstvariaties niet uitsluitend het resultaat zijn van toeval, maar dat zij ontstaan als gevolg van systematische interakties tussen omgeving, gewas-genotype en management. Deze interakties, die samen 'agrodiversiteit' genoemd kunnen worden, hebben belangrijke relaties met de heterogeniteit van de omgeving en de diversiteit van huishoudens op hogere schaal-niveau's. Op dit moment bestaat er geen integrale aanpak voor de analyse van agrodiversiteit die zowel haar multidimensionale, als haar meer-schalige karakter integreert.

Het doel van deze studie was om een bijdrage te leveren aan het begrip van diversiteit in agro-ecosystemen door het onderzoek te concentreren op opbrengstvariaties en hun verklaring op veld- en huishoudniveau. In de periode van 1991 tot en met 1993 is een veldonderzoek uitgevoerd in één

dorp in het noorden van Kameroen. Van drie gewassen is de opbrengstvariatie gemeten en zijn de karakteristieken van velden, gewassen en hun management, als ook de karakteristieken van de huishoudens bepaald. Verschillende statistische technieken zijn toegepast om de omvang van de variatie te bepalen en de agrodiversiteit te definiëren.

In het agro-ecosysteem van het geselekteerde dorp werden belangrijke variaties in de opbrengsten van regenafhankelijke sorghum, katoen en sorghum van het droge seisoen gemeten. De mate van variatie was min of meer constant over de meetjaren, maar verschilde sterk tussen de gewassen onderling. De opbrengstvariatie, uitgedrukt als variantie-coefficient, bedroeg voor katoen 75%, voor regenafhankelijk sorghum 51% en voor sorghum van het droge seizoen slechts 34%.

Twee regenafhankelijke teeltsystemen werden onderscheiden en binnen één van deze teeltsystemen werden drie veldtypen gedefinieerd op basis van de afstand van het veld tot de woning. Het veldtype op korte afstand van de woning onderscheidde zich van de andere twee veldtypen door o.a. een hogere intrinsieke bodemvruchtbaarheid en hogere organische mestgiften. Het veldtype op grote afstand van de woning kenmerkte zich o.a. door de rotatie met katoen, het gebruik van kunstmest en de korte teeltperiode gevolgd door een braak. Het resultaat van deze stratificatie was een vermindering van de variatie binnen elk stratum en de mogelijkheid om haar met een beperkt aantal variabelen te verklaren. Geconcludeerd kon worden dat de samenstelling van de agrodiversiteit niet gelijk was tussen de strata. Opbrengst niveau's en knelpunten van de regenafhankelijke sorghum produktie bleken specifiek te zijn voor elk sorghum teeltsysteem en veldtype.

Ondanks veel pogingen van de katoenorganisatie om de teelt te standaardiseren was de opbrengst variatie van katoen het hoogste van de drie gewassen. Deze variatie kon verklaard worden door een onderscheid te maken tussen typen variabelen die de katoen opbrengstvariatie op een verschillende manier en in een verschillende mate verklaarden. Ondanks de hoge mate van omgevingsstress was de variatie in sorghum van het droge seizoen het laagste van de drie gewassen. Gewas sub-cultivars en management bleken aangepast te zijn aan één dominant omgevingskenmerk, het waterhoudend vermogen van de bodem. Verschijnselen op veld niveau die agrodiversiteit tot gevolg hebben, konden samengevat worden door (1) spatiale differentiatie van velden, (2) mechanisatie van handarbeid en (3) aanpassing van de teelt aan de omgeving.

Diversiteit tussen ethnische groepen verklaarde het absolute verschil in katoenproduktie en het onderscheid tussen regenafhankelijke sorghum teeltsystemen binnen het agro-ecosysteem. Binnen de ethnische groepen verklaarde sociaal-economische diversiteit de variatie in katoen opbrengst en het onderscheid tussen regenafhankelijke sorghum veldtypen. Tenslotte verklaarden man-vrouw verschillen opbrengstvariaties binnen het huishouden en verschillen in niet-agrarische inkomsten. Diversiteit in ethnische groepen, sociaal-economische diversiteit en man-vrouw verschillen bleken aan elkaar gerelateerd te zijn, hetgeen resulteerde in het onderscheid tussen drie groepen boerinnen met kenmerkende opbrengstniveau's en inkomsten.

Geconcludeerd kan worden dat gewasopbrengsten sterk kunnen variëren binnen één agro-ecosysteem. De agrodiversiteit die deze variatie verklaart, blijkt gewas-specifiek te zijn. Eén agro-ecosysteem kan verschillende teeltsystemen en veldtypen van één gewas omvatten. Deze agrodiversiteit kan belangrijke spatiale dimensies kennen en wordt in hoge mate bepaald door de diversiteit in huishoudens en in producenten. Opbrengstniveau's en problemen van gewassen en velden blijken ook boer-specifiek te zijn. Binnen de context van rurale ontwikkeling is het daarom essentieel om goed gedefinieerde doelgroepen te onderscheiden om ineffectieve generaliserende interventies te voorkomen. Om dit te bereiken moeten variatie, heterogeniteit en diversiteit geaccepteerd worden als realistische fenomenen in agro-ecosystemen en moeten ze beschouwd worden als een belangrijke bron van informatie over die systemen.

Curriculum vitae

Carolus Bartholomeus de Steenhuijsen Piters was born in Tilburg, the Netherlands, in 1963. In 1989 he graduated from the Wageningen Agricultural University with a major in tropical agronomy. During his studies, he spent one year in Mali to do his MSc research. In 1990, he joined the Department of Agronomy of WAU as a PhD student. From November 1990 to June 1993 he did his field work in northern Cameroon and during this period, he also worked as a short-term consultant for several rural development agencies.