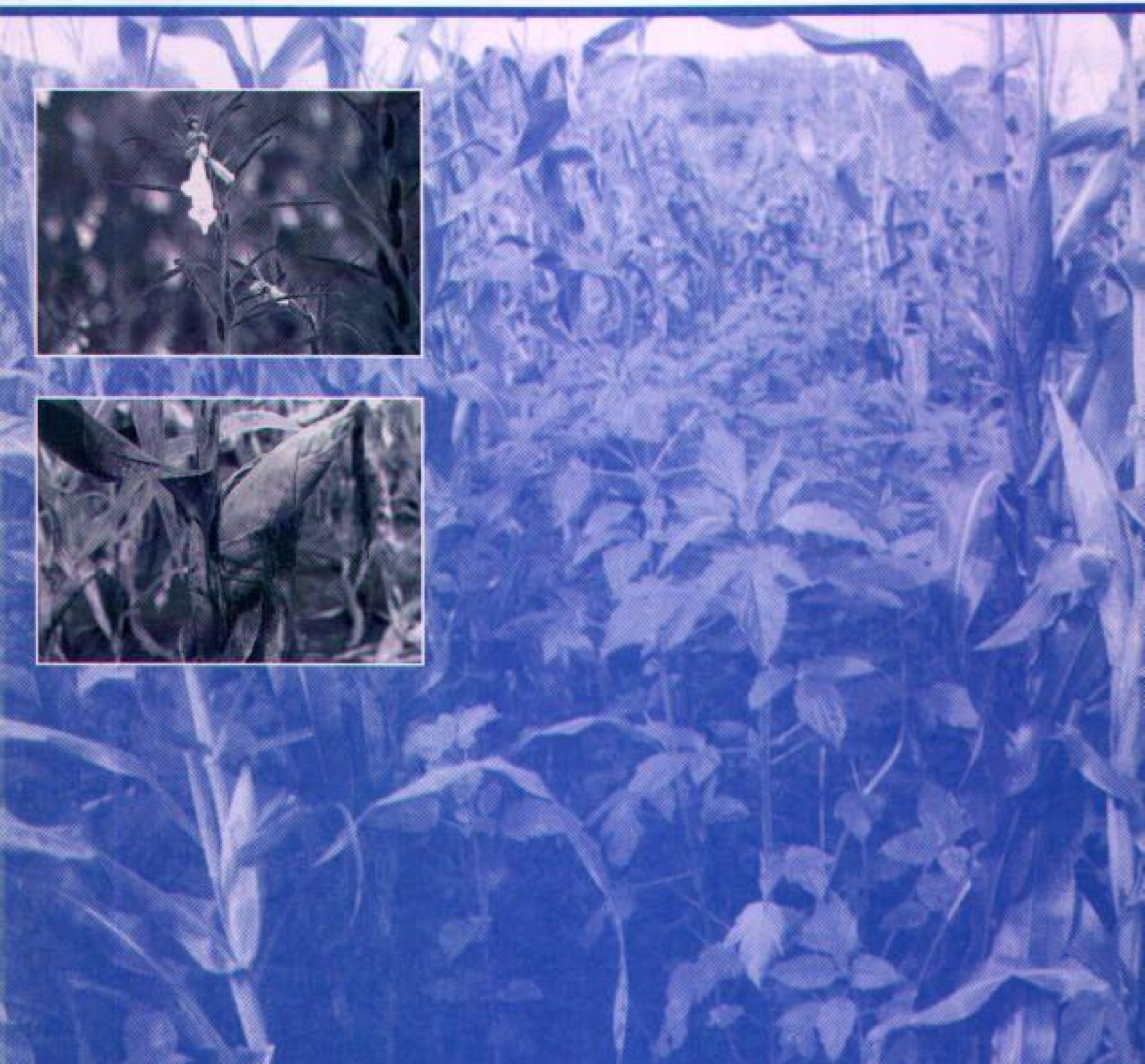
Maize-sesame intercropping in Southeast Tanzania: Farmers' practices and perceptions, and intercrop performance

Geoffrey S. Mkamilo



Propositions

1. Complementarity between maize and sesame, in both ecological and socio-economic context, is the main reason for the success of maize-sesame intercropping in Southeast Tanzania.
   This thesis

2. Breeding programmes for improved sesame varieties in Southeast Tanzania should include characteristics such as competitive ability and growth duration that determine the suitability of sesame in intercropping systems.
   This thesis

3. To make research relevant for target groups of farmers, the set up and evaluation of experiments should be based on farmers' objectives.

4. In empirical research, planning is the most important phase.
   Rasch, D., Verdooren, L.R. and Gowers, J.I., 1999. Fundamentals in the design and analysis of experiments and surveys. Oldenbourg Wissenschaftsverlag GmbH, München.

5. Food security in Tanzania can best be achieved by improving maize-based systems.

6. The secret of producing an outstanding piece of writing is to always keep the reader in mind.

Propositions belonging to the PhD thesis of Geoffrey S. Mkamilo:
Maize-sesame intercropping in Southeast Tanzania: Farmers' practices and perceptions, and intercrop performance.

Wageningen, 29 March 2004

Maize-sesame intercropping in Southeast Tanzania: Farmers' practices and perceptions, and intercrop performance

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Dit onderzoek is uitgevoerd binnen de onderzoekschool: Production Ecology and Resource Conservation

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Geoffrey S. Mkamilo

Proefschrift
ter verkrijging van de graad van doctor
op gezag van de rector magnificus
van Wageningen Universiteit,
prof. dr. ir. L. Speelman
in het openbaar te verdedigen
op maandag 29 maart 2004
des namiddags te vier uur in de Aula

Geoffrey S. Mkamilo (2004)

Maize-sesame intercropping in Southeast Tanzania: Farmers' practices and perceptions, and intercrop performance.

Mkamilo, G.S. –[S.l.:s.n.]. Ill.

PhD thesis Wageningen University. –With ref.–

With summaries in English and Dutch

ISBN: 90-5808-985-1

Abstract

Mkamilo, G.S. 2004 . Maize-sesame intercropping in Southeast Tanzania: Farmers' practices and perceptions, and intercrop performance. PhD Thesis, Wageningen University, The Netherlands, 112 pp., with English and Dutch summaries.

In Southeast Tanzania, the major food crop maize is often inter-seeded with the cash crop sesame using an additive design. Farmers consider maize an essential crop for securing their basic food requirements, whereas sesame is added to generate cash. In this research, farmers' motives for adopting maize-sesame intercropping systems were studied. Concurrently, experiments were conducted to evaluate the performance of the maize-sesame intercropping systems and to explore options for improvement.

A household survey revealed that in the study area arable cropping is the main occupation, responsible for 75% of the mean annual household income. Cashew, maize and sesame were found to be the most important crops contributing to the household income. About 90% of the farmers intercropped maize and sesame to diversify their cash income. All farmers consider maize the more important crop, as it should secure the basic food requirements of the household. The risk of crop failure associated to growing sesame in pure stand is an important reason for adding sesame to maize. Growing the intercrop also puts less demand to labour and fertile land, both of which are limited in supply. Furthermore, maize and sesame are regarded as good companion crops, which additionally contribute to restoration of soil fertility and weed suppression.

Simultaneous sowing of maize and sesame caused reductions in maize grain yield, of on average 27%. These reductions decreased with delayed inter-seeding times. Conversely, delayed seeding led to significant reductions in sesame yield, caused by a direct effect of sowing time and an increased competitiveness of maize. Based on a long-term average maize : sesame price ratio of 1:3.5, simultaneous sowing turned out to be the option with the highest gross financial returns. At the same time, the study demonstrated that there are associated risks with simultaneous sowing such as seedling mortality of sesame due to water logging and severe reductions in maize grain yield (up to 60%). Farmers generally introduce sesame about two weeks after maize, to reduce those risks. This study showed however that the recently developed improved sesame varieties are not very well suited for late introduction, due to their poor competitiveness. As sesame is mainly grown in intercrop, future breeding efforts should not only consider characteristics as yield, seed colour and seed oil content, but should also take into account characteristics as competitive ability and growth duration, that determine the suitability of sesame in intercropping systems.

Density experiments revealed that maize was more competitive than sesame, but more importantly the experiments also demonstrated that maize and sesame are partially complementary in resource acquisition. Niche differentiation forms the basis for a yield advantage in intercropping. This observation confirms the notion of farmers that maize and sesame are good companion crops. At both the relatively high fertile site and the poorly fertile site, P/N ratios of shoot tissue of maize and sesame were high (between 1/1.5 and 1/6.4), indicating that nitrogen was a major limiting factor in the study area. At the low soil fertility site (Mkumba), both maize and sesame in pure stand responded significantly to N and NP-fertilization. At this site, the application of nitrogen fertilizer resulted in 2.5 and 3.6 fold increases in pure stand yield of maize and sesame, respectively. In intercrop, N fertilization increased the dominant position of maize in the intercrop. Consequently, only maize profited from N fertilization, as for sesame the advantage of additional N was counterbalanced by the presence of a more competitive maize crop. Nitrogen recovery was highest in the intercrop. The

results question the general fertilizer recommendations, which advice to supply N and P in nearly equal amounts.

Studies on spatial arrangement showed that, both in pure stand and intercrop, sesame seed yield was independent of sowing method (row or broadcast). In the intercrop, grain yield of maize was affected by the method of sowing sesame. When broadcast sown, sesame caused reductions in maize grain yield ranging from 53 to 69%. These reductions were only 19 to 55% with row sowing. Two to three maize plants per station were found optimal in pure stand as well as in intercrop. This last result indicates that farmers' practice of growing two-three plants per station is superior to the institutional recommendation of growing one plant per station

The results of this study clearly indicate that recommendations for intercropping should be based on intercropping research and cannot simply be extrapolated from results obtained with pure stands of the respective component crops. Efforts for breeding improved varieties should also consider the use of the crops in intercropping. Furthermore, a proper analysis of experimental results requires a thorough understanding of farmers' objectives and production constraints. At the same time, an inventory of farmers' objectives and production constraints without exploring the options for improvement seem ineffective. For these reasons it was recommended that future projects should put emphasis on participatory research in teams of social scientists, technical scientists and farmers in the process of co-innovation to improve the well being of farmers and rural households.

Key words: Intercropping, farm household objectives, marginal factor returns, cost-benefit analysis, inter-seeding time, Land Equivalent Ratio, maize, sesame, niche differentiation, spatial arrangement.

Preface

Shortly after successfully completing my MSc-study at Wageningen University and Research Centre in The Netherlands in 1998, I was awarded a sandwich fellowship by Wageningen University to start a PhD programme on maize-sesame intercropping systems in Southeast Tanzania. Without the support of Prof. Dr. M.J. Kropff, Dr. Ir. Lammert Bastiaans and Dr. Kees Eveleens, I would most likely never have had the chance to begin this adventure. Thank you for making it possible through the sandwich fellowship. This four years research started in February 1999 and was conducted as a collaborative project between the Crop and Weed Ecology Group of Wageningen University, Naliendele Agricultural Research Centre in Mtwara, Tanzania and Sokoine University of Agriculture in Morogoro, Tanzania.

Many people have helped me at different stages of this work but it is impossible to adequately acknowledge everyone who contributed to this work, in one way or the other, within the space provided here. Should I miss your name please do not consider it as an act of ingratitude. I consider this achievement is part of your assistance and I am grateful to everyone whose contribution has enabled this work to be concluded fruitfully.

I have benefited tremendously from the support, supervision and generosity of my Promoter, Prof. Dr. Martin Kropff, and co-promoter, Dr. Ir. Lammert Bastiaans. I am grateful for your special interest in my work and for your profound scientific advice. Your constructive critique, comments, stimulating discussions and intellectual advice throughout the years have been of great value to me. Thank you for providing your invaluable guidance and experiences and always being there when I needed your help. In the finishing stages, your weekly, daily and sometimes hourly attentions were very crucial and immeasurable. Very few times in life it is possible to find persons with such a good combination of professional capacity and human qualities such as Martin and Lammert. Thanks to you and your families for your friendship.

I am also very grateful to my second co-promoter, Dr. Ruerd Ruben, for his invaluable guidance of the socio-economic part of this research. Ruerd, you have been of much help to study the complexity of the maize-sesame intercropping systems. Your valuable critique, remarks, inspirational discussions and intellectual guidance were immense and indispensable. Day to day supervision during data collection was under Prof. Dr. K.P. Sibuga of Sokoine University. Her support and assistance during fieldwork, the critical review of annual reports and advice has greatly contributed to this research. It was an enjoyable working experience with her for which I am grateful. She educated me on the rule of thumb in conducting thesis research, which is to collect

as much data as possible in order to have a better explanation of the system. The input of Gon van Laar of the Crop and Weed Ecology Group, Wageningen University, in editing the thesis is highly appreciated. I am also grateful to her for helping me on the organization of the manuscript.

The Tanzanian Agricultural Research Project Phase Two (TARPII) financed most of the field research. Without Dr. M.E Shayo, TARPII Project Training Officer, and David Mpiri, former Director of Research and Development, both from the Division of Research and Development in Dar-Es-Salaam, I would probably never have had the opportunity to commence this exciting experience. My gratitude also goes to Ninatubu Mathias Lemma, Senior Farming Systems Research Agronomist, Division of Research and Development in Dar-Es-Salaam, for the challenging insight for the need to support demand driven research of this kind for the benefit of farmers. Your invaluable assistance to keep a ball rolling will always be remembered and appreciated. I am as well indebted to the Zonal Director Dr. S.H. Shomari and Zonal Research Coordinator, Dr. M.R. Salum both from Naliendele Agricultural Research Centre, for provision of good working environment and facilitation of this research. I express my gratitude to officer in-charge of Mkumba research sub-station, Mr. R.O Kapinga, for his assistance and help whenever it was needed. This gratitude is extended to Nachingwea District Agricultural and Livestock Development Officer, Mr. Membe, for providing extension staff to assist me in data collection. Particular thanks are due to Messrs Richard Chande, M.M. Mohamed, Bernard Chiamba, Adrian Njega and J.Y. Mkama who did much of the fieldwork. In addition, Halima Kwikwega, Moses Mumina, M. Mapua, George Chikala, L. Emanuel, Bernard Mirola and Juma Ng'onye assisted me in data entry. My fellow researchers, Dr. O.K. Mponda, Dr. E.M. Kafiriti, N.A., Katinila, S.E. Mugogo, Chijinga, Msangi and Bashiru provided technical support in this research. I am also grateful to Corstiaan van Aalsburg, a student from Wageningen University, for conducting the 2001 spatial arrangement experiments as part of his MSc thesis.

Living in Wageningen also gave me an opportunity to meet an amazing number of people from many different corners of the world. The Central Students Administration provided all logistical support for my stay in Wageningen, which is greatly appreciated. In June 1999, my father died while I was writing my research proposal at Wageningen. I am very grateful to Ankie Lamberts for facilitating my return ticket to Tanzania for the funeral. My gratitude is also extended to the secretaries of the Crop and Weed Ecology Group, Hilde Holleman and Leonie van Scherrenburg, for their logistical support and friendship. I would like to thank the International Christian Fellowship (ICF) and Wageningen Salem Church, for the spiritual nourishment. There are also other persons who showed friendship and support to me especially Henriette Drenth, Manneh Baboucarr, Arnold Bray Mashingaize, Peter Ebanyat, Esnati Chaggu, Gerson Nyadzi, F. Baijukya, C. Nombo, M.A. Wende, F. Mrosso, J. Dominic, J. Kussaga, E. Marijani, R. Mziray, D. Kweka, A. Chitiku, Max and Sonja van Gestel, Hans Hamoen, Jan Boersema, Jouke, Maja Slingerland, Corine Zegelaar, Jan Buddingh, Henny, Jonathan and Sara Ware.

To every one there is always this special person in life with whom one shares the good times and the bad times. To Geoffrey, this special person is his dear wife Priscar Semwenda who was patient with me. I was often absent for weeks away in the field and worse when I had to leave you with family responsibilities for eleven months. Priscar, thank you for being both a mother and father to our three sons in my absence. Dudley, Stanley and little Joshua please, do not take it as a deliberate action of leaving you for solid eleven months. To you, I dedicate this thesis.

Those acknowledgements would not be complete without mentioning my parents. I very much regret that my father Ignatius could not live to see this thesis completed; he would be as proud and happy as I am. Without my parents (Ignatius and Milicar), my brother (Nahory Mkamilo), my brother in law (Shangwe Kaguo) and my sister (Mrs Anne Kaguo), my dearest friends (Nathaniel Katinila and Amos Mwijage) I would not be what I am now. To all, very warm and sincere thanks for everything you gave me on my way. I also appreciate various church ministers especially Clement Mrope, Frank Nkembo, Francis Chiwango, Frank Mchihama, Evans Mussa, Simon Mwakasaka, Willium Gurisha, Janathan Gondwe, Chanjarika and Mwakalukwa for the prayers, moral support and encouragement. Finally, I am grateful to God for giving me the inspiration to move on amidst hardships. To you O God, I ascribe all the greatness and glory.

Geoffrey S. Mkamilo Wageningen, March 2004

Contents

CHAPTER 1

General introduction

General introduction

Economic importance of maize in Tanzania in relation to population growth rate

Maize (*Zea mays* L.) is the most important cereal crop grown and consumed in Tanzania (TARO, 1987a; Katinila *et al.*, 1998; Kaliba *et al.*, 1998). It is estimated that the annual per capita consumption of maize is approximately 100 kg and the national maize consumption is estimated to be three million tons per year. On average, the maize crop is grown on two million hectares or about 45% of the cultivated area in the country. Maize contributes to 60% of dietary calories to Tanzanian consumers (FSD, 1992, 1996). Most of the maize is produced in the Southern Highlands (46%), the Lake Zone, and the Northern Region of the country.

Maize is not only a staple crop, but a cash crop as well. For instance, in the Lake Zone, maize competes aggressively with cotton (*Gossypium* spp.) for land, labour, and farmers' cash (Mafuru *et al.*, 1999). In the Southern Highlands, maize has completely replaced the traditional coarse grains such as finger millet (*Eleusine coracana)* and sorghum (*Sorghum bicolor*), which used to be the dominant food crops (Bisanda *et al.*, 1998). Realizing the importance of the maize crop to the lives of Tanzanians, the government has committed human and financial resources to develop the maize industry. Peasants whose farms are smaller than 10 hectares grow about 85% of the maize produced in Tanzania. About 10% of the maize production occurs on medium-scale commercial farms (10-100 ha), and the remaining 5% occurs on large-scale commercial farms (> 100 ha). The average national maize yield is less than 1.5 t ha^{-1}, though grain yields tend to be higher in areas with high potential such as the Southern Highlands (Moshi *et al.*, 1990, Mafuru *et al.,* 1999).

The population in Tanzania is estimated to be around 35 million and the annual growth rate is 2.9% (Census counts, 2002). The consequences of a rapid population growth are felt acutely and visibly in the public budgets for agriculture and other related fields of human resource development. This implies that food production needs to increase to cope with population growth. It is, therefore, inevitable that location-specific research, development policy and strategies should be put in place to promote maize production in the country in hot pursuit of food self-sufficiency.

Economic importance of sesame in Tanzania

Sesame (*Sesamum indicum* L.) is an important traditional oilseed crop in Tanzania. Its economic value exceeds that of most other crops, particularly in areas where marketing and haulage systems are efficient. Sesame became a cash crop as early as 1949, and in 1959, about 3,600 tons of seed were exported (Weiss, 1983). During the last two decades, oilseeds were a substantial source of foreign exchange earnings in

Tanzania (Banda, 1992). Between 1980 and 1991, sesame export was leading among the oilseeds crops in the country, followed by castor bean (*Ricinus communis*). In terms of total value, sesame, castor bean, sunflower (*Helianthus annuus*), and soybean *(Glycine max)* accounted for over 90% of the value of exported oilseeds in this decade. The major export markets for sesame are Western Europe and Asia (Mponda, 1996). Demand for sesame has been increasing both in the international and domestic markets for confectionery and crushing and in domestic mills. The latter led to increased producer prices, particularly after the liberalization of the market of oilseed crops (Kamwela, 1993).

Slightly over 78% of national sesame production comes from the Mtwara and Lindi Regions in Southeast Tanzania, and approximately 14% is produced in the Ruvuma Region in the Southern Highlands. Southeast Tanzania is also the major producer of cashew (*Anacardium occidentale* L.) accounting for more than 80% of the national cashew production. Sesame is the second major cash crop in Southeast Tanzania, and plays a significant role as a source of farmers' income in those areas where cashew production is poor. It follows that there is justification in giving priority to research on sesame as an alternative cash crop for farmers to diversify their cash incomes instead of heavily depending on cashew.

There has been an increased demand for white coloured sesame seeds in the world market, for both food and oil crushing industries (Kamwela, 1993). At the same time, a shortfall in the supply of sesame in the major producing countries of India, USA, China, Sudan, Brazil and Argentina has been stated. The increased demand for sesame as well as the shortfall in world production provides an opportunity for Tanzania to increase its production and export.

Maize and sesame production system in Southeast Tanzania

Tanzania is divided into seven agro-ecological zones (Samki *et al.*, 1981; NALRM, 1991). These are the Northern Zone, the Eastern Zone, the Central Zone, the Western Zone, the Southern Highlands Zone, the Lake Zone and the Southern Zone. The Southern Zone, also known as Southeast Tanzania, comprises the Mtwara and Lindi Regions, and the Tunduru District in the Ruvuma Region (Fig. 1.1). This zone covers 103,500 km^2, of which 17,750 km^2 is in Mtwara, 67,000 km^2 is in Lindi, and the remaining 18,750 km^2 is in the Tunduru District. About two million people live in Southeast Tanzania of which 50% live in the Mtwara Region (Katinila *et al.*, 1998).

