Seeds, hands, and lands

Maize genetic resources of highland Guatemala in space and time

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Dit onderzoek is uitgevoerd binnen CERES Research School for Resource Studies for Development en C.T. de Wit Graduate School for Production Ecology and Resource Conservation.

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Jacob van Etten

Proefschrift
ter verkrijging van de graad van doctor
op gezag van de rector magnificus
van Wageningen Universiteit,
prof. dr. M.J. Kropff,
in het openbaar te verdedigen
op woensdag 11 oktober 2006
des namiddags te vier uur in de Aula

Keywords: plant genetic resources, Guatemala, maize
ISBN: 90-8504-485-5
Cover design: Marisa Rappard

For Laura and Hanna

Acknowledgments

This work was financially supported by Wageningen University and Research Centre through the CERES Research School for Resource Studies for Human Development and through the C.T. de Wit Graduate School for Production Ecology and Resource Conservation.

I am grateful for having such good supervisors, who advised me on crucial points but also allowed me much freedom. Paul Richards has been a source of inspiration since I began my studies in Wageningen. Even before this research started, Paul procured finances to write a research proposal. Arnold Bregt welcomed me in his group after which I disappeared to the field to come back three years later. Arnold has supported me greatly in many ways, but especially in helping to structure my work and time efficiently. Sytze de Bruin suggested classification trees as an interesting method and helped to write Chapter 4. Harro Maat, among other things, read many radically different versions of the Introduction, giving helpful suggestions until the end. He also supported me with practical matters.

Mario Fuentes generously supported my field work in Guatemala by helping to procure an experimental plot, and by organising the genetic analysis. He also made it possible for me to learn about ongoing maize breeding projects in Guatemala and participate in several activities. ICTA as an institute also supported my work in various ways.

Many persons helped me doing surveys and field experiments. I would like to mention Juan Espital, a constant factor in Guatemalan agricultural research. I would also like to thank Adela, Belinda, Filemón and Melvin for their dedicated work.

The men and women who took time to answer our sometimes silly questions are thanked again here. I hope that my work contributes to a better understanding and use of the green riches they maintain on their farms.

My colleagues at CGI and TAO made work very pleasant. Gerd Weitkamp endured many disturbances of his work. I enjoyed the lengthy conversations with Edwin Nuijten about crop genetic resources.

Mijn familie wil ik bedanken voor het helpen met het vinden, inrichten en schoonmaken van ons huis in Wageningen. Mijn ouders hielpen met alles wat er gedaan moest worden in Nederland terwijl wij weg waren. Bedankt!

Mi familia política hizo sentirme en casa en Guatemala. Mis suegros y mis cuñados nos ayudaron con un sinnúmero de cosas. ¡Muchas gracias!

Laura me ha apoyado en estos cuatro años más que nadie. Te amo. En Hanna maakte alle dagen speciaal. Ik hou van jou.

Soli Deo Gloria.

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Chapter 1

Introduction

Chapter 1: Introduction

Examining crop improvement

This study examines the genetic resources of maize in the western highlands of Guatemala. Genetic diversity of crops is an important component of farming systems and agricultural innovation. New cultivars and varieties can improve the performance of existing farming systems. Better understanding of the mechanisms underlying crop diversity may help innovation in these systems in order to support food security. Agricultural research and, more specifically, the development of improved varieties through plant breeding, is an important and efficient approach to enhance food security and economic development (Morris and Heisey 2003).

Studies of current farmer practices dealing with crop diversity are important, because modern varieties and breeding techniques have failed to reach a large part of the world's farming systems. Beginning in the 1960s, the Green Revolution, which promoted the use of modern varieties, had a major impact on agricultural productivity (Evenson and Gollin 2003b). However, at present, some 1.4 billion persons still depend largely on self-produced seed (FAO 1998).[1] Maize, the subject of this study, is a typical case. At the end of the 1990s, 52.9% of the area under maize in tropical regions was planted with landraces or modern varieties that were recycled at least three times. In Latin America, this percentage is even slightly higher (Morris 2001). The impact of the Green Revolution on farming systems has also been unequal, geographically and socially (Evenson and Gollin 2003a).

To overcome the geographical and social limitations of the Green Revolution, beginning in the 1970s and 1980s (but drawing on older scientific traditions), agricultural researchers have emphasised the need for more specific targeting of crop improvement by means of farming systems or on-farm research (Hildebrand and Poey 1985, Simmonds 1985). Farming systems research was done on farms in order to take into account the specific conditions and limitations of those environments. However, the quantitative approaches followed in farming systems research soon came under critique. For instance, Suppe (1984) argued that the diversity among different farms is too high to allow for generalisations of the kind pursued in farming systems research. Agricultural research outcomes are only made useful to farmers by careful interpretative translation to the context of the farm, not by extrapolation of statistical results. Participatory approaches to development were in part an attempt to address these issues of contextuality. Scientific innovations are seldom readily translated to the conditions of farms, but are actively reworked by farmers to incorporate them in the socio-technological fabric of their livelihoods. Participatory or collaborative approaches recognise that farmers are not only passive recipients of scientific innovations but play (and should play) an important, active role in innovation and knowledge development. Participatory or collaborative approaches are being promoted and used in the context of crop improvement as well (Almekinders and Elings 2001, Almekinders and Louwaars 2002, Cleveland and Soleri 2002, McGuire et al. 2003, Weltzien et al. 2000). The emerging approaches in this broad field underpin a

[1] This is a rough estimate only; precise figures are lacking. The global agricultural population is estimated at 2.6 billion persons (96 % living in developing countries) (FAOSTAT 2005a).

new set of insights or assumptions about farming practices, which tend to emphasise the local, specific nature of farmer innovation.

This study contributes to the proposed approaches, which have to be seen as evolving and open for improvement. The next section will offer a conceptual critique of some ideas prominent in the literature on participatory crop development. As will be argued below, many studies treat farming practice from an individualistic point of view. This distracts attention from the connections between households and villages which are materialised through the exchange of seeds. Directing attention to these components may bring into focus different, possibly more effective strategies of connecting the modern plant sciences to farmers' practices.

This study will pursue this argument in relation to maize farming in Guatemala. It will focus on regional seed exchange. It will be argued that insight derived from studying regional seed exchange is useful to devise new ways of injecting scientific-based seed improvement into maize farming. In the following section, the philosophical underpinnings of this critique will be elaborated. Then, the problem, conceptual framework and research questions are presented. The section after that shortly describes the context in which the study was done, the western highlands of Guatemala. The last section of this chapter gives an outline of the remaining chapters.

Rationale

The present study will present a complementary perspective to research that has been done to support farmer participatory plant breeding. Much research on farming practice in relation to plant genetic resources is conceived from an individualistic perspective, focusing on decision making by farmers.

This individualistic perspective may stem from the analogy that is usually drawn between professional breeders and 'farmer breeders'. The continuity between farmer breeding and professional breeding is argued on the basis that both do skilful selection of planting materials (Duvick 1996, Berg 1997, Tracy 2003). From this 'evolutionary' continuity between farmers' and breeders' practices it follows that farmer breeders can be expected to have the same theoretical principles underlying their dealings with plants and seeds as professional plant breeders, with variations only in the details (Cleveland et al. 2000). Thus published biological models of farmer breeding have seed selection and variety/cultivar choice as their core (Cleveland et al. 2000, Johannessen et al. 1970). By putting selection in the centre of the model, the other mechanisms at work acquire a clear sequence in relation to selection. These models follow the Darwinian view that selection acts on the *pre-existing* genetic variation. When farmers discover and isolate a new variety in their crop population, diffusion may *follow* selection (Johannessen et al. 1970). Networks of seed exchange may constrain the access of individual farmers to certain types of germplasm and thus constrain selection (Cleveland et al. 2000). Thus, in this model networks of seed exchange are important to the extent in which they constrain individual decision making, which is at the centre of the model.

A contrasting view to the evolutionary views on plant breeding is that of ideotype breeding (Donald 1968, Donald and Hamblin 1983). According to the advocates of the ideotype concept, farmers maintain crops in equilibrium with their environment due to unintentional artificial selection. However, this equilibrium of crops with their environment is not optimal from an agricultural perspective. Crops need to be redesigned following the outlines of an ideal model or an ideotype, based on ecological and physiological scientific insights. Ideotype plant breeding is conceived as a break with crop evolution as it occurs under farmer conditions. Thus, this view assumes that local cropping systems are closed systems in equilibrium, which need to be opened up by professional plant breeders. The premises of this view are similar to the views which defend evolutionary continuity in that they accentuate selection as the main creative force in crop evolution under farmer conditions.

The present study will study processes of seed exchange and replacement not only because they are important in relation to individual decision making in seed selection and variety choice but also because seed exchange is important in itself. Not only selection but also gene flow is a *creative* process in the evolution of crop populations, and not merely a constraint to selection (Slatkin 1987). What is left out of the individualistic models is how farming households are connected in wider networks of seed exchange and how change in the social and spatial structure of these networks affects crop populations over time. Individual seed transactions may jointly have outcomes that cannot be predicted from individual seed exchange transactions alone.

Both in the biological and the social sciences, such supra-individual perspectives have been elaborated. On the one hand, plant scientists are developing analyses of how crop gene pools evolve as influenced by the shape of breeders' networks of germplasm exchange (Srinivasan et al. 2003, Smith et al. 2004, Mikel and Dudley 2006). Networks may become more closed or open over time. Mapping such networks allows not only for better decision-making by individual plant breeders, but also gives insights into the social and institutional processes from which a crop gene pool emerges as a larger entity (cf. Mikel and Dudley 2006).

On the other hand, in the social sciences, scholars have argued that technological practice, like building a Gothic cathedral or navigating a ship, cannot be characterised as the application of a single design or manual. The work is done through complex ongoing social coordination and *ad hoc* problem solving, which no single person oversees (Turnbull 1993, Hutchins 1995, Ingold 2000). It could be characterised as a system of 'distributed cognition', which as an aggregate system may give rise to emergent forms of organisation that cannot develop in the component parts (Hutchins 2000). Crop gene pools could also be understood as the collective outcome of social and biological complexity resulting from the interactions of many different farmers, communities, farming practices and environments over extended periods.

Indeed, students of crop genetic resources have argued that crop biodiversity should be seen as evolving in open systems. They have emphasised the value of the ecological concepts of the metapopulation (Louette 1999, Brush 2004), highlighted the importance of considering seed exchange (Zimmerer 2003) and expressed doubts about the occurrence of local adaptation (Wood and Lenné 1997). However, with a few exceptions, this has not yet given rise to systematic studies of the translocal character of farmers' dealings with crops and how farming practices may result in crop gene pools as broader entities that emerge from the interactions between and among people and places. This study begins to make such a contribution.

There are important practical reasons to focus research on farmer seed exchange and how its shapes broader gene pools. Current participatory or collaborative approaches in crop genetic management need to be up-scaled to reach sustainability (Smith and Weltzien 2000, Visser and Jarvis 2000). However, if participatory plant improvement is to avoid a 'cookie-cutter' approach to up-scaling (replication in more localities), up-scaling should involve a rethinking of the very premises of participatory agricultural research, away from individualistic, localist approaches (Zimmerer 2003). Seed exchange is an important aspect of innovation in farming systems and has its own dynamics. Also, from an institutional point of view, there is no reason to favour localist discourse. The localist perspective fails to address the more structural dimensions of underdevelopment and downgrades the role of the state in importance (Mohan and Stokke 2000). Recent developments in the international sphere place the state firmly at the centre of the scene to address issues of food security and access to genetic resources.[2] It would be fruitful to conceive possible reforms of agricultural research in this context. Those who plan activities in agricultural research should start thinking about connections between individuals, households, communities and localities. These connections materialise in the exchange of seeds.

Problem, conceptual framework and research questions

In the previous section, it has been argued that insights into the temporal and spatial dynamics of networks of seed exchange are important to understand farmers' dealings with crop genetic resources. For Mesoamerican maize farming systems, seed exchange (and especially its regional component) remains an understudied component of farmers' dealings with seeds. Detailed studies of seed exchange exist for Oaxaca, Mexico, but these do not cover aspects of space and scale (Badstue et al. 2002, Badstue et al. 2005). Also, some genetic studies have focused on regional patterns of genetic diversity of maize (Aguirre Gómez et al. 2000, Perales et al. 2005, Pressoir and Berthaud 2004b), but these studies have not been paralleled with a study of the processes that produce these patterns (especially gene flow). This study tries to fill this gap. It will describe processes of maize seed exchange in the western highlands of Guatemala, provide explanations for these processes and relate them to geographical distributions of maize diversity which form the outcome of these processes. These insights will lead to practical recommendations about the management of maize genetic resources in this area.

In this study, *seed exchange* is defined broadly as any social transaction, commercial or not, that introduces seed into a household. It will emphasise regional seed exchange. *Regional* is defined very loosely here and refers to any form of extracommunity seed procurement. It will attempt to connect observed patterns and processes in a coherent way in reference to a conceptual framework (Figure 1.1).

In contrast to the models which place seed selection or variety choice at the centre, in this study seed dynamics are at the centre of the model (Figure 1.1). Several mechanisms are at work (left), which influence seed dynamics. The resulting seed dynamics produce a geographical pattern (right). The mechanisms that contribute to the shaping of seed dynamics are divided in five. The term in the first box, 'social connectivity', refers to the presence of pre-existing social networks that enable seed

[2] E.g. the *Voluntary Guidelines to Support the Progressive Realization of the Right to Adequate Food in the Context of National Food Security*, adopted by the FAO Council in 2004, and the *International Treaty on Genetic Resources for Food and Agriculture*, signed in 2001 and entered into force in 2004.

exchange to take place. This includes personal ties (family, friends, neighbours) but also ties that are being formed on an *ad hoc* basis, like economic transactions. These presuppose the existence of a social environment which influences the occurrence and direction of seed exchange. Technological needs, the next factor, may trigger seed dynamics as they call for seed with different characteristics. Seed quality loss and seed loss may also directly motivate searching for new seed. The new seed needs to be adapted to the new environment in both ecological as in socio-cultural terms. This is expressed in the last box.

This study will evaluate this framework. It will determine the relevance and relative weight of the factors that are involved and describe the resulting seed exchange processes. The resulting geographical distribution of diversity is also studied. It is of importance because it will determine the outcomes of future seed exchange, but also because it contains information from which to deduce past seed exchange.

The research questions follow from the conceptual framework and read as follows.

1. Which factors play a role in regional maize seed exchange and replacement?
2. How do farmers exchange and replace maize seeds and cultivars in space and time?
3. What is the role of maize seed exchange and replacement in shaping regional spatial distributions of maize diversity?

The aim of moving beyond an individualistic perspective and bringing into focus long-term, regional dynamics of crop genetic resources has methodological consequences. To be able to address the supra-individual dimension of genetic change, research needs a relational, spatial approach, in which people and places are seen as open systems that depend on relations with other people and places. The approach also needs to be historical, as open systems are not in a self-constituted equilibrium, but open to historical forces (Winterhalder 1994). This study elaborates an approach which combines geographical and historical methods. To grasp long-term change, a survey of the regional historiographic literature was done. This literature was interpreted from the perspective of changes in maize agriculture and social networks. To investigate in detail the historical changes during the twentieth century, one township was investigated because early ethnographic descriptions were available. By using methods from cognitive anthropology, the collective memory about maize diversity was investigated. To investigate geographical variation from a synchronic perspective, an analysis of data from a regional survey combined with geo-information was undertaken. This analysis uncovered the geographical extent and direction of seed exchange in the recent past. Patterns of diversity were investigated using two types of data. The geographical distribution of cultivar names was analysed as preliminary evidence of general patterns of seed exchange. An analysis of genetic data of maize collections in their spatial context gave additional evidence about the processes of exchange and their spatial, environmental and crop related constraints.

The methods used cover various spatial and temporal scales and uncover processes using different analytical perspectives. For geographical research, Lane (2001:252) argues that *closure* or the elimination of competing space-time views is an inevitable characteristic of method, but that “we must avoid doing is giving priority to any particular types of closure”, and that using multiple methods “allows us to compare the different space time views that emerge as a result of different sorts of closures, and hence compare and contrast the implications that result.” This rationale underlies the present study.

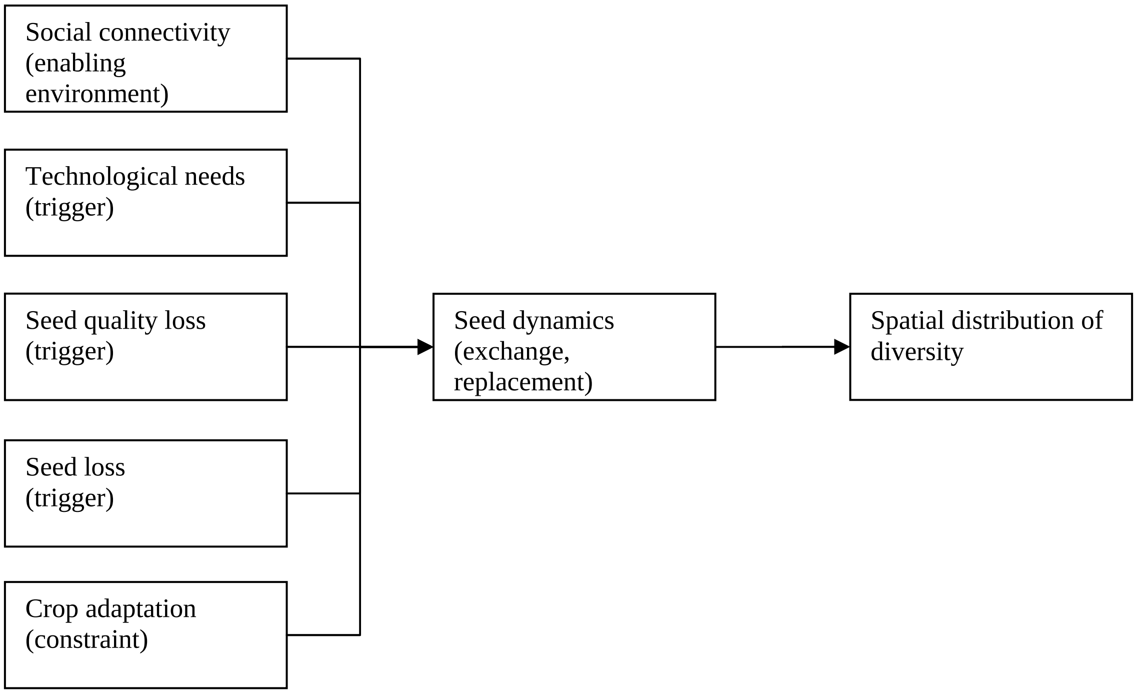

Figure 1.1. Conceptual framework
The boxes on the left indicate potential factors, which have an influence on seed dynamics (middle box). Seed dynamics can also be inferred from the spatial patterns they produce in cultivar naming and genetic diversity (right).

Study area

This study focuses on maize farming systems in the Guatemalan western highlands. Guatemala is the country with the largest population and economy of the six countries that make up Central America. Although the status of food security for Latin America is better than for Sub-Saharan Africa, large differences exist among the countries of the continent. Food insecurity concentrates especially in Central America and the Caribbean. In Guatemala, one of the worst cases, 23 % of the population is undernourished, well above the average for Latin America (10 %) and also above the average for Central America (20 %) (data for 2001-2003) (FAOSTAT 2005b).

In Guatemala and other parts of the Mesoamerican region, traditional agriculture is dominated by the *milpa*: maize often grown in association with other crops, like beans or squashes. Maize is the staff of life for most Guatemalans. Increasing maize yields is crucial to increase household food security, especially for smaller farms (Fuentes et al. 2005, Immink and Alarcón 1992). The impact of modern varieties on agricultural production in Guatemala is low. In 2003, seed production by the formal sector covered less than nine percent of the area under maize (Fuentes et al. 2005). Also, most varieties are produced for the lowland areas (seed production is dominated by the lowland variety HB-83), while the highlands are largely untouched by modern varieties (Fuentes 1997, Fuentes et al. 2005, Immink and Alarcón 1992). This trend is not unique to Guatemala, as this difference between lowlands and highlands also occurs in Mexico (Perales R. et al. 2003a). The Guatemalan highlands might be in need of strategies for crop improvement and seed supply that are different for those employed for the lowlands. For the highlands, currently a participatory maize breeding project is underway (executed by ICTA). This initiative is an indication of the interest that exists for participatory breeding in this area. The present study aims to support the refinement of the design of future activities in this area.

Chapter outline

Chapter 2 takes a long-term perspective. It sets the issue of seed exchange in its social-historical context and points out relevant regional differences that play (or might play) a role in the exchange of seeds. It reviews the secondary historical and ethnographic literature written about the western highlands of Guatemala from this perspective, and attempts to integrate the material within a historical-geographical narrative.

Chapter 3 focuses on a particular township, but maintains the long-term perspective, covering change during the twentieth century. It analyses change from the point of view of farmer knowledge. Although farmers' definitions of crop diversity units may not correspond in a straightforward way to genotypic or phenotypic categories, they are nevertheless relevant indicators of the type of diversity that is important for production systems in the area.

Chapter 4 focuses on the process of seed exchange through a social survey of households. It draws out quantitative and qualitative variables that are associated with different seed procurement options. This gives indications about the reasons why farmers engage in regional seed procurement and their relative importance. Also the spatial distributions of farmer cultivar names and the motivations to discard seeds are reported on, as these give additional insights into regional seed exchange and the motivations to replace seeds.

Chapter 5 concentrates on the genetic patterns of maize populations in the study area. Genetic studies may corroborate or indicate the relative importance of the observed mechanisms and processes of seed exchange discussed in previous chapters. Since the studies reported in Chapters 4 and 5 are both located in the same area, some direct comparisons are possible between the two. The fifth chapter uses genetic markers to evaluate the spatial structure of maize populations, and the influence of altitude. It also investigates the association of quantitative traits of the populations with genetic distance, in order to evaluate some of the mechanisms at play in seed exchange and the possible influence of modern varieties in the area.

Chapter 6 compares the outcomes of the different studies in relation to the research questions. Also, it reflects on the possible implications of the findings for different modes of managing maize populations in highland Guatemala for enhanced food security.

Chapter 2

Historical change of maize diversity in regional context (±1500-2005)

van Etten J. 2006. Molding maize: the shaping of a crop diversity landscape in the western highlands of Guatemala. *Journal of Historical Geography* (in press).

Chapter 2: Historical change of maize diversity in regional context (±1500-2005)

Introduction

It is likely that the domestication of maize occurred around 7000 BC in the Balsas catchment, Oaxaca (Mexico), from Mexican annual teosinte, although competing hypotheses exist (Matsuoka et al. 2002, Wilkes 2004). In the millennia following maize domestication, seed selecting agriculturalists dramatically changed the appearance of maize and developed dozens of maize races. The biological diversity embodied by these races is of great value for the future of global food production. It forms a source of old and new genes to assure continued crop evolution and production. Maize biodiversity also embodies a cultural heritage. Certain crop types are connected to specific ecological and culinary uses. The multifaceted value of global crop biodiversity is increasingly recognised in emerging policy, which seeks to conserve crop germplasm both *in situ* and in seed banks, and enhance its value through selection done by both farmers and scientists.

In all of this, geography has an important role to play. Some central claims in studies on diversity in maize and other crops have an important geographical dimension. Many past studies state that rural communities in Guatemala and Mexico are relatively closed to seed materials coming from outside sources (Johannessen 1982, Johannessen et al. 1970, Stadelman 1940). This view reinforced the common association between native populations and good conservation practices, which are often described in terms of closed ecosystems of humans in equilibrium with nature, and often combined with some kind of antimodernism (clear traces of this view are to be found in Steinberg and Taylor 2002). However, a broad range of empirical studies of native conservation practices now deeply questions such views, and proposes non-equilibrium models based on ‘open’ systems, in which contingency and uncertainty play an important role (Smith and Wishnie 2000).

Dominique Louette (1999) has proposed that farmer maize landraces are genetically ‘open’ on the basis of her community study of Cuzalapa in Jalisco (Mexico). Louette found substantial exchange and replacement of seed lots at community level. Also, fields exchanged genes because of moderate levels of cross-pollination. However, although farmer landraces might be open to other landraces in the community, the community might be rather closed to regional exchange of seeds. This and subsequent studies in other parts of Mexico did not directly address the question of seed moving in larger territorial units, and over longer periods of time. Work on the regional geography of maize biodiversity has focused on Chiapas and Oaxaca, Mexico. Perales, Benz and Brush (2005) hypothesised that maize biodiversity may be spatially associated with ethnolinguistic diversity in Chiapas. An isozyme analysis showed that the maize cultivars grown by Tzotzils and Tzeltals (speakers of closely related languages) were not consistently different from each other. However, phenotypic differences were evident, including different broadness of adaptation to environments. On the basis of these data, the authors suggest that place-specific selection is effective in maintaining phenotypic differences in maize diversity, in spite of gene flow between the populations. Pressoir and Berthaud (2004b) reach similar conclusions in a study on communities in the Central

Valleys of Oaxaca. However, direct evidence on regional seed exchange is lacking to further corroborate these findings.

The contribution of this chapter to the existing geographical knowledge on crop diversity is twofold. First, it concentrates on an understudied area with regards to maize genetic diversity: the western highlands of Guatemala. Previous biological studies of the geographic distribution of maize diversity (Hanson 1984) enable a rough comparison between Mexico and Guatemala. Genetic diversity in the highlands of Guatemala seems to show more localised patterns than in Mexico. This justifies a more detailed spatial analysis for Guatemala.[3]

The second way in which the research reported in this chapter contributes to crop diversity studies is by its focus on process. The lack of process-based evidence for regional distributions of diversity is paralleled by a blind spot for geography and history in crop diversity studies. Compared to the investigation of agricultural origins and domestication in geography, little attention has been paid to the historical aspects of the emergence of uneven geographical concentrations of biological variation of cultigens. There is especially a "lack of inquiry into the economic and social history of agricultural biodiversity" (Zimmerer 1993:15). A historical approach might be especially important, since for maize diversity, the Latin American archaeological record suggests spatial distributions in pre-Columbian and early colonial times radically different from present ones. Most evidence for this point comes from maize depictions in the indigenous literature and from ceramic objects containing decorative impressions from real maize ears (Anderson and Finan 1945, Eubanks Dunn 1975, Eubanks Dunn 1979). (For a critique of the visual method, see Benz [1994]). Understanding regional crop diversity as an outcome of historical processes might also increase our insight into the options for managing and conserving crop populations.

The chapter considers how scholars and scientists might envisage local and regional social processes over several centuries affecting the shaping of the maize diversity landscape in the western highlands of Guatemala. The geographer Carl O. Sauer was a pioneer of the use of controlled speculation as a way to develop fruitful hypotheses concerning processes of diffusion in regional and historical perspective (Haggett 1992).[4] His work suggests that one way to test such hypotheses would be to 'map' the likely consequences of the putative processes, and compare these mappings with actual geographical distributions of phenomena. The approach thus assumes that current crop populations are analysable as 'living fossils', offering testimony to past processes.

For the approach to work, however, it would also be necessary to identify and describe relevant processes and mechanisms. The recent, and rapidly expanding, ethnographic literature on farmer seed management is a rich source for candidate processes and mechanisms. The candidates would need to be located within a historical-geographic context to generate predictions about outcomes. Methodologically, the aim would be to assume processes and mechanisms to be working within a given area and to work out likely temporal and spatial consequences; candidates could then be winnowed

[3] In Chapter 5, which was written after the publication of this chapter as an article, an alternative interpretation of the Mexican studies is given. The situation in Mexico and Guatemala may not be so different after all.

[4] For an assessment of Sauer's deductions on agricultural origins, see the contributions in Mathewson and Kenzer (2003).

through quantitative testing against present geographical distributions of crop genetic diversity.

This chapter is a first step in a research sequence based on such a logic, directed at actual patterns of maize genetic diversity in western Guatemala, and their possible historical antecedents. It first identifies some processes previously marked in the literature as relevant to seed-related innovation and crop diversity. Then it reviews the available secondary literature for the different periods in Guatemalan history (from the Postclassic period to the present) describing the general socio-economic context of each period and discussing the findings on identified processes. More direct observations on maize changes, where these happen to be available from the secondary literature, are placed in this context, as being potentially useful to illustrate the possible outcomes of the identified processes. This feeds into a broader discussion of the historical, regional, and community components of present maize diversity landscapes. A key argument will be to substantiate the possibility that historical events are potentially more important in shaping maize diversity geographies than continuous seed exchange. The chapter concludes by outlining the possible relevance of this emphasis on an event-oriented history for debates about the future of maize diversity in highland Guatemala.

Imagining seed dynamics

Most documentation of maize seed dynamics (exchange, replacement, and loss of seeds) in Guatemala reaches only back to the first half of the twentieth century. Extrapolation and imagination will be necessary to explore the processes in earlier times. From the literature on contemporary seed dynamics three dynamic human factors of influence on crop biogeography can be suggested.[5]

1. Seed choice An important dimension of crop type preferences is related to ecology and technology. Relative land and labour availability are important triggers for technological change, including seed-based technology (Zimmerer 1991).

2. Disasters Disruptive moments in history require special attention. A small body of ethnographic literature deals with the effects of disasters on crop biodiversity (Richards and Ruivenkamp 1997, Sperling 2001). Political conflict, natural disasters, and epidemics lead to loss of seeds and crop types and to the erosion of trust and social solidarity that underpins the exchange of seeds and knowledge.

3. Seed exchange In the Mesoamerican culture area no specialised social institutions or networks for farmer seed exchange exists, in contrast with, for instance, parts of Africa, where seeds are exchanged as ritual gifts (Badstue et al. 2002). Consequently, maize exchange in Guatemala between households and communities tends to occur occasionally and along the lines of pre-existing social contacts, inside and outside local communities. If social contacts (trade, marriage, political connections) across space are constant and frequent, seed exchange is likely.

[5] Another set of factors comprises biophysical processes (e.g. volcanic eruptions, hurricanes, climate change).

Postclassic Maya societies (until 1524)

Guatemala and Southern Mexico form the home of the Maya civilisation. Maya culture reached its apogee during the Classic period, between 300 and 900 AD. The classic Maya cities were concentrated in lowland environments. The highlands formed a peripheral area during the Classic period, and the more cosmopolitan culture of the lowland cities had only superficial reception in the area.

At the moment of Spanish intrusion into the region (1524), several polities controlled territory in western Guatemala. One of the biggest polities was the K'iche' state, which included around one million inhabitants. The ecological home area of K'iche' culture was the central highland basin. Around the central highland valleys, smaller groups were settled. Some of these polities, like the Tz'utujil on the south-western side of Lake Atitlán, were devoted to specialised irrigated agriculture, unlike the K'iche'. Even more outlying were Maya groups such as the Ixil and the Mam who were subsistence producers with a rustic culture (Figure 2.1).

Archaeologist John W. Fox has elaborated in detail the idea that the social organisation of the K'iche' polity was based on segmentary lineages (Fox 1987, Fox and Cook 1996, Sahlins 1961, Southall 1988).[6] This type of social organisation is associated with expanding or predatory states. Anthropologists like Sahlins understand it as a flexible way of organising solidarity when populations are growing and centralised power is difficult to uphold. The main unit of social organisation is the lineage segment, based on the 'mechanical' solidarity of kinship. Segmentary lineages are able to erect a light-weight form of co-ordination when it is necessary. Seeking allies through kinship ties, under the rule 'closest kin first', otherwise loosely associated groups join forces against common enemies, without requiring a constant hierarchical infrastructure for mobilisation when such co-ordination, as and when unnecessary. Consequently, segmentary lineage solidarity occurs mainly or only in situations of (ecological) competition with other groups.

Tribute collection in kind was the main integrating economic principle within the domain of each polity. The cultivation of maize and other food crops took place mainly in the highlands, while cacao, a prestige item, was exclusively grown in the lowlands. The importance of political control over basic grain production for the K'iche' and Kaqchikel elites becomes clear in the fact that all central settlements are found in the highland maize production zone (Feldman 1971).

The K'iche' polity and the Kaqchikel derivative polity had a preference for the broad highland basins because of their suitability for 'generalised' dry-land agriculture. These two groups showed less interest in parts of the landscape where specialised hydraulic agriculture was possible. Lowland cacao production only interested them in the later stages of state formation. Through highland subsistence production they ascertained the independence of their polities and lineage segments, as each was able to attain self-sufficiency. Although highland maize production was generally reliable, once in a while it failed. Maize production in the lowlands supplemented the highland harvest, especially in moments of crisis.

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[6] For a more nuanced evaluation of the segmentary lineage view, see Popenoe de Hatch and Ivic de Monterroso (1999).