The zone is characterized by mixed farming systems whose elements change with variations in climate and environment. There are two main seasons: a humid and hotter wet season (November to May) and a cooler, less humid dry season (June to October). The mean annual rainfall ranges from about 800 mm in inland and central areas to

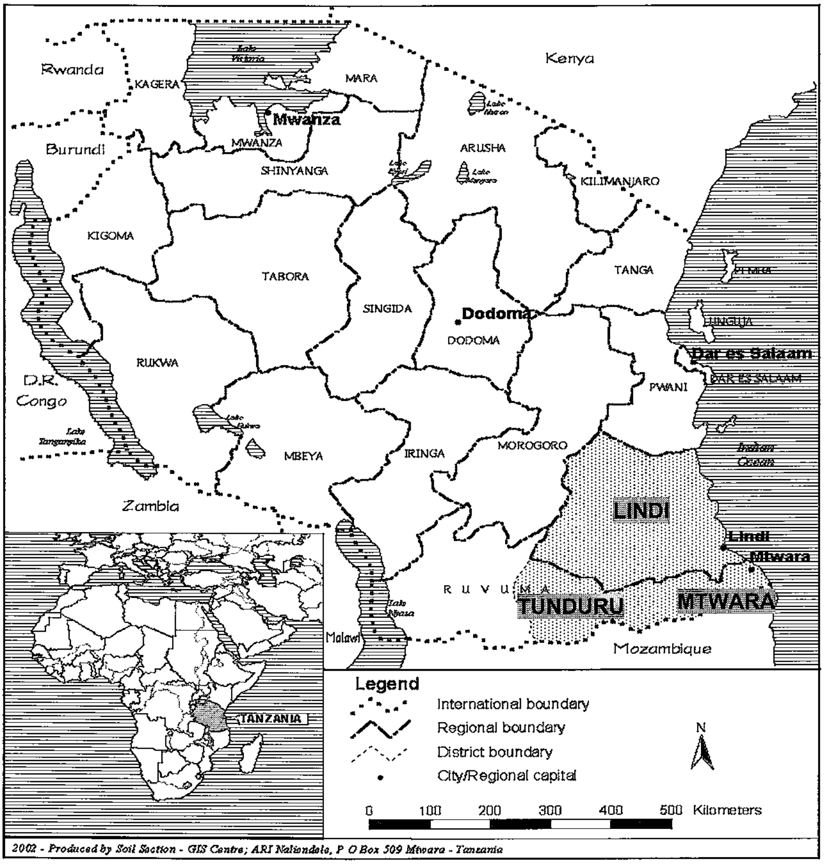

Fig. 1.1. Location of the Mtwara and Lindi Regions, which together with the Tunduru District in the Ruvuma Region comprise Southeast Tanzania.

1,200 mm in the hills and plateau near the Coast. Soils are variable, ranging from the deep, well drained, but not very fertile sandy soils of the sedimentary zones, to the deep, well drained, and somewhat more fertile red clay soils (FSR, 1992).

The most important crops grown are: starchy staples, i.e., sorghum (*Sorghum bicolor*), maize, rice (*Oryza sativa*), cassava (*Manihot esculenta*) and millet (*Eleusine coracana*); leguminous crops, i.e., pigeon pea (*Cajanus cajan*), cowpea (*Virgina unguiculata*), lablab bean (*Lablab niger*), green gram (*Virgna aureus*) and bambaranut (*Voandzeia subterranea*); oilseeds, i.e., sesame, groundnut (*Arachis hypogaea*), soybean; vegetables, i.e., onion (*Allium cepa*), tomato (*Lycopersicon esculentum*); and trees crops as cashew, coconut (*Cocos nucifera*), orange (*Citrus sinensis*), banana

(*Musa* spp.). Livestock (goat (*Caprine* spp.), cattle (*Bovine* spp.), sheep (*Ovine* spp.) and poultry (*Avian* spp.) are also part of the farming systems. The main cash crops are cashew, sesame, cassava, maize, coconut, and groundnut (Lamboll, 1991). Most cultivated area is rainfed. A number of valley basins periodically experience uncontrolled flooding.

Bennet *et al.* (1979) classified Southeast Tanzania into 14 Farming System Zones. The criteria used were soil type, rainfall, population distribution and the relative importance of the major food and cash crops. Farming System Zone 8, which in Southeast Tanzania is also known as the '*maize and sesame belt*' is approximately 700,000 ha (Emmanuel, Naliendele Agricultural Research Center, Mtwara, Tanzania, pers. comm.). This area is located between latitudes 9°40′58″ and 11°00′54″ South and longitudes 38°31′01″ and 39°23′05″ East, covering parts of the Mtwara and Lindi Regions. Its elevation varies from 400 to 500 metres above sea level. It is characterized by predominantly red clay soils, particularly in the central and northern part of the area, and a fairly high population density. Agricultural potential also appears to be higher than in most other areas, probably because of the combination of adequate rainfall (900-1000 mm annually), rather fertile soils, and the presence of valleys with streams originating on the plateau (FSR, 1992; Katinila *et al.*, 1995, 1998). Major food crops are maize, cassava, pigeon pea, sorghum and rice while the main cash crops are cashew, sesame, groundnut, maize, cassava and rice (FSR, 1992). Maize and sesame are often found in intercropping systems, and quite often combined with other crops such as sorghum, cassava, pigeon pea, groundnut and cowpea (FSR, 1992; Katinila *et al.*, 1995). In this area, maize is the most important source of carbohydrates, and sesame is an important source of income (FSR, 1992; Katinila *et al.*, 1998).

Need for intercropping research on maize and sesame in Southeast Tanzania

The Southern Zone Agricultural Research Centre is based at Mtwara in Southeast Tanzania. The Centre conducts research on maize, sesame, cashew, groundnut, sorghum, rice, cowpea, pigeon pea, cassava and sweet potato. It also has a mandate to conduct socio-economic studies, soil fertility and management, and livestock research with small ruminants.

Research on maize and sesame crops has been conducted for more than 20 years. Most agronomic recommendations related to choice of variety, plant spacing, time of planting, plant density, fertilizer rate, weeding regime, and pesticide use have been developed for both crops based on pure stands (TARO, 1987a, b). Even though most farmers grow maize and sesame in intercropping systems, there has been little research initiated to improve these existing systems. Understanding the efficiency of maize-sesame intercropping systems and farmers' basis for adopting these systems were the key objectives and motivation for this research. It was hypothesized that:

- Farmers have fundamental reasons for intercropping maize and sesame.
- Performance of maize and sesame intercrops would be improved by simultaneous sowing of the component crops.
- Productivity of maize and sesame intercrops would be improved through application of nitrogen and phosphorus fertilizer combinations.
- Maize and sesame intercrops share resources in a complementary way.
- Maize and sesame intercrop productivity would be reduced by increased number of maize plants per station.
- Adding sesame into a maize crop by row sowing would improve maize yield compared to broadcast sowing.

Objective and approach

The central objective of the present research was to understand farmers' fundamental reasons for intercropping maize and sesame and quantitatively assess the performance of maize-sesame intercropping systems. For this purpose, farm household surveys and experimental methods were combined. Main focus of the survey was to understand farmers' rationale for intercropping maize and sesame. Field experiments were conducted to quantitatively assess the performance of maize-sesame intercropping systems. Intercrop performance was studied using static descriptive models at a system level. Specifically, the experiments aimed at: (1) examining the effect of sowing time of sesame on the performance of a maize-sesame intercrop; (2) studying competition and crop performance in a maize-sesame intercropping system under nitrogen and phosphorus fertilizer combinations; (3) evaluating the effect of row and broadcast sowing of sesame on the performance of maize-sesame intercrop; and (4) assessing the effect of number of maize plants per station on the performance of maize-sesame intercrop. The complementary roles of the survey and experimental methods were useful to amalgamate farmers' knowledge and scientific knowledge for better insights into the maize-sesame intercropping systems, something that could not have been possible if the research would have used only one approach. Combining the two approaches for this research is in line with the agricultural and livestock research policy of Tanzania (URT, 1983, 1997) which emphasizes that 'there is a great scope for raising agricultural production through the application of both scientific and technical knowledge to local conditions and crops, especially if modern knowledge is married effectively with the accumulated experiences of the peasant farmers . Various development practitioners encourage a similar approach (Biggs, 1989; Biggs and Farrington, 1990; Ashby, 1990; Bentley, 1990, 1994; Sperling, 1992; Bentley and Andrews, 1992).

To achieve this goal, the survey and experiments were carried out in selected villages in the '*maize-sesame belt*' in Southeast Tanzania (Fig. 1.2). The survey was conducted at Lupota, Marambo, Chiola, Mkoka, Rweje and Likwela villages, which were selected based on the importance of the maize and sesame production. The experiments were conducted at the Mkumba and Marambo sites, which were selected based on soil fertility: Mkumba (a relatively low soil fertility site) and Marambo (a comparatively high soil fertility site).

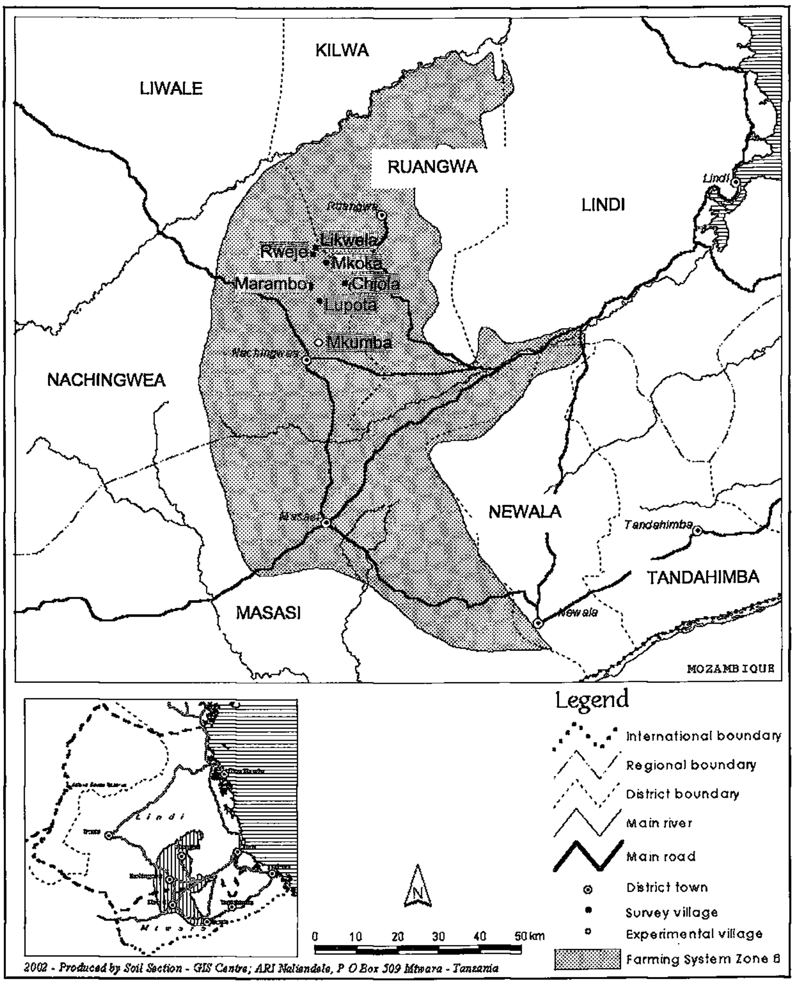

Fig. 1.2. Location of the experimental sites (Marambo and Mkumba) and survey villages (Lupota, Chiola, Marambo, Mkoka, Rweje and Likwela) in Southeast Tanzania.

Outline of the thesis

This thesis includes the results of three years of field research. The thesis is organized into six chapters. Chapter 2 follows this general introduction. It provides an understanding of farmers' rationality for intercropping maize and sesame. Chapter 3 describes the effect of sowing time of sesame on the performance of a maize-sesame intercrop. Competition and crop performance in a maize-sesame intercropping under nitrogen and phosphorus fertilizer combinations are studied in Chapter 4. Row and broadcast sowing of sesame in maize planted as single or multiple plants per station in a maize-sesame intercrop is studied in Chapter 5. Finally the general discussion of all results and main conclusions are provided in Chapter 6.

CHAPTER 2

Understanding farmers' rationality for intercropping maize and sesame

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Abstract

In Southeast Tanzania, the major food crop maize (*Zea mays* L.) is usually intercropped with the cash crop sesame (*Sesamum indicum* L.). To understand farmers' rationality for maize-sesame intercropping, a baseline survey was carried out in six villages in Southeast Tanzania, whereby information was collected from ten randomly selected households in each village. The survey revealed that in the study area arable cropping is the main occupation, responsible for 75% of the mean annual household income. Only 14% of the annual household income is generated through off-farm activities, resulting in low-opportunity cost for labour. Consequently, nearly all labour in the maize-sesame system is provided through family and exchange labour. External inputs such as fertilizer, pesticides and improved planting materials are hardly used. After the cash crop cashew, maize and sesame were found the second and third most important crops. Most farmers (90%) intercropped maize and sesame, but in nearly all cases one or more other crops, such as pigeon pea, cassava and pumpkins, were included. In the intercrop, maize is considered most important, as it provides the main source of food for the household. On average almost 70% of the produced maize was left for domestic consumption. Sesame complements maize in achieving the household objectives, as it is a good and reliable source of cash, which comes available shortly after harvest. To assure good maize production, the most fertile soils are allocated to maize, and sesame is only introduced at about two weeks after maize sowing. Sesame is added to a maize crop, as growing sesame in pure stand is not considered a good option because of the associated risk of crop failure (seedling mortality because of water logging, snails or sesame flea beetle). Furthermore, adding sesame to maize puts less demands on labour and fertile land, both of which are available in short supply. Finally, maize and sesame are regarded as good companion crops, which also contribute to restoration of soil fertility and weed suppression.

Key words: Intercropping, farm household objectives, marginal factor returns, cost-benefit analysis, diversification.

Introduction

In Southeast Tanzania, the major food crop maize is usually grown as an intercrop. Among the component crops that are added in maize intercropping systems, sesame is the one that is most frequently used (FSR, 1992; Katinila *et al.,* 1995). While sesame is a common component of mixtures, the crop is considered secondary to maize, as maize should secure the basic food requirement of the household. Sesame is mainly added as a source of additional farm-household income and is, therefore, considered a bonus crop. The maize-sesame intercropping systems are the results of many years of evolution; developed from generation to generation. Selection of such system by farmers is generally directed towards accomplishing their goals and priorities. Katinila *et al.* (1998) reported that 77% of farmers in Southeast Tanzania intercrop maize with other crops in order to permit consumption and income diversification; other frequently mentioned reasons are scarcity of good quality land and labour shortage.

Also elsewhere a lot of research on intercropping has focused on identifying the reasons for farmers to practice mixed cropping systems. Increased land productivity (Minae *et al.,* 1998; Grisley and Mwesigwa, 1994; Jiang *et al.,* 1994; Rhoades and Bebbington, 1990), demand for extra food and fluctuating or unpredictable prices of cash crops (Onsongo, 1997), reduced risk of crop failure (de Wit, 1960; Cowell *et al.*, 1989; Lynam *et al.*, 1986; Minae *et al.,* 1998), increased labour utilization efficiency (Rhoades and Bebbington, 1990), crop diversification (Minae *et al.,* 1998; Innis, 1997; Lynam *et al.,* 1986), soil and water conservation practice (Michael, 1998; Kebede-Asrat *et al.*, 1996; Innis, 1997; Rhoades and Bebbington, 1990) and control of insect pests, diseases and weeds (Innis, 1997) are among the motives reported in literature. Far less attention has been given to the quantitative appraisal of farmers' objectives for practicing intercropping and the potential efficiency of the intercropping system. In addition, there has been too much emphasis on just comparing yields in intercropping experiments without considering farmers rationale (Anandajayasekeram *et al.,* 1989).

The major objective of this research was to provide a better understanding of farmers' rationality for intercropping maize and sesame in Southeast Tanzania. The total production system of farm households in the region under study was described, with a particular emphasis on maize-sesame intercropping. Production functions for maize, sesame and maize-sesame intercrop were estimated based on quantitative information provided by sample households, to reveal the marginal returns to factors that accrue to farmers. Additionally, cost-benefit ratios were determined for all three systems. Finally, the outcomes of this economic analysis were related to the opinions provided by farmers, to reveal the rationale for this intercropping practice.

The study area

Southeast Tanzania comprises the Mtwara and Lindi Regions, and the Tunduru District in the Ruvuma Region (see Fig. 1.1 in Chapter 1). This zone covers 103,500 km^2, of which 17,750 km^2 is in Mtwara, 67,000 km^2 is in Lindi, and the remaining 18,750 km^2 is in the Tunduru District. About two million people live in Southeast Tanzania of which 50% live in the Mtwara Region (Katinila *et al.,* 1998). Bennet *et al.* (1979) classified Southeast Tanzania into 14 Farming System Zones. Criteria used were the soil type, rainfall, population distribution, and the relative importance of the major food and cash crops. The survey described in this chapter concentrated on Farming System Zone 8, which in Southeast Tanzania is also known as the '*maize and sesame belt*'. This area is located between latitudes 9°40′58″ and 11°00′54″ South and longitudes 38°31′01″ and 39°23′05″ East, covering parts of the Mtwara and Lindi Regions (Fig. 1.1). Its elevation varies from 400 to 500 meters above sea level. It is characterized by predominantly red clay soils, particularly in the central and northern part of the area, and a fairly high population density. Agricultural potential also appears to be higher than in most other areas, probably because of the combination of adequate rainfall (900-1000 mm annually), rather fertile soils, and the presence of valleys with streams originating on the plateau (FSR, 1992; Katinila *et al.,* 1995; 1998). The maize-sesame belt is estimated to be approximately 700,000 ha (Emmanuel, Naliendele Agric. Res. Center, Mtwara, Tanzania, pers. comm.).

Sampling and survey procedures

The survey was conducted in six villages that were selected based on their importance in production of maize and sesame. In each village, local authorities provided a list of all households and ten were drawn by random sampling technique. The sampled villages, household number and respondents are presented in Table 2.1. The survey was carried out in two main phases: a reconnaissance phase and a quantitative phase. During the reconnaissance phase, whose objective was to collect information necessary for planning the quantitative survey, the selected households were interviewed in a group using a checklist relating to cropping systems, general objectives of intercropping and objectives of intercropping maize and sesame in particular. The information was summarized and used to plan and undertake the quantitative survey. This second survey involved the same villages and households as in the earlier survey. Individual households were interviewed using a questionnaire. Farmers' fields were inspected for a better understanding of the production systems. At the end of the season, intercrop yield and data on material inputs and seasonal labour were collected from the sample households. The results of the first survey revealed that growing maize and sesame in pure stands was not common to most of the

Table 2.1. Villages and number of households in the study, Southeast Tanzania.

Village	Household number	Respondents		
		Male	Female	Total
Lupota	318	9	1	10
Chiola	400	7	3	10
Marambo	652	7	3	10
Mkoka	511	9	1	10
Rweje	306	8	2	10
Likwela	275	9	1	10
Total	*2462*	*49*	*11*	*60*

farmers. For that reason, farmers were asked to provide presumed estimates on yield, material inputs and seasonal labour for maize and sesame in pure stands, to facilitate a comparison between growing maize and sesame in pure stand and intercropping.

Analytical framework

Data were compiled and analysed using the SPSS statistical program (SPSS, 2001). An analysis was conducted to identify differences in marginal returns between the different sources of seasonal labour (family, exchanged and hired) in the maize-sesame intercropping system. Therefore, a Cobb-Douglas function was used to relate the output of maize-sesame intercrops to a set of observed inputs used in producing these intercrops (Upton, 1973). The function was written as:

$$\text{Log}\, Y = a + b_1 \log X_1 + b_2 \log X_2 + b_3 \log X_3 + b_4 \log X_4 \qquad [1]$$

where, Y is the physical output from the maize-sesame plot expressed in monetary value (US$), X_1 is the area of the plot used for maize-sesame intercropping (acres; 1 acre = 0.4 ha) and X_2, X_3 and X_4 are man-days of seasonal family labour, exchange and hired labour, respectively. Parameter a is a multiplicative constant, and the coefficients b_1, b_2, b_3 and b_4 are direct measures of elasticity of the response for each of the input variables. When there are diminishing marginal returns, the sum of the b coefficients will be less than one. A sum of exactly 1 implies constant marginal returns and a sum greater than 1 implies increasing returns. Labour inputs (man-days per acre) were recorded for the major operations: seedbed preparation, sowing, weeding, thinning and harvesting. For those situations where households did not make use of a particular type of labour (in this case either hired or exchange), prior to logarithmic transformation, a value of 1 man-day was used for that specific type of labour, to avoid computational errors.

In addition, a cost-benefit analysis of the various cropping systems was conducted to evaluate each system. Subsequently, a Cobb-Douglas function was estimated to relate the output of maize and sesame in pure stands and intercrops to the set of labour and material inputs used for producing the crops. The function was written as:

$$\text{Log } Y = a + b_1 \log X_1 + b_2 \log X_2 + b_3 \log X_3 + b_4 \log X_4 \quad [2]$$

where, Y is the physical output expressed in US$ per acre. For conversion of physical yield into monetary value, the actual unit prices received from the local traders were used. For maize, this unit price refers to the surplus maize, which was brought to the market. X_1 denotes the cost of labour for preparation (seedbed preparation and sowing), X_2 is the cost of maintenance labour (weeding, thinning and gap filling), X_3 is the cost of harvesting labour (harvesting and shelling/threshing) and X_4 is the cost of material inputs (transport and seed costs), all expressed in US$ per acre. Parameter a is a multiplicative constant, and the coefficients b_1, b_2, b_3 and b_4 are direct measures of elasticity of response for preparation labour, maintenance labour, harvesting labour and material inputs, respectively.

Descriptive analysis

Table 2.2 lists the characteristics of households in the study area of Southeast Tanzania. The average age of the household head was about 50 years, and the average level of formal education was 4.7 years. The mean farm experience was 28 years and experience in intercropping was about 23 years. The average household size was 5.6, of which on average 3.2 contributed to labour. About 18% of the households were female headed. The average farm size was 7.8 acres, of which about 90% was under cropping. Most of the land was allocated to cashew, maize, sesame and pigeon pea. A very low livestock population exists in Southeast Tanzania. About 73% of sample households owned chicken, 35% owned goats and 28% owned ducks. Cattle and pigs were rarely found. The low livestock population was most likely because of insufficient pastures, particularly during the dry season (Katinila *et al.*, 1998). Farmers owned an average of 4.3 hand hoes, about 1.5 machetes, 2 axes and 2 knives that they used for different farm operations.

Relative importance of maize and sesame in the farm household

All respondents reported that they obtain income from selling crops, 63% reported to obtain income from livestock sales, and 43% reported to get income from off-farm activities. In the sample households mean annual income from crops was estimated at US$ 364, mean annual income from livestock sales was US$ 47, whereas contribution of off-farm activities was US$ 67 (Fig. 2.1a). Of all crops, cashew, maize and sesame

Table 2.2. Demographic characteristics, land resources and allocation for the households under study, Southeast Tanzania.

Characteristics	Mean	Standard deviation
Household characteristics		
Age of the household head (yr)	49.5	12.9
Years lived in a village	32.1	13.2
Farm experience (yr)	28.0	13.1
Formal education (yr)	4.7	2.6
Intercropping experience (yr)	22.6	14.9
Family labour:		
Size of household (number)	5.6	3.9
Male adults	1.3	1.0
Female adults	1.7	1.2
Children (12 – 17 years)	0.8	1.1
Children (<12 years)	1.7	2.2
Labour availability (persons)	3.2	1.8
Land resources and allocation		
Farm plots (number)	2.9	1.2
Land area owned (acres)	7.8	4.0
Land area under cropping (acres)	7.0	3.7
Land area under cashew (acres)	3.8	3.6
Land area under maize (acres)	3.5	1.9
Land area under sesame (acres)	3.3	2.2
Land under pigeon pea (acres)	2.3	1.9
Livestock		
Chicken	11.0	10.6
Ducks	2.0	4.1
Goats	2.4	4.3

turned out the most important sources of income for the sample households in the study area (Fig. 2.1b). Other relevant crops were cassava, rice, sorghum and pigeon pea. Crops of minor importance were groundnut, onions, bananas, sweet potatoes, millet, lablab bean and green gram, which in total only contributed 5%.