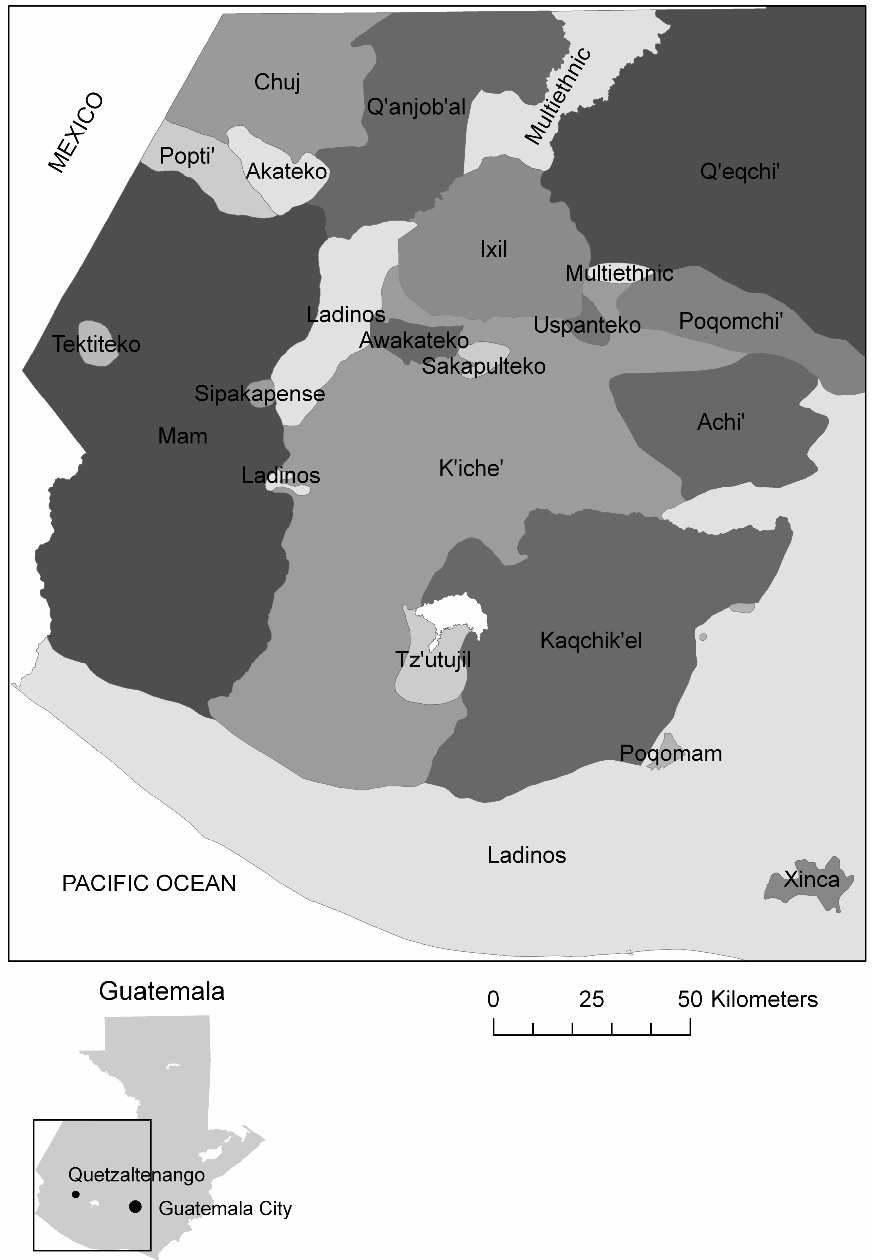

Figure 2.1. Ethnic groups in Guatemala today. The current distributions of these groups largely reflects their pre-Columbian distribution (except Ladino and multiethnic areas). Data from FLACSO-Guatemala.

Little is known about maize cultivation and maize exchange in Postclassic times, and much has to be inferred. From the segmentary lineage model it follows that trade and specialisation were relatively unimportant in the Postclassic Guatemalan highlands. This type of social organisation "develops among societies with a simple, neolithic [sic] mode of production and a correlative tendency to form small, autonomous economic and political groups" (Sahlins 1961:342). According to Fox, cosmopolitan influences in the Maya culture area are probably not the outcome of trade but of migratory movements. Interregional trade in the Guatemalan highlands was limited to some prestige items, unlike the intensive trade along the Gulf coast. And in contrast to the existence of the well-known Pochteca traders in the area under Aztec influence, interregional trade specialisation in the Guatemalan highlands was still in an incipient state when the Spanish conquerors arrived.

It might be concluded therefore, that in terms of maize germplasm the late Postclassic era represented a rather static situation. Seed exchange through trade can be expected, in any case, to be virtually non-existent for a high volume, low value item like maize. However, other political forms of social integration might have provoked sparse but significant seed exchange, especially among the K'iche' and Kaqchikel ethnic groups. This contrast between the latter and the peripheral Maya groups could be formulated as a geographic hypothesis to explain the current maize diversity distribution. However, such occasional seed exchange might be unimportant for two reasons. First, seed change was unlikely to be motivated by any drive for agricultural intensification. Maize cultivation was mainly part of an extensive subsistence agricultural system. Second, in their expansion, the K'iche' and Kaqchikel groups are thought to have taken over pre-existing social formations, only placing a light-weight political structure on top of what already existed. Adding to this consideration the 'leapfrog' character of segmentary lineage migrations, it is improbable that the expanding political frontier of these states corresponds to a slowly demographic and ecological expansion causing the smooth spreading out of crop types. It seems more probable that migrating groups simply took over the seeds of the groups that had become established in the area in earlier times.

Colonial society (1524-1821)

After the Spanish Conquest, Guatemala, devoid of major deposits of gold or silver, became a somewhat marginal part of Spanish America. The colony in Guatemala formed a relatively self-sufficient regime. It is telling that the colonial administration from the very beginning had its central base in the highland maize production area. One decisive reason for this was that supply of basic grains to the capital was crucial for the colonial economy, in remarkable continuity with the pre-Columbian period (Feldman 1971, van Oss 1982).

Also in other aspects, the Spanish occupation followed pre-Colombian patterns. Initially, the Spanish colonial administration limited itself to adding a layer of centralised tribute collection on top of the existing system. Native rulers (*caciques, principales*) fulfilled an intermediary function. They ensured that their subjects delivered the demanded products and shared it with the Spanish. Later, the colonial administration would atomise the tribute system by defining separate tribute demands for each of the communities previously under the control of a wider lineage hierarchy (Piel 1989, Zamora Acosta 1985).

The burden of colonial domination for the Indians was mitigated by several factors, especially the presence of the Church (van Oss 1986). Unlike the natives under other European colonial powers, the Spanish American Indians became subjects and vassals of the Crown of Castile with certain rights to protection (Seed 1993). The abolitionist New Laws (1542), implemented in Guatemala in 1549, forbade the holding of indigenous slaves (Lutz 1984). Another mitigating factor had to do with the conflicting interests of administrators and traders. During the export cycles of the colonial period, state interests (tribute, urban supply) would form a check on the interests of the plantation economy (labour extraction), as the first, more than the latter, required a vigorous rural economy (McCreery 1994).

However, under colonial rule incisive changes also occurred. The native population diminished sharply upon the Conquest. Epidemic diseases reached the Guatemalan highlands even before the first Spaniards did (Lovell 1985). Native population estimates decrease from 2,000,000 for 1520 to the all-time low of 220,500 for 1770 (Lovell and Lutz 1994). Falling land pressures would form the precedent for the spread of new, less intensive forms of agriculture, like sheep herding (Whitmore and Turner 1992).

Also massive resettlement (*congregación*) might have had an important impact. Priests and tribute collectors found the sparse settlement pattern of the indigenous population little conducive for evangelisation and tribute collection and decided to resettle the Indians massively in nucleated villages. It is difficult to know in what degree these resettlements were disruptive for the native population, especially because *congregación* was the topic of a fierce debate between the religious orders at the time of its implementation (Lovell 1990). However, it is clear that the Indians tended to resist *congregación* and often repopulated the countryside (Lovell and Swezey 1990).

Colonial domination did not invariably lead to ‘closed' indigenous communities. Although the communities were generally endogamous, community boundaries were often permeable to outside economic, cultural and political forces (Smith 1990a).[7] In spite of local variation, there might be a broad distinction between the communities of the *core* and *periphery* of the Spanish colonial presence (Lutz and Lovell 1990).

One important way in which the indigenous communities articulated with the colonial economy was through commerce. Two circumstances stimulated trade. The first is the mentioned atomisation of tribute units (from indigenous polities to colonial *pueblos*). As this development undermined previously existing social integration across ecological floors through tribute, it stimulated the development of regional markets to regain symbiosis through trade (Zamora Acosta 1985). The other factor was the demand for food stuffs and other items among the urban Spanish and Creole population. The various export ‘business cycles' were paralleled by increasing urban demand, stimulating production in the indigenous communities.

Trade specialisation occurred especially in the central K'iche' region, probably due to its high population density and the resulting land shortages. Around the colonial capital, urban demand stimulated specialisation in crops and crafts among towns. In other areas, like the Lake Atitlán area or Sacapulas, under close control by the friars, the agricultural economy developed in more ‘involuted' directions, while the Cuchumatanes mountains remained a refuge area where agricultural expansion and subsistence cultivation were still possible (Lutz 1984, Mathewson 1984, Veblen 1978).

The typical mercantile goods (cacao, cotton cloth, indigo) were generally restricted to Spanish traders, although K'iche' traders would gain an important share in the late colonial period (Lutz and Lovell 1990). Throughout the colonial era, the Indians delivered with relative freedom inexpensive goods like maize, vegetables and firewood, exempt from sales tax payment (*alcabala*) (Solórzano Fernández 1997).

[7] Not all communities were endogamous during the period. For a number of trade oriented K'iche' communities around Quetzaltenango, high rates of exogamy (20-62%) were recorded (Grandin 1997).

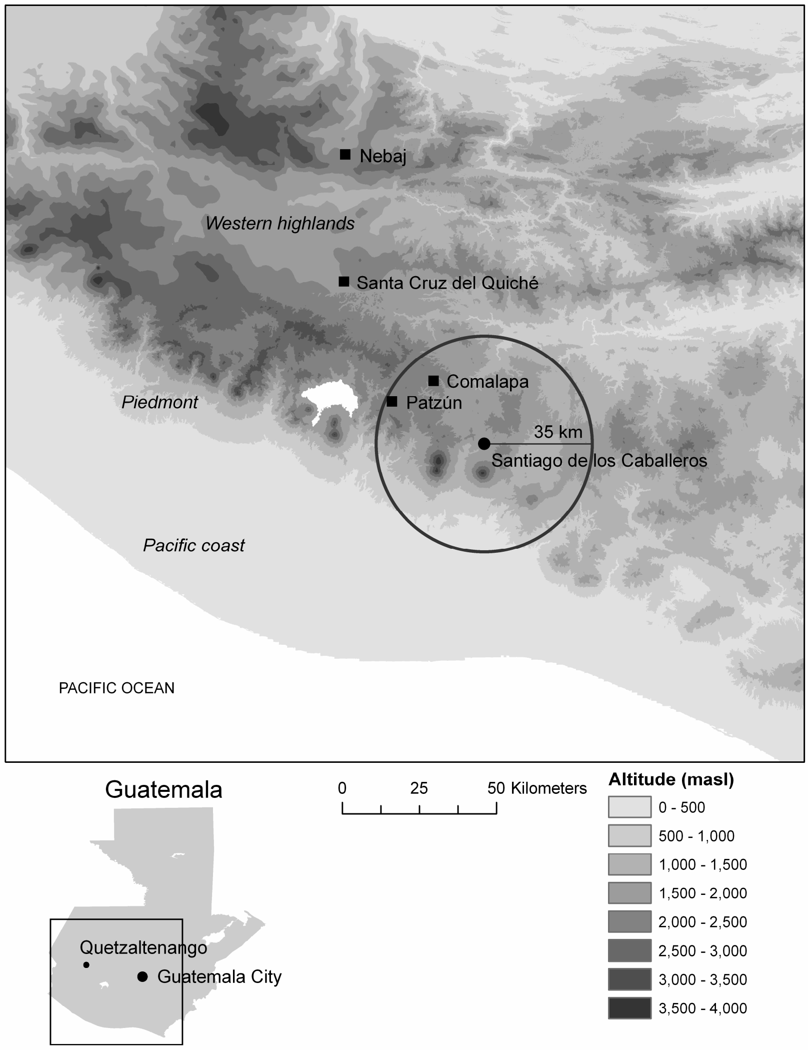

Figure 2.2. Maize trade in colonial western Guatemala.
Trade was intensive around the capital, Santiago, but between Nebaj and Santa Cruz del Quiché, no trade was observed. Sources: Van Oss (1982) and Luján Muñoz (1988).

Trade in maize, however, was localised. The capital city Santiago de los Caballeros, the geographic point where maize demand was most concentrated, received all of it from within a radius of 35 km, even when maize became scarce (Figure 2.2) (Luján Muñoz 1988, van Oss 1982).[8] In areas more remote from the colonial core area, bad communications constrained trade of maize.

> In 1768, Santa Cruz del Quiché obtains a very bad harvest of maize, while on the northern slope of the Cuchumatanes, a few tens of leagues from there, but under the condition of crossing the river Chixoy and of traversing a pass of 3,000 meters high, the village of Nebaj drowns in its excess of cereals. The commentary of

[8] Luján presents the replacement by wheat as a hypothetical cause for maize scarcity. This intuition is confirmed by the colonial chronicler Fuentes y Guzmán (1933) in his description of Comalapa.

> visiting archbishop Cortés y Larraz is perfectly lucid: “Nebaj has a very abundant harvest with no way out, because even if they would leave it in vain, nobody would accept it, only because of the work of collecting it” (Piel 1989:220).

For the highland periphery, not trade but migration was a common solution to food shortages. The migrants either went to work on the commercial lowland plantations or grew a second cycle of maize in this region (McBryde 1947).What happened to maize genetic resources during the colonial period? Two dimensions of possible change deserve attention: the disruptive effect of the Conquest on native maize culture and the effects of the new economic order on maize exchange.

Anthropologist Ronald Nigh (n.d.) states, without giving evidence, that for Mexico, Eurocentric suppression of native maize culture (favouring wheat) reduced maize diversity from possibly 200-300 races before the Conquest to 42 today, a reduction of 79-86%. However, no such suppression seems evident for Guatemala. If any maize diversity was lost, it was mainly the result of the dramatic reduction in population of roughly 90% between 1520 and 1770. The impact of the epidemics must have affected agriculture and maize cultivation profoundly. The testimony of a colonial official in Soloma on a typhus epidemic in 1806 illustrates this point.

> Having returned to their town the Indians who survived are without homes to live in, without resources to pay their expenses and tribute, and without corn to feed themselves and their families. If no measures are taken to assist these wretched people, they will without doubt starve to death, because they did not plant corn in the places where they sought refuge and so have nothing to live on, both for this year and for the next, since it is now too late to plant their fields (AGCA, A2.16.249.5036, ff. 2 and 2v., cited in Lovell 1985:169).

The impact of disasters on maize genetic resources depends on the geography of disease and the previous geographical distribution of the crop’s diversity. The epidemics did not strike all villages equally. Also, if certain maize landraces were distributed over various villages, their chance of survival was higher. The stirring up of rural society during the consecutive epidemics, the migration that followed, and the loss of seed stocks, might all have stimulated exchange of seeds between persons from different places. Given the dearth of data on historical maize diversity distributions, an assessment of the impact of the epidemics is difficult.

The other break with the past after the Conquest was the establishment of nucleated Indian villages. However, it seems that the impact of the *congregación* was not only negative. For maize genetic resources, the joining of several lineages might have provided new opportunities for seed exchange and hybridisation.

The low trade volume and poor infrastructure likely constrained seed exchange during the colonial period. Probably there was much continuity with pre-Columbian times. Nevertheless, it is likely that there were differences in the frequency of translocal seed exchange between the trade oriented central valleys and the subsistence oriented highland periphery. Also, as the lowland environments were the focus of migrations from the highlands, much seed exchange and broader geographic distributions can be expected there.

Independence and the Conservatives (1821-1871)

In 1821 a period of more than two and a half centuries of *Pax Hispanica* ended. Independence marked the beginning of a confused period of political conflict between Liberals and Conservatives. Initially, the Liberal party emerged victorious from the conflicts and governed Guatemala after 1831. The Liberals attempted to boost the economy with foreign investments, but their experiments began to founder in the late 1830s, popular uprisings followed, and the Conservatives, led by Rafael Carrera, took over government in 1841. The Conservatives were gentler towards the Indian population than the Liberals. Instead of relying on foreign investments, the Conservatives opted for a much more moderate export policy.

Although the export economy revived only slowly after 1840, the exemption of taxes and the relaxation of other colonial restrictions may have stimulated production and commerce in the Indian economy (Smith 1984, Smith 1990c).[9] Data to support this are scarce, however. Robert Carmack's studies confirm the intensity of Indian commerce for Momostenango in the Conservative period. However, two additional facts strongly qualify the implications of these findings for the intensity of trade for the whole highlands region. Momostenango is part of the K'iche' area, where trade tended to be a more frequent occupation than in other parts of the highlands, even in the colonial period (see above). It must also be noticed that for this community "most of the trade was local and did not significantly alter the peasant condition of the vast majority of Indians. […] The Indians increasingly turned to weaving, but it largely supplemented rather than replaced subsistence farming" (Carmack 1995:161).

Oliver La Farge has argued that the Conservative period was a golden one for Maya culture, which acquired its typical characteristics of which the vestiges were documented by the ethnographers of the early twentieth century (La Farge 1940). As state and church lessened their presence, independent Indian community institutions developed. Also in this period, an indigenous form of religious syncretism took further shape, blending Spanish Catholicism with pre-Columbian beliefs and forms.

Beginning in the late colonial period, land pressure increased because of a recuperative trend in population numbers. Demographic growth after 1850 caused the 'reruralisation' of the *municipio*, as families from the colonial nucleated centre established *aldeas* as a part of a centrifugal movement in search of land (Piel 1989). Township solidarity, which had evolved with the social atomisation under colonial rule and was reinforced through the retreat of church control, was an important ingredient of conflict. Most of the territorial conflicts occurred between individuals towns, while conflicts within the communities were resolved by the local community authorities (Davis 1997). David McCreery (1994:150) indicates the possibility that between communities "some conflicts over land did have less to do with economic concerns than with the reinforcement of internal unity and the routine boundary maintenance that is part of the constitution and reaffirmation of community identity".

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[9] Carol Smith has defended the thesis that during the Conservative period local community resistance inhibited the coffee boom. She proposes that during the period evolving trade caused stratification and broke down village egalitarianism, weakening community defenses against labour exploitation, and giving way to the Liberal reforms in the 1870s. However, Smith's trade thesis seems to be an artefact of her wish to emphasise the importance of the 'local', in defence of a locally grounded historiography.

For maize cultivation, the Independence period might be thought of as a relatively stable period. The economic orientation of the highland communities remained inward looking. Society did not urbanise and specialise but rather ruralised. Population numbers increased, but the resource base allowed for land reclamation. Even in some of the most land-scarce and commercially oriented areas, like Momostenango, trade remained largely local. The strong community identity might have prevented the introduction of maize from 'foreign' communities. With no acute social or demographic changes, and deepening local atomisation, the Independence period might be presumed to represent a 'freezing' of diversity of regional landscapes.

Liberal reforms (1871-1944)

After a period of warfare, the Liberals took over from the Conservatives in 1871. The Liberal reforms were led by coffee planter Justo Rufino Barrios. After 1873, Barrios effectuated a series of radical reforms to facilitate coffee cultivation. The *Reforma* was largely a class project. The Liberals disrupted the traditional values that – despite class and ethnic differences – had cemented society during the Conservative period, but did little to convince the masses of the good the new ideology would bring. More concerned with order and progress than with democracy, the coffee elite imposed itself and its economic ideas with force.

In an attempt to modernise the economy, the Liberal government removed the traditional protection of Indian communities and their collective rights to resources, and initiated a large-scale land titling project. Private property had to become the cornerstone of the economy, freeing land resources for sale. In a similar way, the government tried to free labour. In practice, this meant allowing and supporting forced recruitment and debt servitude. This meant that the labourer was tied to a particular plantation through debt acquired by advanced payments, which he then could not pay off over the course of one season. Although the labour arrangement was based on a free contract, as the Liberals would argue, it bound the labourer to the coffee plantation in indefinite servitude, often for life.

As government officials set up office in the highlands, they blamed the Conservatives for the sorry state of the villages and the destruction of the heritage of colonial government (Watanabe 2000). Ladinos in the western highlands became an instrument of control of the indigenous population, as military, office-holders of departmental and municipal government, and labour contractors.

The highland economy transformed. The marginal trade of the Conservative period was seriously curtailed, as labour was forcedly drawn to the coffee plantations (Swetnam 1989). Also, pressures on land augmented. By the end of the Liberal period, many communities had insufficient land to support themselves. Plantation labour had become necessary for their survival. Rural Indians became more and more integrated in the wider economy. However, with the growth of the coffee economy new kinds of trade emerged. Both the monetary income of the coffee labourers and the emergence of the coffee growing elite created demand for trade items.

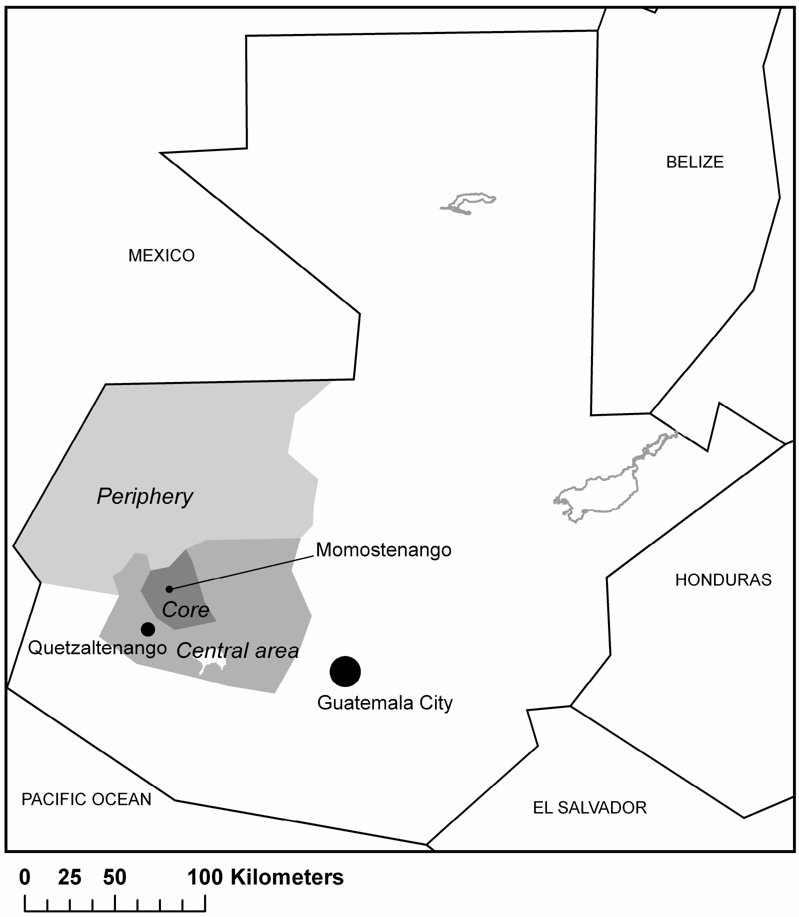

Figure 2.3. Economic subsystems in the western highlands of Guatemala (schematic map).
These differences deepened during the Liberal period, but originated before. Momostenango, a community with a long trading tradition, is part of the central area. Drawn after: Smith (1979).

A clear sign of the integration of the highlands into the capitalist export economy was the deepening specialisation between highland locales. In a rough characterisation of the regional specialisation pattern, three zones can be distinguished (Smith 1979). The heavily populated core zone (Totonicapán) specialised in provisioning the new plantations with goods through trade, gaining relatively little income from farming. The central zone (Chimaltenango, Quetzaltenango, southern Quiché, and Sololá) specialised in basic food production to supply the lowland plantations and to cancel out the internal shortages caused by intra-zone specialisation in vegetable production. The periphery (Huehuetenango, northern San Marcos, and northern Quiché) supplied labour through seasonal migration (Figure 2.3).

Freedom to engage in long-distance trade was generally restricted to those close to the local sources of authority. In spite of the small number of persons who could engage in long-distance trade, these traders would have a profound impact on community life. Due to their broader connections and outlook, they formed important sources of innovation (Carmack 1979). Trade grew after 1934, when debt servitude was abolished and replaced with a vagrancy law, which allowed for capital accumulation among some coffee labourers, who became involved in trading business.

Beginning in this period, documentation on maize seed dynamics is available. In his study of Momostenango, Robert Carmack (1995) documents a particular maize seed innovation. A short discussion of this case will inform the interpretation of historical data on resource dynamics.

In 1920, two traders who had resided in Quiché migrated back to their hometown, Momostenango (*departamento* Totonicapán). They introduced maize seeds and a new planting technique. The new seed could be planted in March, earlier than the usual planting which is done at the start of the rainy season in May (probably the new seed was of longer duration). This system of early planting (**jumba'** in K'iche') results in a higher overall productivity than under the conventional system, called **rechjab'**, which consists in planting with the rains or just before the rains establish.

Jumba' planting requires more than two times the labour of **rechjab'** planting. Thus the shift to **jumba'** planting implied land use intensification, preceded by an increase in land shortages due to population growth. Land fertility levels in Momostenango had been declining up to the point that milpa intercropping with broad and common beans was no longer possible (Falla 1972). Seed innovation became a way to mitigate land shortages, facilitated by the new cosmopolitan traders who provoked an influx of new ideas and seeds.[10] These two circumstances would become even more important after 1944.

Revolutionising society (1944-1978)

During the presidency of Jorge Ubico, urban middle class discontent grew, resulting in civic agitations in 1944. The resulting October Revolution initiated an exceptional period of democracy in the nation's political history. A highlight of the period was the massive agrarian reform launched by President Jacobo Arbenz Guzmán. Although democracy was soon smothered by a US-led coup (1954), rural perceptions changed profoundly during this short period.

The revolution heralded times of economic progress for the highlands. Whereas the abolishment of debt servitude by Ubico in 1934 had stimulated trade, the repeal of Ubico's vagrancy law by the revolutionary government in 1945 made the trader's occupation even more accessible. Consequently, long-distance trade became more important.

The new long-distance traders were important agents of change. In various places traders introduced *Acción Católica*, a movement aimed at reviving Catholic orthodoxy, into their communities (Falla 1978). Orthodoxy was more compatible with their life as travelling traders and their more cosmopolitan outlook.

Jim Handy (1988) has argued that although the communities lost much of their traditional structure, there was much community identification during the agrarian reforms. Even so, during the revolutionary period, political consciousness augmented. Not only were local parties formed after 1944, but also labour unions and local committees

[10] Also in 1920, a new type of seed was introduced into San Pedro La Laguna. This synchrony supports the idea that broader societal changes influenced in local seed innovation (Butler and Arnold 1977).

emerged to assist the massive land reforms beginning in 1952. This would be the base for popular resistance in the coming period.

The CIA-assisted 1954 invasion tragically ended the first democratic experience in Guatemala and initiated a period of greater US interference in the region. Following the developments around Cuba, Kennedy's Alliance for Progress promoted a mix of democracy, social welfare policy and military assistance in Latin America during the 1960s. Although the objective of democracy was far out of reach, the new policy created a stable climate that attracted foreign investment, and stimulated economic growth and diversification. The development of the Central American Common Market also contributed to wider marketing possibilities for agricultural products.

The new, foreign clergy coming to Guatemala in this period were influenced by the more social ecclesiastic policy of Vatican II and began to set up co-operatives, taking advantage of the new economic climate. Being able to sell fertilisers at a lower price than the commercial houses, the co-operatives soon gained an important position in the Indian villages, and became vehicles of social change. The introduction of industrial fertilisers during the 1960s was also part of a general tendency towards land use intensification. Natural fertility had dropped during a long period of land shortages, and agricultural innovation responded to this.

Ricardo Falla (1978) describes how religious change and economic development in the 1960s created a multiplicity of social and political domains in the Indian *municipio* (township) he studied. Different groups within the community began to derive symbolic and economic power from a variety of outside organisations, including development organisations and merchandising agencies. Traditional community arrangements shattered and smaller sub-*municipio* units emerged, each directly articulating a sense of its own needs at regional and national level. Falla calls this process 'aldeización' (*aldea* is the main sub-*municipio* unit).

The state promoted development through the National Development Plan 1971-1975. It emphasised agricultural sector development and led to the establishment of the agricultural development bank BANDESA, the agricultural commercialisation institute INDECA, and the agricultural research institute ICTA. One of the effects of the new policy was that it reduced the 'margin of autonomy' of the co-operatives, as the state encapsulated the co-operatives in a patron-client network. The co-operatives were neither participatory towards their members nor participating in governance (Reyes Illescas 1998).

The opening of the communities favoured some community members more than others. Merchants, moneylenders, government officials, co-operative presidents, they all earned more than the peasants from the new economy. Class divisions became pronounced, especially after the economic crisis of the 1970s.

> By the mid-1970s the community was found divided among three groups: the costumbristas, the commercial sector now clearly delineated as the Indian bourgeoisie, and the radicalized Indian campesinos, who no longer recognized either of the two groups as their natural leaders. […] The radicalized Indian campesinos leaned to the left, seeking convergence with poor ladinos, organizing a mass movement that was situated outside the prevailing limits of legality (Arias 1990:251).

This radicalised movement had part of its roots in Acción Católica. When political channels for the claims of the radical groups closed definitively, and state terror increased, many Indians joined the rebel forces.

Agricultural change in this period had effects on maize cultivation and diversity. Falla (1972) documents the case of fertiliser introduction in San Antonio Ilotenango, Quiché. Previously unproductive land could become productive with the use of fertilisers. The augmented acreage of maize, in turn, led to temporary labour shortages. As a result, labour intensive **jumba'** agriculture was largely replaced by **rechjab'** agriculture. The intensification process that had occurred earlier (see previous section on the introduction of **jumba'** in Momostenango) was now partially reversed.

In Santiago Chimaltenango, a Mam speaking town, a similar process occurred (Watanabe 1981). Here, dry season plantings functioned not so much as a labour-intensive technology, but more as a hunger breaker crop. Labour expenditures were lower for dry season than for wet season plantings. Like in the previous cases, different seeds were used for dry season and rainy season plantings. A seed called **'aqal** was suited for early planting, while **aq wa'** seed was planted when the rains had started (Stadelman 1940). Fertilisers, when introduced, were mainly applied to **aq wa'** maize, augmenting its acreage by decreasing fallow. Dry season **'aqal** plantings still underwent long fallowing periods and decreased in relative importance.

The introduction of fertiliser itself also changed seed technological needs. Increased fertilisation made that the tall, top heavy plants leaned over and fell (lodging), especially when strong winds blew. This motivated a change towards the use of seeds that produced more stable, lower plants. Beginning in the 1970s, the maize breeders of the new research institute, ICTA, became aware of the problem and selected for lower plant stature. However, the promotion and adoption of modern varieties, a slow process, was sparse. In a few occasions the institute taught maize seed selection methods to groups of farmers (cf. Ponciano 1984). Two successful cases of farmer mass selection for earliness and low plant stature beginning in the pre-war years have been documented for western Guatemala (van Etten 2001, Lotter 2003).

The process of *aldeización* may have had consequences for the distribution of crop diversity and agricultural knowledge. As communities became increasingly fragmented locally, but more outward looking regionally, crop diversity distributions would tend to become more disparate over short distances, at the same time as intraregional differences may have lessened. We might also expect that local knowledge to become socially fragmented. Communities are less likely to know what the next community cultivates, while being very knowledgeable on what was available at the regional market.

Political violence (1979-1984)

While the highlands were previously considered an area where Marxist revolution was unlikely, in the late 1970s the situation had changed. Given the geopolitical climate and historical fears of Indian revolt in Guatemala, an explosive situation had developed. In 1979-1980 the army began a bloody counterinsurgency campaign. Initially, the army used inefficient, indiscriminate tactics. Young officers led a coup in 1982 to replace the inefficient and corrupt command, and formed a military corporatist state. The new command organised the most organised and bloodiest massacre campaign in the history of the country, based on a scorched earth policy. An army policy document from the period, *Firmeza 83-1*, explicitly ordains the destruction of livelihoods as a counterinsurgency strategy (in clear breach of the Geneva Conventions):

> Their sowings must be destroyed to cut them off from their sources of supply and to oblige them to surrender due to hunger or to reveal themselves for their movements through the areas they visit and thus be able to fight them, with the objective of disorganising them (cited in Comisión de Esclarecimiento Histórico 1999:II 220).

The number of persons killed during the armed conflict between 1978 and 1996 was roughly estimated as 132,000, excluding 'disappeared' persons, and the numerous victims before this period (Comisión de Esclarecimiento Histórico 1999:XII, An. III.5). Many people fled from their homes. It has been suggested that in the most affected *departamentos* some 80% of the population or 1.3 million persons left their home communities at least temporarily (AVANCSO 1990). Counterinsurgency policy had also an enduring impact on community social organisation through the formation of armed civilian self-defence patrols under close military control. These were often still functioning in the 1990s and maintain some of their cohesion even today (2005), demanding compensation from the national government.

Unfortunately, an assessment of the impact on crop resources of the 'undeclared' civil war in Guatemala must remain speculative. There exists a world-wide dearth of data on the impact of armed conflict on crop genetic resources (Sperling 2001). Guatemala is no exception. The few data available come from a small number of foreign social scientists.

For communities in Cobán, northern Guatemala, Wilson reports the loss of crop seeds during the armed conflict (Wilson 1995). However, the loss of maize seeds was not obvious, while vegetable seeds did appear to be lost. Maize was the first crop to be recovered. Steinberg and Taylor conducted a preliminary study in Huehuetenango, in the western highlands, comparing the lists of maize names recorded in 1937 by Raymond Stadelman with farmers' knowledge in 2001 (Steinberg and Taylor 2002). The study concludes that a considerable loss of knowledge of maize varieties seems to have taken place. The chapter supposes that this is a result of biodiversity loss caused the armed conflict. This is questionable, since in the intermediate years there was not only political violence, but also the socio-economic transformation of the traditional Indian community. Especially the process of *aldeización* might have led to a breakdown in the transmission of knowledge about crop diversity. This cognitive fragmentation is perhaps what was in fact recorded, while the crop types persist. There is a need for more fine-tuned studies to sort out the effects of socio-economic transformation on maize diversity from changes imposed by armed violence.

Democratic capitalism (1985 to present)

The army developed a clear nationalist identity after the 1982 coup. The military distrusted the oligarchy, and saw the army as the only institution disciplined enough to manage the country. The army broadened its goals and included economic development and equality in its vision for the nation. Consequently, the state became fully militarised.

The likely military victory of the army had become evident already in 1982. However, the army lacked clear criteria to put an end to the conflict. With the economy spiralling downwards, the military became obliged to seek some kind of accommodation with the business elite. The clashes between military and business elites were slowly resolved by adhering to democratic rules. Rachel McCleary (1999) points out that the Guatemalan instance of democratisation contrasts with other Latin American countries, as democracy in Guatemala was 'imposed' from above by elite factions, not forced from below through leftist violence. In 1996, the government and the revolutionary forces signed a peace agreement.

An important transformation of the business elite during the first half of the 1980s preceded this accommodation. USAID's policy to encourage agroexports since the late 1970s, the export openings to the US provided by the Caribbean Basin Initiative since 1984, and the trend towards outsourcing of western companies, had resulted in a new generation of business leaders. This group of modern reformers was of crucial importance for the transition to a consolidated democracy after 1985 (McCleary 1999). After the signing of peace in 1996, this new business elite continued to play an important role in national politics, especially under presidents Arzú (1996-2000) and Berger (2004 to present). It now seems that the corrupt, military-minded Portillo government (2000-2004) was only a temporary interruption of this trend.