For livestock, 47% of farmers reported to sale chicken, 27% to sale goats, 7% to sale ducks and 2% to sale milk. The main off-farm activities reported to contribute in the household annual income were selling out of labour (12%), logging, carpentry, food vendors and weaving (5% for each activity). Other activities reported were

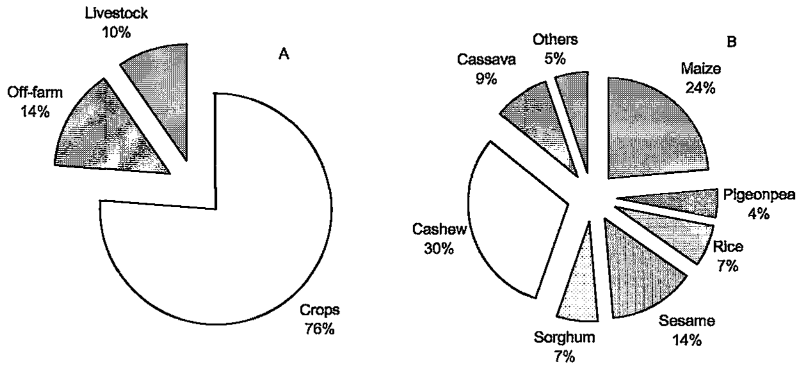

Fig. 2.1. Relative contribution of crops, livestock and off-farm activities in the mean household annual income (A) and the relative contribution of various crops (B).

brewing, tailoring and selling various items, such as fuel wood, clay pots, salts and thatch grass.

Management practices of maize and sesame intercropping systems

Out of the 60 households, only 8.3% had a pure stand plot of maize and only 6.7% had a pure stand plot of sesame (Table 2.3). Majority of the households (90%) intercropped maize and sesame in one of their plots. Of these households 92.6% added other crops in their plots under maize-sesame intercropping. In general, more than one crop was included. Pigeon pea, cassava and pumpkins were the crops most frequently added to a maize-sesame intercrop. This suggests that, among the pulses, pigeon pea is the most important relish. Cassava is an alternative source of carbohydrate and is regarded an important crop for household food security. Furthermore, many farmers added a maize-sesame intercrop in a plot of cashew trees.

Land preparation

Land preparation for the virgin lands, comprising 10% of all plots, was conducted between January and July. The virgin lands whose operations include bush clearing, burning and soil tillage, were prepared early in the season to avoid the incidence of buffalo bean (*Mucuna pruriens*) locally known as *uwangu* in the *Kimwera* language. This plant prevents people from working on their fields because of its irritation effects when it is fully mature. Plots under continuous cultivation, which constitute about 90% of all plots, were prepared from September till December, before the onset of the first rain. Most households do not practice deep hoeing or ploughing for various reasons:

Table 2.3. Households with plots of maize and sesame in various cropping systems, Southeast Tanzania.

	Number of farmers	Percentage of farmers
Cropping systems	N=60	
Maize in pure stand	5	8.3
Sesame in pure stand	4	6.7
Maize/sesame intercrop	4	7.4
Maize/sesame intercrop with additional crop(s)	50	83.3
Crops found in maize/sesame intercrops	N=54	
Pigeon peas	45	83.3
Cassava	33	61.1
Pumpkins	28	51.9
Cashew	25	46.3
Cowpea	10	18.5
Cucumber	7	13.0
Sorghum	4	7.4
Watermelon	4	7.4
Rice	3	5.6
Others (banana, mango trees, papaya, groundnut, sweet potato, bambaranut, tomato)	9	16.7

(*i*) there is inadequate access to tractors to till the soil, as tractors are not readily available; (*ii*) farmers lack money for hiring tractors; and (*iii*) it is perceived that the soils are fertile enough and, therefore, deep hoeing is not required. Deep hoeing is done when soil fertility is depleted, as reported by Likanda *et al.* (1995) in their report on indigenous soil fertility improvement in Southeast Tanzania. Furthermore, deep hoeing is considered an energy-demanding task because at the time of land preparation the soil is so dry that it is difficult to work on with hand hoes. For those reasons, about 97% of households practice flat cultivation, i.e., they scrape the weeds by hand hoe, collect and burn them.

Planting techniques (time and method)

Planting of maize and sesame commences from November to February. The majority of farmers plant their plots in December and January after the onset of rain to ensure good germination and emergence of the seed (Table 2.4). Maize is planted by dibbling.

Table 2.4. Time of planting of maize and sesame in plots with an intercrop (N=54).

Time/method	Number of farmers	Percentage of farmers
Time of planting of maize		
November	6	11.1
December	35	64.8
January	12	22.2
February	1	1.9
Relative time of planting sesame		
One week after maize	14	25.9
Two weeks after maize	28	51.9
Three weeks after maize	8	14.8
Four weeks after maize	4	7.4

Three quarter of the respondents planted in rows whereas the rest planted without row-structure. Farmers perceive that row planting produces higher yield and makes the field operations, particularly weeding and harvesting, easier. All households added sesame in a maize crop by broadcast method, as this is regarded as a labour-saving practice. About half of the farmers planted sesame two weeks after maize. Farmers perceive that simultaneous sowing of maize and sesame might result in a severe reduction of maize yield because of an increase in competitiveness of sesame. Other reasons given were to avoid competition for labour, to avoid prolonged vegetative growth of sesame that may lead to low yields, and to avoid too much rain, which may result in poor germination or seedling mortality because of water logging.

Maize and sesame varieties used

Most respondents used local varieties for maize (59%) as well as for sesame (91%). Improved varieties were rarely used, except for the maize variety Ilonga that was used by 26% of the farmers. Most farmers indicated that improved varieties are not readily available (60%), are too expensive (10%) or that they were not aware of their existence (10%). In addition to this, just over 10% of the farmers perceived that improved maize varieties are low yielding and susceptible to storage pests (*Stophilus zeamays*). For sesame, about 23% reported that they dislike improved varieties for their short growth duration, because these varieties mature during the rainy period and are, therefore, difficult to dry in the field. For both maize and sesame, most farmers (88%) reported to use seed from the previous harvest while other sources of seed reported were neighbours and the local market (8%), and extension and research (4%).

Weeding

On average, farmers weeded the maize and sesame plots two to three times per season. Most households weeded twice (about 60%). Farmers reported that weeding frequency depends on soil fertility and type of weeds. Weeding frequency is higher in lowland fields than upland ones because the lowland fields have relatively higher fertility that stimulates weed growth. According to farmers, the first weeding is very important and is done depending on the emergence of weeds. The majority of the households carried out the first weeding in January. None of the farmers used herbicides in weed control, for various reasons: 55% reported that they were not aware of herbicides, 33% said that herbicides were not readily available, whereas 12% said that herbicides were too expensive. Half of the farmers reported that intercropping maize and sesame suppressed weed growth. The most common weeds mentioned were guinea grass (*Panicum alata*), wandering jew (*Commelina benghalensis*) and itchgrass (*Rottboellia cochinchinensis*). Other weed species mentioned were wild lettuce (*Launaea cornuta*), P.W.D. weed (*Tridax procumbens* L.), goat weed (*Ageratum conyzoides* L.) and sedges (*Cyperus* spp.). The common and scientific names were identified using field books (Terry and Michieka, 1987; Ivens, 1989; Phillips, 1991).

Pest and disease control

For maize, no real important pests and diseases were reported. Only 25% of the households mentioned the maize stalk borer (*Busseola fusca*), whereas 12% mentioned termites to be a problem, especially during a prolonged dry spell. For sesame, flea beetle (*Alocypha bimaculata* Jacob) was reported a problem by nearly all households (97%). Other pests and diseases were only rarely mentioned: grass hopper (reported by 6.7% of respondents), root and stem rot (*Fusarium* spp.; 3%) and snails (2%). None of the households used pesticides to control insect pests and diseases in these crops. Around 42% of farmers reported that pesticides were not available, while 35% of respondents reported that they were unaware of the existence of pesticides and 23% mentioned that pesticides were expensive.

Fertilizer use and soil fertility management

None of the interviewed farmers used organic and inorganic fertilizers in their plots. About 92% of respondents reported that inorganic fertilizers are not required because their soils are fertile enough, about 27% said that fertilizers are not readily available, whereas 22% mentioned that they lack cash to buy this input. Similar reasons were mentioned for manure. Moreover, it was reported that manure use requires much transport labour and this was pointed out as another reason for not using manure. About 80% of farmers leave crop residues for decomposition on the plot, while the rest burn crop residues especially during land preparation. About 52% of households fallow their land, to restore soil fertility (97% of respondents) and minimize weed incidence (7%). About 48% of households do not rotate maize and sesame with other crops. Of these farmers, 59% cited land scarcity as a reason for not rotating the crops, whereas 41% reported that they are unaware of the benefit of the practice.

Harvesting and transportation

All maize was harvested by hand, using two methods: a cob remains with part of the stem on both ends or a cob is harvested without a stem. The maize harvest stretched from late April to early August, with about 20, 48 and 26% of maize harvested in May, June and July, respectively. About 67% of households used head loads, 31% used bicycles and 2% used tractors for transporting harvested maize from the field to the homestead for post-harvest processing and storage.

For sesame, about 41, 52 and 7% of sample households harvested in May, June and July, respectively. This was done by cutting the plants using knives or machetes and tying the plants in bundles. To avoid termite damage, drying was done on raised platforms known as *uchanja*. Drying took two to three weeks. After drying sesame bundles were taken from the drying poles and threshed using sticks either on mats or large pieces of cloth. Winnowing cleaned the seed, which was then kept in bags waiting to be sold.

Marketing of maize and sesame

The average number of maize bags (of approximately 90 kg) produced by the sample household was 7.8. About 38% of the households consumed all of their maize, whereas 62% sold the surplus maize. On average, 5.3 bags were left for home consumption and 2.5 bags were sold. Most sales transactions were conducted either in July, shortly after harvest, or in November and December (Fig. 2.2). No transactions took place in April and May. During the 2000 season, the average maize price was 11 US$ per 90 kg bag. The maize price was lowest (about 5 US$) immediately after harvest (June) and highest (15 US$) prior to the next harvest (February and March). Most respondents sold their produce from their home, either to traders or to consumers within their village. Just few sold their maize at a nearby trading centre.

Average number of sesame bags (approximately 80 kg) produced by the sample households was 2.5, of which 98% was sold. The remaining part was left for consumption and as seeding material. All respondents mentioned that they sold sesame to traders in their village. About 88% of the respondents were selling in July, whereas the rest was selling in August. A bag of sesame (approximately 80 kg) was sold at an average price of about 18 US$ (minimum: 11 US$; maximum 32 US$).

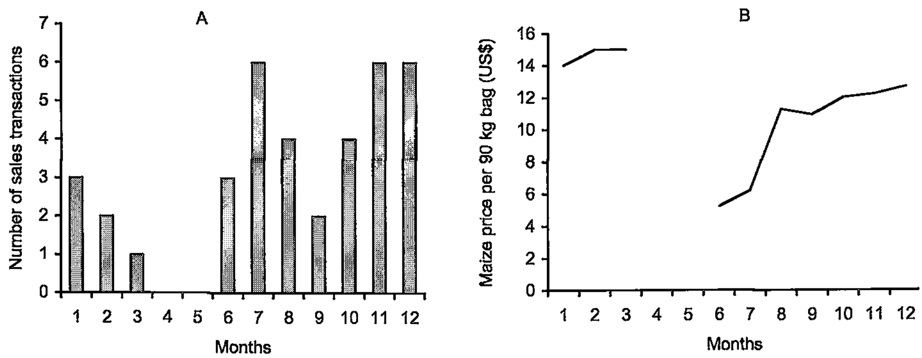

Fig. 2.2. Sales transactions (A) and annual price trend of maize in US$ per 90 kg bag (B) reported by the sample households (N=37) from January (month 1) to December (month 12) in 2000.

Economic analysis of maize and sesame in mono- and intercropping

Average labour per season for the intercrop (from seedbed preparation till harvesting) was estimated at 38 man-days per acre, but ranged from 11 to 71 man-days per acre between individual farmers. Most labour (61%) was provided by the family, 26% was exchange labour and only 13% was hired labour. On 57% of the farms no hired labour was used and all labour was provided by either family or a combination of family and exchange labour. An analysis of the marginal returns to family, exchange and hired labour was conducted for the intercropping system. Marginal returns to all three labour categories were significant (Table 2.5; $P<0.1$). Marginal return to family labour was substantially higher than to exchange and to hired labour. Furthermore, the sum of input coefficients in the intercropping system was greater than one, indicating that increasing returns to scale hold.

To assess the financial attractiveness of the maize-sesame intercropping system relative to that of maize and sesame in pure stands, an economic analysis was carried out. The survey revealed that growing maize and sesame in pure stands was not common to most of the households. For that reason, farmers were asked to provide estimates of labour requirement for various activities (preparation, maintenance and harvesting) and material inputs for the maize-sesame intercrop as well as for maize and sesame in pure stands. These estimates were given in Tanzanian shillings, based on market prices for labour and material input. Yields of the pure stands were estimated, whereas yield of the intercrop was measured in farmers' fields. Yields were expressed in bags per acre and converted to Tanzanian shillings based on actual prices

Table 2.5. The Cobb-Douglas model estimates for marginal returns for all labour spent on seedbed preparation, sowing, weeding, thinning and harvesting (in man-days) and plot area (acres) for maize and sesame intercrops by sample households in Southeast Tanzania (N=49). (1 acre = 0.4 ha)

Input/output	Mean	Standard deviation	Coefficient	Standard error	P-value
Family labour (man-days)	1.684	0.251	0.222	0.127	0.087*
Exchange labour	1.065	0.748	0.092	0.045	0.045**
Hired labour (man-days)	0.580	0.725	0.086	0.045	0.062*
Plot area (acres)	0.427	0.221	0.735	0.151	0.000***
Summed revenue per plot	2.159	0.294			
Y intercept			1.32	0.227	0.000***
Adj R^2			0.51		

Note: * significant at 10% level; ** significant at 5% level; *** significant at 1% level.

received for selling sesame and surplus maize to the local market. Those farmers who did not sell maize in 2000 provided an expected unit price of maize in case surplus-maize would have been brought to the local market in 2000. For the analysis, Tanzanian shillings were converted to US$ at a conversion rate of 1000:1.

First, the cost structure of mono- and intercropping systems is analysed. On average, the total estimated costs for labour and material inputs were about 1.5 and 1.4 times higher for intercrops compared to respectively maize and sesame as pure stands (Table 2.6). A closer comparison of the cost structure among the three systems revealed that main differences between pure stands of maize and sesame were found in the higher labour costs for preparation and maintenance activities of the latter system. On the other hand, material inputs for sesame were estimated to be lower. Intercropping resulted in higher demand for all discerned types of seasonal labour activities, as well as for the material inputs.

A comparison of the Cobb-Douglas model estimates for marginal returns to labour and material inputs between the three systems showed that if more time was spend on preparation the marginal return to preparation labour decreased (Table 2.7). In pure stand maize, with the lowest investment on preparation, the highest marginal returns were found. In the intercropping system, where the highest investment on preparation was made, the estimate for marginal return to preparation labour did not differ significantly from zero. For each system no significant marginal returns to maintenance labour were observed, suggesting that estimated labour inputs were optimum. Maintenance labour mainly consists of weeding operations, which is time-

Table 2.6. Independent samples *t*-test estimates for labour and material costs and revenue per acre for maize and sesame in mono- and intercropping in Southeast Tanzania. Numbers in brackets show standard deviation. (1 acre = 0.4 ha)

Input/output	*Maize monocrop*	*Maize-sesame intercrop*	Mean difference	P-value
Labour in US$ per acre for preparation	17.5 (6.19)	26.5 (9.16)	−8.97	0.0000
Labour in US$ per acre for maintenance	28.3 (10.51)	38.4 (14.87)	−10.08	0.0000
Labour in US$ per acre for harvesting	14.0 (6.49)	22.7 (7.58)	−8.71	0.0000
Material inputs in US$ per acre	11.8 (6.52)	16.3 (8.73)	−4.50	0.0030
Total Cost in US$ per acre	70.8 (16.14)	103.8 (28.60)	−33.05	0.0000
Revenue in US$ per acre (yield × price)	64.6 (28.69)	65.5 (33.20)	−0.83	0.8880
Revenue/Total cost ratio	0.91	0.63		
	Maize monocrop	*Sesame monocrop*		
Labour in US$ per acre for preparation	17.5 (6.19)	23.6 (9.26)	−6.09	0.0000
Labour in US$ per acre for maintenance	28.3 (10.51)	33.3 (13.70)	−5.02	0.0310
Labour in US$ per acre for harvesting	14.0 (6.49)	13.0 (4.43)	0.94	0.3680
Material inputs in US$ per acre	11.8 (6.52)	5.7 (2.66)	6.14	0.0000
Total cost in US$ per acre	70.8 (16.14)	75.6 (21.96)	−4.82	0.1860
Revenue in US$ per acre (yield × price)	64.6 (28.69)	62.3 (25.33)	2.31	0.6520
Revenue/Total cost ratio	0.91	0.82		
	Sesame monocrop	*Maize-sesame intercrop*		
Labour in US$ per acre for preparation	23.6 (9.26)	26.5 (9.16)	−2.88	0.1040
Labour in US$ per acre for maintenance	33.3 (13.70)	38.4 (14.87)	−5.06	0.0660
Labour in US$ per acre for harvesting	13.0 (4.43)	22.7 (7.58)	−9.66	0.0000
Material inputs in US$ per acre	5.7 (2.66)	16.3 (8.73)	−10.63	0.0000
Total cost in US$ per acre	75.6 (21.96)	103.8 (28.60)	−28.23	0.0000
Revenue in US$ per acre (yield × price)	62.3 (25.33)	65.5 (33.20)	−3.14	0.5780

consuming but relatively simple labour. If labour is hired, it is generally for weeding.

Significant marginal returns to harvesting labour were obtained for all three systems. This might indicate that during the harvest period labour is scarce. Harvesting requires care, and for that reason it is generally conducted by family and exchange labour. Marginal returns for harvesting labour for sesame in pure stand and the maize-sesame intercrop were higher than for the maize pure stand. This finding might be related to the critical timing of the sesame harvest, caused by capsules that open and

Table 2.7. The Cobb-Douglas model estimates for marginal returns for labour and material inputs for maize and sesame in mono and intercropping system for the sample households, in Southeast Tanzania.

Input/output (US$/acre)	Mean	Standard deviation	Co-efficient	Standard error	P-value
Maize in monoculture (N=57)					
Labour in US$ per acre for preparation	1.2211	0.15668	0.419	0.177	0.022**
Labour in US$ per acre for maintenance	1.4228	0.16905	0.056	0.160	0.726
Labour in US$ per acre for harvesting	1.1105	0.18868	0.280	0.144	0.057*
Material inputs in US$ per acre	1.0105	0.25120	0.178	0.106	0.098*
Revenue in US$ per acre (yield × price)	1.7807	0.21830			
Y intercept			0.699	0.321	0.029**
Adj R^2			0.190	0.196	
Sesame in monoculture (N=56)					
Labour in US$ per acre for preparation	1.3429	0.16826	0.254	0.147	0.090*
Labour in US$ per acre for maintenance	1.4964	0.18187	–0.072	0.143	0.617
Labour in US$ per acre for harvesting	1.0929	0.16718	0.418	0.159	0.011***
Material inputs in US$ per acre	0.6982	0.22843	–0.047	0.109	0.666
Revenue in US$ per acre (yield × price)	1.7768	0.17683			
Y intercept			1.119	0.228	0.000***
Adj R^2			0.144	0.164	
Maize-sesame intercrop (N=53)					
Labour in US$ per acre for preparation	1.4057	0.15617	–0.132	0.164	0.423
Labour in US$ per acre for maintenance	1.5623	0.18525	0.086	0.139	0.539
Labour in US$ per acre for harvesting	1.3377	0.15594	0.359	0.185	0.059*
Material inputs in US$ per acre	1.1623	0.22890	–0.018	0.124	0.884
Revenue in US$ per acre (yield × price)	1.7453	0.16591			
Y intercept			1.338	0.266	0.000***
Adj R^2			0.050	0.162	

Note: * significant at 10% level; ** significant at 5% level; *** significant at 1% level.

shatter seed immediately after physiological maturity. Finally, significant marginal returns to material inputs were observed in maize monoculture. The intercropping system gave the highest intercept coefficient, indicating that in the absence of any input, the highest yield is estimated to be obtained with this system.

According to Table 2.6, output levels for the three systems were not significantly different (P>0.05). This indicates that maize-sesame intercrop is not expected to provide higher revenues than pure stands while at the same time the intercrop is expected to require more inputs. Calculation of revenue/cost ratios showed, however, two remarkable outcomes. First the estimated revenue/cost ratio for all three systems fell well below one, with values of 0.91, 0.82 and 0.63 for maize pure stand, sesame pure stand and maize-sesame intercrop, respectively. Secondly, the estimated revenue/cost ratio for the intercropping system, being the commonly practised system, was clearly the lowest.

It should be realized that, except for the yield of the intercrop, all figures were based on estimates. Furthermore, estimated costs for labour were based on market prices, whereas in reality majority of labour (87%) is not directly accounted for as it concerns family and exchange labour. The current results suggest that rather than growing maize and/or sesame one would be better off with selling labour off-farm and use the salary to buy food. However, in the study area there is low-opportunity cost for labour. Only 14% of the estimated annual household income is generated through off-farm activities. Farming is thus the main opportunity for converting input into output. Physical yields for maize and sesame were converted into monetary revenue using prices based on selling to the market. For sesame this is a valid approach, as nearly all sesame was sold. For maize on the other hand only 32% of the total production was sold and over one third (38%) of the farmers did not sell maize at all. Most maize is kept for home consumption and is an important component in sustaining the household. The value of this maize is difficult to estimate. Furthermore, the market price is very much related to time of selling. Just after harvest the prices are low, after which they gradually increase to obtain their maximum value just prior to the next harvest (Fig. 2.2). In the current analysis just one farmer-specific price was used, and this price was used for all three systems. It is not unlikely that in systems with sesame, the quick release of the revenues of this crop allows farmers to postpone selling maize till a more favourable moment. An increase in the sales price of 20% would already make the cropping system fully profitable. Such an increase can be reached when the maize is sold 30-40 days after the harvest. Given the availability of sesame revenues, delaying the selling moment of maize becomes more feasible.

Farmers' rationality for intercropping maize and sesame

In Farming System Zone 8 of Southeast Tanzania, locally known as the maize-sesame belt, crop production is a primary occupation since on average around three-quarters of the annual household income is derived from it. Consumption and selling patterns are, to a large extent, determined by what is produced locally. The most important cash crop cashew covered the largest fraction of the totally cropped land area (54%) and also contributed most to the mean annual household income (22%). With respect to land area and income, maize and sesame turned out to be the second and third most important crops. All farmers grew maize, whereas 90% of them had a maize-sesame intercrop. Plots with maize-sesame alone were rarely found (only 7% of the farms), as most farmers added one or more crops to this intercrop. Particularly pigeon pea, cassava, pumpkins and cashew were crops frequently found on plots with maize-sesame.

Important factors of production are land and labour. Capital investment is rare as external inputs such as fertilizer, pesticides and improved planting materials are hardly used. Management decisions of the household head are, therefore, mainly related to the allocation of land and labour. Quite often, farmers allocate fertile land for maize cultivation, which is commonly found on the foot slopes and the valley bottoms. This land covers around 15% of the total land area in Farming System Zone 8. Family and exchange labour turned out the most important sources of labour (87%). In some instances labour was hired, mainly for weeding. Only 14% of the annual household income is generated through off-farm activities, suggesting that there is hardly any alternative demand for labour, resulting in low-opportunity cost.

Sample households were asked for their motives for practising intercropping in general as well as for growing a maize-sesame intercrop (Table 2.8). A major difference between the general and the specific situation is that the latter does not contribute to consumption diversification, whereas 70% of the sample households mentioned this as an important reason for intercropping in general. Crops such as cassava, pumpkin, cowpea, cucumber, rice and sorghum that are often added to a maize-sesame intercrop, are indeed mainly consumed by the household and thus contributing to a more diverse diet. Opportunities for income diversification on the

Table 2.8. Objectives of intercropping reported by sampled farmers, Southern Tanzania (N=54).

Objectives	Intercropping in general	Maize-sesame intercrop
Saves labour	100	100
Minimizes risks of total crop failure	92.6	83.3
Permits consumption diversification	70.4	0
Permits income diversification	50.0	50.0
Crops do not interfere severely in intercrop	46.3	74.1
Replenishes soil fertility	40.7	74.1
Shortage of fertile land	33.3	33.3
Suppresses weed growth	20.4	20.4

other hand were reported as an equally important rationale for the general as well as for the specific intercropping situation of maize-sesame (50%). Farmers are indeed growing maize and sesame for very different purposes. Maize is primarily grown as a main source of food, and considered very important, as it should secure the basic food requirement of the household. Data for the year 2000 indicated that 38% of households did not sell any maize, and that on average almost 70% of the produced maize was left for home consumption. The remainder was sold on the local market throughout the year, with the first peak shortly after harvest (July), when prices are still relatively low. This indicates that shortly after harvest there is a demand for cash. Sesame is primarily grown as a reliable source of cash that comes available immediately after harvest. The presence of sesame thus prevents farmers from overselling maize. It allows them to sell maize at a later moment in the year, when a more accurate estimate of the amount of surplus-maize can be made and when they receive a better price for their maize (Fig. 2.2). Despite the argument of diversification, there is a clear difference in importance between the two crops. Maize is considered the priority crop and this is reflected in the fact that maize is planted first and other crops, such as sesame, are only introduced later to the maize crop, to avoid severe reductions in maize yield. When cropped in this way, 74% of the respondents indicated that maize and sesame do not interfere severely, leaving sufficient space for the development of both crops. For intercropping in general only 46% mentioned that crops in an intercrop do not severely hinder one another, indicating that maize and sesame are perceived as good companion crops.

All framers that grew a maize-sesame intercrop mentioned labour saving as a reason for preference of the system. To some extent this is surprising as the farmers, when asked to estimate the labour requirement for the pure stands and the intercrop, came up with an estimated labour requirement of the intercrop that was on average 42% higher than that of the pure stands (Table 2.6). This apparent contradiction demonstrates how the farmers perceive the intercropping system. Growing one acre of a maize-sesame intercrop is compared with growing one acre of maize and one acre of sesame in pure stand. Obviously, adding sesame to maize then indeed is a labour saving activity compared to preparing and maintaining an additional field of sesame. It illustrates that both crops in the intercrop are considered full crops, an observation that is in line with data presented in Table 2.2 on land allocation, where the sum of land area allocated to individual crops exceeds the total land area under cropping.

Another important reason for intercropping is risk avoidance. Avoiding risk of total crop failure was mentioned by 83% of the respondents (93% for intercropping in general). This risk is particularly associated with growing sesame in monoculture. During early stages sesame is reported to be prone to seedling mortality because of water logging (Weiss, 1983). Moreover, sesame might be completely wiped out by sesame flea beetle and snails, especially during the first six weeks after emergence. These problems are equally likely to occur in an intercrop, however in that case still a maize crop will be left and even part of the yield loss of sesame may be compensated by maize. Finally, farmers perceive that sesame is associated with risk of drought, specifically if the rains stop before the end of April. Even though severe drought spell will also effect the production of maize, the problems encountered with sesame are more severe because of its long growth duration.

Scarcity of fertile land was mentioned as another reason for intercropping (33%). As maize is the main food crop, farmers prefer to grow it on fertile soils. At the same time, sesame is considered a crop that only performs well on fertile soils. As fertile land is scarce, farmers make optimum use of this commodity in short supply by combining the two crops. The observation that after clearing of virgin land the first grown crop generally is a maize-sesame intercrop, illustrates this point. The maize-sesame intercrop was also mentioned to contribute to the replenishment of soil fertility (74% versus 41% for intercropping in general). This superior replenishment of the intercrop was attributed to the difference in decomposition rate between the maize and sesame crop residues. Sesame leaves were reported to decompose fast, whereas the decomposition rate of maize residues takes more time. This may contribute to the perception of farmers that their fields are fertile enough and additional organic or inorganic fertilizer is not required. Some farmers also mentioned that intercropping minimizes weed problems. Local sesame varieties were considered to suppress weed growth through shading because they are tall, leafy and heavily branching. The crops that are commonly added to maize-sesame intercrops (e.g., cowpea, pumpkins and watermelon) are creeping types and perceived to act as cover crops and suppress weed growth.

In conclusion the survey revealed that in the maize-sesame intercrop, maize is considered the most important crop, producing the main source of food for the household. Sesame on the other hand is considered a reliable source of cash, which comes available shortly after harvest. In this way the two crops complement one another in fulfilling different purposes. Growing sesame in pure stand is not considered a feasible option, due to associated risks and scarcity of fertile land. Introduction of sesame into a maize crop is regarded as labour-saving and the interference of sesame with maize is considered acceptable when introduced at about two weeks after maize sowing.

CHAPTER 3

Effect of sowing time of sesame on the performance of a maize-sesame intercrop

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Abstract

In Southeast Tanzania, the major food crop maize is often inter-seeded with the cash crop sesame using an additive design. Farmers consider maize an essential crop for securing their basic food requirement, whereas sesame is added to generate cash. The objective of this research was to study the influence of the relative sowing time of sesame on the performance of the intercrop. Four experiments were conducted at two sites in Southeast Tanzania in 2000, 2001 and 2002. Improved sesame variety *Nal-92*, recommended for its high yield and white seed colour, was inter-seeded into the maize variety *Staha* at 0, 2 and 4 weeks after sowing of the maize. This study showed that simultaneous sowing of maize and sesame caused significant reductions in maize biomass and grain yield, of on average 26%. This reduction in maize production decreased with delayed inter-seeding time of sesame. Conversely, delayed seeding led to significant reductions in dry matter and seed yield of sesame, caused by a direct effect of sowing time and an increased competitiveness of maize. A financial analysis revealed that the attractiveness of the intercrop relative to that of maize in pure stand, was strongly determined by the maize:sesame price ratio. For the intercrop with the weakly competitive cultivar *Nal-92*, simultaneous sowing turned out the option with the highest gross financial return. At the same time, the experiments demonstrated that there are associated risks with simultaneous sowing, such as seedling mortality of sesame because of water logging and severe reductions in maize grain yield (up to 60%). This explains why most farmers prefer to introduce their local sesame varieties at two weeks after sowing of the maize. Efforts for breeding of improved sesame varieties should not only consider characteristics as yield, seed colour and seed oil content, but should also take into account characteristics as competitive ability and growth duration, that determine the suitability of sesame in intercropping systems.

Key words: Intercrop, inter-seeding time, Land Equivalent Ratio, maize, sesame, relative gross financial returns, *Sesamum indicum* L., sowing time, *Zea mays* L.

Introduction

In Southeast Tanzania, maize (*Zea mays* L.) is one of the most important food crops and sesame (*Sesamum indicum* L.) is a major cash crop. Farmers usually grow maize and sesame in an intercrop system for various reasons such as increased labour utilization efficiency, reduced risk of crop failure, increased land utilization efficiency, income and consumption diversification, soil fertility and improved weed management (Katinila *et al.,* 1998). While sesame is a common component of mixtures, the crop is considered secondary to maize, as maize should secure the basic food requirement of the household. Sesame is just added as a bonus crop, to obtain cash. The maize-sesame system, therefore, is a typical example of the first intercropping situation described by Willey (1979a), where intercropping should give full or near to full yield of a main crop and any additional yield of a second crop is considered a benefit.

To secure maize yields, maize is planted first and sesame is commonly inter-seeded into the maize crop at two weeks after sowing of maize. Farmers perceive that simultaneous seeding of maize and sesame may result in a severe yield loss of maize because of an increased competitiveness of sesame. There are indeed examples in which early inter-seeding of a secondary crop reduced the yield of the main crop. Sodsai-Changsaluk *et al.* (1993) found that yield and yield components of baby corn (*Zea mays* L.) were reduced by an early introduction of cotton (*Gossypium hirsutum*) in a maize-cotton relay cropping system. Akanvou *et al.* (2002) found that, in contrast to later inter-seeding, rice biomass and grain yield were significantly reduced when legumes (*Cajanus cajan* and *Stylosanthes hamata* Taub.) were introduced between 0 and 28 days after rice sowing. On the other hand, late inter-seeding might give a poorly-yielding secondary crop. In Southeast Tanzania, Taylor (1986) showed the importance of early inter-seeding of sesame into a crop of local sorghum (*Sorghum bicolor* (L.) Moench). Compared to sowing both crops simultaneously, sesame yield was only 47%, 32% and even 0% with delays of ten days, two weeks and four weeks, respectively. The major objective of the current research was to assess the effect of inter-seeding time of sesame into a maize crop on the performance of both maize and sesame. Performance of the intercrop as a whole was evaluated and the effect on gross financial returns was determined.

Materials and methods

In between 2000 and 2002, four identical experiments were carried out to study the maize-sesame intercropping system in Southeast Tanzania. The experiments were conducted in 2000 and 2001 at Marambo, and in 2001 and 2002 at Mkumba. Characteristics of both sites are presented in Table 3.1. Monthly rainfall data for three growing seasons are presented in Table 3.2. These data were collected at the Mkumba

Table 3.1. Characteristics of the experimental sites Mkumba and Marambo in South-east Tanzania. Physical and chemical characteristics of soil refers a depth of 0-20 cm.

	Mkumba	Marambo
Soil class	Rhodic ferralisol	Eutric cambisol
Soil texture	Loamy sand	Sand clay loam
pH (KCL)	4.3	5.3
Organic C (%)	0.56	1.97
CEC (me/100 g)	4.81	74.85
Total N (%)	0.05	0.12
Available P (Bray 1) (mg kg^{-1})	5.03	45.9

Table 3.2. Monthly rainfall distribution (mm $month^{-1}$) at the Mkumba meteorological station in Nachingwea, Southeast Tanzania during three cropping seasons.

Months after sowing	Total rainfall (mm $month^{-1}$)		
	2000	2001	2002
January	44	262	237
February	107	150	220
March	295	115	240
April	46	75	92
May	3	0	0
June	12	0	0
July	0	0	0
Total (mm)	507	602	789

meteorological station, but also represent the rainfall pattern at Marambo as this site is located circa 20 km away from the station.

Design and treatments

A randomized complete block design with seven treatments and four replications was used. The treatments consisted of (1) maize in monoculture sown in week zero (M_0), (2-4) sesame in monocultures sown at zero (S_0), two (S_2) and four (S_4) weeks after maize sowing and (5-7) sesame inter-seeded into maize at again zero (M_0S_0), two (M_0S_2) and four (M_0S_4) weeks after the sowing of maize. Individual plot size was 4.5 m × 6 m for both sites. Maize and sesame were sown according to densities recommended for monoculture crops, which were 6.7 plants m^{-2} for maize and 22.2 plants m^{-2} for sesame (TARO, 1987a, b). Both maize and sesame were sown in rows at an inter-row distance of 75 cm, whereas interplant distances within the row were 20 cm and 6 cm for maize and sesame, respectively. In the intercrops an additive design was used, with alternating rows of maize and sesame at 37.5 cm apart.

Sowing of the experiment was conducted at the beginning of the rainy season. First sowing was done on January 3 in 2000, February 9 in 2001 and January 1 in 2002 and the second and the third sowing were done with intervals of two and four weeks, respectively. Late planting in 2001 was caused by seedling mortality of sesame due to water logging with early sowing, which necessitated replanting of the experiments. Maize was sown by dibbling, whereas sesame was sown in furrows and covered with soil. At three weeks after sowing, the plants of both crops were thinned to the desired density. No fertilizer was applied to reflect farmers' practice. The trial was sprayed with the standard insecticide *Karate* (active ingredient: lambda-cyhalothrine) at a rate of 5 ml l^{-1} of water to protect sesame against the sesame flea beetle (*Alocypha bimaculata* Jacoby). Application of the insecticide was done on a weekly basis during the first six weeks after emergence of sesame. Hand weeding was used to keep the experiment weed-free throughout the season, resulting in weeding operations at two, four and six weeks after the first sowing.

Maize variety *Staha*, which possesses white grains and out-yields other recommended varieties for Southeast Tanzania, was used in the experiments. It is a composite variety formed from superior families of *Ilonga* composite and *Katumbili.* Its growth duration ranges from 100-120 days (medium maturing), depending on location. The variety is tolerant to maize streak virus. (TARO, 1987a; Katinila *et al.,* 1998). The recommended sesame variety *Nal-92* was used. The variety matures between 100-110 days, has a white seed colour, 2-4 primary branches and a final plant height ranging between 120-140 cm. Capsule length is 3-4 cm. The seed oil content is around 53% on moisture-free basis (Mponda, 1996; Mponda and Chambi, 1992).

Data collection

For both maize and sesame, the final harvest was conducted at physiological maturity. A net plot of 3.6 m^2 (2.4 m × 1.5 m) in the middle of the experimental plot was used. Before harvesting, plant stand (density) of maize and sesame was recorded. For each species, ten plants were randomly selected to determine additional growth and yield variables. The variables determined for maize were total plant height (cm), number of cobs per plant and cob length (cm). For sesame, total plant height (cm), plant height to first capsule (cm), number of primary branches and number of capsules per plant were determined.

Fresh weight of the samples collected from the 3.6 m^2 area was recorded in the field for maize and sesame, separately, by using a weighing balance. Representative sub-samples of three maize plants and ten sesame plants were taken from these samples and weighed. Weight of the sub-samples was again recorded in the laboratory to check whether material was lost during transport. In the laboratory, the grains of maize were separated from the straw (mainly cob stem, stem, leaves, tassels) and fresh weight of both grains and straw were determined. Of the sub-sample, a sub-sub-sample of the straw was taken, and weighed. The grain sub-sample and the sub-sub-sample of the straw were dried in the oven for 16 hours at 105 °C. Dry weight was determined directly after weighing the materials out of the oven. Grain size was determined based on a sample of 100 grains. For sesame, the capsules were separated from other organs (mainly leaves and stem) and both components were weighed separately and then oven-dried at 105 °C for 16 hours. Weight of both components was again determined directly after drying. The capsules were threshed and seed yield was recorded. Additionally, seed size was determined based on a sample of 1000 seeds. For both crops, harvest index was determined by taking the ratio between seed yield and shoot biomass.

Data on growth and yield variables of maize and sesame both in monoculture and in intercrop were subjected to combined (treatment × site) analyses using General Linear Model (GLM) of the SAS program (SAS, 1999). If appropriate, least significant difference (LSD) was used to compare treatment means. To study overall productivity of maize-sesame intercrops, data on biomass and marketable yield were used to calculate Land Equivalent Ratios (LER). The LER, which was described by Mead and Willey (1980), was calculated according to the following equation:

$$LER = \frac{Y_{\mathrm{m,s}}}{Y_{\mathrm{m,m}}} + \frac{Y_{\mathrm{s,m}}}{Y_{\mathrm{s,s}}}$$

where Y is the crop yield in g m^{-2} and suffixes m and s denote maize and sesame. $Y_{\mathrm{m,m}}$ and $Y_{\mathrm{s,s}}$ are the mean pure stand yield for maize and early-sown sesame, respectively, which were used as reference yields (Mead and Willey, 1980; Oyejola and Mead, 1982). $Y_{\mathrm{m,s}}$ and $Y_{\mathrm{s,m}}$ refer to the yields of maize and sesame in mixture.

Results

Performance of maize and sesame in the intercropping system

Time of inter-seeding of sesame into a maize crop had a significant effect on dry matter yield, grain yield, total plant height and cob length of maize. (Table 3.3; $P<0.05$). For dry matter, grain yield and total plant height the introduction of sesame simultaneously with maize caused significant reductions compared to maize in pure stand and introduction of sesame at 4 weeks after maize sowing (WAS).

Table 3.3. Effects of inter-seeding time of sesame into a maize crop on growth and yield variables of maize at Mkumba and Marambo sites in Southeast Tanzania, 2000-2002. M_0 is maize in monoculture, M_0S_0 denotes sesame sown simultaneously with maize (week zero), M_0S_2 is sesame sown two weeks after sowing maize, and M_0S_4 is sesame sown four weeks after sowing maize.

Relative time of sesame sowing and environment	Dry matter ($g\ m^{-2}$)	Grain yield ($g\ m^{-2}$)	Harvest Index (HI)	Total plant height (cm)	Cobs per plant (nr)	Cob length (cm)	100-grain weight (g)
Time of sowing (TS)							
M_0	646.8a*	280.2a	0.43	184.9a	0.94	12.7ab	19.0
M_0S_0	487.4b	204.9b	0.41	162.0b	0.91	11.9b	18.6
M_0S_2	575.8ab	239.5ab	0.40	179.1a	0.94	12.7ab	18.4
M_0S_4	599.9a	256.8a	0.43	185.4a	0.95	13.6a	17.2
P-value**	0.0260	0.0325	0.645	0.0021	0.7687	0.0348	0.7146
LSD (P=0.05)	103.19	50.34	NS	12.81	NS	1.07	NS
Environments (E)							
Marambo 2000	672.9a	295.3a	0.44a	Nd	Nd	Nd	13.8
Marambo 2001	763.9a	341.6a	0.45a	190.6	1.00a	14.1a	17.3
Mkumba 2001	407.2b	181.4b	0.45a	167.8	1.03a	11.4c	20.8
Mkumba 2002	465.8b	163.1b	0.33b	175.1	0.78b	12.7b	21.2
P-value	0.0002	0.0001	0.0006	0.1297	0.0001	0.0049	0.1092
LSD (P=0.05)	103.67	50.58	0.06	NS	0.06	0.94	NS
Interaction (TS × E)							
P-value	0.5332	0.9725	0.8716	0.7469	0.3507	0.6438	0.6215
Mean	574.6	243.2	0.42	178.2	0.93	12.8	18.5
CV (%)	26.0	30.0	20.0	9.1	9.5	10.6	25.4

* Means within a column belonging to the same classification (TS or E) followed by the same letter are not significant different; NS = not significant; Nd = not determined; ** significance level.

Conversely, time of inter-seeding did not significantly affect harvest index, number of cobs per plant and 100-grain weight of maize (Table 3.3; $P>0.05$). There was a significant effect of environment on dry matter, grain yield, harvest index, number of cobs per plant and cob length (Table 3.3; $P<0.01$). For dry matter and grain yield this effect was strongly related to location; maize performed better at Marambo site than at Mkumba. Within each location no significant effect between years was observed. Harvest index at Mkumba 2002 was remarkably low (0.33) compared to values of around 0.45 in the other environments. There were no significant interactions between

Table 3.4. Effects of inter-seeding time of sesame into a maize crop on growth and yield variables of sesame at Mkumba and Marambo sites in Southeast Tanzania, 2000-2002. M_0S_0 denotes sesame sown simultaneously with maize (week zero), M_0S_2 is sesame sown two weeks after sowing maize, M_0S_4 is sesame sown four weeks after sowing maize.

Relative time of sesame sowing and environment	Dry matter ($g\ m^{-2}$)	Seed yield ($g\ m^{-2}$)	Harvest Index (HI)	Total plant height (cm)	Plant height to first capsule (cm)	Primary branches (nr)	Capsules per plant (nr)	1000-seed weight (g)
Time of sowing (TS)								
M_0S_0	87.6a*	15.9a	0.18a	96.4a	61.6a	0.50a	12.9	2.78
M_0S_2	39.1b	5.1b	0.13b	76.7b	56.8a	0.22b	12.6	2.66
M_0S_4	17.7c	1.7c	0.07c	54.2c	41.8b	0.11b	7.6	2.48
P-value**	0.0001	0.0001	0.0001	0.0001	0.0017	0.0004	0.2607	0.5075
LSD (P=0.05)	16.96	2.33	0.020	13.95	10.45	0.190	NS	NS
Environments (E)								
Marambo 2000	96.5a	16.3a	0.15	Nd	Nd	Nd	Nd	Nd
Marambo 2001	14.3c	1.9c	0.09	59.2	43.2	0.32	5.0	2.87
Mkumba 2001	8.2c	1.6c	0.16	48.9	36.5	0.10	3.8	2.46
Mkumba 2002	73.5b	10.5b	0.11	119.2	80.6	0.42	24.3	2.59
P-value	0.0006	0.0018	0.2981	0.1649	0.5580	0.3950	0.9875	0.5712
LSD (P=0.05)	19.68	2.71	NS	NS	NS	NS	NS	NS
Interaction (TS × E)								
P-value	0.0001	0.0001	0.0026	0.7617	0.9766	0.1249	0.2352	0.9435
Mean	50.2	7.8	0.13	80.1	56.3	0.28	12.6	2.65
CV (%)	48.6	43.0	27.4	21.6	23.1	82.0	71.2	24.6

* Means within a column belonging to the same classification (TS or E) followed by the same letter are not significantly different, NS = not significant, Nd = not determined; ** significance level.

environment and time of sowing (Table 3.3; P>0.05).