The new 'democratic capitalism' imprints itself on the Guatemalan highland landscape in a very visible way. Many highland communities specialise in vegetable production for the North American market. Small-scale farmers sell broccoli, vetch beans, and other 'non-traditional' fresh products through co-operatives, intermediaries and contracts with exporting companies. The impact of non-traditional production has not been equal among communities. Some communities engage in the production and sale of the vegetables while other communities play a more passive role, supplying labour and land. Also within communities, differences became more pronounced, especially as some peasants began to sell lands and rely more on off-farm work. This shift to off-farm sources of income was facilitated by a parallel change in the rural market for labour. Textile assemblage (*maquila*) industries that produce for the world market financed with foreign capital take advantage of the rural labour market. This has forged new social relationships, as workers from various places meet each other in the factories, and migration between communities occurs (Goldin 2003).

The new export crops introduced over the last few decades decisively changed land and labour availability for traditional crops. However, the new crops have only partly replaced milpa cultivation. Many hold on to the milpa for food security, as in the past. One study has pointed out that dedicating land to milpa cultivation serves as a labour saving strategy (von Braun et al. 1989). As the new vegetables are more labour-intensive than maize, planting milpa helps the diversification into off-farm occupations, like work in the *maquila* factories. The milpa is very apt for this situation, as maize is a flexible, relatively undemanding crop with a great capacity to absorb marginal resources. On the other hand, maize is now more heavily fertilised to ensure greater harvests per unit of land. Short duration and low stature varieties are being adopted to allow sequential cropping and to prevent the lodging that results from a heavy fertilisation regime. Fullblown genetic erosion of the original maize varieties in Santiago Sacatepéquez, one of the most economically progressive Indian highland communities, is prevented by use of an older variety for corn-on-the-cob, for which the introduced varieties seem less suited (author's interviews, 2002). The new economy obviously signifies a major change for local crop diversity – and this might translate in massive genetic erosion as no measures are taken.

Discussion

Historically, the horizons of Guatemala's highland society have been narrow; most daily social interactions were local in scope. However, a small portion of the activities involved trading between communities. Also, several catastrophic events caused sudden massive migrations. Regional interaction was concentrated in these periods, and in the peaceful periods was confined to a few persons or occasions. Seed dynamics seem likely to have followed this pattern, being mostly concentrated in the eventful periods. Seed changes are not only formed by slow changes due to selection and local seed exchange, but also by the sudden discovery of good seed in another location, and seed replacement due to sudden losses. Given this likelihood, it might be argued that the relevance of event-based history for maize genetic distributions deserves further testing.

The historical perspective worked out in this chapter, even though it is still largely based on inference, might also be read as a challenge to conventional thinking which posits a modern-versus-native opposition, in which crop diversity decreases linearly as modernity advances. Change in local crop biodiversity is unlikely to be solely or mainly the result of the suppression of Maya culture. Seed innovations serve as endogenous strategies to cope with change and to intensify or disintensify land use according to circumstances. Seed introductions occur as spontaneous acts of innovation, as exemplified in the case of the 1920 seed introduction to Momostenango. In this case, the freedom to trade was of crucial importance in the introduction of seeds from elsewhere. Also in cases of maize mass selection mentioned, a genuine local interest in crop improvement becomes clear.

In spite of the contingent nature of evolutionary change in a non-equilibrium model, it has been suggested that seed innovations take place in broader socio-economic context determining the limits of social relationships across space. Trade, a visible and important expression of such ties between communities, was generally embedded in a political economy narrow in its geographical scope. This implies that most maize diversity units are to be found in bounded areas of the highlands.

The regional trade hypothesis needs to be juxtaposed against the association sometimes posited of a milpa complex and 'closed' communities over long time periods. Maize was not exclusively a subsistence crop that defied taxing or surplus extraction, nor is there much evidence that it slotted into a closed community defence strategy, as has been suggested (Annis 1987). In the colonial period and beyond, maize was traded relatively freely by Indian communities and sold in the capital. When historical incentives were provided, this trade and its associated seed innovations developed even further, during the Liberal period, and again during the export openings in the 1980s and 1990s. This suggests that instead of looking at communities in isolation, broader patterns within the western highlands should be the focus of the analysis.

Several comparisons can be suggested to further test the hypothesis of the role of regional trade and tribute relationships in seed exchange. Within Guatemala, it is obvious that the peripheral Cuchumatanes mountains are not only rich in biodiversity, reflecting its broken landscape (something which is assumed to stimulate genetic diversification through spatial isolation), but also because it was a refuge zone for many ethnic groups and because trade was less intensive in the area than in the more central parts of the western highlands. Thus it might be expected that the broad highland basins are wealthy in crop biodiversity through material moving inwards. It is also worth considering that diversity units may have a less patchy distribution within this area due to a more intensive exchange than in areas with less intensive trade. Another spatial hypothesis might be that seed exchange along altitudinal transects has been intensive due to temporary migration from the highlands to the piedmont and lowlands during succesive periods in history. Seed exchange between depressions in the highland area and larger low areas seems likely as a result. Quantitative spatial analysis using new genetic data is planned to more rigorously test several of the hypotheses developed in this chapter.

Future perspectives

What role will maize biological diversity play in the new socio-economic and political regime of the Guatemalan highlands? If current economic trends continue, maize diversity is likely to decline gradually over the next decades. An important human heritage would wash away. What management interventions would help to remedy these trends? The antimodern perspective gives a grim picture of the options. If biological diversity is exclusively dependent on tradition, consumption patterns influenced by syncretic Maya-Catholic religion, premodern production methods, and closed communities, then genetic erosion is unavoidable as modernity advances. Only the maintenance of the ancient patterns based on non-economic motivations, e.g. ethnic pride, would provide a brake on the loss of crop biodiversity.

The pan-Maya movement, a Guatemalan cultural revival movement which has gained much strength during the 1990s, would be an obvious platform for such efforts. The movement’s existence is a product of the recent climate shaped by democracy and the new capitalism in Guatemala. The pan-Maya movement consists mostly of sophisticated, urban Maya professionals, less than wholly representative of the interests of the rural, poor Maya majority (Fischer 2001).

The struggle for Maya cultural conservation is unlikely to have many positive consequences for the crops and agricultural methods of poor households. Traditionalism in itself is no default guarantee for the conservation of traditional technology. Industrial fertilisers (which were introduced in the highlands by religious innovators in the 1960s, as described above) were initially received with suspicion by the traditionalists. However, within a few years, when the heyday of the predominantly ideological discussions was over, traditionalists slowly began to adopt the fertilisers as well (Falla 1972). It is unlikely that activists of Maya cultural revival can persuade poor Indian families to bear the costs of conserving maize varieties they would otherwise discard.

Following the interpretation presented above, the breaking down of the colonial corporate boundaries around local communities should not be interpreted exclusively as negative, because their protective functions are now largely outstripped by the restrictions they imply given the new economic opportunities. The biogeography of Guatemalan highland maize further suggests that the presently increasing interlocal exchange of maize variety seeds will not provoke the fade-out of crop biodiversity. Given the history of episodic exchange, most diversity is likely to be found to be distributed at the regional level not locked into localised pockets. Localised pockets of diversity may indeed be bottlenecked. It is a hypothesis to be pursued that increased commercialisation and regional exchange could actually served to enrich local diversity. The main challenge is to sustain a viable fabric of maize culture at the regional level in the face of alternative land-use opportunities.

Socio-economic changes in the area not only represent threats to maize genetic diversity, but also opportunities. History teaches that integration into the national economy does not necessarily lead to the deterioration of local resources. The *departamento* of Totonicapán, during centuries the commercial heart of the highland region, has conserved some of the densest forest cover in the country. The reliance of the local economy on timber has historically stimulated the creation of local resource conservation institutions (Veblen 1978). This fact suggests that it is more sustainable to foster conservation through the continued use of resources in a new economic context than seeking to freeze the use context *per se*. Maize conservation in a modernised highland Indian community like Santiago Sacatepequez relies wholly on continued use of maize as a specialty product, as discussed above.

Use-based opportunities to conserve maize biodiversity should be amplified. The very advance of ‘modernity’ should be exploited for this end. Regional or new products based on native maize biodiversity could be inserted in commercial contexts. These could be transformed into less perishable output or convenience goods, such as tinned *tamales*. Especially the rapidly growing acquisitive power of Guatemalan emigrant workers living in the US provides new channels for culturally specific food products based on maize.

Since most rural highland households practice maize cultivation and processing, this form of economic development builds to a large extent on locally available technological skills. Therefore, it can be expected to have more equal impact across communities, when compared to innovation in non-traditional production. Innovation around maize genetic resources, processing and marketing is needed to make these changes possible. The seed innovations documented above show that there is a local interest with which to work.

Such a transformation of maize culture would recapitulate other elements in Maya culture reaching beyond the borders of the local community. According to a broad Mesoamerican mythological tradition, maize seed was originally obtained from a place in the mountains, often called Paxil (Navarrete 2000). Traditions from various communities converge on this extracommunal origin of maize. In the future, these myths of a common origin might gain new, cosmopolitan meaning.

Chapter 3

Changes in farmers' knowledge of maize diversity (1927/37-2004)

van Etten J. 2006. Changes in farmers' knowledge of maize diversity in highland Guatemala, 1927/37-2004. *Journal of Ethnobiology and Ethnomedicine* 2 (12).

Chapter 3: Changes in farmers knowledge of maize diversity (1927/37-2004)

Introduction

The intraspecific genetic diversity of crops in farmers' fields has increasingly received attention due to several convergent social and academic concerns. Crop genetic innovations for and by poor farming households have become an important focus of food security research (Richards 1986). Attention is being paid to the role of farmers in supplying seeds, given the limitations of seed supply by the formal sector in poor areas (Almekinders and Louwaars 2002). Since the early 1970s, concerns over the loss of genetic diversity as maintained in traditional agriculture ('genetic erosion') have spurred research as well (Brush 2004). Enhancement and protection of crop diversity has also received some international acclaim. The *International Treaty on Plant Genetic Resources for Food and Agriculture* (2004) obliges the signing countries to "promote or support, as appropriate, farmers and local communities' efforts to manage and conserve on-farm their plant genetic resources for food and agriculture."

Monitoring change is central to much research on crop genetic resources. Genetic resources, like other biological resources, are not 'stocks', but ongoing processes. They never remain static and constant energy is spent on maintenance and innovation to secure their reproduction and adaptation. However, long-term change in intraspecific crop diversity is a particularly problematic research subject. To trace change, comparative methods have to be developed, and some type of time series data should be obtained. If change took place over a long period, or in the past, research depends on historical information sources of a varying nature and quality.

This study uses one particular type of historical information, which is available for many areas and crops: lists of farmer-named cultivars or crop types. The aim of the research reported here is to bring out some important aspects of changing farmer knowledge related to their perceptions of intraspecific diversity, which are thought to bear on the biological dimensions of crop diversity. It will describe a methodology for dealing with this type of information to study long-term change in farmer cultivar knowledge. The study concentrates on maize (*Zea mays* ssp. *mays* L.) in one township in the highlands of Guatemala where this methodology was applied.

There are several limitations which have to be taken into account when using a comparative approach based on farmer cultivar names. Definitive answers on questions about the relation between cognition and biological reality might be impossible where biological information was never collected in the past. In spite of the difficulties of relating cognitive and biological categories directly, it might be argued that approaching the issue from the side of farmer knowledge gives a complementary perspective to the biological one. Farmers' perceptions and knowledge might offer privileged insights into the factors that seem most relevant to farmers themselves, and the motivations for choices in crop cultivar management.

Another limitation of this study, which derives from a deliberate methodological choice, is spatial. It concentrated research efforts in one township, thereby limiting itself to a small area. Another study of changes in farmer knowledge of maize cultivar names in the same region has taken a regional perspective (Steinberg and Taylor 2002). The present study will point out the implications of methodological choices of spatial extent and detail. This issue might be relevant to the development of methods in this field of study. In a field of research in which the possibility of manipulating the context is limited, adopting a micro-scale approach might be seen as a form of experimentation, which may produce important new insights (Levi 1991). Fine-grained analysis may uncover the hidden meaning of apparent anomalies, by interpreting them in the light of a larger system. Small-scale observations may also be relevant to the understanding of a larger system, when they can only be interpreted by indicating the incoherence of a larger system that was thought to be unified. Thus, fine-grained research on cognitive aspects of farmer diversity management might have complementary merits compared to other research approaches. One of the aims of the present chapter is to determine what these merits are.

Maize diversity and cultivar naming

The present study relied on a survey about farmer knowledge and concentrated on cultivar names. It did not employ biological specimens or photographs, unlike some other studies in this field, and biological diversity was not measured independently in this study area. Thus the meaning of farmer cultivars as the unit of analysis and the meaning of cultivar names in relation to maize diversity needs some further discussion.

Zimmerer (1992:63) analysed local changes in crop diversity in terms of *cultivars*, without drawing conclusions about the broader implications of local cultivar losses, because "[t]he basic regional biogeography of cultivars belonging to almost all native crops remains so inadequately understood that the overall significance of change at a local scale cannot be estimated."[11] Reservations about the implications of local studies on (farmer-defined) cultivars might be justified in the case of maize, too. To draw out possibilities to link the findings of this study to broader scales and biological units of diversity a discussion of maize biogeography and the relation between maize genetic diversity and farmer maize classification is needed.

Research on the biogeography of maize in Mesoamerica has mainly revealed coarse patterns of genetic diversity. Maize was probably domesticated in Oaxaca, Mexico, around 7000 B.C. (Matsuoka et al. 2002). In Guatemala, like in other parts of the Mesoamerican region, the milpa complex (maize and intercropped species, including different species of beans and squashes) is central to traditional agriculture. The western highlands of Guatemala are areas harbouring some of the highest concentrations of maize diversity worldwide (Mangelsdorf and Cameron 1942, Wellhausen et al. 1957). Anderson (1947) made an early study of maize in Guatemala, noting the phenotypic purity of Guatemalan maize in comparison with other areas of Latin America. Wellhausen et al. (1957) described thirteen races of maize for Guatemala, based on the morphology of the ear, and mapped their geographical distribution in Guatemala.[12] Hanson (1984), relying on the work of McClintock, Kato and others, indicated that geographic patterns in

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[11] A useful and broadly accepted definition of cultivar is "a variety, strain, or race that has originated and persisted under cultivation or was specifically developed for the purpose of cultivation" (Crop Science Society of America 1992).

[12] For a critique of the classification methods followed, see Benz (1994).

phylogeny of Guatemalan maize, as revealed by chromosome knobs, corresponded to a pattern of two-dimensional migration (isotropic diffusion), maize being more related when it was geographically proximate. Also, increased genetic isolation with increasing altitude was evident in this analysis. Bretting et al. (1990) describe the isozymatic variation of the identified Guatemalan maize races, and found a broad distinction between lowland and highland races.

Although these investigations have examined broad patterns of maize genetic diversity in Guatemala, little is known about genetic patterns in smaller areas. However, ongoing investigations in Mexico might have implications for Guatemalan maize as well. Regional maize research in Oaxaca and Chiapas has demonstrated low marker based differentiation values (F_{ST}) between populations (seed lots) and communities (Perales et al. 2005, Pressoir and Berthaud 2004a, Pressoir and Berthaud 2004b). These values are interpreted as evidence for considerable gene (seed) flow between farms and communities. Besides, it is pointed out that maize is a cross-pollinating species. Because of cross-pollination between adjacent plots it may be difficult to maintain genetically 'pure' maize seed lots under farmer conditions (Castillo G. and Goodman 1997, Louette 1999).

However, two points qualify the implications of these findings for the present study. First, the precise implications of the cited genetic studies are not entirely clear. The F_{ST} values from which the conclusions are drawn should be interpreted cautiously, as the model on which they are based does not discriminate between recurrent gene flow and historical events, including the fragmentation of related subpopulations (Templeton 1998). The fragmentation of related subpopulations might prove to be important, as in Mesoamerican maize pollen flow between fields and seed mixing have most likely far less impact than seed exchange and replacement, which is frequent and concerns larger numbers of individual plants. Also, the cited studies do not evaluate differentiation of maize with altitude. Meanwhile, field observations suggest that Guatemalan maize populations might prove to show significant geographical structure.

Native maize farmers in Guatemala generally try to preserve purity in observable characteristics, and are thought to be successful in doing so (Anderson 1947, Johannessen 1982). Isolation of broad maize types in different growing areas may contribute to the maintenance of phenotypic and genotypic differences in some highland communities in Guatemala (Johannessen 1982, van Etten 2001). Farmer cultivars of maize in Guatemala are often grown in different places along an altitudinal gradient, and have different characteristics which make their adaptation specific to these places (Butler and Arnold 1977, Stadelman 1940, van Etten 2001). Characteristics important for farmer classification of maize diversity include the length of the growing season, the shape of the cob, and kernel colour and type (Gillin 1951, Horst 1989, Hostnig et al. 1998, McBryde 1947, Stadelman 1940, van Etten 2001, Wilson 1995, Wisdom 1961).

The second qualifying point is that even if high levels of gene flow and low levels of differentiation are assumed, the observed phenotypic differences that provide the presumed basis for the possibility of farmer classification of cultivars might still be meaningful. In the cited studies it has been argued that selection of maize seed by Mexican farmers effectively maintains phenotypic differences in ear and kernel characteristics vis-à-vis gene flow (Louette and Smale 2000, Perales et al. 2005, Pressoir and Berthaud 2004b). These phenotypic differences are important for crop production and use. Farmers are observed to strive for maintenance of some ideal crop type in spite of the challenges of gene flow (Louette and Smale 2000). It has been argued that phenotypic diversity, as an important dimension of genetic diversity, deserves consideration in its own right, in addition to marker-based diversity (Pressoir and Berthaud 2004b).

Granted that phenotypically distinguished units exist in Mesoamerican maize farming systems, the question remains how cultivar names given by farmers relate to biological units of diversity. It has been established that during several decades a relatively stable classification scheme persisted in one Guatemalan highland community (van Etten 2001). Even so, it was observed in this community that 'new' seed lots introduced from outside the community did not always receive a distinct name, but might be included in existing local categories (also noted by Louette, 1999). Newly introduced cultivars that received a new, distinctive name included a cultivar suited to planting on recently cleared land for which other cultivars were not suited, and a cultivar that showed itself to be better adapted to drought than local cultivars. To generalize from these limited observations, it might be stated that incoming seeds will only receive a distinctive name if they are sufficiently different in appearance from locally present cultivars or suited to new types of ecological (or other) use.

In any case, farmer cultivar names do not correspond to phenotypic categories in a straightforward way, but their meanings imply additional dimensions important in classification, including their specific use context, occurrence, history, and origin. (This also indicates that the value of visual aids like specimens or photographs during interviews to solve the cultivar identity issue is relative – cultivar classification does not rely on readily observable characteristics only, but is to some degree contextual.)

In a quantitative analysis of maize in Cuzalapa (Jalisco, Mexico), Louette (1999) found that seed lots bearing the same cluster name grouped together morphologically. Thus, in spite of the indicated complications, a sufficient degree of association between cultivar names and genetic diversity might be expected to justify a systematic study of cultivar knowledge change as one source of insights into historical change of crop diversity.

Context and baseline data

Jacaltenango is a Guatemalan township (*municipio*) located in western highlands. The last census (2002) reports 34,397 inhabitants for this township. The majority of inhabitants belongs to the Maya ethnic group and speaks the (main) local language, Popti', while a minority is monolingual Spanish (28%). The area is home to a close wild relative of maize, teosinte (*Zea mays* ssp. *huehuetenangensis* Doebley), first documented in Jacaltenango and its surroundings by Kempton and Popenoe in 1935 (Kempton and Popenoe 1937). According to Garrison Wilkes, who has monitored the teosinte populations in the region over recent decades, and visited the teosinte populations around Jacaltenango in 2004, this subspecies is at risk of extinction (G. Wilkes, pers. comm., December 2004).

Several scholars have raised the issue of changing maize cultivars in Jacaltenango. Johannessen observed that the large landholders were especially taking the lead in introducing new maize cultivars into Jacaltenango, and expressed concern about increasing dependence on monetary resources in order to purchase new 'hybrid' seeds repeatedly (Johannessen 1982). On the basis of a comparison between Stadelman's (1940) data and interviews they undertook in 2001, Steinberg and Taylor (2002) concluded that maize diversity knowledge in Jacaltenango and other townships of Huehuetenango seemed to have decreased since 1937. They indicate that the political violence of the 1980s and its consequences might have contributed to loss of agricultural knowledge and biodiversity. The present study evaluates these views for Jacaltenango.

Among the literature on the social aspects of life in Jacaltenango, Casaverde's (1976) ethnography, which focuses on social organisation, was found particularly useful. It suggests a complex ethnic, territorial and social organisation in Jacaltenango. The township was affected by political bloodshed during the armed conflict, which formally ended in 1996. Victor Montejo's (1987) well-known book *Testimony* is an eyewitness account of political violence in a community of Jacaltenango. For Jacaltenango, the Comisión de Esclarecimiento Histórico reports 46 cases of human rights violations and violent acts between 1980 and 1985, which involved more than 105 killed and disappeared persons (Comisión de Esclarecimiento Histórico 1999:An. II). Many people fled from the area, often to Mexico, but others decided to stay or were compelled to do so, often as members of the paramilitary self-defence patrols.

The township of Jacaltenango was chosen as a study site for two reasons. First, the number of cultivar names reported in Jacaltenango is the highest for any township in the region (Stadelman 1940). This indicates the exceptional diversity of maize in this township, and is probably related to the fact that the township territory covers an altitudinal transect (Figure 3.1). Informants usually distinguished three environments: hot (below 1,400 masl) temperate (between 1,400 masl and 2,000 masl) and cold (above 2,000 masl). (The numbers are indicative only; classification is not very precise.) Second, there was a unique opportunity to study historical change with the availability of two independent cultivar lists made up in the first half of the twentieth century by visiting ethnographers.

In 1927, the township of Jacaltenango was studied by two US ethnographers, Oliver LaFarge and Douglas Byers (1931). In the resulting monograph on traditional Indian culture in the township, the authors mention the remarkable number of farmer maize cultivars in Jacaltenango and give a list of thirteen cultivars and some of their characteristics. In 1937, farmers' knowledge of maize cultivars in Jacaltenango was recorded by Raymond Stadelman (1940). Gathering information initially only in Todos Santos, Stadelman soon realised that in neighbouring villages maize diversity was more abundant – perhaps having been informed by Todos Santos maize traders, who travelled across the region (McBryde 1947). Subsequently, Stadelman visited most towns of the region to record data on maize cultivars and maize cultivation. For Jacaltenango he gives 23 names and their main characteristics. Stadelman's lack of reference to LaFarge and Byers' earlier publication, and some discrepancies between the two studies in spelling and interpretation, suggest that the two farmer cultivar lists are independently compiled.

In the following sections, Jacaltec cultivar names in the native language will be written in bold, and cultivar names in Spanish will be capitalised. The chapter follows the modern spelling rules for cultivar names. The unique number between brackets that follows each cultivar name should make comparisons possible, in spite of spelling differences.

Research question and methods

The main question this chapter attempts to answer is "what changes in maize cultivar knowledge occurred during the twentieth century in Jacaltenango?" Changes might include both loss of knowledge, and the acquisition of knowledge about new or newly introduced cultivars. An attempt will be made to answer this question by using the cultivar lists from 1927 and 1937 as a baseline, to be compared with interview data collected in 2004.

During the last quarter of 2004, a field assistant from Jacaltenango interviewed 40 male farmers in the township capital (*cabecera*) and eight other communities (*aldeas*) in of Jacaltenango (Figure 3.1, Table 3.1). Male farmers are generally more knowledgeable on maize diversity than women in this area (Steinberg and Taylor 2002). This is probably due to the gendered labour division; men are generally responsible for maize cultivation. Care was taken to include both older and younger informants in the sample for all communities. The communities were chosen to reflect the altitudinal and social variation of the township area. Jacaltenango has three native ethnic segments, called Jacaltenango, San Andrés, and San Marcos, and several foreign segments (Casaverde 1976). As shown in Table 3.1, the survey covers all three native segments, and several foreign ones.

The available information was processed in five steps. First, the quality of the baseline data was assessed. Then, the commensurability between the baseline and survey data was evaluated. Having established this, continuity and losses of cultivar knowledge were documented and analysed. In the fourth and fifth steps, the spatial and social distribution of this knowledge was subjected to further analysis. New cultivars in the area were also documented. The remainder of this section details the methods used for each of these steps.

Table 3.1. Sampled settlements in Jacaltenango (survey in 2004)

Settlement name	Ethnic composition of the settlement*	Altitude (masl)	Number of interviews
Inchewex	Jacaltenango	900	5
San Andrés Huista	San Andrés	1300	5
Jacaltenango (head town)	Jacaltenango	1400	5
San Marcos Huista	San Marcos	1450	5
Witzobal	San Miguel, Todos Santos, Concepción (all foreign)	1850	5
Cheya	San Miguel (foreign)	1900	5
Acomá	No data	2100	3
El Mul	Foreign	2300	4
Paya	San Miguel, Todos Santos, Concepción (all foreign)	2600	3

* Names of 'segments' taken from Casaverde (1976)

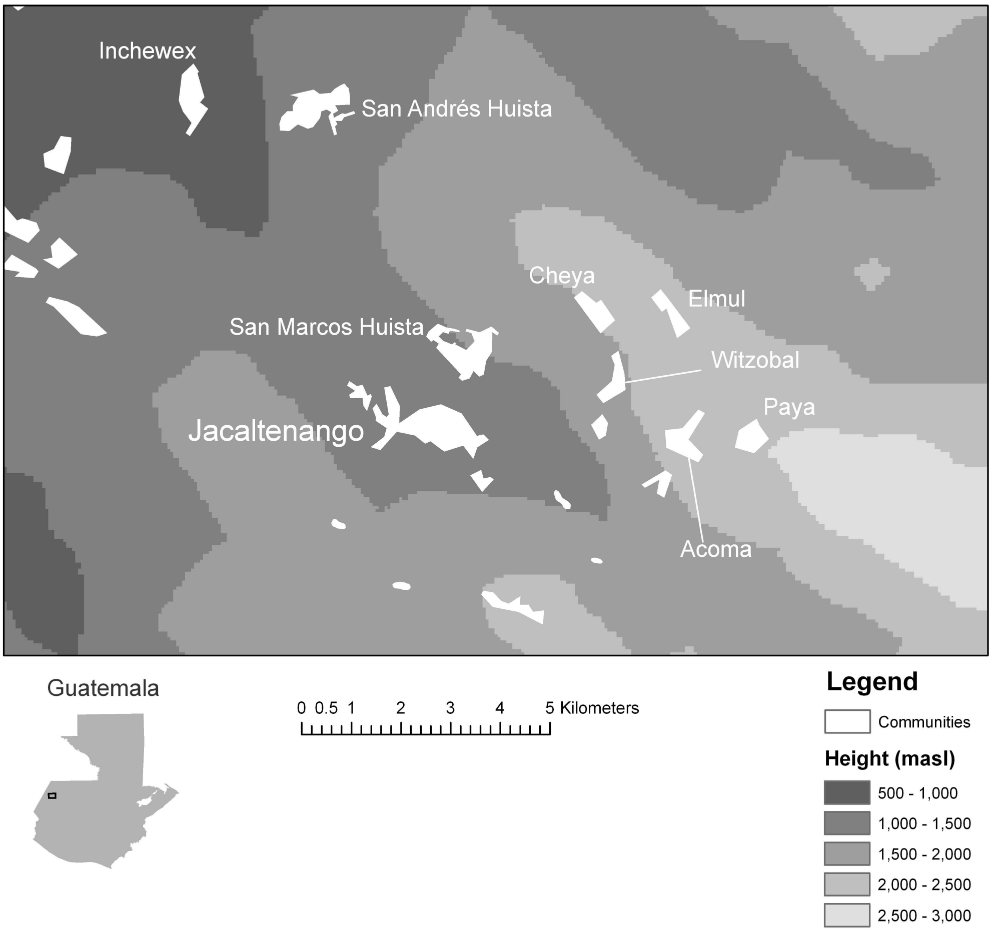

Figure 3.1. Study area: township capital and eight rural communities of Jacaltenango

Quality of the baseline data

The unique historical data available for Jacaltenango (two independent cultivar lists) permit a limited assessment of the consistency of the classification of maize cultivars by farmers in the past. If a cultivar classification system is fully consistent, the criteria farmers use to assign cultivar names to seed lots should be the same for all farmers. This measure of consistency can be used to compare the reported characteristics of the cultivars recorded by ethnographers in 1927 and 1937, to test the value of cultivar naming in terms of phenotypic diversity. Only if some minimal degree of consistency can be shown will the cultivar names have value for tracing diachronic change. The meaning of the cultivar names might contain additional information about the link with biological categories of diversity. The question whether the two cultivar lists give a complete representation of the cultivars present in Jacaltenango at the time they were made also needs discussion.

Commensurability of the baseline and 2004 survey data

Apart from demonstrating that cultivar classification in the first half of the twentieth century is consistent between farmers (previous section) it also necessary to examine the consistency of cultivar naming over time in order to establish meaningful comparisons between two moments. The need to establish the stability of the meaning of cultivar names between 1927/37 and 2004 was foreseen in the interview protocol. In each interview, first, a cultivar name recorded by the 1927/37 studies was mentioned and the farmer was asked if he knew this cultivar. If the answer was affirmative, the farmer was asked what characterised this cultivar. This was asked in relation to (1) adaptation to environment (cold, temperate, hot), (2) grain colour (white, yellow, black, spotted, other), and (3) planting and harvesting dates (given in dates, from which the growing cycle was calculated). This was repeated for all cultivars given in the historical cultivar lists. All three cultivar attributes are available for 1927/37 and these data were used for a comparison to test the consistency of cultivar definitions over time.

Perceived continuity and losses of cultivars

In the interview, the question was asked, for each historical cultivar known to the farmer, whether the cultivar was still grown (answer: yes/no). The informant was also asked to freely list cultivars that had become rare or had disappeared, in the informant's opinion. When the farmer interviewed indicated a cultivar, open questions were asked about the causes of disappearance or rareness.

The answers to the first question were analysed using methods from Consensus Theory to determine probabilities of presence/absence of each cultivar (Romney et al. 1986). The method employs a measure of informant competence to calculate the probabilities that a certain outcome is true. Informant competence is defined as 'the probability that an informant *knows* the answer'. This definition implies a correction for guessing, which might produce pseudo-correct answers, while in fact the informant does not know the answer. The theory takes the overall closeness of a particular informant to the other informants as a measure of informant competency. This assumes that consensus between informants is related to the phenomena under study.

The chosen design in the present study deviates in one important aspect from the method proposed by Romney et al. (1986). Throughout the interview, informants had the possibility to indicate they did not know a certain cultivar at all, or did not know if it was still present in the community (leading to missing observations on cultivar presence). Data with missing values are not suited for the analysis proposed by Consensus Theory (Weller and Mann 1997). A proximate method was taken instead. To calculate agreement between informants, the number of cultivars on which each pair of informants agreed, with respect to absence or presence in the community, was divided by the total number of cultivars for which they both gave a value for present or absent. This leads to a bias: presence/absence opinions about well known cultivars is taken into account many more times than those for little known cultivars in the calculation of informant competencies. Therefore, built into the analysis is the assumption that an informants' competency in judging the presence/absence of broadly known cultivars is a predictor for competency to judge the same for less known cultivars.

Social and spatial distribution of cultivar knowledge

The research design anticipated the possibility of unequal distributions of farmer knowledge between persons and communities. This issue is important for methodological comparisons with regards to sample sizes and distributions. The influence of age on cultivar knowledge will be evaluated, and the influence of environmental conditions and community boundaries. The latter might be important because during the second half of the twentieth century communities in Jacaltenango tended to become more socially isolated (Casaverde 1976).

Knowledge of new cultivars

Another aspect of knowledge about maize diversity and change is the emergence of 'new' cultivars. Through an open question each informant was asked to identify these cultivars together with some defining characteristics (adaptation, grain colour and growing cycle). This question allows assessment of to what extent the loss of older cultivars and the emergence of new cultivars form part of a single dynamic of cultivar replacement.

Results

Quality of the baseline data

To assess the quality of the baseline data, the two cultivar lists from the early twentieth century were compared. Table 3.2 summarises the results of each study and attempts to match the cultivar names from each study to the extent possible. In some cases one class corresponds to several (sub)classes in the other study.

From the table it is evident that the characteristics mentioned for each cultivar are remarkably consistent. Both studies recorded climatic adaptation for all cultivars except one. LaFarge and Byers split the environments in three zones (cold, temperate and hot), while Stadelman splits them in two (cold and warm). For the two extreme environments of LaFarge and Byers' scale, Stadelman's data show full agreement. For the temperate environment of LaFarge and Byer, Stadelman gives two warm and three cold cultivars, an equilibrated mix. Grain colour data are consistent, even for the cultivar names that do not include colour specifications as part of their name. As LaFarge and Byer did not report on growing cycles, comparisons for this aspect are not possible.

Cultivars are not completely distinguishable using the two mentioned characteristics in Table 3.2 (environmental adaptation and grain colour). For instance, **k'ej wah** (1) and **kok k'ej wah** (4) are both cultivars of cold environments and with yellow kernel colour. There are two possible situations. First, the latter might be a subgroup of the former class. (In this example, the names suggest the latter cultivar is a subtype of a class bearing the first name.) The other possibility is that the cultivars have other differences not reported by either LaFarge and Byers or Stadelman.

Examining cultivar names may add some information on other relevant differences. In addition to information about kernel colour, environmental adaptation and growing cycle, names contain information on geographic origin. The cultivar Pantaleón (24), like the other cultivars bearing Spanish names, was introduced from a coffee farm in Guatemala's southern piedmont area. There is indeed an existing coffee farm bearing the same name (McCreery 1994). The name "**xhamaltin**" (19) probably refers to a place called San Martín. However, it could not be determined on the basis of names if cultivar names indeed refer to the smallest units in farmer classifications or refer to broader classes in a hierarchy. Perceptions of farmers in 2004 might not reflect those in the first half of the twentieth century. Therefore, all reported maize cultivar names (n=24) were included in the analysis.