Delayed inter-seeding of sesame into maize significantly reduced dry matter, seed yield, harvest index, total plant height, plant height to first capsule and number of primary branches of sesame (Table 3.4; P<0.01). With few exceptions, this reduction was observed when seeding of sesame was delayed from 0 to 2 WAS of maize, as well as for the further delay from 2 to 4 WAS. Time of inter-seeding did not significantly affect 1000 seed weight and the number of capsules per plant (Table 3.4; P>0.05). Dry matter and seed yield of sesame were significantly different between environments

(Table 3.4; P<0.01). At both Marambo and Mkumba, sesame yields in 2001 were remarkably low compared to the sesame yield obtained at the same site in the other year, suggesting that for sesame, unlike what was observed for maize, the year effect is of primary importance. In 2001 the experiments were replanted, as emergence of sesame in the initial experiment was poor due to water logging. For that reason, first planting was postponed till February 9, resulting in a shortening of the growing period for the second and third planting of sesame (Table 3.4). For all other factors no significant differences between environments were observed (Table 3.4; P>0.05). Particularly for the number of primary branches and the number of capsules per plant

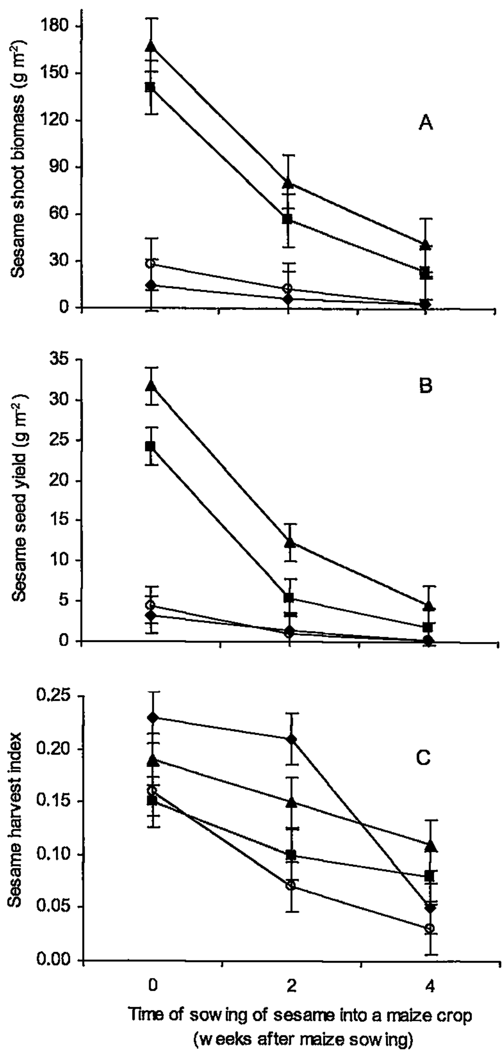

Fig. 3.1. Effect of inter-seeding time of sesame into a maize crop (weeks after maize sowing) on shoot biomass (A), seed yield (B) and harvest index (C) of sesame intercrop at final harvest, Mkumba 2001 (♦), Mkumba 2002 (■), Marambo 2000 (▲) and Marambo 2001 (○) in Southeast Tanzania. Vertical bars indicate the standard errors of the difference between means (SED) for sowing × environment interaction.

this observation will be at least partly because of the high variability that was observed, reflected in coefficients of variation of 82.0 and 71.2%, respectively. For dry matter, seed yield and harvest index significant interactions between time of sowing and environment were observed (Table 3.4; P<0.01). In 2001, dry matter and seed yield dropped gradually with a delay in sowing time. However, at both Marambo 2000 and Mkumba 2002, a sharp reduction was observed from 0 to 2 WAS, followed by a mild reduction due to a delay in sowing time from 2 to 4 WAS (Fig. 3.1). For the harvest index, sharp reductions at Marambo 2001 between 0 and 2 WAS and at Mkumba 2001 between 2 and 4 WAS were most remarkable.

Table 3.5. Effects of sowing time of sesame in pure stand on growth and yield variables of sesame at final harvest at Mkumba and Marambo sites in Southeast Tanzania, 2000-2002. S_0 denotes the first sowing of sesame (week zero), S_2 is sesame sown two weeks after first sowing, S_4 is sesame sown four weeks after first sowing.

Sowing time of sesame and environment	Dry matter ($g\ m^{-2}$)	Seed yield ($g\ m^{-2}$)	Harvest Index (HI)	Total plant height (cm)	Plant height to first capsule (cm)	Primary branches (nr)	Capsules per plant (nr)	1000-seed weight (g)
Time of sowing (TS)								
S_0	179.4a*	39.9a	0.19a	102.0a	56.3	1.34a	24.2a	2.70
S_2	154.9a	29.0b	0.17ab	97.2a	60.8	1.52a	20.9a	2.48
S_4	97.5b	16.8c	0.15bc	81.1b	55.4	0.80b	13.3b	2.39
P-value**	0.0001	0.0001	0.002	0.0013	0.761	0.0012	0.0026	0.2768
LSD (P=0.05)	30.30	7.13	0.025	10.81	NS	0.370	5.88	NS
Environments (E)								
Marambo 2000	277.8a	73.7a	0.26a	Nd	Nd	Nd	Nd	2.75
Marambo 2001	82.0c	11.3c	0.14bc	87.8b	46.6	1.72	19.6b	Nd
Mkumba 2001	24.8d	4.2c	0.16b	60.0c	33.2	0.71	9.1c	2.42
Mkumba 2002	191.2b	25.0b	0.12c	132.4a	92.7	1.21	29.8a	2.61
P-value	0.0019	0.0019	0.0029	0.0075	0.5617	0.0701	0.4844	0.2583
LSD (P=0.05)	35.15	8.27	0.029	10.87	NS	NS	NS	NS
Interaction (TS × E)								
P-value	0.0129	0.0020	0.0776	0.5396	0.9982	0.2392	0.7540	0.8716
Mean	149.0	28.6	0.17	97.0	61.1	1.22	20.51	2.51
CV (%)	29.2	35.8	21.5	13.9	32.7	36.9	35.6	13.5

* Means within a column followed by the same letter are not significantly different. NS = not significant, Nd = not determined; ** significance level.

Performance of sesame in monoculture

As with the mixture, seed yield of sesame in monoculture reduced significantly with a delay in sowing time (Table 3.5; $P<0.01$). Also for dry matter yield, harvest index, total plant height, number of primary branches and the number of capsules per plant a significant effect of sowing time was found. Though for all these characteristics, except number of primary branches, a continuous reduction with sowing time was observed only a delay of 4 weeks caused a significant reduction compared to the first sowing time. Sesame productivity differed markedly between environments. As with sesame in mixture the yields in 2001 were remarkably low. Both in Marambo as well as in Mkumba, seed yields in 2001 were 6-7 times lower compared to the production at the same sites in 2000 (Marambo) or 2002 (Mkumba). Productivity in Marambo was generally higher than in Mkumba. There was a significant time of sowing × environment interaction for both dry matter and seed yield (Table 3.5; $P\leq0.01$). At Mkumba 2001, Mkumba 2002 and Marambo 2001, dry matter yield response to time of sowing was very similar (Fig. 3.2). Yields at first (S_0) and second sowing (S_2) were nearly identical, but clear reductions were observed when sowing of sesame was postponed with four weeks (S_4). For Marambo 2000, there was already a clear reduction from the first to the second sowing time. Seed yields tended to drop gradually from 0 to 2 and from 2 to 4 weeks after the first sowing. In this case, Mkumba 2001 was the exception, as the first delay of 2 weeks did not have a negative effect on seed yield.

Relative contribution of time of sowing and competition to overall yield loss of sesame

In Figure 3.3, biomass and seed yield of sesame in both monoculture and mixture are presented in dependence of sowing time. The figure clearly illustrates that already in monoculture both shoot dry matter and seed yield were reduced with a delay in sowing time. In the intercrops the yield of sesame was even further reduced resulting from competition of maize. The additional reduction due to competition was 51%, 74% and 81% for biomass yield and 60%, 82% and 91% for seed yield with delays in sowing time of 0, 2 and 4 weeks, respectively. This increase in reduction due to competition demonstrates the weaker competitive position of sesame with delayed introduction.

Biological productivity of maize and sesame intercropping

Effect of inter-seeding time of sesame into a maize crop on Land Equivalent Ratios (LER) for shoot biomass and marketable yield of maize and sesame are presented in Table 3.6. Partial LER of maize for both shoot biomass and marketable yield increased with a delayed introduction of sesame, but partial LER for sesame decreased. As the reduction in partial LER for sesame exceeded the increase in the partial LER of maize, there was a decline of overall-LER with delayed time of inter-seeding of sesame into a maize crop. Average yield advantage obtained with simultaneous sowing was 24% and 13% for shoot biomass and marketable yield, respectively. For shoot biomass, LER nearly always exceeded one. Only at Mkumba 2002, with sesame sown at 2 and 4 weeks after maize, LER was smaller than one. For marketable yield, only in 50% of the cases LER exceeded one. Simultaneous sowing always resulted in a LER greater than one, whereas introduction at four weeks after maize sowing always resulted in LER-values smaller than one. With introduction at two weeks a LER larger than one was obtained at two out of the four sites.

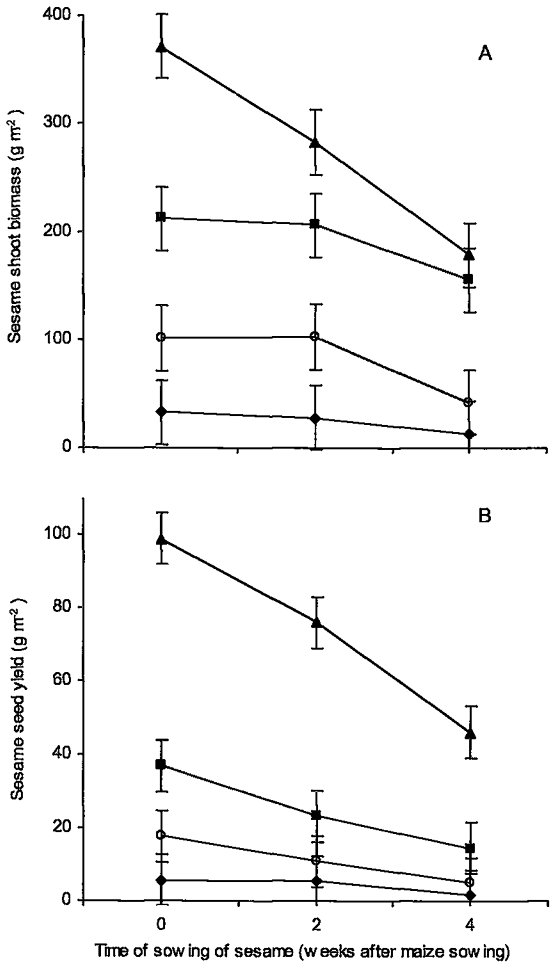

Fig 3.2. Effect of sowing time of sesame (weeks) on shoot biomass (A) and seed yield (B) in pure stand at final harvest, at Mkumba 2001 (◆), Mkumba 2002 (■), Marambo 2000 (▲) and Marambo 2001 (○) in Southeast Tanzania. Vertical bars indicate the standard errors in means (SED) for time of sowing × environment interaction.

Relative gross financial returns

LER-values indicate whether productivity of a mixed crop exceeds that of growing both crops in a monoculture. However, for the system under study growing both crops separately as monoculture is not considered an option. Farmers have a strong preference for growing maize to secure their basic food requirement. The question then becomes whether it is attractive to farmers to add sesame into a maize crop, and if yes, at what time. The reference for evaluating intercrop productivity thus becomes the maize monoculture. Sesame is grown as an alternative source of farmer's income and, therefore, the yield of sesame as well as the loss in maize should be expressed in monetary units. Analysis of the local market prices for maize and sesame was based on 11 years (1992 to 2002) of data collected from 16 villages in the Nachingwea district in Southeast Tanzania. Average prices of maize and sesame (1,000 Tanzanian shillings

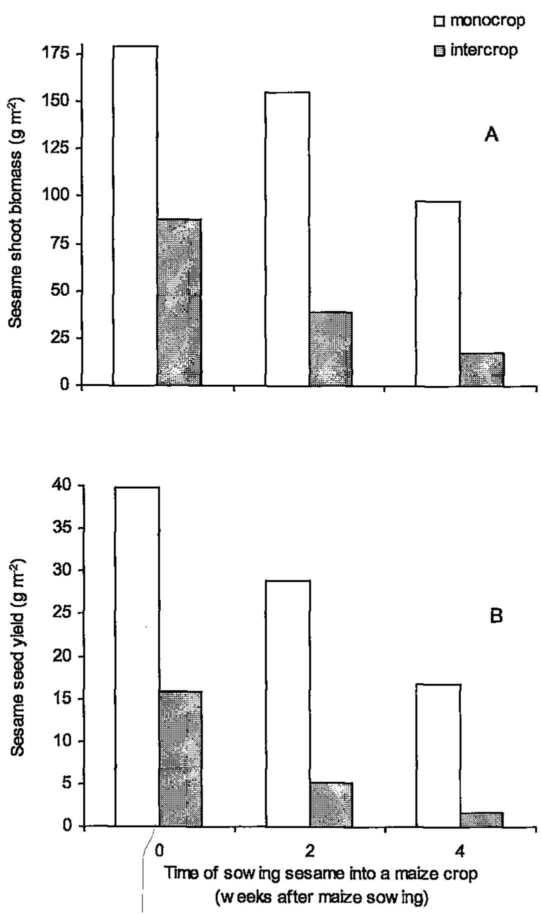

Fig. 3.3. Sesame shoot biomass (A) and seed yield (B) as influenced by competition by maize crop and delayed time of sowing of sesame.

Table 3.6. Effect of inter-seeding time of sesame into a maize crop on Land Equivalent Ratio (LER) for shoot biomass and marketable yields of maize and sesame at Mkumba and Marambo sites in Southeast Tanzania, 2000-2002.

Inter-seeding time (weeks after sowing maize)	Shoot biomass			Marketable yield		
	Maize	Sesame	LER	Maize	Sesame	LER
Marambo 2000						
0	0.92	0.46	1.38	0.80	0.33	1.13
2	1.11	0.22	1.33	0.90	0.13	1.03
4	1.00	0.11	1.11	0.94	0.05	0.99
Marambo 2001						
0	0.84	0.28	1.12	0.88	0.25	1.13
2	0.89	0.13	1.02	0.91	0.06	0.97
4	0.97	0.03	1.00	0.96	0.01	0.97
Mkumba 2001						
0	0.81	0.44	1.25	0.73	0.58	1.31
2	0.86	0.20	1.06	0.89	0.23	1.12
4	0.89	0.11	1.00	0.88	0.03	0.91
Mkumba 2002						
0	0.43	0.63	1.06	0.40	0.62	1.02
2	0.69	0.24	0.93	0.67	0.13	0.80
4	0.82	0.09	0.91	0.85	0.03	0.88
Average						
0	0.75	0.49	1.24	0.73	0.40	1.13
2	0.89	0.22	1.11	0.86	0.13	0.99
4	0.93	0.10	1.03	0.92	0.04	0.96

is approximately equivalent to one US$) as well as the average price ratio was calculated based on these data. A bag of maize (approximately 90 kg) was sold at an average of about 5,600 Tanzanian shillings (minimum: 1,500; maximum 12,000), whereas a bag of sesame (about 80 kg) was sold at an average of 19,300 Tanzanian shillings (minimum: 6,000; maximum 35,000). The price ratio between maize and sesame varied between 1:1 and 1:11, with an average of 1:3.5.

Data on harvestable yield of maize and sesame were used to calculate the gross financial return for intercropping systems at different inter-seeding time and price ratios of 1:1, 1:3.5 and 1:11. The gross financial return of an intercropping system was then divided by the average gross financial return of maize in monoculture to obtain the Relative Gross Financial Returns (RGFR) of maize-sesame intercrops.

At Mkumba 2001 and Marambo 2001, RGFR for all price ratios and inter-seeding times, was less than unity suggesting lower financial benefit in intercropping relative to pure stand maize (Fig. 3.4). In both environments, sesame yield was much lower than in the other two environments and too low to compensate the yield loss in maize financially. In contrast, the results from Marambo 2000 and Mkumba 2002 show that particularly for simultaneous sowing intercropping can be superior to monocropping of maize. For these situations, break-even points for intercropping were obtained at maize:sesame price ratios of 1:2.1 at Marambo 2000, and 1:5.6 at Mkumba 2002.

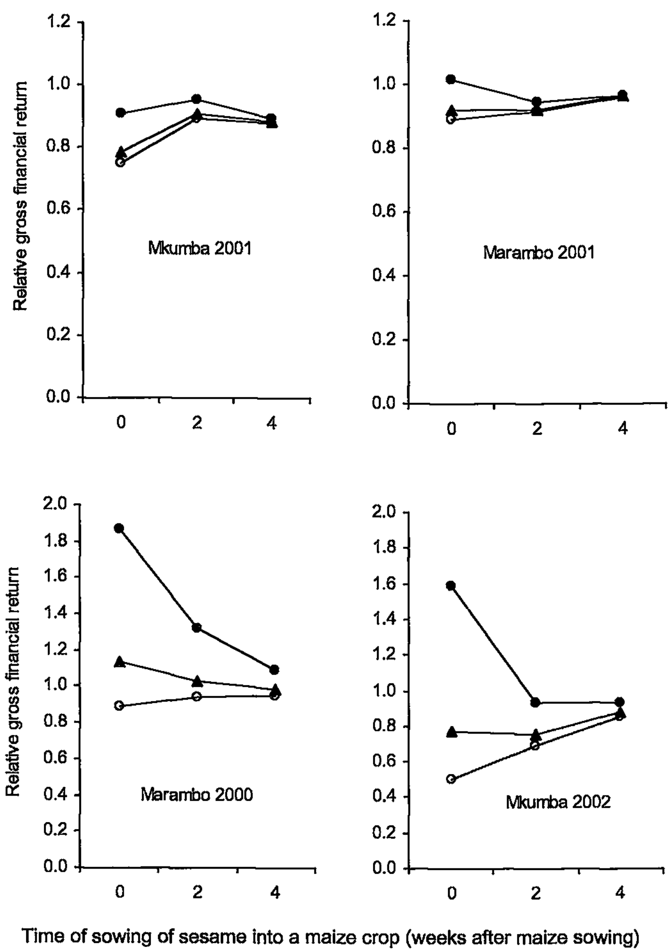

Fig. 3.4. Effect of time of sowing sesame into a maize crop (weeks after maize sowing) on relative gross financial returns of maize and sesame intercrops for maize:sesame price ratio 1:1 (○), 1:3.5 (▲) and 1:11 (●) at Mkumba and Marambo in Southeast Tanzania.

Discussion

Performance of maize in monoculture

In this study, maize variety *Staha* was used and an average yield of 2.8 t ha^{-1} was obtained when maize was grown in monoculture. Yields were relatively stable over years, but clearly higher at the Marambo site compared to the Mkumba site. This difference is in line with the differences in soil fertility between both sites. Soil at the Marambo experimental site is an Eutric cambisol (high fertility) and that at the Mkumba experimental site is a Rhodic ferralsol (low fertility) (Table 3.1).

Performance of sesame in monoculture

The improved sesame variety *Nal-92* was used for these experiments. It was selected based on its good performance in monoculture and preference by farmers (Mponda, 1996). Furthermore, this variety is white seeded, a characteristic which is strongly promoted, because of a high demand in the international market (Kamwela, 1993). Katinila *et al.* (1995) established that the optimum sowing date for sesame in pure stand in Southeast Tanzania is from end of December to mid-January depending on the onset of the first rains. With sowing beyond late January a sharp drop in yield was observed. The current experiments confirm these findings. At Marambo 2000 and Mkumba 2002, first sowing of sesame was done in early January, resulting in seed yields of around 100 and 40 g m^{-2}, respectively. In both experiments, a clear reduction in sesame yield with delayed sowing was observed. The maturity period of sesame variety *Nal-92* ranged from 100-110 days, meaning that with sowing around mid-January maturity was around the first of May. In all years, only marginal amounts of rainfall were encountered after April. Therefore, the lower yield obtained at later sowing was most likely caused by water limitation during the later part of the growing season. In 2001, first sowing of sesame was done on January 3, but there was poor establishment of sesame because of waterlogging, to which sesame is known to be extremely susceptible (Weiss, 1983). Because of the poor emergence, the trial was replanted in both sites on February 9, which was beyond the third sowing date of the other two experimental years. Soil moisture limitation during the last part of the growing cycle was, therefore, even stronger, and this resulted in early maturation of the second and third sowing of sesame at 87 and 78 days after sowing, respectively. This explains the poor performance of sesame in 2001 at both locations, and confirms the sensitivity of sesame to late planting. In 2001 as well as in the years with early planting, seed yields of sesame were clearly higher at the more fertile Marambo site.

Performance of maize and sesame intercrops

Early inter-seeding of sesame into a maize crop reduced the productivity of maize significantly. This reduction in maize yield decreased with delayed inter-seeding time of sesame. In contrast, delayed inter-seeding reduced dry matter, seed yield and yield components of sesame. Following the results in monoculture, this reduction can partly be attributed to a direct effect of a delayed sowing time. The increased competitiveness of maize following late introduction of sesame also played a role, as the reduction in sesame yield in intercropping surpassed the reduction of sesame in pure stand. Severe reduction of sesame yields in mixtures with delayed sowing have been attributed to shading (Van Rheenen, 1973). The currently observed results are very similar to those reported by Taylor (1986), who studied sorghum-sesame intercropping in Southeast Tanzania. The author reported a reduction in sorghum yield with early-sown sesame and this reduction decreased as sesame sowing was delayed. At the same time, a severe reduction in sesame yield with delayed inter-seeding was observed. Also for other mixed cropping systems, e.g., maize-cotton in Thailand (Sodsai-Changsaluk *et al.*, 1993) and rice-legumes in Ivory Coast (Akanvou *et al.*, 2002), it has been reported that competitive relations are strongly influenced by relative sowing time. Similarly, for weeds it has been documented that the period between crop and weed emergence, strongly affects the competitive effects of the weeds on crop production (Håkånsson, 1983; Kropff, 1988).

Benefit of adding sesame to maize

Simultaneous sowing of maize and sesame resulted in average Land Equivalent Ratios (LER) of 1.24 and 1.13 for shoot biomass and marketable yield, respectively (Table 3.6). These figures indicate a clear yield benefit of intercropping compared to monocrops, and hence an apparent increase in resource use efficiency of the intercrop. However, when using an additive design at single densities for both crops, it is not possible to distinguish between a density effect and a true yield advantage through resource complementarity (e.g., Trenbath, 1976; Spitters, 1980). Since the overall density in mixture is higher than densities used in pure stand, these effects are confounded (Andrews and Kassam, 1976; Willey and Osiru, 1972). Even though both crops were sown in their recommended density, it cannot be excluded that the yields in pure stand were sub-optimal. In this case, a yield advantage could also be obtained by growing the pure stands at higher densities (Willey, 1979a, b; Spitters and Kropff, 1989). With delayed inter-seeding time of sesame, there was a decline in LER for both shoot biomass and marketable yield. The increased productivity of maize following later introduction was insufficient to compensate for the decline in sesame yield.