It is evident that Stadelman's list is more comprehensive than LaFarge and Byers's. Stadelman mentions 23 cultivars, while LaFarge and Byers list thirteen. In two instances, Stadelman gives a finer subclassification of a cultivar mentioned by LaFarge and Byers, while only in one case, LaFarge and Byers split a single cultivar mentioned by Stadelman into two minor units. One cultivar, **ockal tsaiik** (17), is mentioned exclusively by LaFarge and Byers, but our 2004 survey revealed that this cultivar name does not refer to maize, but to common bean (*Phaseolus vulgaris* L.). Assuming (1) no cultivar change occurred between 1927 and 1937, and (2) that all cultivars had an equal chance to be reported, it might be suggested that Stadelman's list approaches completeness, as it includes all cultivars reported by LaFarge and Byers. However, the second assumption, especially, may need to be questioned. The fact that some cultivars occur only on one of the lists might be an indication of their relative scarcity. Even so, taken together, the two lists most likely give an adequate and rather complete picture of Jacaltenango's most common maize cultivars between 1927 and 1937.

Commensurability of the baseline and 2004 survey data

The 2004 survey included questions on climate adaptation, growing season and grain colour. Comparing the answers to these questions with the historical data gives a measure of the stability of the cultivar classification in Jacaltenango during the twentieth century. Table 3.3 shows the result of the comparison.

Climatic adaptation data seem inconsistent only in three out of 25 cases. For Chimbo, in the 2004 survey there is consensus among the informants (n=3) that it grows in temperate environments. LaFarge and Byers classify this cultivar as being grown in a hot environment. However, as boundaries between adjacent environments are somewhat arbitrary, this case of misclassification might not be relevant. For **k'ej sat** (6) informants mention all three environments as valid for this cultivar, but a majority assigns it to the hot environments. Perhaps the cultivar shows a broad adaptation, and spread out from the temperate environment (as indicated by LaFarge and Byers) to both warmer and colder environments. The most serious case of misclassification is **q'an wah** (18), which is unanimously classified as a cultivar with adaptation to hot environments (n=5), while Stadelman reported it was adapted to cold growing environments. These cases excepted, the data are generally consistent.

The most common answer on colour data disagrees with the historical data in four of the fifteen cases where the latter data are available. In three of the four cases of disagreement, little current consensus exists and at least some answers agree with the grain colour mentioned in the historical sources (data not shown). In the fourth case, the historical data might be wrong, in classifying **q'an nhal** (7) as white, as the name of this cultivar includes an element (**q'an**) meaning yellow.

Table 3.2. Maize cultivars of Jacaltenango according to two independent sources from 1927 and 1937 (La Farge and Byers 1931, Stadelman 1940)
Spelling according to original. Abbreviations: C = cold; H = hot; T = temperate; W = warm; m = months. Between brackets: identifying numbers of the cultivars. Dashed lines: separation between growing environments following LaFarge & Byers (1931) (see C/T/H classification, second column).

LaFarge & Byers in 1927		Stadelman in 1937	
Name	Characteristics	Name	Characteristics
kĕx-wa' (1)	C, "black tortilla", sweet yellow grain	q'ex wa' (1)	C, 9 m
		nime' q'ex wa' (2)	C, 9 m, yellow, intermediate
		papa q'ex wa' (3)	C, 9 m
		kokh q'ex wa' (4)	C, 9 m, yellow, intermediate
tciletcuwa' (5)	C, sweet, white or yellow	tʃilitʃ wa' (5)	C, 6 m
kĕx sat (6)	T, "black eyes"	q'ex sat (6)	C, 9 m
qan-ñal (7)	T, white	q'an ñal (7)	W, 8 m
sax-ñal (8)	T, "white ripe ear"	saq ñal (8)	C, 9 m, white, dent
ts'ip sat (9)	T	ts'ib sat (9)	W, 8 m
ts'ip sat sax-ñal (10)	T, "white ripe ear with written grains"	ts'ib sat saq ñal (10)	C, 9 m, spotted, intermediate
ocĕp cahua (11)	H, three months, moons	oʃ̲ep ʃ̲xau (11)	W, 4 m, yellow, dent
p:au (12)	H	q'an b:au (12)	W, 8 m, yellow, dent
nimĕx kan p:au (13)	H, "big yellow ear"		
tcimho (14)	H	Chimbo (14)	W, 6 m
tewa' (15)	H, long term	te wa' (15)	W, 9-10 m
		q'an te wa' (16)	W, 9-10 m
ockal tsaiik (17)	H, "sixty days"	–	–
–	–	q'an wa' (18)	C, 6 m
–	–	ʃamaltin (19)	C, 9 m, spotted, flint
–	–	jex ti' (20)	C, 9 m, yellow, dent
–	–	saq po (21)	W, 8 m
–	–	Cuarentano (22)	W, 4 m
–	–	Tejar (23)	W, 4 m, white, dent
–	–	Pantaleón (24)	W, 6 m
–	–	q'ex tʃitam wa' (25)	black, dent

The time difference between planting and harvesting was taken as the length of the growing cycle for each cultivar for both Stadelman's data and the 2004 survey data. There is a significant, positive correlation between the two datasets for growing cycle length (r^2=0.54; p=0.0001). However, there is a systematic change; all but two cultivars have a shorter growing season, while all other cultivars are under the 1:1 line in Figure 3.2 (the 1:1 line represents the no change hypothesis). Stadelman reported planting dates in April for all highland cultivars, while according to the 2004 survey May or June is the norm. Rainfall and soil moisture early in the season might have become more limiting in recent decades. Given that the tendency is present across the whole sample, it does not interfere with cultivar identity. There is, however, one outlier: **txilitxwah** (5). According to Stadelman this cultivar is the only one for cold environments that has such a short growing season (Table 3.2). Exceptional status might explain the discrepancy; Stadelman or his informants may have made a mistake.

Overall, the consistency between the historical data and the data of the survey is strong enough to conclude that the cultivars mentioned are very likely the same ones in 1927/37 and in 2004. This suggests the data on farmer's knowledge of cultivar occurrence are sufficiently reliable to permit approximate assessment of continuity or disappearance of cultivars in Jacaltenango over a 70 year period using data on names as a source.

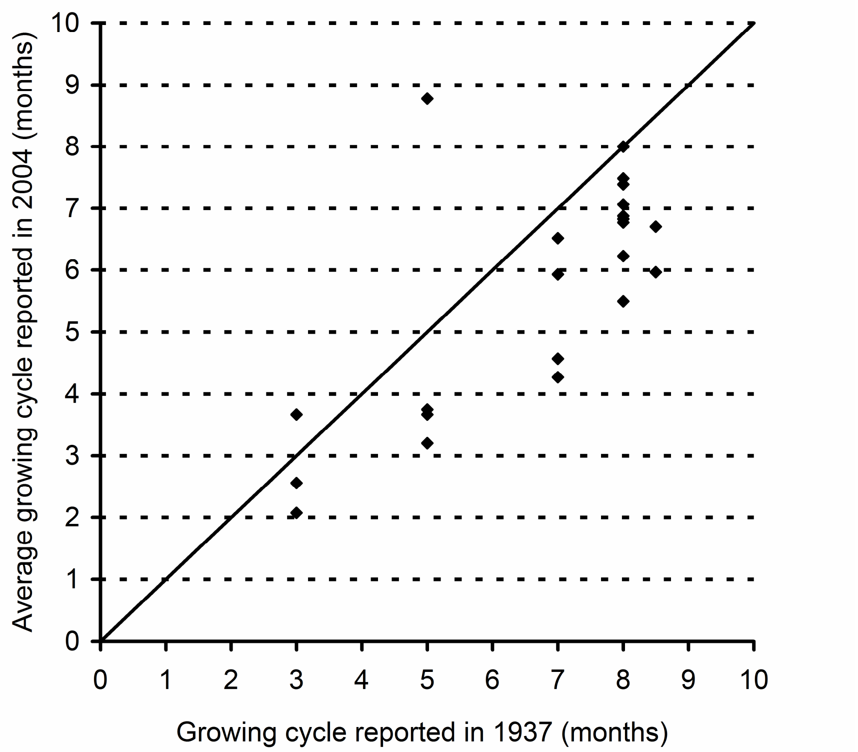

Figure 3.2. Growing cycle of cultivars compared between data of 1937 (Stadelman [1940]) and 2004 (survey)
Diagonal line indicates a hypothetical 1:1 (no change) relationship.

Table 3.3. Comparison for cultivar attributes between historical data and 2004 survey Most frequent answers are given from the survey. Modern spelling was followed. Cases of disagreement are indicated in bold letter type. Abbreviations: C = cold; H = hot; T = temperate; W = warm; LF&B = LaFarge and Byers (1931); S = Stadelman (1940).

Name	Climate adaptation			Grain colour		Maturity (months)	
	Survey	S	LF&B	Survey	S + LF&B	Survey	S
Chimbo (14)	**T**	W	H	-	-	3.7	6
Cuarentano (22)	H	W	-	White	-	2.1	4
k'ej sat (6)	**H**	C	T	Black	Black	7.1	9
k'ejti' (20)	C	C	-	Yellow	Yellow	8.0	9
k'ejti' txitam wah (25)	T	-	-	Black	Black	7.6	
k'ej wah (1)	H/T	C	C	Yellow	Yellow	7.5	9
kok k'ej wah (4)	C	C	-	Yellow	Yellow	6.8	9
nimej k'ejwah (2)	H/T	C	-	**Black**	Yellow	7.4	9
nimej q'anb'aw (13)	-	C	-	Yellow	Yellow	4.1	
oxeb' x'ahaw (11)	H	W	H	**White**	Yellow	2.6	4
Pantaleón (24)	H	W	-	White	-	3.8	6
papa k'ejwah (3)	C	C	-	Spotted	-	6.8	9
q'an b'aw (12)	T	W	-	Yellow	Yellow	5.9	8
q'an nhal (7)	T	W	T	**Yellow**	White	6.5	8
q'an tewah (16)	H	W	-	Yellow	-	6.7	9.5
q'an wah (18)	**H**	C	-	Yellow	-	3.2	6
saj nhal (8)	H/T	C	T	**Spotted**	White	6.2	9
saj poh (21)	H	W	-	White	-	4.3	8
Tejar (23)	H	W	-	White	White	3.7	4
tewah (15)	H	W	-	White	-	6.0	9.5
txilitx wah (5)	C	C	C	Yellow	Yellow / White	8.8	6
tz'ib' sat (9)	T	W	T	Spotted	-	4.6	8
tz'ib' sat saj nhal (10)	T	C	T	Spotted	Spotted	6.9	9
xhamaltin (19)	C	C	-	Spotted	Spotted	5.5	9

Perceived continuity and losses of cultivars

All cultivar names recorded by Stadelman or LaFarge and Byers in the first half of the twentieth century were recognised by some of the informants in 2004 (n=40), varying from 3 informants for the least known cultivars to 39 for the best known (Table 3.4). Informants knew 13.7 cultivars on average (57.1%), varying from 7 to 20 (SD=2.9).

For 39 informants cultivar presence/absence judgments are available. According to the Consensus Theory analysis, 77% (30 out of 39) of the informants have a competence of more than 0.8 and 67% (26 out of 39) exceed 0.9. Average competence is 0.85. These high competence numbers indicate that the judgments are generally consistent among different informants. Thus even though the number of responses for the rare cultivars are low (Table 3.4), as might have been expected, a probability of the presence for these cultivars can be calculated given the informant competencies calculated on the basis of the whole range of cultivars.

There is no significant correlation between informant competence and the number of cultivars informants judged, or their perceived Spanish language skills ($p<0.05$). Age has a weak negative correlation with competence ($r^2=0.14$; $p=0.02$). Since most deviations from consensus are related to absence judgements of cultivars, it follows that older informants tend to be slightly more pessimistic about cultivar presence than younger informants. However, older informants also know more cultivars than younger informants, which is a stronger tendency ($r^2=0.24$; $p<0.01$). Thus, it is judged that age related differences in knowledge probably did not influence the findings of this study.

In Table 3.4, counts for cultivar knowledge and opinions of presence and probabilities of presence (following Consensus Theory) are presented. The data show a general agreement between the (perceived) presence of the cultivar by the informants that know the cultivar and the knowledge of the cultivar across the whole population of informants. However, the association is not complete. For instance, **k'ejti'** (20) is known by only three informants, but according to these informants the cultivar is still present. In contrast, Tejar (23), another cultivar known by only three informants, has probably ceased to exist in Jacaltenango. Another interesting characteristic is that even the rarest cultivars were always known in at least two communities.

On the basis of these findings it can be judged that three cultivars have disappeared in Jacaltenango during a 70 year period. All three cultivars probably lost, have Spanish, not native Popti' names. According to informants, these cultivars were introduced originally from coffee plantations to which Jacalteco workers temporarily migrated for work during the coffee harvesting season. Several causes for the disappearance or scarcity of cultivars are mentioned. There is no clear pattern apparent in the causes in relation to certain cultivars; most causes apply to all. The most important reason is the yield disadvantage of the traditional cultivars against the introduced cultivars. With the same fertilisation levels, traditional cultivars yield less. They also grow taller and are more prone to lodging (the bending over and falling of plants). The introduction of industrial fertilisers in the 1960s (Falla 1972) accentuated this problem, as cultivars developed even more biomass. The higher disease susceptibility of cultivars Chimbo (14) and Pantaleón (24) was also mentioned as a reason for their disappearance. Another reason informants cited was climate change. According to some informants the growing environment has become warmer and drier. Land use change (more coffee) was also mentioned (this is also a primary cause for high teosinte extinction risk, G. Wilkes, pers. comm., December 2004).

Table 3.4. Cultivar knowledge and opinions on presence/absence (n=40) Last column calculated using Consensus Theory (Appendix).

	Informants who know the cultivar	Communities in which cultivar is known (n=9)	Informants who judge presence	Informants who claim continued presence	Informants who claim continued presence as a percentage of all informants who judge presence	Probability of continued presence
nimej k'ejwah (2)	39	9	35	34	97	>0.99
k'ejwah (1)	38	9	34	34	100	>0.99
saj nhal (8)	38	9	33	32	97	>0.99
tz'ib'sat saj nhal (10)	35	9	31	29	94	>0.99
k'ejsat (6)	32	9	31	27	87	>0.99
tz'ib'sat (9)	32	9	30	26	87	>0.99
q'an nhal (7)	31	9	26	26	100	>0.99
q'an b'aw (12)	31	9	26	21	81	>0.99
tewah (15)	31	9	27	19	70	>0.99
kok k'ej wah (4)	30	9	27	24	89	>0.99
txilitxwah (5)	29	9	25	22	88	>0.99
oxeb' x'ahaw (11)	27	9	26	25	96	>0.99
Cuarentano (22)	26	8	23	22	96	>0.99
k'ejti' txitam wah (25)	25	8	24	23	96	>0.99
papa k'ejwah (3)	23	9	22	21	95	>0.99
q'an tewah (16)	19	7	12	9	75	>0.99
nimej q'anb'aw (2)	18	8	15	13	87	>0.99
xhamaltin (19)	12	6	10	9	90	>0.99
saj poh (21)	12	6	11	7	64	>0.99
q'an wah (18)	6	5	5	4	80	>0.99
Pantaleón (24)	4	3	2	0	0	0.07
k'ejti' (20)	3	3	3	3	100	>0.99
Chimbo (14)	3	2	2	1	50	0.25
Tejar (23)	3	2	3	0	0	0.07

Social and spatial distribution of cultivar knowledge

In Table 3.5, the distribution of cultivar knowledge over communities, informants and cultivar adaptation groups is given. A single-factor analysis of variance for differences in cultivar knowledge among communities shows that the community means are not equal (p=0.02) (mean age of informants was not significantly different between different communities).

Knowledge of cultivars grown in cold and temperate environments is roughly stable across communities. The most significant differences exist in knowledge of the cultivars in the hot growing environment. The township capital of Jacaltenango itself is ranking the second lowest in number of cultivars per informant and the total number of cultivars known. Together, the five informants from the township capital only knew three out of eight cultivars adapted to hot environments. The only community scoring worse was Paya, where only three informants were interviewed and which is, of all sampled communities, the most remote from the low area in distance and altitude (Figure 3.1).

These observations strongly suggest that spreading the interview sample over several communities might have enhanced the research design. It also suggests that relying on interviews in the township capital alone would have led to serious underestimates of farmer knowledge of historical cultivars in Jacaltenango. This is an important point about method and will be taken up in the discussion.

Knowledge of new cultivars

Table 3.6 gives the names for mentioned cultivars that were not included in the historical data sets. A large majority on this list of cultivars has been introduced during recent decades. The 2004 survey data provided no evidence of additional historical cultivars (i.e. maize types grown in Jacaltenango for more than 70 years).

More than half of the introduced cultivars are grown only in hot environments, and only four are grown in temperate climates alone. This tendency corresponds to the pattern of cultivar loss: the lost cultivars were adapted to warm environments. Among the grain colours, white dominates. This is generally the commercial grain in Guatemala, whereas most yellow grain is for home consumption. Most of the new cultivars are fast growers (average: 4.4 months). A short growing cycle, lower plant stature, and a higher yield were indicated as important reasons for their introduction.

Informants reported that introduced maize came from various geographical sources, partly reflected in the cultivar names. Seed came from the commercial maize growing areas of the Pacific coast (reflected in the cultivar name "Máquina", which refers to an important maize growing area of the Pacific coast, called La Máquina), the national agricultural institute (ICTA), and Mexico (Tuxpeño, and probably others). The influx of planting materials from Mexico might be related to the return of refugees who fled to Mexico during the political violence of the 1980s. "Rocamey" in Table 3.6 probably refers to Rocamex, a variety introduced in the 1960s in broad areas of Central America, and originally bred by the Mexican Agricultural Program of the Rockefeller Foundation in Mexico. At least two cultivar names contain information on the person introducing it (cultivars "Manuel Juan" and "Lucas").

Table 3.5. Social and spatial distribution of cultivar knowledge per adaptation group
The assignment of cultivars to adaptation groups is based on the results of the 2004 survey (see Table 3.3).

Number of cultivars known per informant	Inche-wex	San Andrés Huista	Jacalte-nango	San Marcos Huista	Witzo-bal	Cheya	Acoma	El Mul	Paya	Mean infor-mant	Total
Hot	2.4	2.2	1.6	3.0	2.0	3.2	2.7	3.25	0.3	2.3	8
Hot and temperate	2.8	3.0	2.8	2.6	2.4	2.6	2.7	2.75	3.0	2.7	3
Temperate	3.8	2.8	2.4	2.6	2.0	3.6	3.7	4.25	2.3	3.1	6
Cold	5.8	5.2	4.4	6.2	5.8	6.4	5.7	5.75	4.7	5.5	7
All environments*	14.8	13.2	11.2	14.4	12.2	15.8	14.6	16	10.3	13.7	24

Total of cultivars known per community	Inche-wex	San Andrés Huista	Jacalte-nango	San Marcos Huista	Witzo-bal	Cheya	Acoma	El Mul	Paya	Mean com-munity	Total
Hot	4	5	3	7	4	7	4	5	1	4.4	8
Hot and temperate	3	3	3	3	3	3	3	3	3	3.0	3
Temperate	5	5	5	5	5	6	5	5	4	5.0	6
Cold	7	7	7	7	7	7	7	7	7	7.0	7
All environments	19	20	18	22	19	23	19	20	15	19.4	24

*The means are not equal among communities (ANOVA; p=0.02)

Table 3.6. Introduced cultivars in Jacaltenango

Cultivar	Grain colour (most common answer)	Climate adaptation (all answers)	Growing season (mean, months)	Number of informants who mention this cultivar
Reina	Yellow	Hot/temperate	5.1	13
Crema	White	Hot/temperate	5.3	8
ICTA	White	Hot/temperate	4.5	7
Grano de oro	Yellow	Hot/temperate	4.3	6
saj sat	White	Hot/temperate	5.0	4
Conejo	Yellow	Hot	2.7	3
Tuxpeño	White	Hot/Temperate	4.0	3
Lucas	Yellow	Hot/Temperate	4.3	2
Taxa	White/Yellow	Hot	5.0	2
Siete hojas	White	Hot	3.0	2
Manuel Juan	White	Hot	5.0	2
Juncanero	White	Temperate	5	1
Mapalu	White	Hot	4	1
Americano	White	Hot	4	1
Yixim chik	Yellow	Temperate	4	1
saj k'o ixim	White	Temperate	6	1
kej k'o ixim	Black	Temperate	6	1
Cinco pies	White	Hot	4	1
Rocamey	White	Hot	4	1
Tropical	White	Hot	4	1
caj chil	Yellow	Hot	3	1
Super enano	White	Hot	4	1
Sintalapa	White	Hot	5	1
Máquina	No data	No data	No data	No data

Discussion

Cultivar names in Jacaltenango

On basis of the criteria applied in this study, cultivar names were generally consistently related to biological characteristics. Cultivar characteristics between the two historical data sources showed close correspondence. The same was true for the comparison between the historical data and the data for the 2004 survey. In the few cases a disagreement was detected a reasonable explication was generally available. This suggests that cultivar names, as distinguished by farmers, refer to the same units of maize diversity.

For the first half of the twentieth century, and also for 2004, classification of maize diversity implied more than phenotypic categories. It included additional information about geographic origin, and in the case of at least one more recently introduced seed type, the person responsible for the introduction. This suggests that in some cases, cultivars might be distinguished not on the basis of visible characters or use, but by their history. This might be an increasing tendency, because of a plethora of incoming diversity. But put the other way round categorisation by phenotypic categories or zone of application is a feature of older material. A similar observation has been made by Nuijten (2005), and it is unclear whether this is simply a reflection of the fact that knowledge of form and usage will tend to increase over time. In Nuijten's view rice names in The Gambia tend to become more functional and less personal/historical as they become more widely used and better established historically.

Here it may be concluded that farmer cultivar names at least partly reflect the use and history of seeds, but that for the cultivars included in the baseline data, phenotypic differences played a relatively important role in classification and naming. Morphological and genetic studies are needed to probe the biological meaning of cultivar names in Jacaltenango and other parts of the western highlands of Guatemala. Meanwhile, it may be assumed that differences in cultivar names have some biological significance, and that this is especially true for older-established varieties.

Cultivar turnover in Jacaltenango

The findings suggest that a small loss of historical maize cultivars may have occurred. There has also been important addition of new material. Mainly factors related to production shape the way in which maize cultivar turnover occurs in Jacaltenango. Motivations for change are related to maize production ecology. These are, specifically, plant height, growing cycle and disease problems. Broader underlying causes included a perceived climate change and the introduction of fertilisers. Lower annual precipitation and higher annual temperatures over the last century have indeed been documented for the region (Watson et al. 1997).

Cultivar loss Loss of cultivars is localised in the lower areas of the township and limited to those cultivars introduced before 1937 from coffee farms outside the community. Since the original source of the replaced historical cultivars was regional, the abandoned varieties are probably not of unique value. A regional assessment of cultivar loss is necessary to determine if this phenomenon is general. However, the production problems reportedly associated with lost cultivars suggest farmers do not regret these losses. The consistencies between the earlier period and 2004 and the prevalence of crop ecological factors in cultivar loss does not support the notion of dramatic loss of cultivars due to the political violence of the 1980s. The data here analysed tend to make a case against Steinberg and Taylor's (2002) suggestion that political violence in the 1980s would have led to a sweeping loss of maize cultivars. In spite of many deaths and massive migration, the continued residence of some groups in the village even at the heights of violence (civil patrols, for instance), the short absence of others, and the possible exchange and recuperation of seeds, apparently helped to conserve farmer cultivars. This is in keeping with finding from other studies of the impact of war and civil violence on seed systems from other parts of the world. A detailed study of the impact of the genocide and violence in Rwanda reported little *absolute* loss of bean, potato and sorghum genetic diversity, although noting problems in accessing diversity by particular farmers and (in the case of potatoes) in acquiring sufficient volumes of planting materials (Sperling 1997). The facts that no single informant knew all historical cultivars, and that no single community, in aggregate, provided an exhaustive listing of all historical cultivars suggests that a change in the relative abundance of the historical cultivars may have occurred (but see below for the possibility of a complicating effect resulting from changed distribution of knowledge.) The likelihood of such a shift in relative abundance seems strongest for the cultivars adapted to warm environments. This is an important finding, which may be related to another aspect of cultivar change - the introduction of seeds from other areas into Jacaltenango.

Cultivar gain The many new cultivars mentioned by informants are largely confined to the lower areas of Jacaltenango. Several foreign cultivars have been introduced to temperate parts of the townships, but less than to warm environments. No new cultivar for cold environments was reported. This difference in the relative openness of low and high parts of the landscape for cultivars from outside reflects a broader trend in maize biogeography. Genetic studies based on maize materials available before the introduction of improved varieties observed increased genetic isolation with increased altitude (Hanson 1984). This suggests that rather stable, ecological constraints to seed and cultivar exchange underlie the differences between high and low areas.

Extracommunal seed sources changed over the twentieth century. Before 1937 the sources of cultivars outside Jacaltenango included mostly the coffee farms in the southern piedmont areas. In more recent decades the focus shifted towards the formal seed sector (ICTA, agricultural input shops) and the commercial maize growing areas developed on the Pacific Coast, towards Mexico. Cross-border contacts increased as many people fled to Mexico following political violence in the 1980s. Thus, in this way political violence has had an influence on maize diversity in Jacaltenango. The new cultivars in Jacaltenango are mostly recycled seed lots that stem from modern varieties. Their reported advantages (lower plant stature, shorter growing cycle, higher yields) indicate that the motivations for cultivar change are crop ecological. The production problems motivating cultivar change are also present in the higher areas of Jacaltenango. But in the cold environments no change was observed. It might be true that poor access to foreign cultivars adapted to this area constrains cultivar change in the higher parts. Further examination of this possibility is needed.

Cultivar replacement Three findings suggest that the loss or rareness of older cultivars and the introduction of new cultivars in Jacaltenango might be part of one coordinated long-term trend of cultivar replacement. First, cultivar losses and introductions take place in the same growing environment, the lower parts of Jacaltenango. Second, for both processes, similar ecological motivations are mentioned by farmers in the area. Third, in the interviews, farmers often made direct comparisons between the older cultivars on the one hand, and the newly introduced cultivars on the other hand, especially in terms of yield. In this case there are strong indications that replacement may be an important aspect of cultivar change in the lower areas. However, since many of the cultivars reported in 1927/37 are still present, households apparently have certain reasons to conserve them. The present study was not able to uncover reasons for the endurance of older types.

Methodological comparisons with an earlier study

In 2001, geographers Michael K. Steinberg and Matthew Taylor (2002) did a field study in highland Guatemala with the hypothesis that political violence might have caused major maize cultivar loss. Their study comprised six townships in the department of

Huehuetenango, including Jacaltenango. The authors used Stadelman's (1940) report as baseline data, and interviewed ten persons from each township capital to compare their knowledge to Stadelman's list. Steinberg and Taylor conclude that cultivar knowledge had diminished severely in this area since the early twentieth century, from 30 to 13 cultivars. For Jacaltenango, Steinberg and Taylor found that cultivar knowledge diminished from eight to three cultivars (a loss of 62.5%). Steinberg and Taylor imply that Stadelman reported only eight cultivars for Jacaltenango, while the present study derives 23 cultivars from Stadelman's text (Table 3.1). Steinberg and Taylor used an incomplete table from Stadelman's report, that referred to the ears he collected (Table VII in Stadelman (1940), M.K. Steinberg, pers. comm., 24-06-2005). Steinberg and Taylor emphasise the preliminary character of their study. But since the present study estimates cultivar loss in Jacaltenango to be considerably lower (around 13%), a detailed comparison between the methodologies of the two studies seems warranted.

Steinberg and Taylor modelled their sampling method on the one used by the ethnographers in the first half of the twentieth century. So given equal methods, if farmers reported fewer cultivars to Steinberg and Taylor than to Stadelman in several townships this would suggest real reduction had occurred. However, the method employed by Steinberg and Taylor does not provide information about the certainty of this outcome.

The method of Steinberg and Taylor estimates cultivar loss directly from the total number of cultivars known by a small number of farmers in each township. The present study shows the least known cultivars include those judged to be no longer present. This would support Steinberg and Taylor's method in general, but misleads in the case of the lesser known cultivars that continue to exist. In Jacaltenango, at least one cultivar was as little known as the cultivars deemed to have disappeared but was thought to be still present.

A more important issue, however, is that in Steinberg and Taylor's methodology no judgment can be made about whether the number of interviews is sufficient to have a certain degree of certainty about the outcomes. More intensive sampling will tend to increase the number of cultivars known by informants, thus changing the outcome. A related problem is where to draw the boundary between present and absent cultivars, when in fact all cultivars are still remembered (as is the case of the present study). Steinberg and Taylor's overestimation of cultivar loss (or their suggestion in this direction) is a direct consequence of lack of checks in their method.

One possible interpretation of the study of Steinberg and Taylor is that it provides information on the *relative* abundance of historical cultivars in comparison with the past. However, it should be indicated that this would assume that the township capital in 1937 and 2004 are equivalent units of analysis. This assumption can be discussed in the light of the findings obtained from the methodology applied in the present study, which give some clues about the current spatial distribution of cultivar knowledge (next section).

Social and spatial distribution of cultivar knowledge

Several findings from the present study point to an unequal social distribution of maize cultivar knowledge in 2004. First, informants from some communities knew fewer historical cultivars than informants from other communities. Informants in Jacaltenango in this study proved to be among the least knowledgeable on maize cultivars. The poorer knowledge of farmers in the capital town might have led to the underestimation of farmer knowledge in Steinberg and Taylor's (2002) study, whose informants were encountered in capital towns only. Second, the incoming cultivars have applied to them an extraordinary number of names, many being mentioned by one informant only. It seems as if numerous cultivar introductions overwhelm the local capacity to keep track of seed and knowledge exchange in Jacaltenango.

Stadelman's (1940) data indicate that a knowledgeable male adult living in the township capital of Jacaltenango might know many of the less abundant cultivars of the area. The present study suggests that in 2004 the same was true for many informants from communities in Jacaltenango, but not for all informants, including those from the township capital. This finding might reflect a change in the distribution of maize (and maize knowledge) between the head town and the other communities with a more rural character, and perhaps between rural communities as well.

What factors might explain such a shift in the relative social distribution of maize knowledge? Explanations might be sought in broader socio-economic trends. In the first half of the twentieth century, maize was more important for the monetary economy than in 2004, and a main node in this monetary economy was the head town. Today, maize plays a more minor role in regional trade, while other crops (especially coffee) and other occupations have become more prominent economically. Economic change might have diverted interest away from maize diversity, especially in trading nodes. Another possible explanation is reduction in knowledge transmission. Intergenerational knowledge transmission might still underpin the social memory about disappeared cultivars observed in this study. However the growing population of Jacaltenango, increasing social isolation and independence between communities, and their increasing regional and national orientations (Casaverde 1976, Falla 1978) might also have added to a fragmentation of traditional agricultural knowledge systems in rural Guatemala. Additionally, political violence might have reduced the trust and solidarity formerly underpinning seed and knowledge exchange (Richards and Ruivenkamp 1997, Sperling 2001).

It seems clear, then, that although there are some possibilities to make use of categorisation data to point to real change in distribution and availability of maize genetic resources in highland Guatemala, we probably also need to develop much greater insights into the ways in which categories of social knowledge are bonded to and uncoupled from genetic information in the course of specific trajectories of crop evolution and specific histories of social change.

Conclusions

This study has described the application of a methodology to examine change in farmer knowledge of cultivars. It has been demonstrated that sensible indicative results can be derived from the intensive case-study methodology deployed, and that these results have interesting implications for biological change. By taking a spatially stratified sample in an area of exceptional cultivar knowledge, rich ecological diversity and presumed maize biodiversity, information has been obtained that might have been impossible to obtain in a regional investigation, gaining insights potentially applicable over a much larger area.

The chapter has shown that maize cultivars names identified three generations earlier in a Guatemalan highland township are still present in the social memory. Relative certainty existed about some trends of cultivar change in the township, and that these trends could, in broad terms, be linked to perceptions of biological diversity, where it proved possible to test for consistency. Consensus existed about the disappearance of a small number of cultivars adapted to warm growing environments (below 1,500 masl) due to problems related to crop production. In the warmer, lower parts of the study area also most cultivar introductions from other areas occurred over the period studied. The analysis confirms that ecological factors are important in cultivar change, contributing to a process in which there is slow replacement of older cultivars with new ones. Given the importance of ecological factors, it may be reasonable to extend the specific conclusions to broader areas with similar ecologies. One question that merits special attention is the production problems associated with high environments in the study area. These are perhaps as serious as the problems in the low environments, but seemingly lack obvious (seed-based) solutions.

The research here reported generates various insights into the role of social factors in cultivar change. Political violence did not obviously cause observable absolute loss of cultivars in the study area, contrary to the expectations raised by earlier research. On the other hand, it was observed that the regional social connections underpinning cultivar introductions changed in geographical focus over the twentieth century. As these changes are an aspect of broad socio-economic trends they might affect other parts of the region as well. Also, several findings suggest a change in the social and spatial distribution of cultivar knowledge within the township during the twentieth century. This chapter argues that we need to know more about how (changing) knowledge distributions might affect methodology and interpretation of data sets concerning change in cultivar knowledge.

Appendix: Consensus analysis

For the consensus analysis, the proportion of presence/absence agreement was calculated for each pair of informants for the cultivars known in common only. This was corrected for possible agreement due to guessing, following Romney et al. (1986). The resulting matrix was loaded as a correlation matrix into SAS 9.1 for Windows (SAS Institute Inc. 2003), and analysed using the principal components method of the Factor procedure and a Varimax rotation. The first factor solution corresponded to 79.8 % of the variance, and the second and third corresponded to 10.8 % and 7.3 % respectively. The high value for the first factor compared to the next ones partially confirms the suitability of consensus theory for these data (Romney et al. 1986). Factor loadings for the first factor solution included one negative value (-0.07). Since negative knowledge or sabotage seems unlikely this indicates that the correction for guessing may lead to conservative (underestimated) informant competence values. Constraining presence judgements to known cultivars perhaps filters out much guessing already. The first-factor loadings for each informant were used as competence values. From these, the probability of presence for each cultivar was calculated, following Romney et al. (1986).

Chapter 4

Regional and local maize seed exchange and replacement

van Etten J. and de Bruin S. 2006. Regional and local maize seed exchange and replacement in the western highlands of Guatemala. *Plant Genetic Resources: Characterization and Utilization* (under review).

Chapter 4: Regional and local maize seed exchange and replacement

Introduction

Crop genetic resources managed by farmers (landraces) play an important role in crop production and improvement. In present traditional agricultural systems many cultivars are maintained and are still evolving. In modern plant breeding, genebanks often form the context in which genetic diversity is managed. However, the advocates of recently developed *in situ*, farmer-participatory approaches to crop genetic management suggest that many activities can or should take place on-farm (variety selection, breeding, conservation). However, with regards to *in situ* crop genetic management not only the farm, but also the regional landscape should be considered as part of the *situ*. In more general terms, insight into processes at different levels of geographical scale is needed to support the design of crop improvement and conservation efforts (Zimmerer 2003). Understanding regional crop diversity distributions is crucial for the design of genetic resource management efforts, and it is especially important to consider the extent and location of such interventions. Should plant breeding and cultivar maintenance focus on small areas or have a more regional orientation? This will depend on previous distributions of biodiversity and the processes that underlie them. Community-based efforts may be inefficient if diversity distributions are regional. At the same time, focusing on existing exchange patterns may give useful clues about how to improve the efficiency of seed exchange and innovation.

The processes that play a role in forming regional distributions of crop genetic diversity are insufficiently studied. Over longer distances, seed exchange will tend to be the dominant form of gene flow. However, few studies directly examine the issue of regional seed exchange of food crops (notable exceptions are Dennis 1987, Zimmerer 2003). Zeven (1999) observes that seed replacement in 'traditional' agriculture is very commonly reported in the literature, but that few explanations are offered. Since it is an important factor in crop biogeography and an important source of local innovation, regional seed exchange is an important issue for research.

Zeven (1999) presents various cases in which seeds are obtained from a different growing environment than the one where it will be grown. In some cases, the seed 'degenerates' in the new environment, and regular refreshment from the original area is needed. Thus, it seems that physiological and ecological factors play a role in long-distance seed acquisition. Biological explanations need to be evaluated against other types of hypotheses. Also, if crop biology is an important influence, the precise factors involved need to be identified.

This study focuses on maize (*Zea mays mays* L.) in an area in the western highlands of Guatemala, and aims to explore patterns and processes of seed exchange. Several previous studies of highland Guatemala have demonstrated that maize seed exchange is mainly local in scope (Stadelman 1940, Johannessen et al. 1970, Johannessen 1982). However, the newer literature on seed exchange and innovation, which mainly focuses on Mexico, consistently shows that a small proportion of total seed planted is reported to be imported from outside the community. This is usually between five and ten percent (Louette et al. 1997, Louette 1999, Perales et al. 2003b, Perales et al. 2005). The necessity of obtaining ‘fresh’ maize seeds was documented by Wierema et al. (1993) in several parts of Central America, but without specifying how farmers perceive seed degeneration. The literature suggests that these small proportions of seeds imported from outside local communities can have a significant overall impact. Genetic studies show little genetic differentiation between different communities and ethnolinguistic areas (Pressoir and Berthaud 2004b, Pressoir and Berthaud 2004a, Perales et al. 2005).

This chapter examines regional and local maize seed exchange from different, complementary angles, based on an analysis of social survey and geographical data. It documents the geography of seed movements across the landscape and examines possible explanations of patterns of seed exchange and replacement.

Methodology

Research area

Research was conducted in fourteen townships (*municipios*) of the department of Chimaltenango (Figure 1). Altitude in the study area varies between roughly 1500 and 2500 masl. The central part of the research area is a large highland basin, covered by volcanic deposits. The northern part of the area is part of the Motagua watershed and covered with alluvial soils. Chimaltenango is a section of a wider segment of the western highlands known for its long tradition in food production for urban consumption (Smith 1979). The ethnicity of its inhabitants is mainly Kaqchikel (native Maya group) and Ladino (Spanish speaking persons of European, Maya or mixed descent).

In the 1940s and 1950s, thirteen maize races were documented for Guatemala, and six of these were found in Chimaltenango. These are (in order of importance): Olotón, Negro de Chimaltenango, Comiteco, Imbricado, Nal-Tel Ocho, and San Marceño (Wellhausen et al. 1957). This gives an indication of the broad morphological diversity of maize in the area. Also improved varieties were developed for the highland region, mainly based on native materials (Fuentes 1997).

Questionnaire and questions

A questionnaire was developed with general questions and questions for each maize type cultivated by the household, including those cultivated in the past. Preliminary interviews in different parts of the research area and a literature search were used to design the questionnaire and select potentially important variables.

The questionnaire focused on four basic types of information. First, questions about cultivar names for each cultivated seed lot were asked. It was supposed that mapping these cultivar names might convey information about patterns of seed exchange. Even though cultivar naming applies only to a fraction of the seed lots and reflects a weak, fragmentary classification system (a contrast to the situation encountered in other areas, van Etten 2001, Chapter 3), the exchange of names arguably involves processes similar to those involved in seed exchange. However, the conclusions from these data should not be pushed too far.

A second type of information concerns sources from which farmers obtain seeds. The frequency of different seed sources and their geographical pattern is an important means to assess the impact of seed movements and their role in the formation of regional patterns of maize seed diversity.

A third type of information concerned maize cultivated in the past. The reasons for discontinuation of maize seed lots households had previously utilised were considered important information. Discarding a maize seed lot, if done on purpose, involves a conscious decision about seed with well-known properties. Thus, the motives for this decision have a special weight, and provide an important indication of which are the most relevant dimensions of farmer decision making in relation to maize cultivars. Other moments of choice and outcomes of such choices (cultivar maintenance, looking for new cultivars, experimentation) seem to involve less specific motives (tradition, opportunity, curiosity, etc.). These seem less predictable, or involved factors and rationalisations beyond the scope of a survey.

A fourth type of questions tried to retrieve variables relevant to explaining choices between seed sources. As argued above, it was anticipated that many factors influencing decision making about seed sources may be unpredictable or circumstantial. However, by screening a broad range of variables related to seed characteristics, environment, socio-economic conditions, and geography, some of the most important variables were identified. By comparing these outcomes with the answers to the question why seed lots were discarded, more certain conclusions were obtained.

Data collection

Three bilingual Kaqchikel-Spanish research assistants and the principal researcher carried out 257 interviews across the research area in June and July, 2003. All townships (*municipios)* of the highland part of the *departamento* were visited. For each township the main town (*cabecera*) and several rural communities (*aldeas*) were included. Communities were selected non-randomly from a map of each township to ensure diversity in distance from the main town and ecological conditions (altitude). Households were chosen at random, while within the towns often one or more transects were chosen to avoid bias (for a map of the survey points, see Figure 1). When available, the head of household was interviewed. If no-one answered the door or the household did not grow maize, the closest neighbour was visited. For all households, a GPS provided geographical coordinates and altitude. The interviewers also scored their impression of informant reliability on a three-step scale.

These data were supplemented with geographical data provided by the Ministry of Agriculture's GIS laboratory (MAGA 2005). From this latter source, four environmental variables and three community variables were included in the analysis (Table 4.2).

Analysis of explanatory variables for seed sources

The analysis of the fourth type of information mentioned above required a specific kind of numeric analysis. Nine types of seed sources were distinguished based on questionnaire results. For the quantitative analysis, these nine groups were assigned to four broader groups (Table 4.1). This aggregation was done to obtain groups with sufficient cases and to have more interpretable contrasts between seed sources.

The variables that predict or are associated with certain sources of seeds were identified using classification trees (Breiman et al. 1984, De'ath and Fabricius 2000). The classification tree method makes consecutive, binary splits in the data in order to achieve greater homogeneity in the resulting two groups. The method seeks the best variable, and the best value for that variable to make each split. Two important advantages of the method make it especially suited for the present analysis: it does not assume a statistical distribution for the variables and it readily accepts categorical explanatory variables.

However, the method does not inherently account for spatial relationships. To be able to detect spatial structure in the analysis, GPS coordinates (Northing, Easting) were included. Political boundaries were also used for spatial grouping (community and township). To account for mutual proximity as a factor in the analysis (to detect for spatially correlated variables not included in the analysis) locations were grouped using a grid of hexagons bins at different extents (2, 4 and 8 km high) with an arbitrary origin.

Different comparisons between groups of seed sources were analysed, identifying the most important variables for each comparison. The 'variable importance' reporting modality in the software package CART was used to this end (Salford Systems 2002).[13] The analysis was undertaken for all variables and different subsets of variables separately (for subsets see Table 4.2).

Table 4.1. Seed sources

Seed source in questionnaire	Seed source groups used in analysis
Father of head of household Deceased husband	Own household
Other family (this includes in-laws) Godfather	Family
Neighbour	Neighbour
Market Agricultural input shop Government institution NGO / co-operative (organisation) Acquaintance in another community	Outside community

[13] Due to the high number of splits possible for the categorical variables, and especially the hexagonal binning variables, 'high-level categorical penalty' was set to 1 to balance this with the numeric variables. 'Missing penalty' and 'favouring equal splits' were also set to 1. Informant reliability as perceived by the interviewer (1-3 scale), was used as a weighting variable, and gave marginally better predictions.

Table 4.2. Variables included in the analysis

Unit of analysis	Variable	Variable type
Seed lot	Source (response variable)	Categorical
	Colour	Categorical
	Planting date	Numeric
	Growing cycle*	Numeric
	Difference from mean growing cycle**	Numeric
	Yield	Numeric
	Sown in home community	Binary (yes/no)
	Area sown with seed lot	Numeric
Household	Age of head of household	Numeric
	Profession of head of household	
	Maize surplus / self sufficiency / shortage	Numeric (ordinal)
	Horticultural crops	Binary (present/absent)
	Household members	Numeric
	Land under maize	Numeric
	Spanish proficiency	Numeric
	Number of types of maize	Numeric
	Bean intercropping	Binary
	Distance to provincial capital	Numeric
Informant	Head of household	Binary (yes/no)
	Gender	Binary (female/male)
Community	Percentage Indian	Numeric
	Analphabetism	Numeric
	Urban (*cabecera*) / rural (*aldea*)	Binary
Environment	Evapotranspiration	Numeric
	Rainfall	Numeric
	Soil series***	Categorical
	Physiographic area	Categorical
	Altitude	Numeric
Location	2 km hexagonal bins	Categorical
	4 km hexagonal bins	Categorical
	8 km hexagonal bins	Categorical
	Northing	Numeric
	Easting	Numeric

*Interval between planting and green harvest. This was chosen, instead of the harvest for dry grain, because the latter depends on the period allowed for drying, while green harvest is more closely determined by phenology.
**This was calculated as the interval between planting and green harvest of the seed lot minus the average for all seed lots in a 2 km radius around the seed lot, to account for growing season differences between locations.
***Based on Simmons et al. (1959).

Results

Cultivar names and their geographical distribution

In the research area most farmer cultivar names refer to grain colour (for instance, ‘yellow maize’) only. Farmers also mentioned ‘criollo’; when applied to maize types, this is a generic marker for traditional varieties. For a total of 94 seed lots (21%) more specific cultivar names were mentioned. This included improved varieties and traditional varieties (Table 4.3). In twelve cases, unambiguous references to officially released varieties were made (3% of all seed lots). If also more ambiguous references are included in the category of modern varieties (such as references to the names of old varieties H3 and H5, see below), thirty-three cases (7% of all seed lots) fall in this category.

Traditional varieties show geographic patterns (Figure 4.2a). *Cuarenteño* occurs in the northern part of the area, and below 1900 masl. *Obispo* is found in the western central part (Tecpán, Santa Apolonia), in an area above 2200 masl. *Siete pellejos* is found across a broad area between 2000 and 2300 masl. These names recur in various townships *(municipios)*.

Modern varieties show three clusters: an eastern, northern, and western one (Figure 4.2b). The eastern and the northern cluster are located below 2000 masl, while the western cluster is located above 2000 masl. Even though *different* modern varieties are present in low and high areas, modern varieties are present across the altitudinal gradient.

In the east, around Chimaltenango, the provincial capital, and in the Motagua watershed in the northern part of the study area, many farmers grow improved varieties designated by the names H3 and H5. These names refer to two varieties that were released by the national agricultural research institution of El Salvador, CENTA, in the 1960s, and successfully introduced into many parts of Central America, including Guatemala. However, it seems that both names are now used in a generic sense for early-maturing varieties, also by seed sellers. While the original varieties were white grained, in the research area it is common to find yellow seed lots are named “H3” or “H5”. The original varieties have a lowland adaptation. In the study area they are mainly found below 2000 masl.

The western cluster comprises the communities Caliaj and Caquixajay (Tecpán). Many farmers grow a cultivar introduced by DIGESA (the national agricultural extension agency, now dissolved). This cluster seems to be an exception in the area. Adoption of modern varieties is concentrated very much in this area. Such massive adoption of an improved cultivar was not found in other communities above 2000 masl.

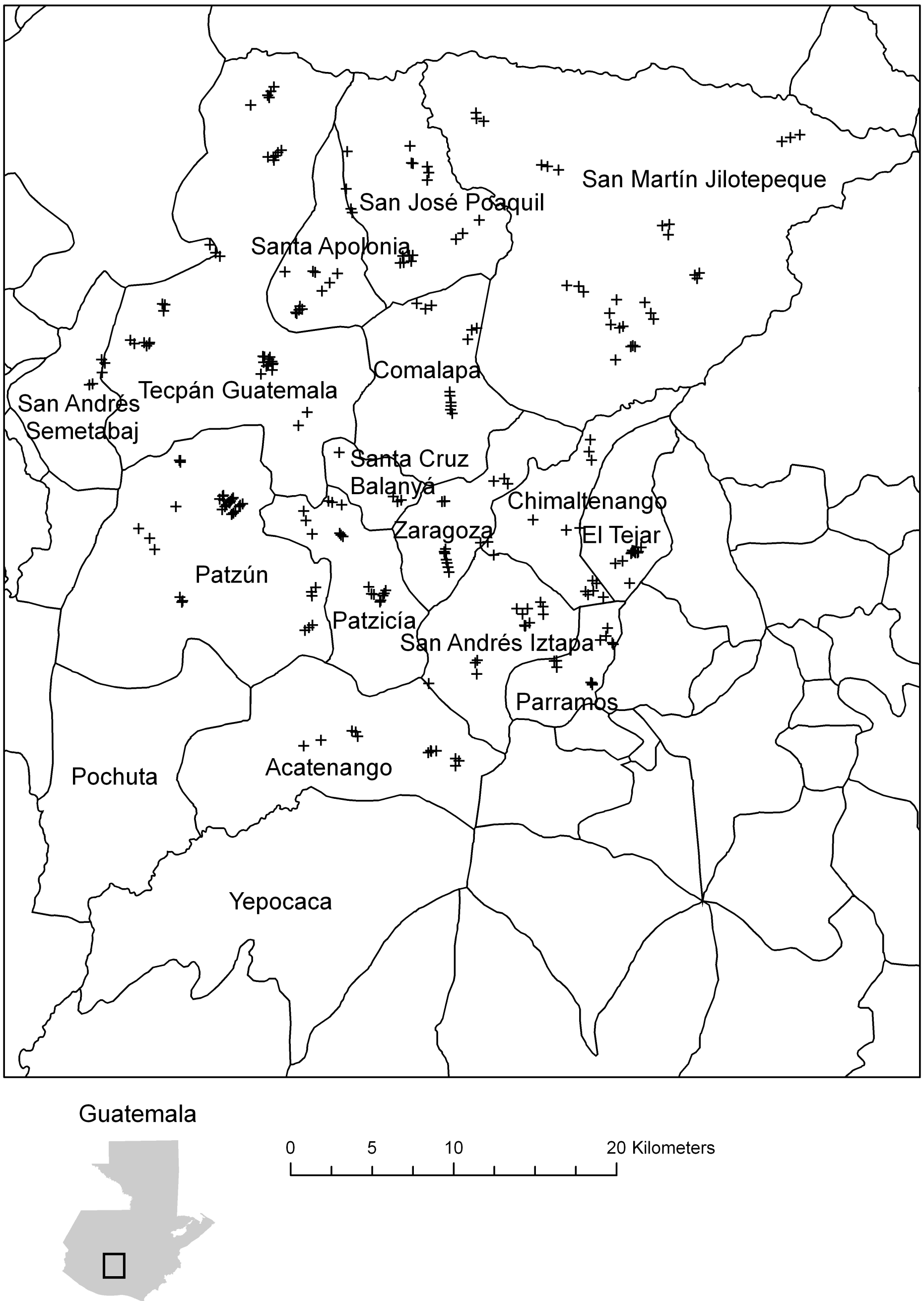

Figure 4.1. Study area (department of Chimaltenango) and survey points (+). Boundaries between townships (*municipios*) are approximate.

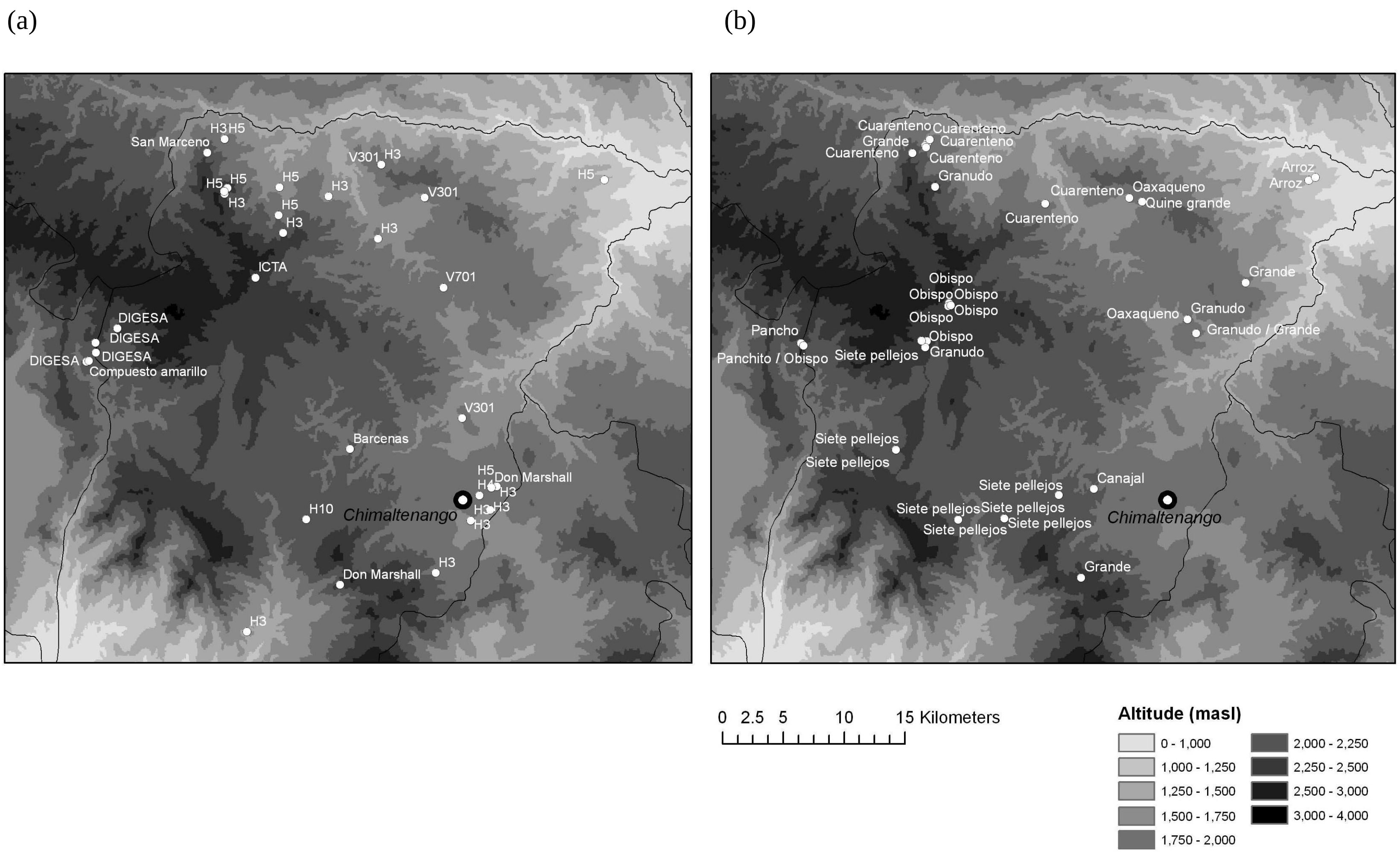

Figure 4.2. Geographical distribution of households reporting (a) improved varieties and (b) traditional and other varieties

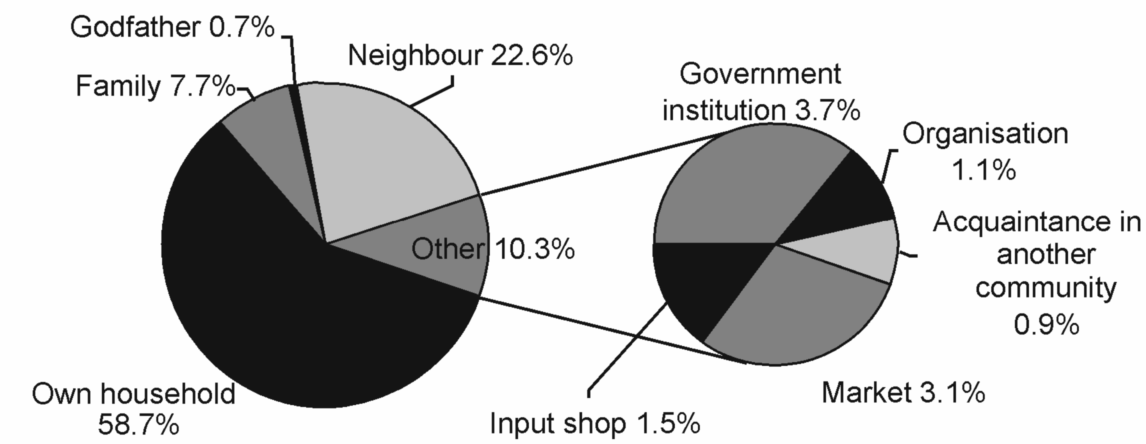

Figure 4.3. Sources of seed lots in Chimaltenango (2003; n=455)

Seed sources

A total of 455 answers on the seed source of individual seed lots were available for analysis (Figure 4.3). Of all seed lots, 267 or 58.7% came from within the household. Thus, household autonomy in seed production is the most common form or seed procurement. Interestingly, seed exchange with neighbours is more frequent than with other (extra-household) members of the family. This tendency in itself indicates that seed procurement is not about replacement only (for which the family would presumably be the default option), but also about change and enrichment of the household portfolio of maize diversity. Containment of transactions within communities is high: 408 or 89.7% of the seed lots came from within the community. Six seed lots (1%) came from outside the research area. Two of these seed lots came from adjacent communities, just outside the *departamento*, and four came from major cities: Guatemala City, Quetzaltenango, and San Marcos (two times).

The cultivar or variety names farmers mentioned for their seed lots served as the basis for a classification in four broad groups (Table 4.3). In Table 4.4 the sources of seeds for different types of seed is given. It is clear that for improved varieties the main sources are outside the community. However, substantial exchange of improved varieties does take place within communities. For traditional cultivars, the main sources are within the community. In Table 4.5 the mean growing season is given, which is an important factor in seed introduction from outside the community (see below). From this table it becomes clear that improved varieties have a shorter growing season, followed by the non-traditional group. Non-traditional varieties introduced from other communities have on average a slightly shorter growing season than traditional ones. In Table 4.6 the sources of seed are split by colour. A contrast exists between yellow and white maize on the one hand, and black and other colours on the other hand: the latter mostly remain within the community. Interestingly, for black and other colours, neighbours are a more important source than the family.

Table 4.3. Categories of cultivars according to names mentioned by informants

Category and examples	Description
Modern: V301, H3, H5, Compuesto Amarillo, San Marceño, Don Marshall, DIGESA, ICTA	Modern variety names or names referring to the institutions that distributed modern varieties
Non-traditional: Cuarenteño, Violento, Arroz, Five/Six months' maize	Names that refer to varieties introduced from outside the village or region in the past, but don't correspond to a modern variety
Traditional – generic name: 'criollo', 'yellow maize', etc.	Traditional cultivars with no distinctive characteristics other than the kernel colour
Traditional – specific name: Siete pellejos, Obispo, Granudo, Grande, Oaxaqueño, Quine Grande, Pancho/Panchito, Canajal	Traditional cultivars with a name that refers to some special characteristic

Table 4.4. Sources of seed lots per category

	Modern (%)	Non-traditional (%)	Traditional generic name (%)	Traditional specific name (%)
Household	3 (9)	14 (42)	238 (66)	12 (44)
Family	2 (6)	5 (15)	27 (8)	4 (15)
Neighbour	7 (20)	8 (24)	77 (21)	11 (41)
Outside community	23 (66)	6 (18)	18 (5)	0 (0)
Total	35 (100)	33 (100)	360 (100)	27 (100)

Table 4.5. Average growing cycle (in days) of seed lots per category

	Modern	Non-traditional	Traditional generic name	Traditional specific name
Household	118	140	161	169
Family	120	142	166	134
Neighbour	119	131	167	173
Outside community	115	157	166	-
Overall average	116	141	163	165

Table 4.6. Sources of seed lots per colour

Source	Yellow (%)	White (%)	Black (%)	Other colours (%)
Household	96 (56)	125 (59)	44 (64)	2 (67)
Family	14 (8)	20 (9)	4 (6)	0 (0)
Neighbour	38 (22)	44 (21)	20 (29)	1 (33)
Outside community	23 (13)	23 (11)	1 (1)	0 (0)
Total	171 (100)	212 (100)	69 (100)	3 (100)

Table 4.7. Reasons for discontinuation of previously cultivated seed lots

Reason	Frequency
1. Height plant (lodging)	22
2. Yield	18
3. Land shortage	7
4. Length growing cycle	6
5. Grain quality / preference	5
6. Land change	3
7. Saleability	3
8. Seed loss	3
9. Admixture of other types	2
10. Bad corn-on-cob qualities	1
11. Difficult to shell	1
12. High labour requirements (weeding)	1
13. Higher rainfall	1
14. Labour shortage	1
15. Low storage quality	1
16. Migration of head of household	1
17. Replacement by ‘better’ seed	1

Reasons to discard or replace seed lots

Only 78 informants reported having had other types of seeds in the past and indicated why these seed lots were discontinued (Table 4.7). In many cases it was motivated by the possibility of replacing the old seed lot with a new better one. Interestingly, excessive plant height (implying a higher proneness to lodging) ranks as more important (no. 1) than low yield advantages (no. 2). Land shortage is given as the third reason to discontinue a maize type. This is related to another reason: admixture of kernels of a different colour in the seed lot is another reason to discard it (no. 9). Often seeds of different grain colours are planted separately to prevent colour change through crosspollination on adjacent plots. When the land base becomes too small to continue spatial separation of seed lots, one kernel colour is discarded. Although the growing cycle (no. 4) is highly correlated with plant height, the length of the growing cycle was often mentioned separately. This indicates that a short growing cycle is also seen as an advantage in itself.

Explanatory variables for seed source decisions

Table 4.8 shows the results of the classification tree analysis. For each comparison between groups of seed sources the most relevant explanatory variables are given from the full set and different subsets of variables. Based on this, the contribution of these variables can be further explored for each comparison.

Comparison 1 Differences between seed lots originating from outside the community and those obtained inside the community or household are mainly related to length of growing cycle. On average, seeds obtained outside the community have a growing cycle of 132 days or 33 days shorter than local seed lots (Figure 4.4). Also seeds from outside sources are on average 28 days faster than the local average (2 km radius). This is mainly due to the higher proportion of relatively fast-maturing modern varieties and 'non-traditional' varieties among the seeds introduced to the community (Table 4.5). Although household characteristics are not among the most important variables, households with fewer types of maize and those with more land under maize, are slightly more likely to have maize seeds from outside sources. Households with at least one seed lot from outside have on average 6.8 *cuerdas* (0.76 ha) with maize, while the others have 5.5 *cuerdas* (0.61 ha).

Comparison 2 Obtaining seeds from the rest of the community as opposed to the own household is more prevalent at lower altitudes. Around 2000 masl an important break seems to take place (Figure 4.5). Variables from other subsets are associated with altitude (yield, growing cycle, horticulture), so this association with altitude should be interpreted with caution. That yield is more important than growing cycle in the seed lot variables subset indicates that growing cycle is of secondary importance for this comparison.

Comparison 3 The first identified variable for the contrast between family and neighbours is the percentage of Indian population per community. In communities with a higher percentage of Kaqchikel inhabitants, seed exchange between neighbours tends to be more common in the sample. Also older heads of household tend to grow more seed lots obtained from neighbours. Those heads of households growing at least one seed lot obtained from neighbours are on average 4.7 years older than others.

Comparison 4 The identification of a spatial variable for the comparison between owns household versus family indicates that a spatial pattern not accounted for by the remaining variables underlies part of the variation.

Comparison 5 Compared with seeds obtained from neighbours, seeds from outside have a shorter growing cycle. This result is similar to that obtained in Comparison 1.

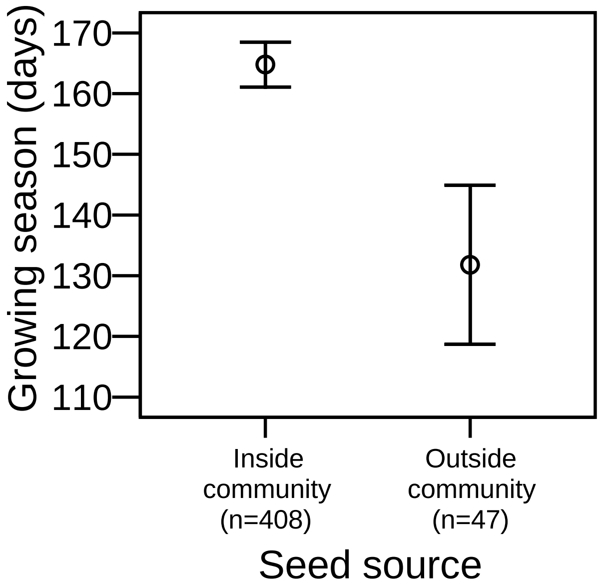

Figure 4.4. Difference in growing season between seed lots from within and outside the community (mean ± 2 * standard error of the mean)

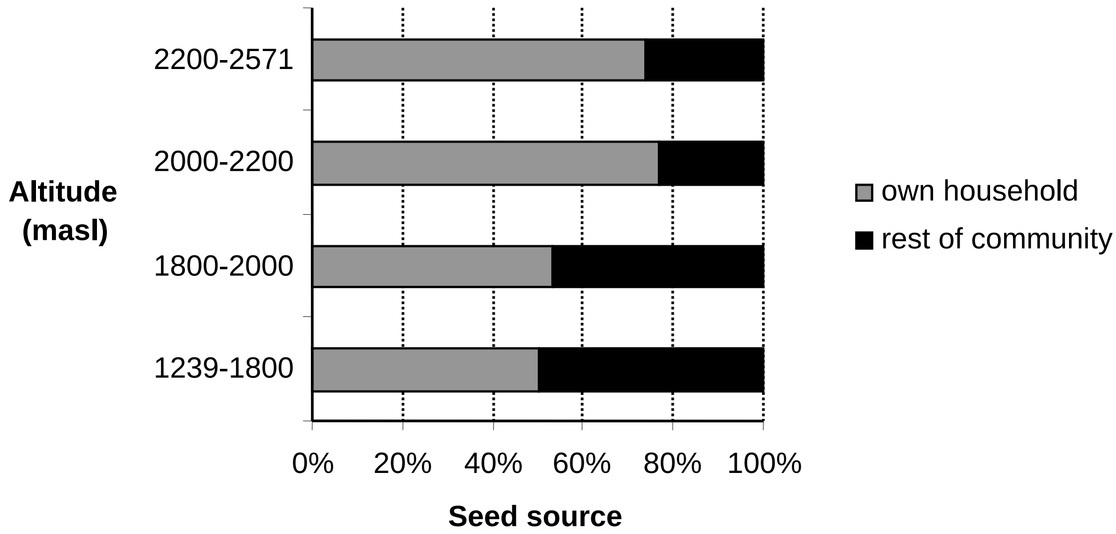

Figure 4.5. Seed sources within the community according to altitude

Table 4.8. The most important factors influencing seed procurement choices, as given by classification tree analysis (‘variable importance’ in CART software). Between brackets class pertinence for the *highest* values of the variable under consideration is given. Only one variable is reported in where the second variable had less than 20% the importance of the first variable. For variable subsets, see Table 4.2. For seed source groupings see Table 4.1 (Community variables were not analysed separately.)

Comparison	All variables	Seed lot variables	Household variables	Location and environment variables
1. i=own household + family + neighbours o=outside community	Difference from mean growing cycle (i) Growing cycle (i)	Difference from mean growing cycle (i) Growing cycle (i)	Number of types of maize (i) Land under maize (o)	Soil series
2. h=own household fn=family+neighbours	Altitude (h)	Yield (h) Growing cycle (h)	Horticulture (h)	Altitude (h)
3. f=family n=neighbours	Percentage Indian (n) Age head of household (n)	Sowing date (f) Growing cycle (f)	Bean intercropping (f) Household size (f)	Municipio
4. h=own household f=family	Easting (f)	Growing cycle (h)	Horticulture (h)	Easting (f)
5. n=neighbours o=outside community	Difference from mean growing cycle (n)	Difference from mean growing cycle (n)	Surplus (o) Household size (n)	Soil series

Discussion

Cultivar names

The absence of traditional farmer cultivar names for many seed lots in Chimaltenango contrasts with other areas in the Guatemalan highlands, including parts of Huehuetenango, and San Pedro La Laguna in Sololá, where cultivar names apply to virtually every seed lot (Stadelman 1940, Butler and Arnold 1977, van Etten 2001, Chapter 3). Farmer cultivar names have a more parochial spatial distribution in these other areas (mostly unique cultivar names in different townships) (Stadelman 1940) than in our study area.

One possible explanation for these differences is the degree of local ecological diversity in these areas, which is high due to pronounced altitudinal differences. In Chimaltenango, altitudinal differences are often not very dramatic. One settlement usually has access to only one type of environment. Differences in seed type do not come from local variation in adaptation, but refer mostly to differences in ear and kernel characteristics, and the length of the growing season.