Farmers in Southeast Tanzania are primarily interested in securing their basic food requirement. Moreover, most farmers do not consider growing sesame in pure stand a feasible option. Two alternatives that are left open are therefore either to grow maize in pure stand or to grow maize and add sesame. LER is not the most suitable criterion for comparing these two alternatives, as it expresses whether the cultivation of an intercrop should be preferred over the cultivation of both crops in pure stand (Willey, 1979a; Mead and Willey, 1980). In evaluating the maize-sesame intercropping system, a first consideration should be whether the reduction in maize yield is compensated for by the gain obtained from sesame. In 2001, with sowing of maize in early February, maize yield was reduced, but sesame yield was very poor, irrespective of the sowing date. This indicates that with late sowing of maize, a pure stand of maize is beneficial over a maize-sesame intercrop. Based on the results of the experiments in 2000 and 2002, it is concluded that with early planting of maize (beginning of January) the attractiveness of the intercrop depends very much on the price ratio between maize and sesame. In 2000, the price ratios between maize and sesame at which the gross financial return of the intercrop equalled that of the maize pure stand was 1:2.1, 1:2.6 and 1:4.5 with introduction of sesame at 0, 2 and 4 weeks after maize sowing, respectively. All of these price ratios fall within the range encountered in the maize-sesame production area in Southeast Tanzania. Also in 2002, early introduction of sesame resulted in the best intercrop performance. In this case, simultaneous sowing turned out the only feasible option, as it was the single mixed cropping situation in which the price ratio at which the break-even point was obtained (1:5.6) was within the existing range. It should be realized that the above-described analysis of gross financial returns did not take into account the cost of production, such as labour and seed material.

Another important aspect in assessing the viability of the intercropping system is whether the reduction in maize yield following the addition of sesame is acceptable. Simultaneous sowing caused an average reduction in maize grain yield of 27%. However, this yield reduction was highly variable and ranged from 12% (2000 in Marambo) up to 60% (2002 in Mkumba). In Southeast Tanzania, where farmers consider securing their basic food requirement as one of their main objectives, risk of encountering such reductions might not be acceptable. There are also other risks associated with early introduction of sesame. Seedling mortality because of waterlogging, responsible for the replanting of the experiments in 2001, is one obvious example. Sesame is very sensitive to waterlogging, and early introduction increases the chances of running into these conditions. Early planting might also mean that the sesame crop matures before the end of the rainy period, whereas farmers prefer to harvest sesame at the beginning of the dry season (May) (Mponda, 1996). Not only does the dry season provide favourable conditions for drying the crop in the field, also the maize crop will have been harvested by that time, creating no competition for labour. For these reasons, most farmers in Southeast Tanzania currently introduce sesame at two weeks after maize sowing. Though this practice seems sub-optimal, it should be realized that in the current experiments the improved, relatively short-statured, variety *Nal-92* was used, whereas most farmers use local varieties of sesame, which are generally tall, leafy and heavily branching. The more competitive nature of farmers' varieties allows later introduction and through that the avoidance of the earlier mentioned associated risks. The present results clearly indicate that, in the development of improved sesame varieties, their suitability in intercropping systems should be taken into account. That means that apart from characteristics such as seed colour and oil content, competitive ability and growth duration should receive specific attention.

CHAPTER 4

Identifying the nature of interaction between maize and sesame in intercropping

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Abstract

In Southeast Tanzania, the major food crop maize (*Zea mays* L.) is often intercropped with the cash crop sesame (*Sesamum indicum* L.) using an additive design. The objective of this research was to study the nature of interaction between the two components of this intercrop. Experiments were conducted at two sites in Southeast Tanzania, which differed in soil fertility. Pure stands and intercrops of maize variety *Staha* and sesame variety *Nal-92* were grown at various total densities and mixing ratios, following a row-based additive design. Data on final shoot biomass and marketable yield under non-fertilized conditions were analysed using an empirical regression model for quantification of intra-specific and inter-specific competition. At both sites, maize showed greater competitive ability than sesame, though, at the more fertile site, relative competitive ability of maize was about four times as high than at the poor soil fertility site. Despite this difference, both experiments revealed niche differentiation between the two crops, indicating that at both sites there was a clear basis for yield advantage in intercropping due to complementarity in resource acquisition. Consequences of the use of a row-based additive design in combination with the method of analysis are being discussed.

In addition, the response to N, P and NP-fertilization was determined, using maize and sesame in their recommended densities. P/N ratios of shoot tissue of maize and sesame varied between 1/1.5 to 1/6.4, indicating that nitrogen was a major limiting factor. This is in correspondence with the observation that at the low soil fertility site N and NP fertilization gave significant increases in yield with both maize and sesame in pure stand. In the intercrop, only maize profited from N and NP-application, as for sesame the advantage of additional N was counterbalanced by the presence of a more competitive maize crop.

Key words: Additive design, fertilizer combinations, intercropping, niche differentiation index, land equivalent ratio, non-linear regression.

Introduction

In Southeast Tanzania, maize is an important food crop and sesame is a major cash crop. Farmers usually grow maize and sesame in an intercrop, in which maize is considered the main crop, as this crop should secure the basic food requirements of the households. Sesame is considered secondary to maize and just added as a bonus crop, to obtain cash. Farmers mention various reasons for growing this particular intercrop, such as increased labour utilization efficiency, reduced risk of crop failure, scarcity of fertile land and income diversification (Katinila *et al.,* 1998; Chapter 2). Apart from these reasons, growing both crops in an intercrop might also have advantages that follow more directly from the interaction between the two species. Vandermeer (1989) distinguished two major categories of interference between crops in an intercropping situation; facilitation and competition. This classification is based on the mutual interaction between crops and their biotic and abiotic environment. A crop is having an effect on the environment, and this modified environment causes a response in the other components of the intercrop. Facilitation is used for a modification that exerts a positive effect on at least one of the species. The introduction of one crop might for instance increase the presence of natural enemies of an important pest of a second crop. For the maize-sesame intercrop no examples of facilitation have been identified, even though one of the important reasons for farmers' preference of growing sesame in a maize-sesame intercrop is linked to sesame flea beetle (*Alocypha bimaculata* Jacoby), a devastating pest of sesame. In this case, the addition of maize is not reducing the incidence of the pest, rather the presence of maize guarantees that after a severe outbreak at least one crop remains.

Competition is used when the modification of the environment by one of the species is having a negative effect on the other species, like through a reduced availability of resources. It is a misconception to believe that competition will always result in a poor performance of the intercrop. In a pure stand, individual plants compete with individuals of their own species. Characteristic for this intra-specific competition is that individual plants have identical resource requirements and equal opportunities for acquisition of resources. In an intercrop, apart from intra-specific competition, plants compete with individuals that are to some extent different. Consequently, their resource requirements and their abilities for resource acquisition are not necessarily the same. This complementarity between species leads to niche differentiation, which forms the basis for over-yielding in intercropping systems. Vandermeer (1983) called this the competitive production principle. Spitters (1983) developed a methodology for determining the level of niche differentiation between the component crops in an intercrop, based on a quantification of intra- and inter-specific competition. In a survey, 74% of the farmers responded that maize and sesame do not interfere severely

(Chapter 2), but so far the competitive relations between both component crops have not been quantified.

The same survey indicated that in maize-sesame intercropping in Southeast Tanzania both organic and inorganic fertilizers are hardly being used. Fertilizer recommendations for pure stands of maize and sesame do exist though. For maize, the recommendation is 20 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (TARO, 1987a; Katinila *et al.*, 1998), whereas, for sesame, 45 kg N ha^{-1} + 40 P_2O_5 ha^{-1} is advised (E.M. Kafiriti, pers. comm.). For the commonly used maize-sesame intercrop no specific recommendations are available, as the response of the intercrop to nitrogen and phosphorus fertilization has not been studied. In an intercropping situation, this fertilizer response is expected to be even more important, as, apart from an effect on overall yield, fertilization might cause a shift in competitive relations among the component crops. For maize-sesame intercropping this appears particularly relevant, as farmers consider maize a more important crop than sesame.

In this study, intra-specific competition, inter-specific competition and niche differentiation between maize and sesame were studied following the approach described by Spitters (1983). The study was conducted under non-fertilized conditions at two sites in Southeast Tanzania, which differed in soil fertility. In addition, the response of the maize-sesame intercrop to N, P and NP-fertilization was studied.

Materials and methods

In 2000 and 2002, two identical experiments to study the maize-sesame intercropping system were carried out in Southeast Tanzania. In 2000, the experiment was conducted at Marambo, at a relatively fertile soil, whereas, in 2002, the experiment was conducted at Mkumba, at a comparatively poor soil fertility site. Characteristics of both sites are presented in Table 4.1.

Table 4.1 Characteristics of Mkumba and Marambo experimental sites in Southeast Tanzania. Physical and chemical characteristics of soil refer to a depth of 0-20 cm.

	Mkumba	Marambo
Soil class	Rhodic Ferralisol	Eutric Cambisol
Soil texture	Loamy sand	Sand clay loam
pH (KCL)	4.30	5.30
Organic C (%)	0.56	1.97
CEC (me/100 g)	4.81	74.85
Total N (%)	0.05	0.12
Available P (Bray 1) (mg kg^{-1})	5.03	45.9

Design and treatments

A split plot design with three replications was used with four nitrogen and phosphorus fertilizer combinations as main plots and seventeen plant densities as sub-plots (Table 4.2). The fertilizer combinations were: (1) No fertilizer, as farmers' practice; (2) 40 kg P_2O_5 ha^{-1}; (3) 45 kg N ha^{-1} and (4) a combination of 45 kg N ha^{-1} and 40 kg P_2O_5 ha^{-1}. In both experiments, maize variety *Staha* was combined with sesame variety *Nal-92*. In pure stand, both maize and sesame were sown in rows at an inter-row distance of 75 cm, whereas interplant distances within the row varied with plant density (Table 4.2). In the intercrops an additive design was used, with alternating rows of maize and sesame at 37.5 cm apart. Individual plot size of 3.00 m × 5.00 m was used.

Table 4.2. Sown densities of maize and sesame in pure stands and in intercrop (plants m^{-2}) at Mkumba and Marambo experimental sites. In pure stand, maize and sesame were sown at an inter-row distance of 75 cm. In intercrops alternating rows of maize and sesame were 37.5 cm apart. Values between brackets refer to in-row plant distances.

Combination	Maize plants m^{-2}	Sesame plants m^{-2}	
		Marambo	Mkumba
Maize alone (M_1)	4.4 (30 cm)		-
Maize alone (M_2)	6.7 (20 cm)		-
Maize alone (M_3)	8.9 (15 cm)		-
Maize alone (M_4)	19.1 (7 cm)		-
Sesame alone (S_1)	-	19.0 (7.0 cm)	11.1 (12.0 cm)
Sesame alone (S_2)	-	22.2 (6.0 cm)	22.2 (6.0 cm)
Sesame alone (S_3)	-	26.7 (5.0 cm)	33.3 (4.0 cm)
Sesame alone (S_4)	-	44.4 (3.0 cm)	66.7 (2.0 cm)
Maize and sesame (M_1S_1)	4.4		11.1
Maize and sesame (M_1S_2)	4.4		22.2
Maize and sesame (M_1S_3)	4.4		33.3
Maize and sesame (M_2S_1)	6.7		11.1
Maize and sesame (M_2S_2)	6.7		22.2
Maize and sesame (M_2S_3)	6.7		33.3
Maize and sesame (M_3S_1)	8.9		11.1
Maize and sesame (M_3S_2)	8.9		22.2
Maize and sesame (M_3S_3)	8.9		33.3

Agronomic practice

Maize and sesame were sown simultaneously, at the beginning of the rainy season, in the first week of January. Maize was sown by dibbling, whereas sesame was sown in furrows and covered with soil. In the main plots with phosphorous fertilization, Triple Super Phosphate (46% P_2O_5) was manually broadcasted evenly to the seedbed at the time of sowing. In the main plots with nitrogen fertilization, Urea (46% N) was applied as banded top dressing four weeks after sowing. This was done manually after thinning both crops to the desired density. Continuous furrows, about 10 cm deep and 5 cm away from the rows, were made along the length of the planting rows of maize and sesame. The fertilizer was then placed in the furrow and covered with soil (TARO, 1987a, b). The experiments were sprayed with the standard insecticide *Karate* (active ingredient: lambda-cyhalothrine) at a rate of 5 ml l^{-1} of water to protect sesame against sesame flea beetle (*Alocypha bimaculata* Jacoby). Applications of the insecticide were done on a weekly basis during the first six weeks after emergence of sesame. Hand-weeding was used to keep the experiments weed free throughout the season, resulting in weeding operations at two, four and six weeks after sowing.

Data collection

For both maize and sesame, final harvest was conducted at physiological maturity. A net plot of 3.60 m^2 (2.40 m × 1.50 m) in the middle of the experimental plot was used. Before harvesting, plant stand density of maize and sesame were recorded. Fresh weight of the samples collected from the 3.60 m^2 area was recorded in the field for maize and sesame separately, by using a weighing balance. Representative sub-samples of three maize plants and ten sesame plants were taken from these samples and weighed. Weight of the sub-samples was again recorded in the laboratory to check whether material was lost during transport. In the laboratory, the grains of maize were separated from the straw (mainly cob stem, stem, leaves, tassels) and fresh weight of both grains and straw were determined. Of the sub-sample, a sub-sub-sample of the straw was taken, and weighed. The grain sub-sample and the sub-sub-sample of the straw were dried in an oven at 70 °C for 48 hours. Dry weight was determined directly after weighing the materials out of the oven. For sesame, the capsules of sesame were separated from other organs (mainly leaves and stem) and both components were weighed separately and then dried in an oven at 70 °C for 48 hours. Weight of both components was again determined directly after drying. The capsules were threshed and seed weight was recorded.

Plant tissue analysis of the entire shoot was conducted for selected oven dried sub-samples. These were the recommended maize pure stand density (M_2; 6.7 plants m^{-2}), the recommended sesame pure stand density (S_2; 22.2 plants m^{-2}) and the corresponding intercrop (M_2S_2). A segmented flow analyser was used to determine nitrogen and phosphorus content in plant shoot tissue according to the procedure outlined by Houba *et al.* (1989).

Data analysis

Results from all densities and density-combinations of the non-fertilized main plot were used to determine the intra- and inter-specific competition coefficients of maize and sesame, using the procedure outlined by Spitters (1983). In this approach the yield of species 1 in an intercrop with species 2 ($Y_{1,2}$; g m^{-2}) is written as:

$$Y_{1,2} = \frac{N_1}{b_{1,0} + b_{1,1}N_1 + b_{1,2}N_2} \tag{4.1}$$

where, N_1 and N_2 are plant densities (plants m^{-2}) of crop 1 and crop 2, respectively, $b_{1,0}$ is a parameter reflecting the reciprocal of the virtual biomass of an isolated plant of crop 1 (plant g^{-1}), $b_{1,1}$ measures the intra-specific competition between plants of crop 1 (m^2 g^{-1}) and $b_{1,2}$ measures the inter-specific competition of plants of crop 2 on the productivity of crop 1 (m^2 g^{-1}). The ratio between the last two parameters ($b_{1,1}/b_{1,2}$) denotes the relative competitive ability between crop 1 and crop 2 with respect to the production of the first crop. For the second crop, an identical equation can be used to describe crop yield in dependence of the densities of both crops, using the competition coefficients $b_{2,2}$ and $b_{2,1}$. Based on all four competition coefficients combined, the niche differentiation index (NDI) can be calculated (Spitters, 1983):

$$\mathrm{NDI} = \frac{b_{1,1}}{b_{1,2}} \times \frac{b_{2,2}}{b_{2,1}} \tag{4.2}$$

which represents the ratio between the intra-specific and the inter-specific competition coefficients of the intercropping system. If this ratio exceeds unity, intra-specific competition exceeds inter-specific competition, indicating there is niche differentiation.

For each density (pure stand) and density combination (intercrop), yields obtained under non-fertilized conditions were averaged over the three replications. The yield-density equation of Spitters (1983) was then fitted to these averages, using the non-linear regression procedure of the SPSS-statistical package (SPSS, 2001), resulting in estimates for the various competition coefficients.

To obtain an error estimate for the relative competitive ability of both crops with respect to the productivity of the first crop ($b_{1,1}/b_{1,2}$), the original model of Spitters (Equation 4.1) was rewritten as:

$$Y_{1,2} = \frac{N_1 W_{1,0}}{1 + a(N_1 + 1/c \times N_2)} \tag{4.3}$$

where, $W_{1,0}$ represents the virtual biomass of an isolated plant of crop 1 (= $1/b_{1,0}$; g plant^{-1}), parameter a represents the ratio $b_{1,1}/b_{1,0}$ (m^2 plant^{-1}) and parameter c represents the ratio $b_{1,1}/b_{1,2}$. This equation was fitted to the obtained average yields, using non-linear regression.

Data from recommended densities in pure stands, which were 6.7 plants m^{-2} for maize (M_2) and 22.2 plants m^{-2} for sesame (S_2), and data of the corresponding intercrop (M_2S_2) were used to analyse the effects of nitrogen and phosphorus fertilization on the performance of component crops. For analysis of treatment effects on shoot dry matter and marketable yield of maize and sesame, data were subjected to the General Linear Model (GLM) procedure of the SAS program (SAS, 1999). The same procedure was used to analyse nitrogen and phosphorus content of maize and sesame shoot tissue in pure stand and intercrop. For comparison of means, least significant difference (LSD) was used wherever appropriate. To study the overall productivity of the maize-sesame intercrop, data on shoot dry matter and marketable yield were used to calculate Land Equivalent Ratios (LER). The LER, which was described by Mead and Willey (1980), was calculated according to the following equation:

$$\text{LER} = \frac{Y_{1,2}}{Y_{1,1}} + \frac{Y_{2,1}}{Y_{2,2}} \tag{4.4}$$

where, Y is the crop yield in g m^{-2} and subscripts 1 and 2 denote crop 1 and crop 2. $Y_{1,1}$ and $Y_{2,2}$ are the mean pure stand yield for crop 1 and crop 2, respectively, which were used as reference yields (Mead and Willey, 1980; Oyejola and Mead, 1982). $Y_{1,2}$ and $Y_{2,1}$ refer to the yields of crop 1 and crop 2 in intercrop. The LER characterizes the performance of an intercrop by giving the relative land area under sole crops, required to produce the yields achieved in intercropping. The ratio of yield in intercrop and yield in pure stand for each crop separately, denoted as partial Land Equivalent Ratio (pLER), was used to analyse the competitive relations in the intercrop.

Results

Competition and niche differentiation

At Marambo, the more fertile site, marketable yield under non-fertilized conditions was around 275 g m^{-2} for maize and around 75 g m^{-2} for sesame. At Mkumba, marketable yield of both crops under these conditions was clearly lower with values of 68 g m^{-2} for maize and 12 g m^{-2} for sesame. For each density (pure stand) and density combination (intercrop), yields obtained under non-fertilized conditions were averaged over three replications. The yield-density equation of Spitters (1983) was then fitted to these averages, using non-linear regression. In nearly all situations Spitters' yield-density equation provided a good description of the response surface. Analysis of the error-structure indicated a homogeneous distribution of residual variance with predicted yield. Percentage variance accounted for by the model was 46% or more (Tables 4.3 and 4.4). The regression on both shoot dry matter and seed yield for sesame at Mkumba 2002 resulted in a negative estimate of $b_{1,0}$. As the inverse of

Table 4.3. Estimates and standard errors (SE) of intercept ($b_{1,0}$), intra-specific ($b_{1,1}$) and inter-specific ($b_{1,2}$) competition coefficients and niche differentiation index (NDI) of maize and sesame for shoot biomass without fertilizer input at Marambo and Mkumba.

Param	Marambo 2000				Mkumba 2002			
	Maize		Sesame		Maize		Sesame	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
$b_{1,0}$	0.00140	0.00038	0.0207	0.0234	0.00553	0.00324	9.9E–09	0.084
$b_{1,1}$	0.00124	0.00006	0.00329	0.00090	0.00466	0.00042	0.0176	0.00292
$b_{1,2}$	0.00003	0.00001	0.0275	0.0050	0.00042	0.00009	0.0627	0.0155
$b_{1,1}/b_{1,2}$	37.8	11.2	0.120	0.039	11.0	2.5	0.287	0.156
r^{2*}	0.88		0.88		0.81		0.64	
NDI	4.54				3.16			

* adjusted r^2.

Table 4.4. Estimates and standard errors (SE) of intercept ($b_{1,0}$), intra-specific ($b_{1,1}$) and inter-specific ($b_{1,2}$) competition coefficients, and niche differentiation index (NDI) of maize and sesame for marketable yield without fertilizer input at Marambo and Mkumba.

Param	Marambo 2000				Mkumba 2002			
	Maize		Sesame		Maize		Sesame	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
$b_{1,0}$	0.00081	0.00199	0.121	0.079	0.0287	0.0105	1.1E-08	0.602
$b_{1,1}$	0.00362	0.00032	0.0107	0.0030	0.0104	0.0012	0.090	0.0184
$b_{1,2}$	0.00009	0.00005	0.124	0.022	0.00108	0.00031	0.308	0.0635
$b_{1,1}/b_{1,2}$	39.5	22.2	0.0862	0.0277	9.62	2.85	0.292	0.152
r^{2*}	0.46		0.91		0.80		0.53	
NDI	3.55				2.81			

* adjusted r^2.

parameter $b_{1,0}$ represents the initial increase of the rectangular hyperbola at low densities, a negative value is biologically unrealistic. For that reason, the fitting procedure for sesame at Mkumba 2002 was repeated under the condition that the estimate of $b_{1,0}$ should be larger than 0. As a result, the goodness of fit decreased from 0.85 to 0.64 for shoot biomass and from 0.88 to 0.53 for seed yield. Not surprisingly, the fitting procedure resulted in an estimate of $b_{1,0}$ which was nearly zero. More important however, was that the procedure resulted in a more realistic estimate of the asymptotic maximum yield attained at high plant densities. In this case, values of 56.8 g m^{-2} (shoot biomass) and 11.1 g m^{-2} (seed yield) were obtained. These values were close to the average yield obtained in the four pure stands (Fig. 4.1), and considerably

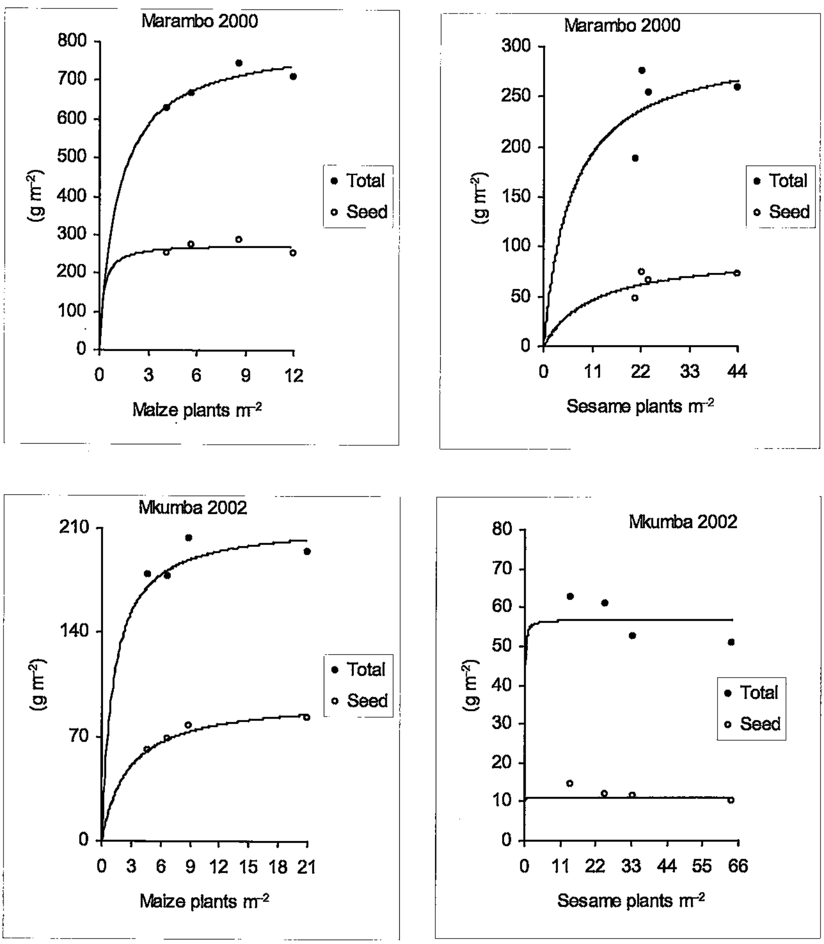

Fig. 4.1. Relationship between plant density and total shoot dry matter and seed yield (in g m^{-2}) for maize and sesame in pure stand without fertilizer input at Marambo 2000 and Mkumba 2002 in Southeast Tanzania.

higher than the estimates attained with the fit that did not contain the restriction to parameter $b_{1,0}$ (shoot biomass: 39.9 g m^{-2}; seed yield: 7.3 g m^{-2}). A reasonable estimate of the asymptotic maximum yield is highly relevant, as the inverse of this value corresponds to the intra-specific competition coefficient $b_{1,1}$. Furthermore, the restriction to the estimate of parameter $b_{1,0}$ hardly affected the estimate of the inter-specific competition coefficient $b_{1,2}$.