The cultivar names indicate that some portion of the collection of seed lots present in the study area derive from improved varieties. Selection for shorter varieties with a short growing cycle has been an explicit goal of the national maize breeding programme, especially since 1973 (Fuentes 1997). At least some portion of the varieties introduced into communities in the study area originated from this plant breeding programme, and sale of these varieties is concentrated in the provincial capital.

It is remarkable that modern varieties and their derivatives are present with almost equal frequency in the higher and lower parts of the study area. In other parts of Guatemala and Mexico, modern varieties are more frequent in lower areas than in higher areas (Chapter 3, Perales et al. 2003a). This area is an exception to this trend. This is at least partly due to the exceptional status of the communities in the west of the study area, which form a commercial maize farming area focusing on the market of Panajachel, where maize is reportedly scarce. These farmers are eager to use and experiment with maize varieties coming from government institutions.

The broad presence of seed lots designated as Cuarenteño is interesting, because the name refers to the important characteristic of the growing cycle (see next section), and it is a cultivar name reported across the country, especially in lower areas (M.R. Fuentes, pers. comm.). This cultivar was already reported in 1976 in the area (Duarte M. et al. 1977). As one informant claimed, this cultivar comes from the coffee farms of the Pacific Coast, to the south of the research area. Especially from the northern part of Chimaltenango, labourers migrated every year for a few months to harvest coffee (Smith 1990). This substantiates that varieties with a short growing cycle were being introduced before the introduction of improved varieties with this characteristic.

The occurrence of traditional highland varieties (*Obispo*, *Siete pellejos*) provides evidence for broader exchange of seed lots within the study area. Also these names refer to specific characteristics (in this case grain related) which contrast with the common ‘nameless’ traditional farmer varieties, which apparently do not have these characteristics.

It was observed that cultivar naming in Chimaltenango did not apply to all seed lots. This lack of names influences seed exchange, as it makes it more difficult to communicate about seed lots and make comparisons between seed lots of different origins or adaptations. The informational aspect of seed exchange was also highlighted by Badstue et al. (2002) for Oaxaca. Modern varieties sold under a certain name tend to have stable characteristics attached to a single name, and this gives them an information advantage over seeds without a name.

Geography of seed exchange

High containment of seed lots is found in the area at different levels. Obtaining seed in a particular year is mostly done from the household as a default option. Seed from outside the household is obtained mostly within the community. Seed that is obtained outside the community is mostly from within the same department (Chimaltenango). No seed was recorded as coming from outside Guatemala.

Farmers indicated that in the past coffee farms in the southern piedmont area were important source of new diversity in parts of the research area. This was also recorded for another area in the western highlands of Guatemala (Chapter 3). This confirms the possibility that this is a wider trend, with a potentially important impact on current maize diversity distributions.

Currently, seed exchange outside the community is mostly focused on cities, including the departmental capital. This means that the economic geography of seed sales plays an important role. Apparently, seed sellers need regional markets to have sufficient demand. This may be due to the infrequency of seed purchases by households. It will be important to take this factor into account when designing new modalities for distributing seeds and varieties.

Past and present directionality in seed flow is important in geographical studies of maize diversity. Genetic similarity of maize from different communities may not signify seed exchange among those communities; these communities may have obtained seeds from common sources. Recent genetic investigations in maize taking a regional outlook failed to point out this possibility (Pressoir and Berthaud 2004b, Pressoir and Berthaud 2004a, Perales al. 2005).

Local and regional seed flows are different for different types of seed. Modern varieties were mainly obtained outside the community, although much exchange of modern varieties was also found within communities. Exchange of modern varieties among farmers was also reported elsewhere in Guatemala and in Chiapas (Saín and Martínez 1999, Bellon and Risopoulos 2001). Regional seed exchange involves mostly improved varieties. Black maize mostly remains within the communities. It was observed in Oaxaca that black maize from different communities was highly differentiated, more so than white maize (G. Pressoir, pers. comm., 25-1-2006).

Influence of plant characteristics

The results show in various ways that specific plant characteristics are an important aspect of seed replacement and the movement of seeds across the landscape. As was discussed in the previous section, cultivar naming practices reflect the importance of growing cycle difference in the cognitive domain (previous section). This is confirmed by two other findings. First, growing cycle and lodging risks form the most frequently mentioned reason for seed replacement. Second, growing cycle is the most important variable associated with the difference between seeds from within the community and those from outside (plant height was not included as a variable, as it was very difficult to document well in a survey, but it is largely correlated with the growing cycle).

Two other field studies confirm the importance of lodging risks in maize cultivation in the Guatemalan highlands. A study of folk soil (land) taxonomy in Chimaltenango by Rainey (2005) shows that the important cold-hot dimension of farmer classification is associated with lodging risks among other factors. Windy plots are being considered ‘cold’ and sheltered plots ‘hot’. Johannessen (1982) reports that winds have been increasingly devastating for maize cultivation during the 1970s due to forest clearings in the highlands of Guatemala.

Thus seed exchange, and more specifically the introduction of seeds from outside the community, is used to achieve change in plant characteristics that are of importance to crop production. The finding that no important growing cycle differences exist between seeds from within the household on the one hand and from the rest of the community on the other hand means that the prime sources of seed lots with a short growing cycle are regional. The use of names that refer to differences in growing cycle indicates that these differences are nevertheless important in seed transactions within communities. As mentioned, these names also provide evidence for plant characteristics being a motive for regional seed exchange and replacement *before* the introduction of modern varieties. This has been reported also for other places in the western highlands of Guatemala (van Etten 2001).

A possible explanation of a preference for regional seed sources is the local 'degeneration' of maize seed mentioned above (Zeven 1999). In the study area, farmers fail to exercise direct selection pressure for growing cycle and plant height within the local plant populations, as selection takes place mostly in the house, where only kernel and ear characteristics can be observed. During field work farmers claimed that after introducing a variety with a short growing cycle the maize stock in question becomes longer in duration and taller as the year go by, making new introductions necessary.

In other parts of Mesoamerica, change in modern varieties has also been recognised by farmers (Almekinders et al. 1994, Morris et al. 1999, Bellon and Risopoulos 2001, Badstue et al. 2005). 'Creolised' varieties in these contexts had advantageous characteristics, uniting the properties of modern and local materials. Most authors attribute change of modern varieties under farmer management to hybridisation between modern and local materials. Segregation may cause change in hybrid varieties, but in the study area mainly open-pollinated varieties or old, recycled hybrid varieties are used for which segregation is probably not relevant. We will here underscore the possible contribution of selection.

Experimental results point to selection as an important candidate mechanism to explain change in modern varieties upon introduction. In a well-known experiment, Gardner (1961) and his co-workers selected individual maize plants for yield while controlling for environmental variation using stratification in Lincoln, Nebraska. As yield increased, days to flowering and ear height increased concurrently (4 days and 25 cm longer over ten generations) (Gardner 1961, Gardner 1969). However, yield reached a plateau after a number of generations. Interestingly, the variety Gardner and co-workers worked with was a variety introduced to the selection environment from elsewhere. Donald and Hamblin (1983), commenting on this particular experiment, interpret this as a process of reaching an equilibrium between increased competitive advantage on the one hand, and increased lodging and reduced harvest index on the other. While local varieties have reached such equilibrium already, an introduced variety is still subject to adaptation. Donald and Hamblin indicate that parallel processes occurred in experiments with other cereal crops, substantiating the existence of a general mechanism.

The same mechanism seems to hold in the study area. Farmers generally select large, well-filled ears from the harvest for seed (Johannessen 1982). In field study of maize in Oaxaca, Mexico, long and thick ears were associated with larger plants (Soleri and Smith 2002). Following Donald and Hamblin (1983), we may expect that such ear based selection will result for introduced short-duration varieties in increased plant height and duration until some equilibrium is reached. On the other hand, local cultivars may be expected to have already achieved equilibrium with their environment.

This scenario seems consistent with other findings in Oaxaca. Farmers in this area did not see artificial selection as a major means to change the characteristics of the crop which are under genetic control (Soleri and Cleveland 2001). Farmer selection of local maize seed (based on ear and kernel characteristics, not plant characteristics) did not have a measurable genetic effect over several years, in spite of significant broad heritability for some characters, including the growing cycle (Soleri et al. 2000, Soleri and Smith 2002). This could be interpreted as local cultivars being in equilibrium with their environment. If such a tendency towards equilibrium of locally grown cultivars exists, constant introductions from elsewhere would be needed to maintain varieties with short growing seasons in the area.

Environmental influences

The influence of altitude is clear in the spatial distribution of cultivar names. The data also showed that in higher areas, households tend to be more self-sufficient in seed procurement. Altitude is a major axis of environmental diversity in the study area, and many other variables are associated with it (climate, land use). Thus, a clear-cut explanation of the impact of this variable is not easy to formulate. However, storage problems are generally more prominent in lower areas, where the seed storage period is longer (shorter growing season) and insect infestation is more serious (Stadelman 1940). Drought is also more prominent at lower attituted in the Motagua valley in the north of the study area. The literature suggests that this difference altitudinal gradients in seed exchange frequency is general. More self-sufficiency in seed at higher altitudes is also evident in a transect study in central Mexico (Perales Rivera 1998).

Ethnic influences

There is an interesting difference between communities with Indian inhabitants and those with a higher percentage of Ladino members (Comparison 3 in Table 6). In the first instance neighbours seem to be more frequent sources for intracommunity seed procurement than in the latter communities. Atran et al. (1999) show that with regards to ecological knowledge exchange, in Petén, Guatemala, the Ladino community is less integrated than the Q'eqchi' community (an ethnic group originally from the highlands). While the Ladino knowledge exchange network is dominated by a few leaders and contains various cliques, the Q'eqchi' one is more egalitarian and is less factionalised. Thus this difference between (highland) Maya and Ladino communities are likely to be part of a regional trend.

Conclusions

In the research area, small proportions of seeds are introduced from regional sources into local communities, consistent with findings for Mexican rural communities (see Introduction). It was observed, however, that seed exchange was largely confined to sources from within the department and from areas within the same altitudinal zone. Thus, since this will generally lead to interregional genetic differences between populations, spatial differences need to be taken into account in planning *in situ* crop genetic management. At lower altitudes households exchange seed more frequently. Local genetic differences between household seed stocks will be more pronounced at higher altitudes.

The focus of regional seed exchange on the departmental capital and other major cities indicates that regional seed flows are not occurring in all directions and thus suggests that also within the region spatial genetic differences are likely. This urban focus of seed flows also indicates that seed sellers need considerable marketing areas to generate sufficient demand. This is another important consideration for future interventions; local seed sales in rural communities are not likely to be sustainable.

The main goal of regional seed exchange is to obtain plant characteristics that are not easily controlled by farmer seed selection, including growing cycle and plant height. Local sources of diversity for these traits are limited and also difficult to access due to problems in information transmission (cultivar names). Also, in the study area degenerative processes take place. This chapter presented unconscious selection (unintentional human selection) as a possible mechanism of degeneration, which is probably at work in the study area. This possibility should also be given attention in the many other cases of regional cereal seed procurement due to degeneration of seed (Zeven 1999). Thus, regional seed exchange should be considered as an important source of innovation in maize farming systems in the study area.

The chapter presented evidence for regional exchange preceding the introduction of varieties (cultivar names, and additional evidence from historical sources). This indicates that the availability of modern varieties did not set in motion a new process of introduction of foreign cultivars. The occurrence of regional seed exchange in the past indicates that spatial genetic differences between localities within the study area will not be based on long-term isolation-by-distance producing ‘deep’ local gene pools. It is more reasonable to expect that within altitudinal zones, different degrees of receptivity to different regional sources of seed combined with relatively frequent local seed exchange, will produce a ‘chequered’ pattern of spatial difference of locally differentiated patches (communities, valleys), which may be rather redundant when broader, regional scales (several *departamentos* or the entire highlands) are considered.

Thus in this study area, variation of maize according to space and scale is important to consider in the design of interventions, which should be conceived from a combined local and regional perspective (cf. Zimmerer 2003). Given the many spatial constraints to regional seed exchange, to support continued innovation in the area, seed collection will need to incorporate diversity in breeding programmes by spatial stratification, taking into account altitude and geographical distance. On the other hand, interventions should foster further regional integration and economies of scale in seed production and crop improvement. In the past, some interventions have tried to improve farmer mass selection skills to enhance innovation (Chapter 2). However, few farmers adopted the promoted techniques systematically. Combining such training with opportunities to establish a broader commercial organisation for seed marketing could provide the economic incentives to make crop improvement activities sustainable. Such experiences with seed production already exist for eastern Guatemala (Warren 2005). A regional approach should also take advantage of environmental similarities and complementarities between places for crop improvement, perhaps through a network of farmer-breeders. Seed sales, even when organised through regional outlets in major towns, should be tailored to the environmental conditions and other requirements of farmers by providing specific information about seed characteristics in an easily understandable format. Information derived from centralised seed sales (especially the demand per variety and geographical provenance of clients) could also be used to monitor diversity dynamically and to adjust breeding and conservation goals and methods accordingly.

Chapter 5

Geographical patterns of genetic diversity

van Etten J., Fuentes M., Molina L. and Ponciano K. Genetic diversity of maize (*Zea mays* ssp. *mays* L.) in communities of the western highlands of Guatemala: geographical patterns and processes. Submitted to *Genetic Resources and Crop Evolution*.

Chapter 5: Geographical patterns of genetic diversity

Introduction

Spatial analysis of the genetic structure of crop populations in traditional agricultural systems may yield important insights for their genetic management. (Greene et al. 2002, Guarino et al. 2002). In conservation ecology, 'landscape genetics' is the study of fine-scale genetic distributions and their association with environmental features in the landscape (Manel et al. 2003). Such studies contribute to insights in the underlying processes (gene flow, selection) and genetic management requirements (spatial sampling, conservation units).

For crops, spatial approaches might prove crucial in supporting *in situ* genetic management of populations (crop improvement and biodiversity conservation). *In situ* genetic management of crops has become more important in the form of participatory or collaborative crop improvement (involving the perceptions and skills of farmers) and *in situ* conservation of crop diversity (Almekinders and De Boef 2000, Almekinders and Elings 2001, Brush 2004, Cleveland and Soleri 2002, De Boef et al. 1993). Most of these efforts have been local in extent, and upscaling has been indicated as a crucial next step (Smith and Weltzien 2000, Visser and Jarvis 2000). Therefore it will be important to understand the current crop diversity situation from a multi-scale perspective (Zimmerer 2003).

This study considers local and regional patterns of genetic diversity and focuses on maize (*Zea mays* ssp. *mays* L.) in an area of the western highlands of Guatemala. For this crop and area, previous chapters have developed insights and hypotheses about seed exchange. The present chapter evaluates these insights using genetic data.

The research reported here focused on three research questions. The *first question* is whether maize populations are genetically structured in space (including altitude). Our previous studies have found that regional seed exchange is relatively low in the area (Chapter 4). Previous studies have investigated the spatial structure of maize populations using neutral markers and found little spatial differentiation (Labate et al. 2003, Pressoir and Berthaud 2004b, Perales et al. 2005). These findings will be contrasted with the results of this study.

The *second question* is about which role phenotypic differences play in seed exchange. Phenotypic differences may play a role in environmental adaptation, and they may show evidence of farmer preferences in cultivar selection. In Chapter 4 we report several, mainly crop-related, motivations for seed introduction and cultivar replacement: to decrease plant height, to increase yield, to decrease the growing cycle, and to improve the grain quality or change its characteristics. In the current study it was attempted to verify these findings with quantitative trait data and to quantify their relative contribution in relation to gene flow for the whole study area.

The *third question* is whether modern varieties or derived materials can be found in the area. Modern varieties tend to be different in quantitative traits from farmer materials and measurements of these traits might reveal which farmer materials derive from modern varieties. However, under farmer conditions, modern varieties change due to admixture and/or selection (Morris et al. 1999, Chapter 4). Thus this study takes a more general approach and investigates whether farmer materials genetically close to improved varieties are also similar to them in plant-related quantitative traits.

Materials and methods

Research area

Seed lots were collected from farmers in thirteen communities (*caseríos, aldeas*) pertaining to four townships (*municipios*) in Chimaltenango, Guatemala (Table 5.1). This area represents altitudinal differences between 1500 and 2600 masl (Figure 5.2). Most seeds are being recycled by farmers and derive from the previous harvest and from family or neighbours, while a few seed lots come from regional sources (Chapter 4). Also modern varieties have been introduced into this area in the past, especially since the execution of the Generation and Transfer of Agricultural Technology and Seed Production Project (PROGETTAPS). This was a major project, of national scope, which started in 1986 and ended in the 1990s (Reyes Hernández 1993, Reyes Hernández and García Raymundo 1990, Saín and Martínez 1999). In Chimaltenango the project promoted the adoption of open-pollinated varieties produced by ICTA, in particular V-301 (white kernel), V-302 (yellow kernel), and V-304 (yellow kernel). The first two are adapted to the climatic conditions of the lower part of highland Chimaltenango (1,500-1,900 masl), the last to the higher Central Valley (1,900-2,100 masl). All these varieties are shorter in height and earlier than local cultivars as a result of selection by professional breeders and clearly contrast with native farmer materials in the area with regard to these characteristics (Fuentes 1997). Adoption of these varieties was more frequent in the lower areas (Reyes Hernández 1993, Reyes Hernández and García Raymundo 1990). Agricultural input shops and co-operatives continue to sell seeds of improved varieties (mostly uncertified).

Plant materials

Eighty households were drawn randomly from a list of households in each community. From each household in the sample seed from the seed lot most important for that household was requested. For each seed lot, the location (X, Y, Z) of the household was recorded with a handheld GPS. For each seed lot the following questions were asked: cultivar name, length of time present in household, immediate source, original source (if different), and various agronomic variables. In addition to these farmer materials, five modern varieties developed by ICTA, Guatemala's national agricultural research institute, were sampled from seeds in stock in ICTA's seed bank and included in the analysis (Table 5.2).

Table 5.1. Seed lots collected from farmers in Chimaltenango

Community	Community code	Township	Number of samples
Chuinimachicaj	CH	Patzún	9
Xeatzán Alto	XT	Patzún	5
Xepatán	XP	Patzún	6
Chuacacay	CC	Santa Apolonia	8
Hacienda María	HM	San José Poaquil	10
Ojer Caibal	OC	San José Poaquil	4
Palamá	PL	San José Poaquil	5
Chuacruz	CZ	San José Poaquil	5
Paxcabalche, Hacienda Vieja	PX	San José Poaquil	8
La Colonia, Pueblo de Dios	LC	San Martín Jilotepeque	4
La Unión, El Molino	LU	San Martín Jilotepeque	8
San Miguel	SM	San Martín Jilotepeque	6
Santo Domingo Centro	SD	San Martín Jilotepeque	2

Table 5.2. Modern open-pollinated varieties developed by ICTA included in the study

Name variety	Code	Grain characteristics and adaptation
San Marceño	ICSM	yellow dent, 2,200 - 2,400 masl
V-301	ICV-301	white dent, 1,500 - 1,900 masl
V-302	ICV-302	yellow dent, 1,500 - 1,900 masl
B-7	ICB-7	white dent, 0-1,400 masl
Don Marshall Amarillo	ICDM	yellow dent, 1,400 - 2,100 masl

Source: Fuentes (2002, n.d.).

Genetic markers

An analysis of Simple Sequence Repeats (SSR) served to determine an index of co-ancestry for the accessions. SSR are neutral genetic markers that are highly polymorphic and therefore very suited for intraspecific studies. Both individuals and genetic markers were bulked in this study. Simple population dissimilarity measures based on bulked samples have been found useful in evolutionary studies, breeding programmes and genetic resource management (Fu 2000). For maize, the feasibility of bulking markers using SSR markers was explored by Xia et al. (2000), who found a high correlation between bulked and non-bulked genetic distances, and a good correspondence with known pedigrees (see also Warburton et al. 2002).

The analysis was conducted at the ICTA biotechnology laboratory. One accession was unavailable for the DNA analysis (n=84).

Fresh tissue from a bulk sample of ten plants per accession was ground to a fine powder using liquid nitrogen. The powder was incubated at 65° C during 30 min with 500 µl CTAB buffer and 120 µl N-lauroyl-sarcosine 5%, shaking constantly, followed by two chloroform-isoamyl alcohol extractions.

The liquid phase was incubated at 37° C during 30 minutes with 30 μl of RNase A 10 mg/ml. DNA was precipitated with 1 ml of absolute ethanol stored at -20° C and incubated at -20° C during 15 minutes. It was centrifuged at 13,000 g during 10 minutes and the pellet was washed with ethanol (70%). The pellet was redissolved in TE buffer (10 mM Tris-HCl pH of 8.00, 1 mM EDTA). It was stored at 4° C. For the obtained DNA dilutions, DNA concentrations were determined with a spectrophotometer using as a conversion factor A 260nm 1.0 = 50.0 μg/ml.

SSR primers were selected on basis of their equal annealing temperature (56° C), and their distribution in the genome (bin location). The selected primers are shown in Table 5.3. PCR amplifications were carried out in a total volume of 50 ul, with 5 ul template DNA, 1 x PCR buffer, 2.5 mM $MgCl_2$, 400 μM dNTPs, 1 μM of each primer, and 2 U *Taq* DNA polymerase.

The samples were mixed 1:1 with ‘stop mix’ (95% formamide, 1 mg xylene cyanole, 1 mg bromophenol blue, 0.5 M EDTA, distilled water) and underwent vertical electrophoresis (Bio-Rad) in a 5% denaturing polyacrylamide gel and silver staining. The thus amplified DNA fragments were recorded manually in an Excel table, coded as present (1) or absent (0).

Table 5.3 SSR primers used in the analysis (see http://www.maizegdb.org)

Name	Repeat type	Bin location	Name	Repeat type	Bin location
phi029	AG/AGCG	3.04	phi053	ATAC	3.05
phi032	AAAG	9.04	phi062	ACG	10.04
phi034	CCT	7.02	phi064	ATCC	1.11
phi041	AGCC	10.00	phi078	AAAG	6.05
phi050	AAGC	10.03	phi121	CCG	8.03

Quantitative traits

On the 18th of May, 2004, the 85 accessions were sown in an experimental plot at the ICTA Chimaltenango station at 1776 masl. The plot was divided in four repetitions, which contained five incomplete blocks each. Each block was subdivided in 17 parcels containing one accession each. Each parcel consisted of two rows of five planting holes each planted with four plants (=40 plants per accession). Repetitions and blocks lay across the ploughing direction. Assignment of accessions to blocks and parcels for the four repetitions followed an alpha-lattice design (Patterson and Williams 1976).

The traits included in this study were measured for each accession following IBPGR (1991) definitions and are given in Table 5.4. Least square means for each variable were estimated using the REML method in the ‘Mixed’ procedure of SAS 9.1 (SAS Institute Inc. 2003), taking into account the effect of differences between repetitions and blocks within repetitions. For all variables, accessions had significant differences. The least square means were used as an input in subsequent analyses.

Table 5.4. Quantitative traits included in the analysis

Variable	Unit	Repetitions measured	Other measurement details
Yield	t/ha	4	corrected for humidity (14%)
Plant			
Masculine flowering (tasseling)	days	4	day 50% of plants flowers
Number of leaves	number	2	5 plants per plot of 40 plants
Plant height	cm	4	estimated average per repetition
Ear height	%	4	percentage of plant height
Stalk diameter	mm	4	10 plants per repetition
Ear			
Grains per row	no.	4	10 ears per repetition
Rows per ear	no.	4	10 ears per repetition
Grain width	mm	4	10 ears per repetition, 10 grains per ear
Grain length	mm	4	10 ears per repetition, 10 grains per ear
Grain thickness	mm	4	10 ears per repetition, 10 grains per ear
Ear diameter	mm	4	10 ears per repetition
Ear length	cm	4	10 ears per repetition

Data analysis

Genetic distances

The binary SSR data for each accession (n=84) served to calculate a matrix of pairwise distances. These were calculated as the number of different bands (e.g. 0,1 and 1,0), using GenAIEx 6 (Peakall and Smouse 2005). This distance measure is equivalent to the simple mismatch coefficient (Kosman and Leonard 2005) and is a Euclidean metric (Huff et al. 1993).

Data visualisation

The genetic distance matrix was used to create an unrooted tree diagram using the neighbour-joining method (Saitou and Nei 1987) in the *Drawgram* programme of the *Phylip* 3.65 package (Felsenstein 2005). To gain a further impression of the spatial structure of these data, the geographic clusters of accessions were identified visually in this tree diagram and coded with letters, which were mapped using the GPS data taken with each accession. Spatial structure and the influence of modern varieties were statistically tested without reference to discrete clustering patterns, so no postprocessing of the tree diagram was undertaken.

Multivariate analysis: general aspects

Several parts of the analysis relied on a multivariate data analysis to evaluate the relative importance of spatial structure, differential environmental adaptation, and the role of quantitative crop descriptors. This was done by decomposing SSR-based genetic variation by (partial) constrained ordination. This method was introduced into ecology by Borcard et al. (1992) to decompose variation associated with spatial as opposed to environmental variables. All ordination analyses were done in CANOCO 4.5 (ter Braak and Šmilauer 2002) using redundancy analysis (RDA). Mathematically, RDA is an ordination method related to both principal components analysis (PCA) and multiple regression. RDA (like PCA) reduces a multidimensional data set to a few dimensions. However, in RDA an additional constraint is added to the reduction of data; the resulting axes have to be linear combinations of a set of explanatory variables. RDA differs from multiple regression in that the Y is composed of a set of several variables.

To be able to analyse the SSR data using RDA, the genetic distance matrix was subjected to a principal coordinate analysis (PCoA), using GenAIEx 6 (Peakall and Smouse 2005). Also, principal coordinates were constructed for parts of the data (see below). Since the distance measure used is a Euclidian metric, all eigenvalues of the PCo's were positive. The SSR-based principal coordinates were used as the set of dependent variables in RDA. Since grain colour was not significantly associated with SSR-based principal coordinates (evaluated with RDA, using dummy variables for grain colour) for the whole area and subareas, the analysis was done for all colours together. For the third part of the analysis, which focused on the lower areas only, colour (the dummy variable for white) was significant ($p<0.01$) and explained 7.1 % of the SSR variation. In this analysis, the dummy variable for white was used as a covariable. All significances were determined with permutations under the reduced model in CANOCO 4.5.

Spatial structure

The first part of the analysis is related to the spatial genetic structure of the maize populations. A spatial correlogram was constructed using the pairwise SSR distances to evaluate the presence and extent of isotropic spatial autocorrelation of selectively-neutral genetic diversity in the sample.

Additionally, a multivariate approach was used to evaluate the relation between the SSR data versus spatial distance and altitude. Spatial descriptors for the area were constructed using *SpaceMaker2* (Borcard and Legendre 2004). This programme makes principal coordinates of a (truncated) matrix of Euclidean distances among sites (principal coordinates of neighbourhood matrixes or PCNM variables) (Borcard and Legendre 2002). The truncation value can be determined using different methods, but the implications of these are not fully understood (Borcard and Legendre 2004). Therefore, two different methods were compared: (1) taking the longest distance in the Delaunay triangulation, and (2) the Relative Neighbourhood Graph. X and Y coordinates were added to the spatial explanatory variables in order to model a plane through the data points. Variables were selected using forward selection in CANOCO with $p<0.05$.

SSR-based genetic variation was portioned between the set of spatial variables and altitude following Borcard et al. (1992). In this method the intersection between altitude and the set of spatial variables is calculated as the difference between the gross effect of the set of selected spatial variables (without covariables) and its ‘pure’ effect (taking altitude as covariable). Theoretically, this difference can be negative (Borcard and Legendre 2002). This analysis was done for the whole study area, and repeated for three subareas (see Figure 5.1).

Quantitative traits

The second part of the analysis extended the first part of the analysis to include various sets of plant descriptor variables, related to the yield, plant and ear, respectively (Table 5.1). After a check for normality of the quantitative traits, using Q-Q plots in SPSS (SPSS Inc. 2003), yield was log-transformed. In the RDAs only the PCNM spatial descriptor made using a truncation value derived from a Delaunay triangulation was used.

To be able to partition variation between many sets of variables, the protocol given by Økland (2003) was followed. First, variables were selected for each set using forward selection ($p<0.05$). The ‘pure’ effects of all significant variable sets were determined by running RDAs taking the complementary sets as covariables. Then, RDAs were run for all combinations of two variable sets, taking the complementary sets as covariables. The first-order intersections were calculated by subtracting the corresponding ‘pure’ effects of the two sets included in each RDA run. Second-order intersections were calculated as the outcomes of RDA runs on all possible combinations of three variable sets with two complementary covariable sets, subtracting the four corresponding first-order intersections and the three ‘pure’ effects. Likewise, higher-order intersections can be calculated. The last intersection (of all variable sets) is calculated by subtracting all lower-order intersections from the total variance explained.

Since in the approach used no significance levels for combined effects of variable sets can be calculated, the results were simplified using a heuristic method: ‘pruning’ the intersections smaller than L = total variance explained / total number of intersections (Økland 2003). This was first determined for the highest order partial intersection. If a certain intersection (<L) was excluded, its variation was equally distributed among the corresponding intersections of one order lower. Subsequently, the intersections of this order were pruned, and so on. The ‘pure’ effects were not pruned. The results were summarised in a flow diagram, indicating the relative contribution of each factor and factor combination to the total explained variation. Analyses on subareas, and on low and high areas (see below) separately, showed that none of the variable sets apart from space and altitude had a significant ‘pure’ effect.

Incidence of modern varieties

The third part of the analysis focused on the possible contribution of improved varieties in the research area on plant characteristics. Modern varieties are different in quantitative variables. Breeding for shorter plants and early flowering have been the main goals of selection (Fuentes 1997). Since farmers reported improved variety names in the lower areas only this analysis focused on the lower part of the study area (communities with average altitude < 2100). The following communities were included: PL, OC, HM, PX, SM, LU, LC, SD (n = 46; see Table 5.1 and Figure 5.2). Principal components based on the SSR-based genetic distance matrix were calculated and used as the dependent variable set in an RDA. Forward selection ($p<0.05$) between different plant characteristics (Table

5.4) was undertaken. If modern varieties have had an impact in the area, it would be expected that farmer cultivars genetically close to these varieties would be more similar in plant-related characteristics. To test this possibility, a regression analysis was carried out using the outcome as the response variable and the genetic distance to the closest improved variety as the explanatory variable. This was undertaken for white and yellow materials together, and then separately, i.e. for white cultivars and V-301 (a white variety) and yellow cultivars and V-302 (a yellow variety) respectively.

Results

Germplasm collection

Of the collected seed lots, 37 were white, 40 were yellow, two were black, and one had all three kernel colours (*pinto*). Names of improved varieties were mentioned for seed lots from the lower areas especially, and might serve as a general indication of the possible impact of modern varieties on local germplasm (Chapter 4). In at least 12 cases germplasm originated from farmers in other communities within the same township.

Data visualisation

In Figure 5.1, the tree diagram for the 84 accessions is presented. From Figure 5.1 it is clear that selectively neutral genetic spatial structure exists, as similar two-letter community codes tend to cluster together. The visually determined groups in Figure 1 contain accessions with a relatively high geographical proximity. Grouping of the accessions is presented geographically in Figure 5.2. Most groups are spread over adjacent communities. In two cases is similar germplasm shared between the different subareas. Group H is found in PX (subarea 2) and SD (subarea 3) while group E includes one case outside of its main community, CC (Subarea 2), and is found also in CH (Subarea 1). These cases provide evidence for the existence of some regional gene flow. Groups with high mutual genetic distances (A, B, E, G) are found in high environments (> 2,000 masl). This might indicate a lower rate of exchange within communities in these environments, a tendency noted for this area (Chapter 4).

The improved varieties are clustered close to accessions from low areas, from both subarea 2 and 3. Group F and D (located in subarea 2 and 3, respectively) contain all of the improved varieties. Don Marshall and B-7 cluster together and are close to the root of group F. Also, San Marceño is closer to the root of the group than any farmer cultivars in its branch. V-301 and V-302 are ‘in between’ farmer cultivars in their respective groups, which could be interpreted as support for their influence on the maize gene pool in the area.

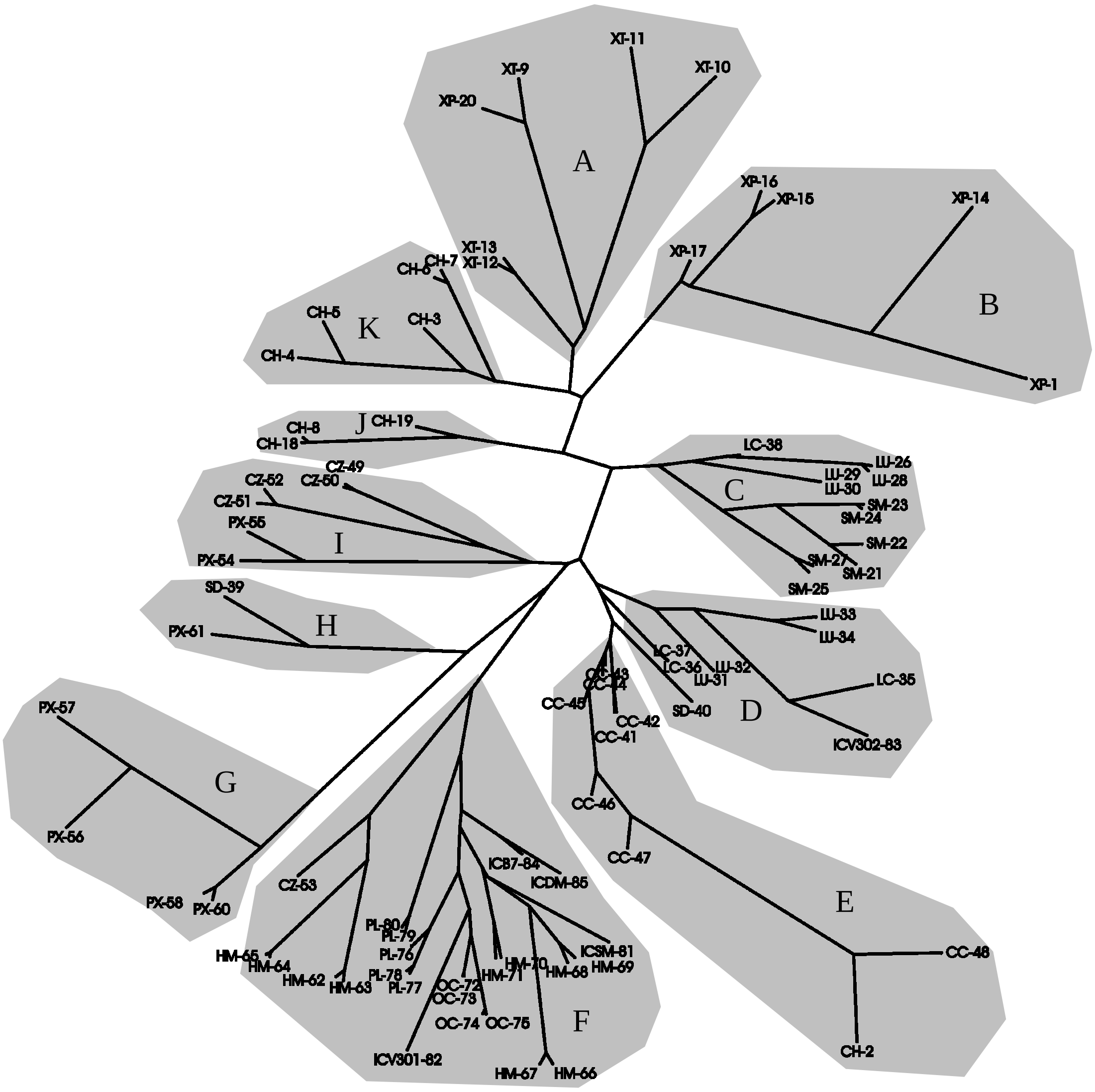

Figure 5.1. Unrooted tree based on the SSR genetic distance using neighbour-joining. Shaded areas (A-K) are visually-determined groups of related and geographically close samples. Samples: two-letter codes indicate the location as given in Tables 5.1 and 5.2.