The standard error of the estimated competition coefficients varied from 5% till 55% of the estimated parameter value. Specifically at Marambo 2000, the coefficient expressing the intra-specific competition of sesame, as well as the coefficient expressing the inter-specific competition of sesame on maize, were estimated with large standard error. In this experiment, the range of established densities of sesame in the intercrop was very narrow and varied from 20-25 plants m^{-2}. In the second experiment the range was much wider, as densities varied from 10-35 plants m^{-2}.

For shoot biomass and marketable yield, nearly identical ratios between intra-specific and inter-specific competition coefficients ($b_{1,1}/b_{1,2}$) were obtained. At Marambo, intra-specific competition of maize exceeded inter-specific competition of sesame on maize with a factor of around 38, meaning that, from the point of maize, maize itself was 38 times as competitive as sesame. Maize thus sensed the presence of a total of 38 sesame plants as strongly as the presence of a single maize plant. For sesame, inter-specific competition was stronger than intra-specific competition. However, in this case the ratio between inter-specific and intra-specific competition was much lower than for maize. Sesame sensed the presence of one maize plant as strongly as the presence of around 10 plants of its own. For the intercropping system as a whole, intra-specific competition thus exceeded inter-specific competition, indicating that maize and sesame were complementary in resource use. This is represented in niche differentiation indices of 4.5 and 3.6 for shoot biomass and marketable yield, respectively. At Mkumba, niche differentiation indices were 3.2 for shoot biomass and 2.8 for marketable yield. In this case, maize was far less dominant as at Marambo. Maize was only around 10 times as competitive as sesame with respect to maize biomass. Sesame experienced maize plants only around 3 times as competitive as it experienced individual sesame plants.

Fertilizer response

At Mkumba, the application of nitrogen fertilizer resulted in 2.5 and 3.6 fold increases in pure stand yield of maize and sesame, respectively (Tables 4.5 and 4.6). Shoot biomass and marketable yield increased to the same extent. Phosphorus fertilization on the other hand did not cause any significant increase in yield. The application of a combination of nitrogen and phosphorus resulted in yields that were not significantly

Table 4.5. Effects of application of nitrogen and phosphorus fertilizer combinations on dry matter, partial Land Equivalent Ratio (pLER) and Land Equivalent Ratio (LER) for shoot biomass of maize and sesame grown in recommended densities (maize, 6.7 plants m^{-2}; sesame, 22.2 plants m^{-2}) at Mkumba and Marambo.

N and P fertilizer	Maize			Sesame			LER
combinations ($kg\ ha^{-1}$)	monocrop ($g\ DM\ m^{-2}$)	intercrop ($g\ DM\ m^{-2}$)	PLER	monocrop ($g\ DM\ m^{-2}$)	intercrop ($g\ DM\ m^{-2}$)	pLER	
Marambo 2000							
0	668.5	625.7	0.94	275.5b♣	95.3	0.35	1.29
40 P_2O_5	662.4	649.3	0.98	217.0c	108.6	0.50	1.48
45 N	762.3	796.3	1.04	319.0b	96.6	0.30	1.34
40 P_2O_5 + 45 N	815.5	884.1	1.08	367.6a	115.0	0.31	1.39
P-value**	0.3793	0.0771		0.0012	0.4590		
LSD (P=0.05)	NS*	NS		47.38	NS		
CV(%)	16.0	14.8		8.0	16.0		
Mkumba 2002							
0	178.2b	143.2c	0.80	61.0c	32.4	0.53	1.33
40 P_2O_5	196.8b	183.2c	0.93	66.3c	56.2	0.85	1.78
45 N	456.8a	425.4b	0.93	217.4a	75.1	0.35	1.28
40 P_2O_5 + 45 N	554.8a	613.4a	1.11	161.0b	58.3	0.36	1.47
P-value**	0.0081	0.0003		0.0005	0.1083		
LSD (P=0.05)	199.72	129.26		48.18	NS		
CV(%)	28.8	19.0		19.1	31.0		

♣ Means within a column followed by the same letter are not significantly different.

* NS = not significant, ** probability of treatment effects (significance level).

different from the yields obtained with the application of nitrogen only, except for shoot biomass of sesame, which was significantly lower with combined fertilization. Fertilizer application did not result in significant increases in N or P content of the shoot. For maize, average N and P content were 0.77% and 0.20%, respectively, corresponding to an extremely high P/N-ratio of 1/3.9. N-uptake in unfertilized conditions was 13.7 kg N ha^{-1}. Application of 45 kg N ha^{-1} caused an increased N-uptake of 35.2 kg N ha^{-1}, corresponding to a fraction nitrogen recovery of 0.48. For sesame, average N-content was 1.03%, and average P-content was 0.18%, indicating a P/N-ratio of 1/5.7. For this crop the uptake under non-fertilized conditions was 6.3 kg N ha^{-1}. N-application caused an N-uptake of 22.4 kg ha^{-1}, corresponding to a fraction nitrogen recovery of 0.36.

Table 4.6. Effects of application of nitrogen and phosphorus fertilizer combinations on marketable yield, partial Land Equivalent Ratio (pLER) and Land Equivalent Ratio (LER) for marketable yield of maize and sesame grown at recommended densities (maize, 6.7 plants m^{-2}; sesame, 22.2 plants m^{-2}) at Mkumba and Marambo.

N and P fertilizer combinations ($kg\ ha^{-1}$)	Maize			Sesame			LER
	monocrop Grain ($g\ m^{-2}$)	intercrop Grain ($g\ m^{-2}$)	pLER	monocrop Seed ($g\ m^{-2}$)	intercrop Seed ($g\ m^{-2}$)	pLER	
Marambo 2000							
0	275.9	251.7	0.91	73.7	24.5	0.33	1.24
40 P_2O_5	284.7	254.5	0.89	61.4	30.7	0.50	1.39
45 N	373.8	351.2	0.94	78.9	24.0	0.30	1.24
40 P_2O_5 + 45 N	418.3	344.9	0.82	79.7	26.5	0.33	1.15
P-value**	0.5470	0.1260		0.1019	0.5244		
LSD (P=0.05)	NS*	NS		NS	NS		
CV(%)	40.2	18.7		11.0	22.0		
Mkumba 2002							
0	68.3b♣	63.4b	0.93	12.0c	6.6	0.55	1.48
40 P_2O_5	74.0b	71.4b	0.96	15.7bc	11.0	0.70	1.66
45 N	180.8a	167.5a	0.93	44.2a	14.0	0.32	1.25
40 P_2O_5 + 45 N	221.4a	193.0a	0.87	30.2ab	11.2	0.37	1.24
P-value**	0.0284	0.0033		0.0073	0.0763		
LSD (P=0.05)	106.60	58.50		15.29	NS		
CV(%)	39.2	23.7		30.0	25.41		

♣Means within a column followed by the same letter are not significantly different.

*NS = not significant, ** probability of treatment effects (significance level).

In intercrop, maize yield under non-fertilized conditions was reduced to 80% (shoot biomass; Table 4.5) and 93% (grains; Table 4.6) of the yield obtained in pure stand. Fertilizer response was largely identical to what was observed in pure stand, though in this case the application of nitrogen and phosphorus combined resulted in a significantly higher shoot biomass than the application of nitrogen only. For sesame, intercrop yield under non-fertilized conditions was just around half of the yield in pure stand. Application of N, P or a combination of these two did not result in a significant increase in sesame yield. This illustrates that in intercrop maize benefited from the application of N-fertilizer, whereas sesame was not able to profit, probably due to the increased competition it received from maize. Partial LER-values of maize remained more or less identical (grain yield), or even increased (shoot biomass) after fertilization, whereas partial LER-values of sesame reduced after N-fertilization. In all situations LER exceeded one.

As in pure stand, fertilizer application did not result in significant differences in N and P content of the shoot. For N-content average values obtained for maize and sesame were 0.86% and 1.13%, respectively, whereas for P-content values of 0.25% (maize) and 0.16% (sesame) were found. N-uptake of the intercrop was 15.6 kg N ha^{-1} under non-fertilized conditions and 44.3 after application of 45 kg N ha^{-1}. This corresponds to a fraction N-recovery of 0.57.

On the more fertile soils of Marambo, yield levels were substantially higher than at Mkumba. Fertilizer application hardly caused significant differences in yield, though yields tended to increase after N-application and the combination of N and P fertilization always resulted in the highest yield. Only for shoot biomass of sesame in pure stand significant differences were observed. In intercrop, yields of maize were largely identical to the yields obtained in pure stand, resulting in partial LER-values varying from 0.82 to 1.08. For sesame, yield in intercrop was only 30%-50% of that obtained in pure stand. This illustrates the dominant position of maize in the intercrop.

As at Mkumba, fertilization did not result in significant differences in N and P content of the shoot tissue. Most remarkable was the high P-content of both maize (0.71% in pure stand; 0.75% in intercrop) and sesame (0.60% in pure stand; 0.52% in intercrop). N-content of sesame (2.25% in pure stand; 1.70% in intercrop) was clearly higher than that of maize (1.26% in pure stand; 1.17% in intercrop). Consequently, the P/N-ratios were even higher than at Mkumba, with values of 1/1.8 and 1/1.6 for maize in pure stand and intercrop, respectively, and values of 1/3.8 (pure stand) and 1/3.3 (intercrop) for sesame. In pure stand, fraction nitrogen recovery was poor with 0.26 for maize and 0.22 for sesame. In intercrop, fraction nitrogen recovery increased to 0.45.

Discussion

Intra-specific and inter-specific competition within a maize-sesame intercropping system were analysed at two different sites in the maize-sesame belt of Southeast Tanzania. In 2000, the experiment was conducted at Marambo, which is positioned in the valley, representing the more fertile area, which is commonly allocated for maize-sesame intercropping. Soil-analysis indicated that the cation exchange capacity (CEC) was very high, whereas the available phosphorus was rated as high (Table 4.1) (Banzi *et al.*, 1992). Organic C-content was 1.97%, which is considered medium, whereas total N-content was rated low (0.12%). The C/N ratio of 16.4 indicates that the quality of the organic matter was moderate. In 2002, the experiment was conducted at Mkumba, which is positioned at the upper slope of the soil catena. The land use system under this soil type is mainly cassava, cashew, sorghum and sometimes maize-sesame. CEC was rated very low, and available phosphorus was low as well. Organic C-content (0.56%) and total N (0.05) were both rated as very low, whereas the C/N ratio of 11.2 indicates that at least the quality of the relatively low amount of organic matter was good. Competitive relations were determined under non-fertilized conditions, reflecting farmers' practices. In a recent survey in the maize-sesame belt of South-east Tanzania, none of the respondents used organic or inorganic fertilizers (Chapter 2). About 92% of the farmers reported that inorganic fertilizers were not required because they perceived their soils are fertile enough. Lack of cash and the fact that fertilizers are not readily available were each mentioned by about one quarter of the respondents. Manure is not readily available, due to scarcity of livestock in the area.

Plant tissue analysis of maize and sesame indicated that at both sites the P/N ratio was very high. Generally, a ratio of 1/10 is considered optimal, whereas a ratio below 1/7 is indicative of nitrogen limitation (Kropff and Spitters, 1990). At Marambo, with ratios of 1/1.8 for maize and 1/3.8 for sesame, these low values were at least to some extent caused by the very high availability of phosphorus, resulting in high P-contents of 0.71% in maize and 0.60% in sesame. At Mkumba, P availability was rated as very low. In this case, the high P/N ratios of 1/3.9 for maize and 1/5.7 for sesame clearly emphasize the very poor availability of nitrogen. This was also demonstrated through the very strong crop response to N and NP fertilization at this site.

At both sites, maize was found to be more competitive than sesame. This was particularly obvious at Marambo, the site with the highest soil fertility. At Mkumba, it was observed that adding nitrogen led to an increased competitiveness of maize. This demonstrates that the availability of nutrients did not only affect yield level, but also affected the competitive relations between the component crops. Farmers have indicated that for them maize is the priority crop, as it should secure the basic food requirements of the households (Chapter 2). For this reason the observed shift in competitive relations following N-fertilization is not considered unfavourable, as it does not interfere with maize production. In the current experiments, the partial Land Equivalent Ratio of maize was always at least 0.80 (Tables 4.5 and 4.6). In other experiments with simultaneous sowing of maize and sesame (Chapters 3 and 5), this practice gave variable results, with reductions in maize yield up to 60%-70%. Due to the uncertainty on the consequences of simultaneous sowing for the reduction in maize yield, the majority of farmers prefer a risk-avoiding strategy, by introducing sesame at around two weeks after maize sowing (Chapter 2).

Comparison of the intra-specific and the inter-specific competition coefficients within the intercropping system indicated that at both sites intra-specific competition exceeded inter-specific competition, resulting in niche differentiation indices varying from 2.8 to 4.5. Since these values exceed one it indicates that maize and sesame are at least partially complementary in resource use, which is the basis for a yield advantage in intercropping. This quantitative observation is in line with the more qualitative perception of farmers, that maize and sesame are good companion crops that are not interfering too strongly.

These conclusions were drawn based on density-experiments that followed a row-based additive design with an inter-row distance of 75 cm. Such a spatial arrangement of plants does not provide the most homogeneous distribution of plants, rather it reflects farmers' practice, where a row-structure is preferred for reasons of practicality. The inter-row distance of 75 cm was based on the recommendation for maize, for which 75-90 cm is advised. There are two issues related to this experimental set-up that need to be considered. First, for sesame, an inter-row distance of 75 cm might be sub-optimal, as 50 cm is the recommended inter-row distance for this crop. Consequently, there is no proof that, particularly in the sesame pure stand, this configuration resulted in the highest attainable yield, as the area in between the rows might not have been fully exploited. The observed saturation of the yield-density curves in pure stand (Fig. 4.1) are not conclusive in this respect, as these curves are characteristic for this particular configuration. A more homogeneous distribution of plants might well have led to a higher maximum yield. For the current analysis, this implies that the intra-specific competition coefficient $b_{1,1}$, which is calculated as the inverse of the maximum yield obtained at high plant densities, might have been overestimated. Accordingly, such an overestimation might have led to an overestimation of the niche differentiation index. Second, it should be realized that additional plants of a particular species were always placed close to other individuals of this species, as plants were added to the existing rows of that species. For the same reason, additional plants of the other species were always introduced relatively far away. This procedure might well have biased the estimation of the competition coefficients, as it might have resulted in an overestimation of intra-specific competition, and an underestimation of inter-specific competition. Consequently, the observed complementarity might, to at least some extent, result from spatial complementarity between the crops, which is exclusively linked to the specific row-based configuration of the experiments. This observation might be more relevant from an ecological point of view than from an agronomic point of view, as farmers, particularly for maize, prefer to grow the crop in rows. These considerations however indicate that the conclusions on niche differentiation between maize and sesame can not simply be generalized to any configuration.

The results obtained by fitting the observed yields to the yield-density equation of Spitters, clearly illustrated that more accurate estimates of the competition coefficients are obtained when using a wider range of densities. Furthermore, in 2002, a negative estimate was obtained for parameter $b_{1,0}$, for both shoot biomass and seed yield of sesame. Spitters, just like other researchers, e.g., Shinozaki and Kira (1956), de Wit (1960), Wright (1981) and Watkinson (1981), based his regression approach on the assumption that in a pure stand, the response of crop yield to plant density can be described by a rectangular hyperbola. In that situation, parameter $b_{1,0}$ represents the reciprocal of the biomass of an isolated plant. Spitters (1983) also demonstrated, with maize as an example, that at very low plant densities there is no interplant competition so that per-plant weight remains constant with decreasing density and does not increase as is suggested by the hyperbolic equation. This implies that the rectangular hyperbola is only a suitable model for describing the yield – density response from a certain plant density onwards. Consequently, the observed biomass of an isolated plant is often smaller than the apparent biomass ($1/b_{1,0}$) obtained from extrapolation of the yield – density response at higher plant densities. For this reason, $b_{1,0}$ does not have a true biological meaning and is defined as the reciprocal of the virtual or apparent biomass of an isolated plant. For sesame in 2002, the estimate for $b_{1,0}$ was extremely low and resulted in a value smaller than 0. This is typical for situations where yields tend to decrease with increasing plant density. For several species this is not uncommon at high densities, as the relation between plant density and harvestable yield often follows a parabolic shape with a clear optimum density (de Wit *et al.*, 1979). However, in this case negative estimates were obtained for both seed yield and shoot biomass. One explanation might be that even at the lowest experimentally used plant density the maximum yield level was already obtained. An apparent negative yield trend with plant density might then simply result from the variability in experimental results. Negative estimates for $b_{1,0}$ have previously been reported by for instance Cousens (1991). He used this observation to illustrate and stress that extrapolation of the fitted yield-density equation outside the experimentally investigated density range is inappropriate. The question that remains is whether the addition of an extra density in between 0 and the lowest plant density (circa 14 plants m^{-2}) would have overcome the current problems. It is likely that an additional data-point in this range would have contributed to obtain a positive estimate for $b_{1,0}$. At the same time, there is also a chance that at such a density the rectangular hyperbola does not hold, as plants are not competing. In that case such an observation point would only obscure the estimate of intra- and inter-specific competition coefficients.

The results clearly illustrate that nitrogen fertilization was far more effective than the application of phosphorus. Particularly at the high fertility site phosphorus content in the plant tissue was very high with values of around 0.65%. This observation strongly questions the validity of the fertilizer recommendations for both maize and sesame, which advise to apply nitrogen and phosphorus in nearly equal amounts (TARO, 1987a; Katinila *et al.*, 1998). Furthermore, the results confirm that fertilization is most efficient at sites that are poor in soil fertility. At Mkumba, fraction nitrogen recovery was 0.48 and 0.36 for maize and sesame, respectively. At Marambo these values were clearly lower with 0.26 for maize and 0.22 for sesame. At both sites, however, fraction nitrogen recovery was highest in the intercropping situation with values of 0.57 at Mkumba and 0.45 at Marambo. These values illustrate the better exploitation obtained in intercropping and support the choice of farmers to combine both crops in an intercrop.

CHAPTER 5

Spatial arrangement does affect the performance of a maize-sesame intercrop

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Abstract

In Southeast Tanzania, the major food crop maize is often inter-seeded with the cash crop sesame using an additive design. Farmers consider maize an essential crop for securing their basic food requirements, whereas sesame is added to generate cash. Institutional recommendations for spatial arrangement based on pure stands, specifically sowing one maize plant per station and row sowing of sesame, do not match with farmers' practices in intercropping. Farmers use 2 to 3 maize plants per station, whereas sesame is introduced through broadcast sowing. Therefore, the objective of this research was to evaluate the effect of row and broadcast sowing of sesame as well as the effect of the number of maize plants per station on the performance of the maize-sesame intercrop. Five field experiments were conducted at two sites in Southeast Tanzania in 2001 and 2002, using maize variety *Staha* in combination with sesame variety *Nal-92*. This study showed that, both in a pure stand and in an intercrop, sesame seed yield was independent of the sowing method. Maize grain yield, however, suffered to a larger extent from the presence of sesame when this crop was broadcast sown. Two to three maize plants per station were found to be optimal in pure stand maize. With sesame present at a low density, this optimum remained, whereas at high densities of sesame, maize yield was independent of the number of maize plants per station. For sesame, seed yield either remained the same (low density) or increased (high density) with increasing the number of maize plants per station. It is concluded that farmers, given their priority for securing maize yield, will benefit most from a maize-sesame intercrop when using two to three maize plants per station, while introducing sesame through row sowing. The importance of developing recommendations for intercropping systems based on intercropping experiments instead of experiments in pure stand is discussed.

Key words: Broadcast sowing, intercropping, maize, number of plants per station, row sowing, sesame.

Introduction

In Southeast Tanzania, maize (*Zea mays* L.) is one of the most important food crops and sesame (*Sesamum indicum* L.) is a major cash crop. Farmers usually grow maize and sesame in an intercrop for various main reasons such as increased labour utilization efficiency, reduced risk of crop failure, scarcity of fertile land and income diversification (Katinila *et al.,* 1998; Chapter 2). While sesame is a common component of the intercrop, the crop is considered secondary to maize, as maize should secure the basic food requirement of the household. Sesame is just added as a bonus crop, to obtain cash. The maize-sesame system, therefore, is a typical example of the first intercropping situation described by Willey (1979a), where intercropping should give almost full yield of a main crop and any additional yield of a second crop is considered a benefit.

In this intercropping system, sesame is commonly added into a maize crop by broadcast sowing, as this is regarded a labour-saving practice compared to adding sesame in rows (Chapter 2). About three-quarters of the farmers sow maize in rows (Chapter 2). Farmers perceive that row sowing produces higher yields and makes the field operations, particularly weeding and harvesting, easier. Inter-row spacing varies from 60 to 200 cm, and in-row spacing ranges from 30 to 120 cm (Katinila *et al.*, 1998). The number of maize plants per station varies from two to five (FSR, 1992). In spite of this variation, maize plant density is generally close to the recommended pure stand density of 6.7 plants m^{-2}. Most farmers use two to three maize plants per station at an inter-row distance of 90 cm and an in-row distance of 60 cm. The use of more than one maize plant per station, as adopted by farmers, is not corresponding to the official recommendation of using one plant per station (TARO, 1987a). This recommendation is based on maize experiments in pure stands and supposes that an increased number of maize plants per station may result in an increased intra-specific competition, and consequently a lower yield. On the other hand, in intercropping situations, the use of wider in-row spacing with multiple plants per station may reduce inter-specific competition of maize on sesame.