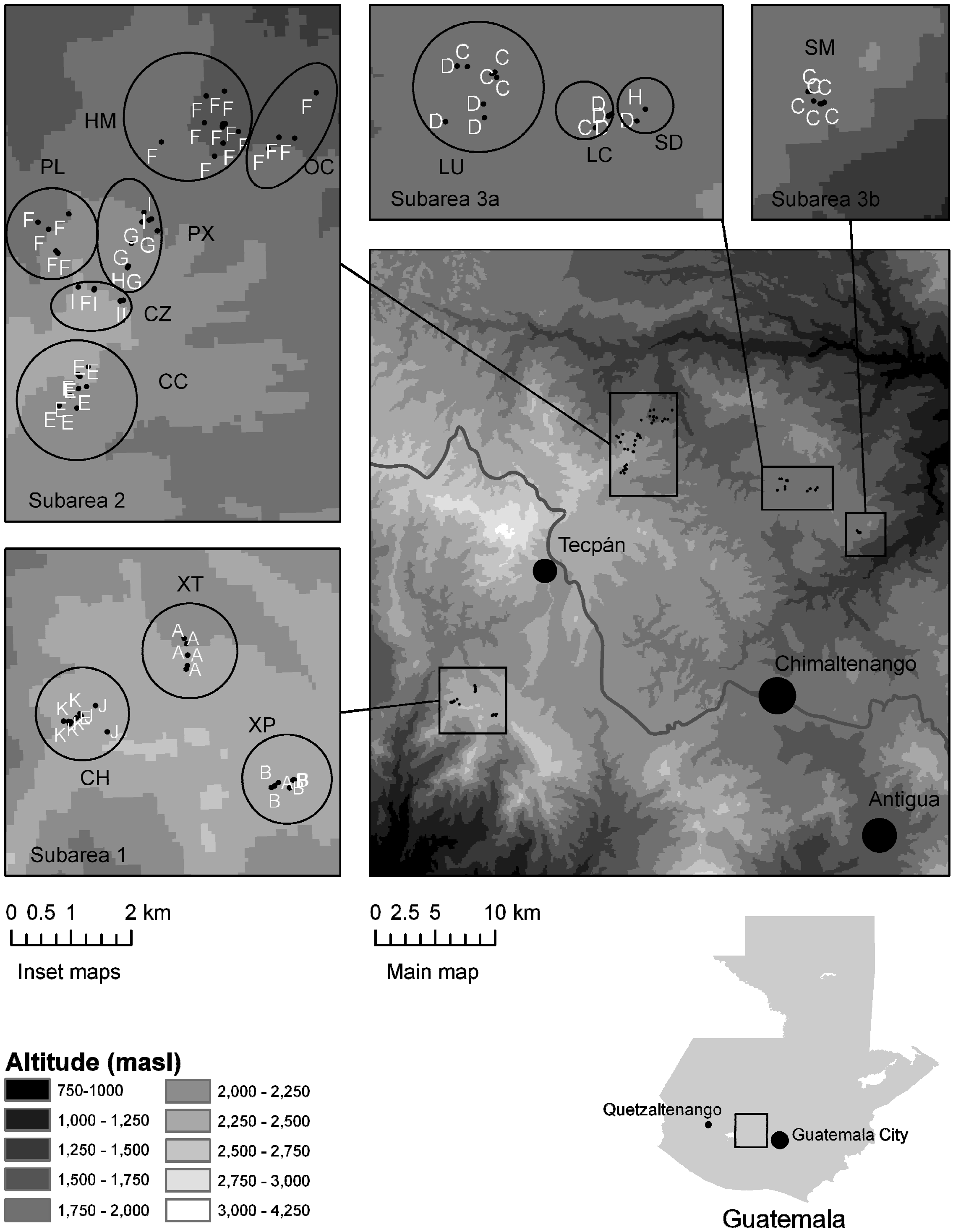

Figure 5.2. Map of communities (two-letter codes; see Table 1) and genetic clusters (one-letter codes; see Figure 1)

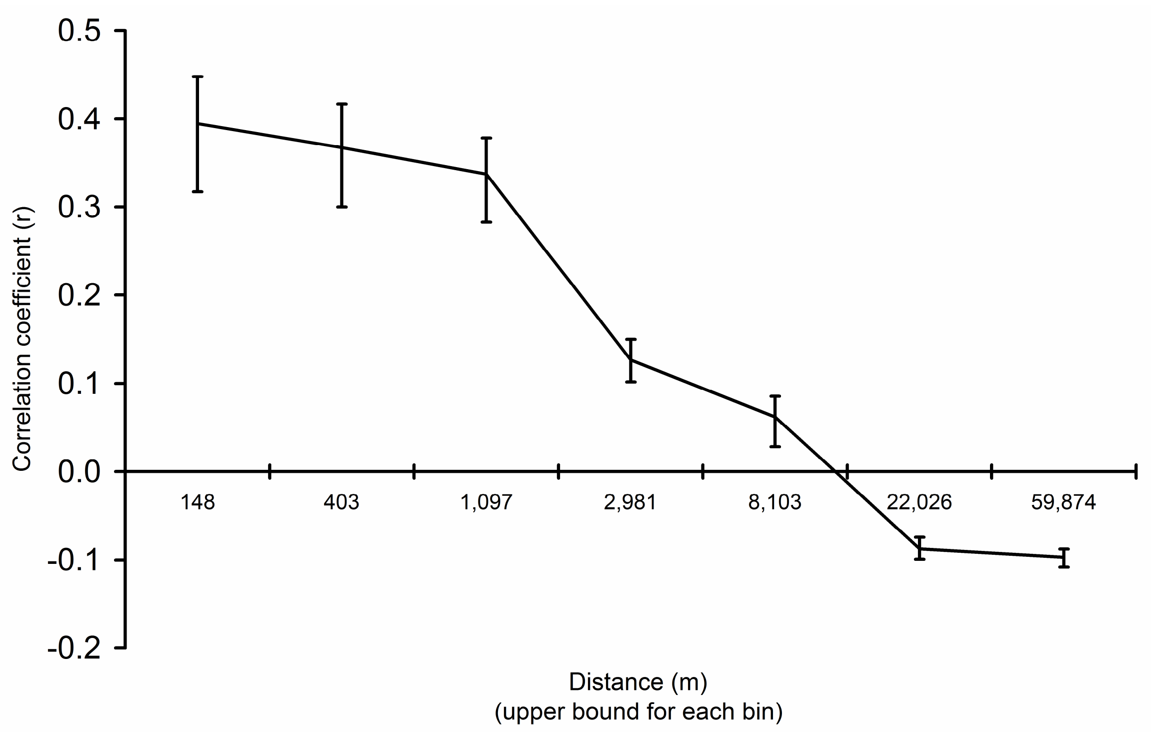

Figure 5.3. Spatial correlogram showing spatial genetic autocorrelation (r) as a function of distance. Interval sizes increase logarithmically. Error bars for 95% confidence interval. The correlogram is significant at $p<0.01$ (Bonferroni-corrected level, determined with 999 permutations).

Spatial structure

In Figure 5.3, a spatial correlogram is presented for the SSR genetic distances of all analysed farmer cultivars (n=79). This figure shows the degree of isotropic spatial structure over different geographical ranges. The highest degree of correlation is found over small distances, as would be expected in an isolation-by-distance model. Over longer distances (>8 km) a negative correlation is found. This would mean that genetic similarity increases with geographical distance; this has no obvious biological explanation and might be due to the suboptimal structure of the sample for these ranges (confidence statistics refer to the sample, not the entire area). Given the gradual decrease of correlation as distance increases, it can be concluded that over longer distances there is an absence of the isolation-by-distance effect. The turnover point, where the correlation becomes negative, corresponds to the largest inter-sample distance within any subarea (subarea 3 = 8 km). Thus, it might be concluded that isotropic spatial structure is absent *between* the different subareas (but not *within* them).

In Table 5.5 the results of the RDA analysis of the genetic structure of maize populations are presented for the whole area and the three subareas. Irrespective of the truncation value used for the calculation of the PCNM spatial descriptors, both space and altitude give a significant, unique contribution to the structure of maize populations in the redundancy analysis results. Using a shorter truncation distance in the construction of PCNM spatial descriptors implies that a potentially finer spatial structure is used in the statistical analysis. However, for the whole study area, reducing the truncation distance from 31 km to 22 km did not improve the overall explained variation much (0.9 %). The

RNG-based spatial descriptors only took over some of the variation explained by altitude in the Delaunay-based method. In all subareas, significant spatial structure was demonstrated. In the subareas, the RNG-based spatial descriptors improved the explained variation substantively. This indicates that for the extent of the three subareas (with maximum distances of 4, 7 and 8 km in subarea 1, 2 and 3, respectively), fine, local structures exists. In the relatively flat subareas 1 and 3, no influence of altitudinal differences was noted. However, in subarea 2, which stretches out over a gradient, altitude explained a substantial portion of the variation. However, this could not be distinguished from spatial structure indicated by the RNG-based spatial descriptors.

Table 5.5. Spatial genetic structure of maize populations. Contribution of spatial descriptors and altitudinal differences and their overlaps in the explanation (%).

	Whole area (n=79)	Subarea 1 (n=20)	Subarea 2 (n=39)	Subarea 3 (n=20)
RDA on PCNM using Delaunay Triangulation for truncation				
Truncation (m)	34,157	3,544	3,948	7,644
Number of PCNM	10	8	11	5
Spatial descriptors retained (p<0.05)	Y,X,5	1	Y	Y,5,4
Spatial	29.9^{****}	12.7^{**}	26.7^{****}	44.1^{***}
Pure spatial	24.3^{****}	10.7^{*}	3.8^{*}	44.3^{****}
Pure altitudinal	9.3^{****}	5.3^{ns}	5.6^{**}	2.5^{ns}
Spatial+altitudinal	5.6	2.1	22.9	-0.1
Undetermined	60.8	81.9	67.7	63.4
RDA on PCNM using Relative Neighbourhood Graph (RNG) for truncation				
Truncation (m)	21,648	519	1,299	4,856
Number of PCNM	8	10	20	5
Spatial descriptors retained (p<0.05)	Y,1,6,7	8,3,X	Y,1,16,4,18	1,Y
Spatial	38.1^{****}	45.7^{****}	56.9^{****}	43.6^{***}
Pure spatial	25.2^{****}	43.4^{****}	28.1^{****}	44.3^{***}
Pure altitudinal	2.0^{****}	5.0^{ns}	1.5^{ns}	4.4^{ns}
Spatial+altitudinal	12.9	2.3	28.8	-0.7
Undetermined	59.9	49.3	41.6	51.3

Significance levels: ^{ns} not significant; * p< 0.1; ** p<0.01; *** p<0.001; **** p<0.0001

Quantitative traits

In the redundancy analysis of the SSR-based co-ancestry data (response) versus the quantitative traits, ear characteristics and yield gave significant results, while the set with plant-related characteristics did not show a significant association with the SSR data.

Ear characteristics, yield, the spatial descriptors (Delaunay triangulation) and altitude accounted together for 43.8 percent of the genetic variation. Variation was partitioned over pure effects and intersections and all intersections with a value lower than L = 43.8/15 = 2.92 were removed. The largest removed intersection was sized at 1.9 percent; one intersection had a small, negative value (-0.3). Two partial intersections between variable sets remained after simplification of the results: the first-order intersection between ear characteristics and spatial descriptors, and the second-order intersection between yield, spatial descriptors and altitude.

The relative contributions of each factor to the total explained variation are represented in Figure 5.4. Spatial descriptors and altitude each have a major share in the total explained variation and their contribution partly overlaps (8.4%). This overlap corresponds to yield (an indicator of environmental adaptation). Yield also gives a small but marginally significant independent contribution (3.8%; $p<0.1$). The ear characteristics also relate to an important share in the co-ancestry data. Much of this variation is patterned in space, but ear characteristics also give an independent contribution (9.2%; $p<0.1$).

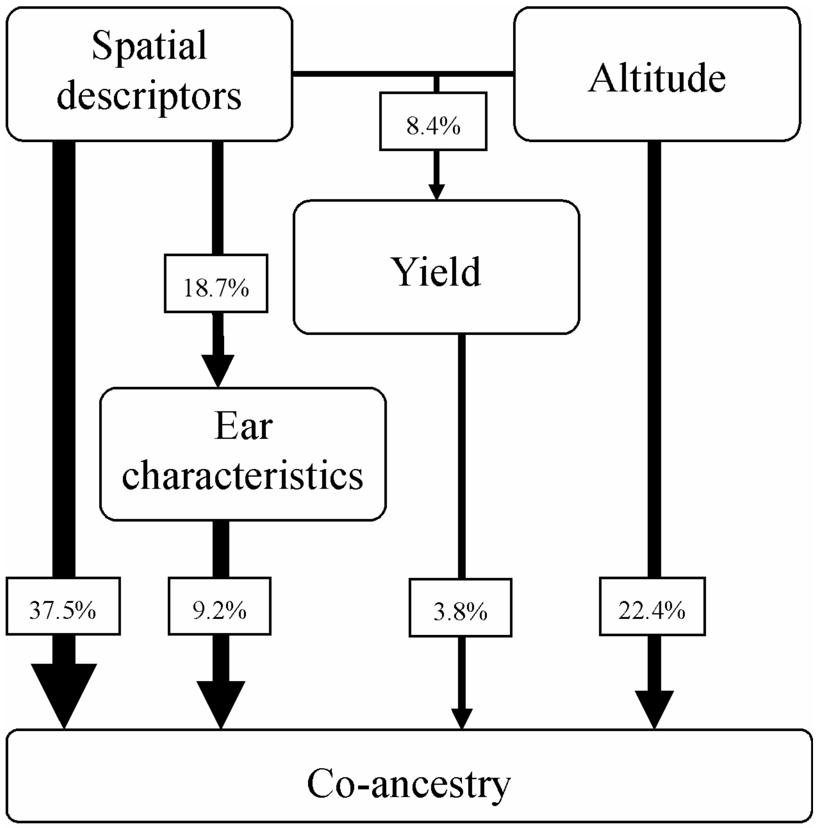

Figure 5.4. Factors related to the SSR-based genetic diversity of maize in the whole study area. Percentages add up to 100, and represent portions of the total ‘explained’ variation (43.8 percent). Arrows directly pointing from ear characteristics and yield to co-ancestry represent the *sum* of the pure effect and the intersection with spatial descriptors and/or altitude.

Table 5.6. Number of leaves of the ICTA varieties as measured in the trial

Name variety	Number of leaves
San Marceño	18.9
V-301	22.2
V-302	22.4
B-7	20.5
Don Marshall Amarillo	20.6

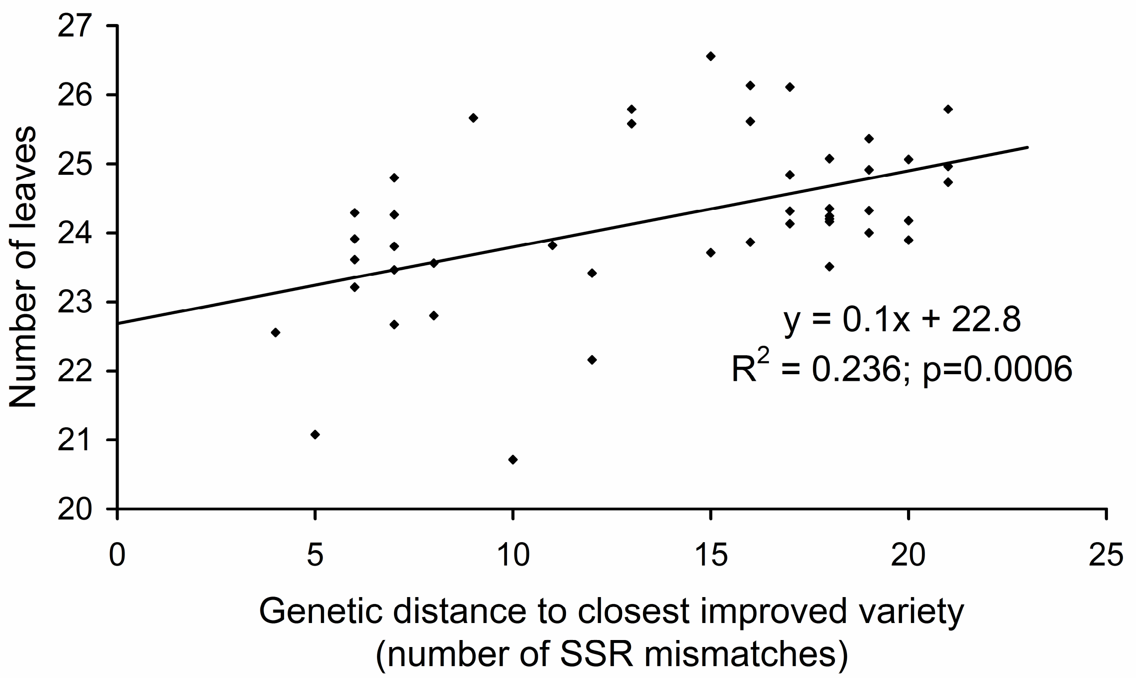

Figure 5.5. Relationship between the genetic distance to the closest improved variety and the number of leaves of farmer cultivars collected in the lower part of the study area (communities below 2,100 masl)

Incidence of modern varieties

The analysis of the possible impact of modern varieties on the germplasm collected focused on the lower area only (communities below 2,100) and included grain colour as a covariable (dummy variable for white vs. other colours). After forward selection on the plant descriptor variable set (Table 5.4) only the variable remaining was number of leaves. This variable explained 8.6 % of the variation ($p<0.001$). However, the other plant-related variables were also significantly associated with genetic diversity ($p<0.05$), and correlated with number of leaves. Regression analysis was used to test whether these genetic differences indeed indicated an influence of improved varieties. In Figure 5.5, the number of leaves of plants was related to the distance to the closest improved variety. This relationship is significant ($p<0.001$), a strong indicator for the influence of improved germplasm on the collected materials. The constant of the equation of the fitted line is 22.8 ± 0.8 (95% confidence interval). The number of leaves of the ICTA varieties V-301 and V-302 fall within this confidence interval (Table 5.6).

Additional regression analyses evaluated the relation between number of leaves and the distance to V-301 and V-302 only, and to V-301 and V-302 separately for white and yellow cultivars respectively. All evaluated relationships showed a positive correlation between number of leaves and distance from improved germplasm, as expected. All correlations were significant ($p<0.05$), except for the white varieties and V-301 ($p<0.11$), which was also the smallest group.

Discussion

Spatial structure

Genetic distances and geographical distances correlate over distances smaller than the maximum extent of the subareas in this study. This finding points to isolation by distance causing local spatial structure, presumably the decreasing intensity of seed exchange over growing distances. Neighbours tend to exchange more seeds with each other than with other community members, community members tend to exchange more seeds with each other than with members of other communities, and also in township-sized areas some containment exists. However, over distances greater than contained within subareas, isolation by distance patterns break down, but spatial structure continues to exist. The importance of the X and Y variables in the RDA demonstrate that there are clear regional differences in the genetic composition of maize population. This suggests that regionally mutual distances do no longer form the main factor of influence on seed exchange, but that space still structures seed movement in other ways.

These findings can be compared with those of similar studies on maize that used neutral markers. In a study on historical Corn Belt cultivars, Labate et al. (2003) found that genetic distances based on SSR markers did not associate with geographical distances, using a Mantel test of matrix association. The spatial correlogram used in this study is an equivalent to the Mantel test, as it tests isotropic spatial structure. The present study also found no isotropic spatial structure regionally (distances > 8 km), but demonstrated it is present locally. Also, by expanding the methods to include non-isotropic spatial structure, it demonstrated regional spatial structure was present.

Using SSR markers, Pressoir and Berthaud (2004b) investigated maize from the Central Valleys of Oaxaca collected from communities (longest distance ~100 km) and found small but significant differentiation levels (F_{ST}) among populations and villages. Also, Perales et al. (2005) concluded from an isozyme analysis that two groups of maize collected from two ethnolinguistic groups in Chiapas (longest distance ~50 km) were not differentiated (low F_{ST}).

In the context of a metapopulation, however, low differentiation does not necessarily imply currently high levels of gene flow, as local bottlenecks after colonisation may reduce F_{ST} between populations (Pannell and Charlesworth 2000). Arguably, maize as managed by Mesoamerican farmers is structured as a metapopulation, and local bottlenecks are common (Louette 1999). In Oaxaca and elsewhere, seed exchange often involves small quantities of seed (Badstue et al. 2005). On the other hand, the low F_{ST} values may indicate intensive gene flow in the past (Slatkin 1987, Templeton 1998). Indeed, studies by Pressoir and Berthaud (2004b) on maternally inherited DNA confirm this interpretation. In the current study area, the divergence between communities demonstrated by means of genetic distances has arguably a relatively recent origin, whereas the lack of divergence demonstrated by F_{ST} measurements in the Mexican studies has a historically more remote origin. The Mexican populations may show divergence when the methods of the present study would be applied to them.

A recent origin for the demonstrated genetic divergence between maize populations of different villages of highland Guatemala has historical grounds, because many rural settlements were created in the course of the nineteenth and twentieth century (Chapter 2). Even so, the study has been able to demonstrate the effect of the contemporary localised seed exchange, which characterises maize agricultural systems in highland Guatemala (Chapter 4), and other parts of Mesoamerica, including Mexico.

Quantitative traits

Two additional crop related factors were shown to relate to co-ancestry: ear characteristics and yield. The relevance of ear characteristics indicates that these are a good independent predictor for genetic diversity. Apparently, both observed variables, ear characteristics and SSR markers, give a similar indication of ancestry. That ear characteristics are indicative for ancestry is of course assumed in racial classifications (Wellhausen et al. 1957). The significant 'pure' effect of ear characteristics also indicates that seed flow based on preferences related to the morphology of ear and grain (Chapter 4) might have an important influence on the spatial structure of maize populations. Yield was mainly associated with altitude and space. This indicates that environmental adaptation is an important constraint to seed flow. However, it is also demonstrated that there is an important independent contribution of spatial descriptors to the explanations. This might indicate that some underlying environmental factors and/or social limitations to seed flow as yet unidentified play an important role. Social limitation seems likely, as there is a strong local tendency to isolation-by-distance. The independent influence of altitude (unrelated to yield) is less easy to explain. It would be expected that altitude would correspond to yield (as an indicator of adaptation), and have little additional explanatory power. It seems that yield (expressed in one location in one year) is not a comprehensive measure of adaptation. In future work it may be important to use yield data collected a period of years and in different locations to improve the evaluation of environmental adaptation.

Incidence of modern varieties

Chapter 4 describes the process of introduction of maize cultivars from outside the community in order to obtain plants lower in stature with a shorter growing cycle. Plant characteristics were significantly related to the SSR co-ancestry data in the lower area (communities below 2,100 masl), but overlapped with other factors, especially space and ear characteristics (data not shown). This indicates that the impact of modern varieties, where it exists, is spatially structured.

Various findings point to an impact of modern varieties. V-301 and V-302 clustered between farmer materials. Plant-related variables, under selection by professional plant breeders, related significantly to co-ancestry in the dataset for the lower part of the study area. Accessions closer to improved varieties had fewer leaves, as predicted if the data on plant-related genetic differences are to be explained by modern varieties. Also, V-301 and V-302 had the number of leaves predictable from the data.

These were the varieties that were introduced successfully in the low part of the study area during the PROGETTAPS project in the 1980s and 1990s (see above).

Taken together, there is strong evidence for an impact of improved varieties in the area in quantitative characters and selectively neutral diversity. However, no (near) identity matches with modern varieties were found. This might be seen as an indication that recent introductions of modern varieties are relatively rare.

Conclusions

The maize populations from Chimaltenango studied in this chapter showed clear spatial structure, corresponding to isolation by distance locally and to clinal variation regionally. This finding points to different patterns of seed exchange for different spatial ranges. Locally, the intensity of exchange may be expected a rather regular decay over distance between neighbours and members of other communities. This would lead to the observed pattern. The regional pattern reflects, however, that seed exchange between different townships follows a different logic. Regional seed exchange may consist in saltatory movements, there may be different acceptation in different localities, or certain geographical sources may dominate regionally.

Apparently, different mechanisms are at work at different levels; the two spatial levels involve different types of social relationships. Family and neighbours dominate at the local end of the spectrum. Regional exchange involves relations with traders, shop-keepers, NGO personnel, or vague acquaintances (Chapter 4). For the first category spatial proximity is relevant, while for the other category different spatial factors dominate, such as centrality (the provincial market). The innovative focus of regional seed exchange may override the spatial factors, as to the innovator the specific characteristics of the seed will tend to be more important than the place it comes from.

Regionally and locally, there is evidence that specific environmental adaptation constrains seed flows, while regionally ear and grain characteristics may influence decision-making on cultivar introduction. The study also demonstrated the impact of improved varieties on genetic diversity and plant characteristics. Comparisons with results for other areas lead to the conclusion that the currently observed patterns of genetic diversity are of rather recent origin.

This study has several implications for genetic management of crop populations in the highlands of Guatemala. Evidence for social constraints to seed flow was found, even though modern germplasm has been successfully adopted in the past. This implies that improved access to (modern) germplasm and information about its availability is needed. As spatial and environmental factors play an important role in structuring the gene pool, spatial sampling imbalances in germplasm for use in breeding will tend to reduce the genetic basis for improvement. Spatial and altitudinal stratification of the area for collection and inclusion of materials in breeding programmes will be necessary to obtain optimal collections. On the other hand, given the relatively small genetic differences between localities and their recent origins, it may not be warranted to constrain gene flow in the study area to maintain diversity. Collaborative farmer-professional maize breeding may be useful in exploiting broad, representative populations in various locations and to strike a balance between improvement and conservation.

Chapter 6

Conclusions

Chapter 6: Conclusions

Main findings of this study

The main findings of this study are now presented in order to answer the three research questions. The research questions address seed exchange and replacement (and cultivar change as a special category of seed change) in its geographical and historical context (Research question 1), the mechanisms that produce seed exchange (Research question 2), and the outcomes of seed exchange and cultivar change in terms of the geographical distribution of crop diversity (Research question 3).

Research question 1: Which factors play a role in regional maize seed exchange and replacement?

The conceptual framework of this study (see Figure 1.1 on p. 17) indicates various factors which may determine seed exchange and replacement. Their contribution and relative importance will be discussed below in the light of the outcomes of this study.

Social connectivity Regional seed exchange is an important source of local innovation (Chapter 3, 4). The influence of pre-existing social connectivity on the direction of seed exchange was shown to be particularly important (Chapter 2, 3, 4). Also, the informational aspect of seed exchange is important (Chapter 4). The lack of clear names for maize cultivars connected to stable genetic crop characteristics may limit effective seed exchange to a large extent.

Technological needs One important factor is the wish to achieve a change in plant characteristics. As has been argued throughout this study, the potential of farmer selection to change plant related characteristics in maize is limited, and seed exchange is the major possibility offered to farmers to achieve significant change. Shorter, faster maturing plants are those involved mostly in introductions from outside the local community. That these characteristics are indeed desired by farmers is confirmed by the main reasons given for replacement of previous seed lots: lodging (caused among other factors by high plant stature) and lack of earliness. This thesis also argues, with evidence, that the wish to change plant related characteristics of the crop preceded the introduction of modern varieties (Chapter 4). Low yield was another major motivation to discard a certain seed type. That yield is a factor involved in seed exchange was also inferred from genetic data (Chapter 5). These research outcomes were further confirmed for cultivar change over longer time periods (Chapter 3). This points to the general importance of this factor.

Seed quality loss Quality loss of seed was related to plant-related characteristics (Chapter 4). It is suggested that obtaining a specific seed type from regional sources may be related to local losses in quality of this seed due to unintented selection for longer growing seasons. Compensation requires repeated introductions of faster-maturing varieties.

Seed loss The loss of seed by a particular household does not seem to have a major influence on regional seed exchange patterns. It was not a major reason for the discontinuation of older seed lots (Chapter 4). Also, seed losses did not seem to lead to local cultivar losses during the political violence of the 1980s (Chapter 3). Replacement of lost seed lots occurs through local exchange. However, if the maize stock of an entire community is destroyed by disaster, e.g. colonial epidemics, regional exchange of maize seed will be unavoidable (Chapter 2).

Crop adaptation Altitudinal difference influences the geography of seed exchange. Adaptation of maize to different ecological strata based on altitude was a main criterion in maize naming in ecologically diverse areas (Chapter 3). Farmers in Jacaltenango reported that many maize cultivars were adapted to one, and some to two, of these ecological strata. Also, regional seed exchange examined in Chapter 3 involved seed from relatively low, warm areas (Pacific Coast, Southern piedmont area) that were being grown in the warm or temperate part of the township. The same connections with the Southern piedmont area were evident for the lower parts of the Motagua valley (Chapter 4). Therefore, altitudinal constraints may be of general importance for regional seed exchange in the whole western highlands of Guatemala. However, it may be envisaged that locally maize becomes progressively adapted to different altitudes. Local movements of seeds from household to household over prolonged periods may slowly lead to drift across an environmental gradient in a certain population. The present study has not given evidence that this happens. However, it was suggested that dynamic adaptation to climatic change (Chapter 3). Cultivars may show the same flexibility when subjected to changing selection pressures in slightly different environments.

Research question 2: How do farmers exchange and replace maize seeds and cultivars in space and time?

Since geographical movements of people and goods are embedded in the wider human geography of the area, seed exchange closely tracks of historical changes in socio-economic factors. In the analysed cases of translocal seed exchange, directionality is contingent on different forms of social connectivity in other social spheres, including trade between localities (Chapter 2, 4), labour migration (Chapter 3 ,4), and migration due to human disease epidemics or political violence (Chapter 2, 3). Also the social integration of communities within townships is an important aspect of social connectivity (Chapter 3).

There are also geographical differences in the patterning and intensity of exchange both in present-day Guatemala and during different historical periods. There are differences in the degree of openness between different communities and areas, which persisted from pre-colonial to present times (Chapter 2). The introduction of modern varieties was found to be more intensive in lower areas (Chapter 3), and was spatially concentrated in particular places in higher areas (Chapter 4). The different names employed at different altitudinal levels (Chapter 3, 4), are evidence that altitude is an important constraining factor in the directionality of seed flow. Geographical areas with altitudinal differences beyond a certain level will tend to have minimum seed exchange. This factor is rather stable in time (Chapter 3).

Triggers for regional seed exchange also work differently in different places and at different times and lead to differences in the patterning and intensity of exchange. Lodging problems, a trigger for seed innovation, is more prominent in places more exposed to wind (Chapter 4). In addition, lodging problems were specific to a period in time as they were exacerbated by the introduction of industrial fertilisers (Chapter 2), in ways comparable to the situation in the US in the first half of the twentieth century. Changes in the availability of labour was found to be an important trigger for seed exchange, and showed divergent patterns as for the central area of the highlands land was scarcer than in the periphery.

Research question 3: What is the role of maize seed exchange and replacement in shaping regional spatial distributions of maize diversity?
This question was answered using two types of data. The first type of data consisted of cultivar names and their (changing) distribution over communities and townships. The second type of data used to answer this question was quantitative and genetic.

In the case of Jacaltenango, cultivars were adapted to three locally defined ecological zones (Chapter 3). This indicated the constraints on cultivar exchange between ecological zones. In the case of Chimaltenango cultivar names were relatively rare and did not refer to local ecological differences but mainly to differences in ear and kernel characteristics and growing season (Chapter 4). Cultivar names in Chimaltenango are generally constrained to altitudinal zones, but have broad, regional distributions. This indicates the importance of regional seed exchange in the recent past.

Some aspects of the geographical distribution of maize populations could be evaluated using quantitative data (Chapter 5). The findings in Chapter 5 confirm the importance of altitudinal differences for the current structure of maize populations, found to be related to differences in environmental adaptation among populations. Locally, spatial genetic structure pointed to isolation by distance. This confirms the local nature of seed exchange, which shows a decay in intensity over short distances (<8 km).

Regionally, maize populations also show spatial structure, taken as confirming the relative isolation of maize populations at this spatial level as well. A few cases of regional seed exchange could be identified. The regional spatial pattern was not indicative of regular isolation by distance. From this it was concluded that local and regional seed exchange transactions involve different mechanisms and social relationships. Local seed exchange involves family and neighbours and spatial proximity is important. Regional seed exchange involves traders, vague acquaintances and others and the specific characteristics of the seed are more important than spatial proximity.

Ear characteristics are associated with marker-based genetic diversity, which means that these traits are conserved relatively well among related populations, and might play an important role in seed exchange. The present study did not aspire to evaluate the genetic structure of maize populations for the whole of the western highlands of Guatemala, however.

An open system perspective

An important theoretical claim made in Chapter 1 was that farmers' dealings with crop seeds should be analysed from the perspective of open systems. This claim can be further substantiated for maize production systems in highland Guatemala with the empirical findings presented in this study. Two dimensions of openness were mentioned in Chapter 1 and can be further elaborated here: (1) openness in the relations with other people and places (geographical) and (2) openness to historical forces.

The study has shown that although maize seed exchange often takes place in apparently self-contained units, like the household, the community and the *departamento*, systematic seed introductions also occur from time to time. Innovation around crop characteristics is an important motivation for past and present introductions. Where maize tends to become longer and tardier, farmers counteract this by introducing shorter and faster varieties. Thus, while the crop tends towards equilibrium with the environment, farmers deliberately keep the system in a non-equilibrium state by opening it to genetic material from outside.

This empirical evidence needs to be considered in relation to the plea for locally adapted crops and local breeding strategies. These strategies aim at providing local systems – perceived to be fundamentally self-contained – with greater access to a broader range of genetic materials or focus on boosting local skills for selection. However, the dynamic behind introduction traced in this study is not to broaden local possibilities for future innovation, but to take *direct* advantage of differences between particular places while the system remains dependent on continued introductions. In other words, it is wrong to conceive local maize farming in Guatemala as a closed system. It is contended that a rather different support strategy may be needed for the maintenance and enhancement of an open system than generally envisaged by proponents of farmer-participatory plant improvement.

These findings should also be considered in relation to ideotype breeding. The premise of ideotype breeding that local systems remain closed and in equilibrium with their environment, is questioned by findings this study. The current non-equilibrium situation is not simply the result of the introduction of modern varieties, since such introductions preceded professional plant breeding activities in Guatemala. It is argued that modern varieties merely expanded an existing practice. The implication is that an advantageous non-equilibrium situation may be reached *without* design.[14] This resonates strongly with theoretical perspectives in technology studies (Ingold 2000). Tim Ingold's (2000) argument, in a nutshell, is that practice (not scheme) produces design, i.e. design is effect not cause.

Historical findings also point to the openness of local systems. The predominantly local character of seed exchange is clearly traceable in the genetic diversity currently found in the area. However, divergence between crop populations of communities at roughly the same altitude in the same *departamento* tends to have rather recent origins (to be measured in decades rather than centuries). This study has identified likely occasions of broad regional seed exchange in various historical periods. Given these findings, differences between local gene pools should not be seen as results achieved over millennia, but as products of the current local character of seed exchange combined with locally different receptivities to different genetic materials from outside. Thus there is no reason to see the current spatial structure of maize populations as somehow static or inherent, and thus worthy of conservation as such.

One view of gene pools (extending the hydrological metaphor) is that of increasingly isolated pockets in a drying river bed. An open system perspective, as argued here for maize, envisages currents in an open ocean. This radically different perspective has several implications for genetic management of maize in highland Guatemala.

[14] In fact, the ideotype breeding idea may be seen as *a posteriori* reasoning about design, where no design is present or necessary (cf. Turnbull 1993, Tracy 2003). The ideotype rationale was based on the success of Green Revolution plant types (Donald 1968). However, semi-dwarfs in rice and wheat were discovered and appreciated by farmers long before design-based breeding started (Dalrymple 1985).

Implications for genetic management

What are the implications of an open system perspective for genetic management of maize populations in highland Guatemala? Past interventions in Guatemala have focused on modern varieties development, the enhancement of local skills in selection (Chapter 2) and local seed production of modern varieties (Chapter 5). Although some of these interventions have had results which are notable even today, they do not necessarily add up to an innovation system leading to sustainable, long-term improvement of local crops. The empirical insights and theoretical arguments presented above offer a rather different conceptualisation with possibilities to combine different interventions in a coherent system of innovation. The remainder of this section elaborates three possible strategies from this perspective, comparing them with those applied in the past.

Varieties should not be designed but developed

Variety development for highland Guatemala has been done mainly by selecting on local materials for short growing seasons (with lower stature as an intended secondary effect) and higher yield, with limited crossing with foreign materials. Selection has been done on two experimental stations in Chimaltenango and Quetzaltenango to account for ecological differences. This strategy has had several limitations. Adoption of varieties has occurred mainly in ecologies similar to those of the two stations. In Chimaltenango, modern varieties with high-altitude adaptation were rare (Chapter 4, 5). Design-based breeding may not facilitate, but contrarily may limit breeders' success in the diverse environments of the Guatemalan highlands

Instead of a design-based method based on a static concept of environmental adaptation (altitude only) selection should be conceived in a framework which allows for more flexible and diverse strategies. To use fully the genetic diversity of maize in this area in crop improvement programmes, it will be important to design a scheme that permits the incorporation of broad, multiple populations. Populations might be assembled from materials from a limited range of local areas, yet genetically broad enough to permit population improvement through selection.[15] Populations could be assembled for different end uses according to grain types, colours and ecological adaptation. Each population might then be split into several populations undergoing selection for divergent goals regarding agronomic characteristics, following the Multiple Populations Breeding Strategy proposed by Namkoong et al. (1980) for tree breeding. Such breeding could be done by farmer-breeders trained for this purpose. The broad, multiple, populations could also serve as base populations to draw from for line breeding when this was required.

Seed selection should be complemented with seed exchange

Past intervention in the area has focused on improving the selection skills of farmers by teaching stratified mass selection (Chapter 2). A few farmers did this over prolonged periods and succeeded to sell the resulting seed to their neighbours. However, the effects remain local and rare. Repeating this over more locations would be very cost-intensive and given the time frame involved, would demand that a large group of farmers do this without receiving short-term benefits. It seems more logical to expand the more common

[15] Perhaps there are possibilities to combine similar populations from different, discontinuous areas on basis of an evaluation of spatial genetic structure for the whole highlands. This is an issue for future research.

process of innovation through introduction of materials from elsewhere, i.e. build on the trader rather than the farmer-breeder model.

To reinforce this form of innovation, rural farmers need to reach beyond local forms of coordination of crop innovation and integrate wider networks of crop improvement and trade. The current spatial limitations to social networks are the product of a colonial past. The protective functions of locally isolated corporate communities are being outstripped by the opportunities and challenges of the present state of the political economy (Chapter 2). To be able to draw on the broad gene pool of maize in this area, spatial and environmental stratification will be essential in germplasm collection. Also, adaptation will be determinative for the adoption of improved germplasm in a certain area. However, there is no reason to maintain spatial structure *per se* by constraining gene flow.

Selection might be enhanced by coordination of selection strategies and by taking advantage of geographical differences in a network of locations in which selection takes place. Multiple populations may circulate through such a network and be subjected to divergent selection pressures in various locations. Such a network would exploit differences between locations, which would not be possible when working towards local adaptation in the farmer-breeder model. Locations differ in their discriminating ability and representativeness regarding different selection goals. The characteristics of different places may be investigated using multivariate techniques applied to trial data, combined with environmental data using a Geographical Information System (GIS) (Loffler et al. 2005, Yan 2002).

Seed production and sales should be regional

Local seed production activities have been successful in the past in introducing improved varieties into the areas studied, especially through the PROGETTAPS project (Chapter 5). However, at present, seed production is sustained only by commercial sale in the regional capital (Chapter 4). This indicates that local production and local sale might not be sustainable, due to the capacity of self-reliance of local farmers and the instability of local demand due to the small size of markets. Therefore, in the future it will be crucial, if seed production is to be reinvigorated, to link seed producers to regional markets, where sufficient demand exists. Opening regional outlets with good quality seed will certainly fill a need.

To be able to mediate between local and regional levels, management of information should be improved (Chapter 3, 4). Providing information about adaptation and other characteristics of improved materials will be crucial to make commercial distribution rational. Maps or lists of place names with their potential suitability for certain varieties or cultivars might serve sellers and buyers to decide upon one or more varieties to try in their specific location. Such lists could be retrieved from a Geographical Information System (GIS). Geographical information will be crucial to transfer seed technologies between places and thus improve the channels of seed distribution and crop innovation.

The conditions under which such a system might emerge and prove sustainable are as yet rather unclear. This is therefore a topic for clarification through further research. But this study is by no means the first occasion on which it has been suggested that spatial organisation and spatial analysis are important to improvement of supply chains and trading strategies. Seed passes to and from lands via hands, and the hands of traders are – it is here suggested – as important to the rational management and exploitation of maize genetic resources as the hands of the cultivator.

Summaries in English, Dutch and Spanish

Summary

Crop genetic resources are an important aspect of agricultural production. Agricultural innovation through plant breeding is generally seen as an efficient means to support food security and economic development in poor areas. Modern varieties of maize, a major cereal and the subject of this study, are at present used on roughly half of the tropical acreage of this crop. Several strategies are being developed to reach the other half, which involve farmers being more active in the innovation process. Field studies of farmers' seed and crop management aim to support the design of farmer-participatory plant breeding activities. In these approaches and studies there is a tendency to focus on seed selection as the core process of plant genetic innovation. The present study concentrates on the gene pool of maize in the western highlands of Guatemala, as shaped by seed exchange and replacement by farmers. Maize is traditional in this area, and the main food crop.

Chapter 1 gives a conceptual critique of existing models in participatory plant breeding. There is a tendency to focus on seed selection as the core process of plant genetic innovation. The present study argues that this model should be broadened and sees gene flow as a part of the creative process of crop evolution. This conceptual change implies that more attention should be paid to seed exchange, as seeds are a main vehicle for gene flow in cereals. Also, attention should not be paid only to individual decision making but also to the connections and structures which provide the conditions under which exchange takes place. Over longer periods, individual seed exchange transactions add up to a collective gene pool structure, with 'emergent' properties beyond the scope of individual farmers, but nevertheless important for the design of management strategies for crop genetic resources. The goal of this research is to gain insight into the shaping of the gene pool as a collective entity in the case of highland Guatemala. To reach this goal, this study combines different research methods in an interdisciplinary way to reconstruct historical change and explain the current geographical structure in the maize gene pool.

Chapter 2 explores the historiographic and ethnographic literature on highland Guatemala to sketch five centuries of change in social connectivity and technological needs and identifying disasters with consequences for maize seed. It suggests that events like human disease epidemics of the colonial period, resulting in demographic decline, have had an important influence on the continuity and spatial distribution of maize genetic resources. Also it is pointed out that the twentieth century brought both regional social integration and local fragmentation, and that this, together with demographic recuperation, is important in relation to the maize biodiversity and farmers' knowledge about it. Concerns about diversity conservation should not lead to attempts to resist economic integration; the formerly closed character of communities is largely a colonial product and historical connections between communities are perhaps deeper than often thought. The same may go for maize genetic resources. Instead, maize agriculture should confront the challenges of modernity in ways that support collaboration between communities.

Chapter 3 elaborates a more detailed study on historical change in farmer knowledge about maize diversity between 1927/1937 and 2004. In 1927 and 1937, two

lists with local cultivars and their characteristics were drawn up by ethnographers for the township of Jacaltenango. Close inspection made clear that these two lists were rather consistent, and that a useful comparison with data on farmer knowledge in 2004 could thus be made. By using a sample of informants spread across several communities and ecologies in the township, an unequal spatial distribution of farmer knowledge was anticipated. A technique from cognitive anthropology, consensus analysis, was used to assess the likelihood of consensus about the presence of each cultivar. The current study found that absolute diversity losses were few, and involved cultivars that are probably not genetically unique, since they were introduced before 1937 as a result of labour migration to coffee farms. Many newly introduced maize types were reported by farmers. Seed introductions corresponded to different forms of regional mobility, including forced migration and maize trade. This chapter further highlights the importance of taking into account spatial differences in knowledge between communities in the same township. A previous study in the same area, based on interviews in several township head towns, concluded, incorrectly, according to the present study, that substantial cultivar losses had occurred.

Chapter 4 investigates contemporary farmer seed exchange and replacement based on 257 formal interviews in the highland townships of Chimaltenango. The study focuses on (1) the spatial distribution of cultivar names, (2) seed sources and flows, (3) reasons to discard seeds and (4) variables explaining choices between different seed sources. The fourth element was based on the application of classification trees to the interview data, supplemented with spatial data from another source. The distribution of cultivar names suggested that regional exchange of seeds of traditional and modern varieties occurs, but is constrained by altitudinal differences in the landscape. The data also indicate that most seed flows are local, and that regional seed flows are mostly taking place within the administrative department. Regional seed flows originate often in cities. When farmers discarded seed lots they were mainly motivated by their disadvantages (high plants and long growing cycles). This result was consistent with the finding that regional seed introductions were associated with seed lots with short plants and short growing seasons. This confirms that regional seed exchange is an important source of innovations. It is argued that farmers are dependent on regional sources to counteract the local tendency of cultivars to become taller and tardier. This tendency is probably the result of unintended selection for more competitive plants.

Chapter 5 is a study of the spatial distribution of maize populations. By investigating a collection of 80 samples of maize seed from the department of Chimaltenango, and five modern varieties, it attempts to infer the seed exchange processes shaping the current spatial structure of the maize gene pool. Location, altitude, morphological, phenological, and molecular marker (SSR) data were analysed. The analysis identified altitudinal differences in the landscape as an important constraining factor in seed exchange, which is related to adaptation as measured by yield. Locally it found evidence for an isolation-by-distance effect, which points to a falling intensity of seed exchange over longer distances. However, over longer ranges (>8 km), this effect disappears. This was interpreted as evidence for the existence of different mechanisms for local and regional seed exchange. In this chapter, evidence for the influence of modern varieties is also presented. This influence was detected for the lower areas only.

Chapter 6 argues on the basis of the findings in the preceding chapters that farmers in highland Guatemala maintain maize genetic resources in open systems. Although local seed exchange is common and is an important shaping force for the maize gene pool, occasional regional seed exchange is important in both past and present. The present spatial distribution of maize populations reflects dynamic processes and should not be conserved as such. To innovate, farmers take direct advantage of the differences between crop populations evolving in different places, in order to achieve phenotypic changes in their own fields. It is not artificial selection that is the main creative force in local innovation – the dominant view among advocates of participatory plant breeding – but the flow of seed lots in the landscape. Consequently, efforts to support seed-based innovation should not only focus on selection or local adaptation, but strengthen the capacities of innovation through seed exchange between locales. Innovation should seek to further exploit ecological complementarities between areas (and not only the representation of broader zones of ecological adaptation). For this end, new regional infrastructures to handle seeds and information may need to be created.

Samenvatting

De genetische bronnen van gewassen zijn een onmisbaar aspect van landbouwproductie. Innovatie in de landbouw door middel van plantenveredeling wordt over het algemeen gezien als een efficiënte manier om voedselzekerheid en economische ontwikkeling in arme gebieden te ondersteunen. De helft van het tropische areaal van de belangrijkste voedselgewassen wordt verbouwd met moderne variëteiten. Om de andere helft van het areaal te bereiken zijn verscheidene strategieën van gewasverbetering ontwikkeld die boeren op een actiever manier in het innovatieproces betrekken (participatie). Veldstudies over het beheer van zaden en gewassen door boeren proberen het ontwerp van participatieve activiteiten in de plantenveredeling te ondersteunen. Deze studie concentreert zich op het boerenbeheer van zaden en genetische bronnen van maïs in de westelijke hooglanden van Guatemala. Maïs is traditioneel in dit gebied en het belangrijkste voedselgewas.

Hoofdstuk 1 geeft een conceptuele kritiek van bestaande modellen in de participatieve plantenveredeling. Er bestaat een tendens om zich vooral te richten op zaadselectie als het centrale proces in de gewasverbetering. Deze studie bepleit echter dat het model zou moeten worden verbreed en ziet de uitwisseling van genen als deel van het creatieve proces van gewasontwikkeling. Deze conceptuele verandering impliceert dat meer aandacht aan zaaduitwisseling zou moeten worden gegeven; zaden zijn een belangrijk voertuig van genenuitwisseling in graangewassen. Daarnaast zou er niet alleen aandacht moeten uitgaan naar de vorming van persoonlijke beslissingen, maar vooral ook naar de verbindingen en structuren die de condities vormen waaronder uitwisseling plaatsvindt. Afzonderlijke zaaduitwisselingen vormen samen over langere tijdsperiodes de structuur van het collectieve reservoir van genen. Genenreservoirs ontwikkelen zich als een collectieve entiteit met emergente eigenschappen buiten het directe blikveld van afzonderlijke boeren, maar hun eigenschappen zijn niettemin belangrijk voor het ontwerp van beheersstrategieën voor de genetische bronnen van gewassen. Deze studie heeft tot doel om inzicht te krijgen in de vorming van het genenreservoir als een collectieve entiteit in het geval van maïs in het hoogland van Guatemala. Daartoe combineert deze studie op een interdisciplinaire manier verschillende onderzoeksmethoden om de historische verandering in het genenreservoir van maïs te reconstrueren en de huidige geografische structuur te verklaren.

Hoofdstuk 2 verkent de geschiedkundige en etnografische literatuur over de hooglanden van Guatemala om vijf eeuwen van veranderingen in sociale verbindingen en technologische behoeften te schetsen en rampen met gevolgen voor maïszaad te identificeren. Het suggereert dat gebeurtenissen zoals de koloniale epidemieën van menselijke ziektes en de daaruit volgende afname van de bevolking een belangrijke invloed hadden op de continuïteit en ruimtelijke verdeling van de genetische bronnen van maïs. Het hoofdstuk geeft ook aan dat de twintigste eeuw zowel regionale maatschappelijke integratie als lokale fragmentatie met zich mee heeft gebracht en dat dit, samen met het demografisch herstel, belangrijk is om te overwegen in verband met maïsbiodiversiteit en boerenkennis hierover. Zorgen over de conservatie van diversiteit zouden niet moeten leiden tot pogingen om economische integratie tegen te gaan; het voormalige ‘gesloten’ karakter van gemeenschapen is overwegend een koloniale erfenis en de historische verbindingen tussen gemeenschappen zijn wellicht dieper dan vaak wordt gedacht, ook voor de genetische bronnen van maïs. In plaats daarvan zou maïslandbouw zich moeten confronteren met de uitdagingen van de moderniteit door de samenwerking tussen gemeenschappen te ondersteunen.

Hoofdstuk 3 bevat een gedetailleerde studie over de historische verandering van boerenkennis over maïsdiversiteit tussen 1927/37 en 2004. In 1927 en 1937 werden twee afzonderlijke lijsten van lokale cultivars en hun eigenschappen opgetekend door etnografen voor het gebied van Jacaltenango. Deze lijsten bleken na nauwkeurige bestudering behoorlijk consistent te zijn en dus kon een zinvolle vergelijking worden gemaakt met interview-data verzameld in 2004. Vanuit de verwachting van een ongelijke verdeling van huidige boerenkennis werd de steekproef van informanten gespreid over verscheidene gemeenschappen en ecologische omgevingen. Een techniek vanuit de cognitieve antropologie, consensus-analyse, werd gebruikt om de waarschijnlijkheid van consensus over het aanwezig zijn van cultivars te berekenen. Deze studie vond weinig absolute verliezen van diversiteit; het kleine aantal verloren cultivars waarschijnlijk niet genetisch uniek waren omdat ze voor 1937 geïntroduceerd werden door arbeidsmigranten vanaf koffieboerderijen. Veel nieuw geïntroduceerde maïstypes werden door boeren genoemd. Zaadintroducties correspondeerden met verschillenden vormen van regionale mobiliteit, waaronder gedwongen migratie en maïshandel. Dit hoofdstuk benadrukt verder het belang van het in rekening brengen van ruimtelijke verschillen in kennis tussen gemeenschappen in dezelfde gemeente. Een vorige studie in hetzelfde gebied concludeerde onterecht dat substantiële verliezen van cultivars hadden plaatsgevonden gebaseerd op interviews gedaan in gemeentelijke hoofdplaatsen.

Hoofdstuk 4 beschrijft de huidige zaaduitwisseling en –vervanging door boeren gebaseerd op 257 formele interviews in gemeentes gelegen in het hoogland van Chimaltenango. De deelstudie richt zich op (1) de ruimtelijke verdeling van cultivarnamen, (2) de bronnen en stromen van zaden, (3) de redenen om zich van zaden te ontdoen en (4) variabelen die keuzes tussen verschillende bronnen van zaad verklaren. Het laatste doel werd gerealiseerd met de toepassing van classificatiebomen op de interview data, aangevuld met ruimtelijke data van een andere bron. De ruimtelijke verdeling van cultivarnamen suggereert dat regionale uitwisseling van zaden van traditionele en moderne variëteiten plaatsvindt, maar dat het wordt geremd door hoogteverschillen in het landschap. De data geven ook aan dat de meeste zaadstromen lokaal zijn en dat regionale zaadstromen meestal binnen het departement hun oorsprong hebben. Regionale zaadstromen vinden hun oorsprong vaak in steden. Wanneer boeren besloten zaad niet langer te telen, was dit hoofdzakelijk vanwege de nadelen van hoge planten en lange groeiperiodes. Dit bevestigt dat regionale zaaduitwisseling een belangrijke bron van innovaties is. Het hoofdstuk laat zien dat boeren afhankelijk zijn van regionale zaadbronnen om te compenseren voor de lokale tendens dat cultivars langer en langzamer worden. Deze tendens is waarschijnlijk het gevolg van onbedoelde selectie van competitieve planten.

Hoofdstuk 5 is een studie van de ruimtelijke verdeling van maïspopulaties. Deze deelstudie probeert de processen van zaaduitwisseling die de huidige ruimtelijke structuur van het genetische reservoir van maïs vormden, af te leiden door middel van een onderzoek van 80 maïszaadmonsters uit het departement Chimaltenango en vijf moderne variëteiten. Locatie, hoogte, morfologische, fenologische en moleculaire marker (SSR) data werden geanalyseerd. De analyse identificeerde hoogteverschillen als een belangrijke beperkende factor voor zaaduitwisseling. Dit is gerelateerd aan aanpassing, gemeten als de opbrengst. Lokaal werd er bewijs voor een isolatie-door-afstand effect gevonden, wat betekent dat er een verval is in de intensiteit over groter wordende afstanden. Over langere afstanden (>8 km), verdween dit effect echter. Dit werd geïnterpreteerd als bewijs voor het bestaan van verschillende mechanismen voor lokale en regionale zaaduitwisseling. In dit hoofdstuk wordt ook bewijs voor de invloed van moderne variëteiten gepresenteerd. Deze invloed was alleen aangetoond in de lagere gebieden.

Hoofdstuk 6 stelt op basis van de bevindingen in de voorgaande hoofdstukken dat boeren in Guatemala genetische bronnen van maïs handhaven in open systemen. Al hoewel lokale zaaduitwisseling vaak voorkomt en het een belangrijke vormende kracht is voor het vormen van het genenreservoir van maïs, zijn ook gevallen van regionale zaaduitwisseling belangrijk in verleden en heden. De huidige ruimtelijke distributie van maïspopulaties weerspiegelt dynamische processen en moet niet als zodanig gehandhaafd worden door conservatie. Om innovatie te bewerkstelligen profiteren boeren direct van de verschillen tussen gewaspopulaties die zich ontwikkelen op verschillende plaatsen om zo fenotypische veranderingen in hun eigen veld te realiseren. Kunstmatige selectie is niet de belangrijkste creatieve kracht in lokale innovatie – zoals de dominante voorstellingswijze van de voorstanders van participatieve benaderingen voorstaat – maar de verplaatsing van zaad over het landschap. Daaruit volgt dat inspanningen om innovatie op het gebied van zaad te ondersteunen zich niet alleen op selectie of lokale aanpassing moeten richten, maar vooral op het versterken van de capaciteiten voor innovatie door zaaduitwisseling tussen locaties. Innovatie zou moeten worden bereikt door het verder uitbuiten van de complementaire ecologische eigenschappen tussen gebieden (en niet alleen de representatie van contrasterende zones van ecologische aanpassing). Voor dit doel moet een nieuwe regionale infrastructuur voor het beheer van zaden en informatie worden gecreëerd.

Resumen

Los recursos fitogenéticos son fundamentales para la producción agrícola. La innovación agrícola a través del fitomejoramiento es considerado un medio importante para apoyar la seguridad alimentaria y el desarrollo económico en áreas pobres. La mitad de la superficie tropical cultivada con los principales cultivos alimentarios está ocupada por variedades modernas. Para cubrir la otra mitad de la superficie se han desarrollado diversas estrategias, las cuales involucran a los agricultores de una forma más activa en el proceso de innovación. Estudios de campo sobre el manejo campesino de semillas y cultivos tratan de apoyar el diseño de actividades de fitomejoramiento participativo campesino. Este estudio se concentra en el manejo campesino de los recursos genéticos y semillas del maíz en el Altiplano occidental de Guatemala. El maíz es tradicional en esta área y el cultivo alimentario más importante.

El Capítulo 1 ofrece una crítica conceptual de los modelos existentes en el fitomejoramiento participativo. Existe una tendencia a enfocarse en la selección de semillas como el proceso medular de la innovación fitogenética. El presente estudio presenta el argumento que este modelo debe ser ampliado y concibe el flujo de genes como parte del proceso creativo de la evolución de cultivos. Este cambio conceptual implica que se debe prestar más atención al intercambio de semillas, puesto que éstas son el vehículo más importante para el flujo de genes en los cereales. También se debe prestar más atención a las conexiones y estructuras en vez de sólo a la toma de decisiones individual. A largo plazo, las transacciones individuales de intercambio de semillas forman juntas la estructura del acervo genético. Los acervos genéticos se desarrollan como una entidad colectiva con propiedades emergentes más allá de los agricultores individuales, pero a pesar de eso sus características son importantes para el diseño de estrategias de manejo para los recursos fitogenéticos de cultivos. El objetivo de este estudio es entender la formación del acervo genético como una entidad colectiva en el caso del maíz del Altiplano de Guatemala. Para este fin el estudio combina de una forma interdisciplinaria diferentes métodos de investigación para reconstruir el cambio histórico en el acervo genético y explicar su estructura geográfica actual.

El Capítulo 2 explora la literatura historiográfica y etnográfica sobre el Altiplano guatemalteco para esbozar cinco siglos de cambios socio-económicos. El capítulo se enfoca en los cambios de la conectividad social y las necesidades tecnológicas y identifica los desastres con consecuencias para las semillas de maíz. Los hallazgos sugieren que los acontecimientos como las epidemias coloniales de enfermedades humanas y la disminución de la población resultante, han tenido una influencia importante sobre la continuidad y distribución espacial de los recursos genéticos de maíz. También indican los hallazgos que el siglo XXI ha traído tanto integración social a nivel regional como fragmentación a nivel local y que esto, junto con la recuperación demográfica, es importante para considerar en relación a la biodiversidad del maíz en los conocimientos campesinos sobre ella. Preocupaciones sobre la conservación de la diversidad no deberían conducir a intentos para resistir la integración económica; el anterior carácter cerrado de las comunidades es sobre todo un producto colonial y las conexiones históricas entre las comunidades son probablemente más profundas de lo generalmente se piensa, también para los recursos genéticos de maíz. En cambio, la agricultura de maíz debe confrontar los desafíos de la modernidad apoyando la colaboración entre comunidades.

El Capítulo 3 contiene un estudio detallado sobre los cambios históricos en el conocimiento campesino sobre la diversidad del maíz entre los años 1927-1937 y el año 2004. En el 1927 y el 1937 dos etnógrafos compilaron un listado de cultivares locales y sus propiedades para el área de Jacaltenango. Una inspección minuciosa demostró que estos listados son bastante consistentes, permitiendo una comparación con entrevistas sobre los conocimientos campesinos hechas en el 2004. Para hacer estas entrevistas se distribuyó la muestra sobre varias comunidades y ecologías del municipio anticipando así una desigualdad en la distribución espacial del conocimiento campesino. Se utilizó una técnica de la antropología cognitiva, el análisis de consenso, para estimar la probabilidad de un consenso sobre la presencia de cada cultivar. El presente estudio encontró pocas pérdidas absolutas de cultivares que correspondieron a un pequeño número de cultivares que probablemente no eran únicas porque se habían introducido antes del 1937 a través de la migración laboral a las fincas cafetaleras. Los agricultores mencionares muchos nuevos tipos de maíz. Las introducciones de semillas correspondieron a diferentes formas de movilidad regional entre ellas la migración forzada y la comercialización de maíz. Este capítulo enfatiza la importancia de tomar en cuenta las diferencias espaciales en conocimiento entre las comunidades de un mismo municipio. Un estudio previo en la misma área concluyó incorrectamente, que ha habido una pérdida sustancial de cultivares, basándose en entrevistas hechas solamente en las cabeceras municipales.

El Capítulo 4 describe el intercambio y reemplazo entre campesinos. El análisis se basa en 257 entrevistas formales realizadas en los municipios del Altiplano de Chimaltenango. El estudios se enfoca en (1) la distribución espacial de nombres de cultivares, (2) las fuentes y los flujos de semillas, (3) las razones para descartar semillas, y (4) las variables que pueden explicar la decisión entre diferentes fuentes de semillas. El último objetivo se realizó a través de una aplicación de árboles de clasificación a los datos de las entrevistas, suplementos con datos espaciales de otra fuente. La distribución de los nombres de cultivares sugirió que ocurre el intercambio regional de semillas de variedades tradicionales y modernas, pero que se restringe por las diferencias en altitud en el paisaje. Los datos también indican que la mayoría de los flujos de semillas son locales y que los flujos regionales ocurren generalmente dentro del departamento. Los flujos regionales de semillas se originan frecuentemente en ciudades. Cuando los agricultores descartan cierto lote de semilla se ven motivados generalmente por sus desventajas, siendo las más importantes el tener plantas altas y ciclos de producción largos. Este resultado es consistente con el hallazgo de que las introducciones regionales de semillas se asocian con lotes de semillas con plantas bajas y período cortos de crecimiento. Esto confirma que el intercambio regional de semillas es una fuente importante de innovaciones. Se demuestra que los agricultores dependen de las fuentes regionales para contrarrestar la tendencia de los cultivares de volverse más largos y tardíos. Esta tendencia es probablemente el resultado de una selección no intencionada de plantas más competitivas.

El Capítulo 5 contiene un estudio de la distribución espacial de poblaciones de maíz. A través de investigar 80 muestras de maíz del departamento de Chimaltenango y de cinco variedades modernas trata de inferir los procesos de intercambio de semillas que moldearon la estructura espacial actual del acervo genético de maíz. Se analizaron datos de localidad, altitud, datos morfológicos, fenológicos y de marcadores moleculares. El análisis identificó las diferencias de altitud en el paisaje como uno de los principales factores limitantes para el intercambio de semillas, lo cual se relaciona con la adaptación, medida como el rendimiento. Localmente se encontró evidencia de aislamiento-por-distancia, lo cual significa que hay una mayor intensidad de intercambio de semillas menguante sobre distancias más cortas. Sin embargo, sobre distancias largas (>8 km), este efecto desapareció. Esto se interpreta como evidencia para la existencia de diferentes mecanismos de intercambio de semillas a nivel local y regional. En este capítulo también se presenta evidencia para el impacto de las variedades modernas. Esta influencia se ha detectado solamente para las áreas más bajas.

El Capítulo 6 argumenta, basándose en los hallazgos presentados en los capítulos anteriores, que los agricultores del Altiplano de Guatemala mantienen los recursos fitogenéticos del maíz en sistemas abiertos. Aunque el intercambio local de semillas es común y constituye una fuerza creativa importante para el acervo genético del maíz, el ocasional intercambio regional de semillas también es importante en el pasado y el presente. La distribución espacial actual de las poblaciones de maíz refleja procesos dinámicos y no se debe conservar por sí. Para innovar, los agricultores se aprovechan directamente de las diferencias entre poblaciones de cultivos que se desarrollan en diferentes lugares a fin de lograr cambios fenotípicos en sus propios campos. La selección artificial no es la fuerza creativa principal en la innovación local – como declara la perspectiva dominante entre los que abogan por el fitomejoramiento participativo – sino el flujo de semillas en el paisaje. Por consiguiente, los esfuerzos por apoyar la innovación de semillas no deben enfocarse solamente en la selección o la adaptación local sino sobre todo en fortalecer la capacidad de innovación a través del intercambio de semillas entre localidades. La innovación se debe hacer a través de un aprovechamiento de las complementariedades ecológicas de las áreas (y no sólo la representación de diferentes zonas de adaptación ecológica). Para este fin, se necesita crear una nueva infraestructura regional para manejar semillas e información.

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About the author

Jacob van Etten was born in 1978 in Berkel en Rodenrijs, The Netherlands. In 1996 he came to Wageningen University and in 2001 he completed a ‘free orientation’ MSc programme with an interdisciplinary social and biological focus on agriculture. During his study he worked and did research in Nicaragua, United Kingdom, and Guatemala. In 2002 he started a PhD study following up on his MSc thesis research, focusing on genetic resources of maize in Guatemala.

Completed Training and Supervision Plan

Description	Department/Institute	Month/year	Credits
I. Orientation			
Orientation course CERES	CERES	April 2002	4
Writing of research proposal for CERES	WUR	January-February 2002	4
Writing of research proposal for PE&RC	WUR	March-April 2002	4
II. Research Methods and Techniques			
Basic Statistics	PE&RC	June 2005	1
Advanced Statistics	PE&RC	June 2005	1
ArcGIS 9	GISCover	June 2005	1
III. Seminar Presentations			
"Thinking about scale in seed system research"	TAO	9 April 2002	1
Discussion research proposal	ICTA, Guatemala	June 2002	1
"Avances de una investigación: ecología humana del maíz en Guatemala"	Academia de Geografía e Historia de Guatemala	16 February 200	1
"Avances de una investigación: ecología humana del maíz en Guatemala"	Universidad del Valle de Guatemala	28 March 2005	1
"A geographical framework for crop genetic management"	Annual International Conference, RGS-IBG (London)	1 August 2005	5
Presentation for Workshop on Realistic Explanation	TAO/CERES	14 June 2006	1
Organization / presentation of paper "GIS as a research method in crop genetic resource research"	Summer School, CERES	27 June 2006	4
Total			29