The major objective of this research was to study spatial arrangement of component crops in an intercrop situation, as institutional recommendations do not match with farmers' practices. Specific objectives were to evaluate the effect of row and broadcast sowing of sesame as well as the effect of the number of maize plants per station on the performance of the maize-sesame intercrop.

Materials and methods

Design and treatments

In 2001 and 2002, five experiments on maize-sesame intercropping systems were conducted at Mkumba and Marambo in Southeast Tanzania. A first series of field experiments, consisting of Experiment I (Marambo 2001) and Experiment II (Mkumba 2002), was carried out to evaluate the effect of row and broadcast sowing of sesame on the performance of a maize-sesame intercrop. A second series of experiments, consisting of Experiment III (Mkumba 2001), Experiment IV (Marambo 2001) and Experiment V (Mkumba 2002), was conducted to assess the effect of the number of maize plants per station. An overview of the treatments used in both types of experiments is presented in Table 5.1. In all experiments, maize variety *Staha* was combined with sesame variety *Nal-92*. Both crops were sown according to recommended pure stand densities, which were 6.67 plants m^{-2} for maize and 22.2 plants m^{-2} for sesame (TARO, 1987a, b). An inter-row distance of 75 cm was used for

Table 5.1. Overview of the spatial arrangements of sesame (row sowing and broadcast sowing) and maize (number of plants per station (Pl/st)) used in pure stand and intercrop in Experiments I-V. Plant densities of maize and sesame were fixed at 6.7 and 22.2 plants m^{-2}, respectively.

Experiments I, II

Pure stand					Intercrop			
Maize		Sesame			Maize	Sesame		
Pl/st	Code	Row	Broadcast	Code	Pl/st	Row	Broadcast	Code
1	M1	X		SR	1	X		MSR
			X	SB	1		X	MSB

Experiments III, IV, V

Pure stand					Intercrop			
Maize			Sesame		Maize	Sesame		
Pl/st	III, IV	V	Row	Code	Pl/st	Row	III, IV	V
1	M1	M1	X	S	1	X	M1S	M1S
2	M2				2	X	M2S	
3	M3	M3			3	X	M3S	M3S
4	M4				4	X	M4S	
5	M5	M5			5	X	M5S	M5S
7		M7			7	X		M7S

both crops, whereas in the intercrops an additive design was used, with alternating rows of maize and sesame at 37.5 cm apart. In-row distances varied from 20 cm (1 plant per station) to 140 cm (7 plants per station) for maize and was 6 cm for sesame. When broadcast sown, sesame was spread evenly by hand. In all experiments, a randomized complete block design was used, with either four (Experiments I-IV) or five (Experiment V) replications. Individual plot size was 4.50 m × 6.00 m.

Agronomic practice

Maize and sesame were sown simultaneously, in the first week of January, except for Experiment I, which was sown on February 10, this was because of sesame seedling mortality due to water logging, which necessitated re-sowing. Maize was sown by dibbling, whereas sesame was sown in furrows and covered with soil. When broadcast sown, sesame was spread evenly by hand and incorporated into the soil. Both maize and sesame were thinned to their desired density at three weeks after sowing. No fertilizer was applied to reflect farmers' practice. The experiments were sprayed with a standard insecticide *Karate* (active ingredient: lambda-cyhalothrine) at a rate of 5 ml l^{-1} of water to protect sesame against sesame flea beetle (*Alocypha bimaculata* Jacoby). Application of the insecticide was done on a weekly basis during the first six weeks after emergence of sesame. Hand weeding was used to keep the experiments weed-free throughout the season, resulting in weeding operations at two, four and six weeks after sowing.

Data collection

For both maize and sesame, final harvest was conducted at physiological maturity. A net plot of 3.60 m^2 (0.75 m × 4.80 m) in the middle of the experimental plot was used. In the second series of experiments, the net plot size was adjusted to 3.75 m^2 (0.75 m × 5.00 m) for the treatments with five maize plants per station and to 3.15 m^2 (0.75 m × 4.20 m) for the treatments with seven maize plants per station. In this way, the length of the net plot represented a multiple of the distance between adjacent plant stations. Before harvesting, plant stand (density) of maize and sesame was recorded.

Fresh weight of the samples collected from the harvested area was recorded in the field for maize and sesame, separately, by using a weighing balance. Representative sub-samples of three maize plants and ten sesame plants were taken from these samples and weighed. Weight of the sub-samples was again recorded in the laboratory to check whether material was lost during transport. In the laboratory, the grains of maize were separated from the straw (mainly cob stem, stem, leaves, tassels) and fresh weights of grains and straw were determined. Of the sub-sample, a sub-sub-sample of the straw was taken, and weighed. The grain sub-sample and the sub-sub-sample of the straw were dried in the oven for 16 hours at 105 °C. Dry weight was determined directly after weighing the materials out of the oven. Grain size was determined based on a sample of 100 grains. For sesame, the capsules were separated from other organs (mainly leaves and stem) and both components were weighed separately and oven-dried at 105 °C for 16 hours. Weight of both components was again determined directly after drying. The capsules were threshed and seed yield was recorded. Additionally, seed size was determined based on a sample of 1000 seeds. For both crops, harvest index was determined by taking the ratio between seed yield and shoot biomass.

Data analysis

To assess intercrop yield of maize and sesame under row and broadcast sowing of sesame, data on shoot dry matter and seed yield of maize and sesame were analysed using General Linear Model (GLM) of the SAS program (SAS, 1999). If appropriate, the least significant difference (LSD) was used to compare treatment means. The orthogonal polynomial method (Gomez and Gomez, 1984) was used to select the lowest degree polynomial that best described the relationship between number of maize plants per station and dry matter and seed yield for maize mono and maize-sesame intercrop using the SAS program (SAS, 1999). To study productivity of the maize-sesame intercrop, data on biomass and marketable yield were used to calculate Land Equivalent Ratios (LER). The LER, which was described by Mead and Willey (1980), was calculated according to the following equation:

$$LER = \frac{Y_{\mathrm{m,s}}}{Y_{\mathrm{m,m}}} + \frac{Y_{\mathrm{s,m}}}{Y_{\mathrm{s,s}}}$$

where, Y is the crop yield in g m^{-2} and suffixes m and s denote maize and sesame. $Y_{\mathrm{m,m}}$ and $Y_{\mathrm{s,s}}$ are pure stand yield for maize and sesame, respectively, which were used as reference yields (Mead and Willey, 1980; Oyejola and Mead, 1982). $Y_{\mathrm{m,s}}$ and $Y_{\mathrm{s,m}}$ are yields of maize and sesame in intercrop, respectively. The ratio of yield in intercrop and yield in pure stand for each crop separately, denoted as partial Land Equivalent Ratio (pLER), was used to analyse the competitive relations in the intercrop.

Results

Influence of sowing method of sesame (Experiments I and II)

In sesame pure stand, no difference in shoot dry matter and seed yield between row and broadcast sowing was observed (Table 5.2). The yield level at Marambo 2001, with a relatively fertile soil, but with late sowing, was much lower than at Mkumba 2002. In an intercrop, dry matter and seed yield were significantly lower than in a pure

Table 5.2. Effect of row sowing and broadcasting of sesame on shoot dry matter and marketable yield of maize and sesame in pure stand and intercrop in Experiment I (Marambo 2001) and Experiment II (Mkumba 2002). pLER indicates partial Land Equivalent Ratio while LER designates Land Equivalent Ratio. For sesame, average of broadcast and row sown yield in pure stand was used as reference for calculating LER. For an explanation of treatment abbreviations see Table 5.1.

	Sesame				Maize						
Sowing method of sesame	DM ($g\ m^{-2}$)	Seed ($g\ m^{-2}$)	pLER (DM)	pLER (seed)	DM ($g\ m^{-2}$)	Grain ($g\ m^{-2}$)	HI	pLER (DM)	pLER (seed)	LER (DM)	LER (seed)
Experiment I											
M1					834.8a*	394.8a	0.47				
SR	49.7	8.6									
SB	47.6	8.7									
MSR	30.9	5.2	0.64	0.60	720.7a	321.3a	0.45	0.86	0.81	1.50	1.41
MSB	35.5	6.7	0.73	0.77	454.7b	185.2b	0.41	0.54	0.47	1.27	1.24
P-value**	0.1154	0.2529			0.0033	0.0059	0.3678				
LSD (P=0.05)	NS	NS			162.52	99.93	NS				
CV (%)	27.6	35.6			14.0	19.2	13.6				
Experiment II											
M1					322.5a	134.5a	0.42a				
SR	114.3a	19.5a									
SB	110.0a	19.0a									
MSR	60.1b	9.7b	0.54	0.50	154.3b	60.0b	0.38ab	0.48	0.45	1.02	0.95
MSB	60.3b	10.0b	0.54	0.52	109.6c	41.8c	0.36b	0.34	0.31	0.88	0.83
P-value**	0.0017	0.0004			0.0001	0.0001	0.0366				
LSD (P=0.05)	27.67	4.18			36.61	17.39	0.04				
CV (%)	20.1	18.0			10.8	12.8	6.5				

* Means in the column followed by the same letter do not differ significantly, NS=Not significant, ** Significance level.

stand. In the presented results, this significant difference is only obvious for Mkumba 2002. However, a two-way analysis based on cropping system (pure stand and intercrop) and sowing method (row and broadcast) revealed that also for Marambo 2001 significant differences between pure stand and intercrop were present for dry matter ($P < 0.05$), but not for seed yield ($0.05 < P < 0.10$). Similar to what was observed in pure stand, shoot dry matter and seed yield of sesame in intercropping were independent of sowing method. For both experiments, no significant differences between treatments for harvest index and 1000-seed weight were observed. The harvest index was 0.18, whereas the 1000-seed weight was 2.32 g at Marambo 2001 and 2.56 g at Mkumba 2002.

In the intercrop, sowing method of sesame did have a significant effect on maize shoot dry matter and grain yield (Table 5.2; $P<0.01$). In both experiments, broadcast sowing of sesame into a maize crop caused a significant reduction in shoot dry matter and grain yield of maize compared to pure stand maize and the intercrop with row sown sesame. For row sowing, shoot dry matter and grain yield of maize in Experiment II were significantly lower than maize yield in pure stand, whereas in Experiment I no significant difference was observed. In Experiment II, the harvest index in the intercrop with broadcast sown sesame was significantly lower than the harvest index of the pure stand maize. In the intercrop with row sown sesame, an intermediate value was obtained that did not differ significantly from the harvest index in the other two treatments. In the first experiment, a similar trend was found, though the differences were not significant.

For both experiments, the average of broadcast and row sown sesame yield in pure stand was used as reference for calculating partial LER, as pure stand yield in both systems was nearly identical. For sesame, partial LER was always at least equal to 0.50, indicating that sesame was performing well. No significant difference was observed between row and broadcast sown sesame. For maize, partial LER in intercropping with row sown sesame was significantly higher than that in intercropping with broadcast sown sesame. For row sowing, partial LER varied from over 0.80 in Experiment 1 to around 0.50 in the second experiment. For broadcast sowing, partial LER of maize varied from around 0.50 in Experiment 1 to just over 0.30 in the second experiment. The stronger inter-specific competition of sesame on maize when broadcast sown, was responsible for a poor performance of the intercrop in the second experiment. In the first experiment LER exceeded one, but also in this case the intercrop with broadcast sown sesame performed considerably less than the intercrop with row sowing.

Influence of number of maize plants per station (Experiments III, IV and V)

The experiments in 2001 (Experiment III in Mkumba; Experiment IV in Marambo) suffered from a poor establishment of sesame, because of waterlogging. In Experiment IV, establishment of sesame was very irregular, and for this reason only the plots with pure stands of maize were analysed. In Experiment III, the desired density of sesame (22.2 plants m^{-2}) was not obtained. Average density at final harvest was found to be 6.3 plants m^{-2}.

For maize in pure stand in Experiments III (Mkumba 2001) and IV (Marambo 2001), a quadratic relationship was observed between number of maize plants per station and maize dry matter and grain yield (Fig. 5.1). For Experiment V (Mkumba 2002), the relationship between number of maize plants per station and yield was cubic. Based on the results of all three experiments combined, 2-3 maize plants per station seem to be optimal, resulting in maximum or close to maximum shoot dry matter and grain yield. Harvest index (average 0.46) and 100-grain weight (average 21.9 g) were not significantly affected by number of plants per station. As observed in the preceding experiments (I and II), dry matter and grain yield at Marambo (Experiment IV) were higher than at Mkumba (Experiments III and V).

In the intercrop, a quadratic relationship between number of maize plants per station and dry matter and grain yield of maize was observed in Experiment III (Fig. 5.2.). The relationship was to a large extent identical to what was observed in pure stand, indicating that maize did not suffer a lot from the presence of 6.3 plants m^{-2} of sesame. Optimum number of maize plants per station for both shoot dry matter and grain yield was around three. Only at five plants per station shoot dry matter and grain yield of maize were considerably lower than in pure stand. In Experiment V, maize production in intercrop was found to be independent of the number of maize plants per station and yielded an average of 256 g m^{-2} and 115 g m^{-2} for shoot dry matter and grain yield, respectively. Compared to maize in pure stand this was a considerable reduction, particularly at the two lowest numbers (1 and 3) of maize plants per station.

In Experiment III, average shoot dry matter and seed yield of sesame in pure stand were 58.1 and 11.9 g m^{-2}, respectively. In the intercrop, both shoot dry matter and grain yield were nearly half of pure stand yield. No clear relation between number of maize plants per station and sesame yield was observed, though variability increased with a higher number of maize plants per station (Fig. 5.3). In Experiment V, average shoot dry matter and seed yield of sesame in pure stand were 206 and 41 g m^{-2}, respectively. In the intercrop, shoot dry matter and seed yield of sesame increased with greater number of maize plants per station, and this increase was best described by a quadratic function. The rate of increase was highest at a low number of plants per station, whereas with higher number of plants per station a plateau was approached. In

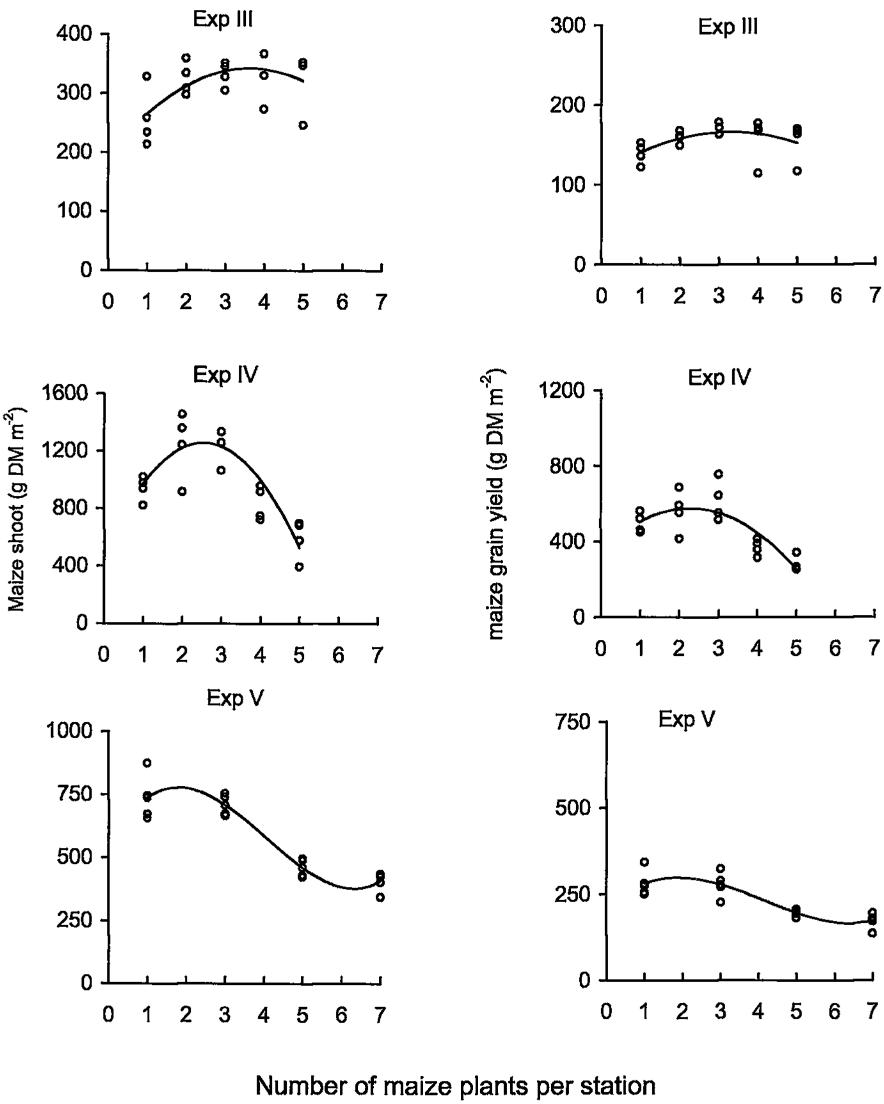

Fig. 5.1. Relationship between the number of maize plants per station and yield (shoot dry matter and grain) of maize in monoculture in Experiment III (Mkumba 2001), Experiment IV (Marambo 2001) and Experiment V (Mkumba 2002), Southeast Tanzania.

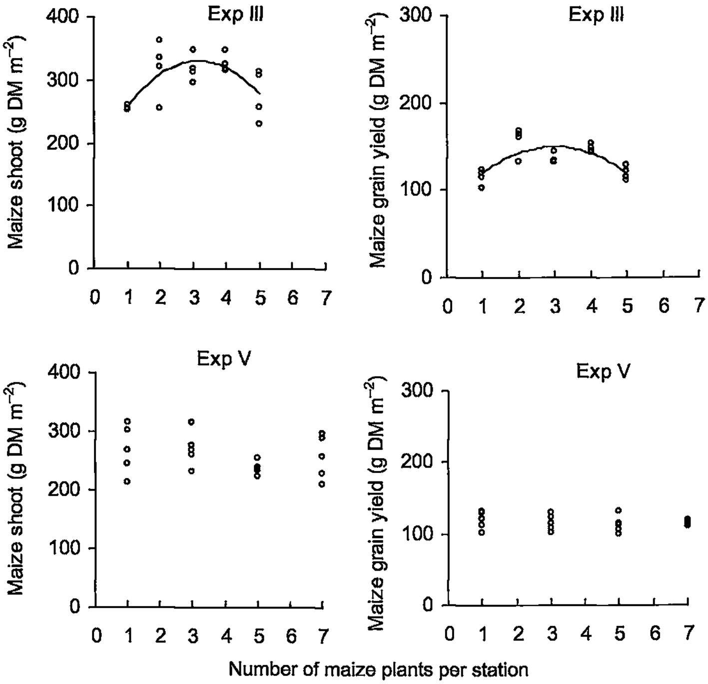

Fig. 5.2. Relationship between the number of maize plants per station and yield (shoot dry matter and grain) of maize in intercropping in Experiment III (Mkumba 2001) and Experiment V (Mkumba 2002), Southeast Tanzania.

both experiments, harvest index (average 0.20) and 1000-seed weight (average 2.88 g) was not significantly affected by the number of maize plants per station. In the intercrop, sesame near to a maize station was harvested separately from sesame growing in between two stations. For this purpose, the neighbouring maize row was projected on the row of sesame. Sesame growing within 10 cm to the right or the left side of the projected maize station (nearby) was harvested separately from the remaining sesame (far away), to analyse the in-row variability of sesame. The results are presented in Fig. 5.4. In treatment M1, there was no distinction, as all sesame plants were growing nearby the maize station. In M3, with an in-row distance of maize of 60 cm, both the sesame plants nearby the maize station as well as the sesame plants far away from the station were benefiting from the aggregation of maize plants. With a higher number of maize plants per station, the sesame plants close to the maize station started to suffer from increased inter-specific competition, whereas the sesame plants further away from the station profited even further, resulting in an increased in-row variability of sesame.

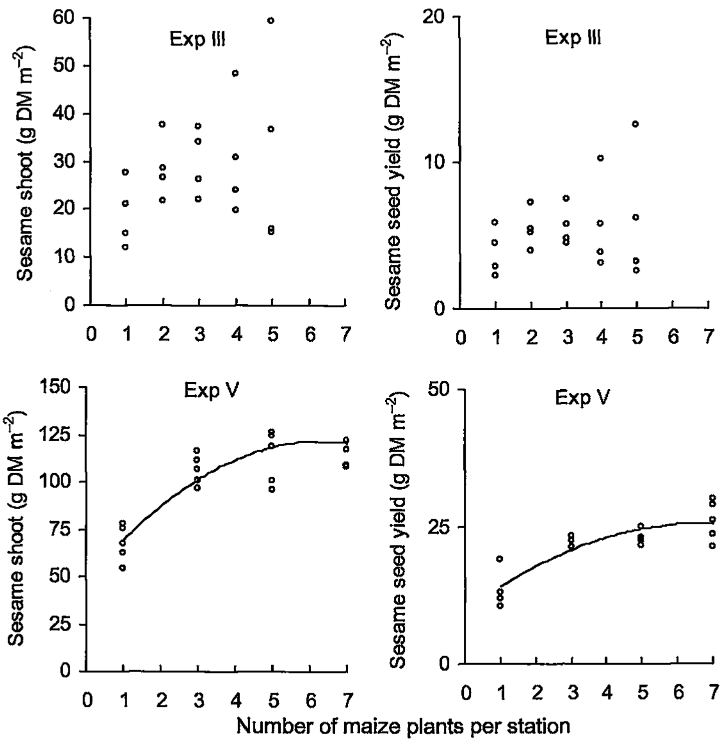

Fig. 5.3. Relationship between the number of maize plants per station and yield (shoot dry matter and seed) of sesame in intercropping in Experiment III (Mkumba 2001) and Experiment V (Mkumba 2002), Southeast Tanzania.

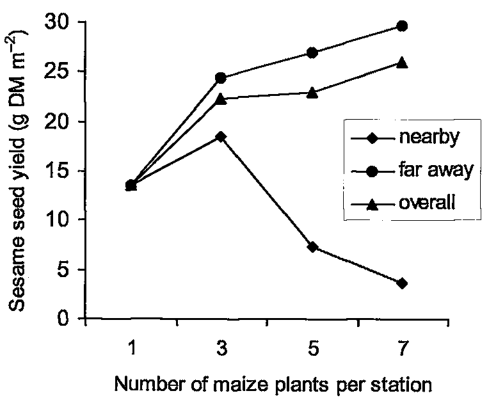

Fig. 5.4. Relationship between the number of maize plants per station, overall sesame yield and sesame yield nearby and away from the maize station in a maize-sesame intercropping system (Experiment V; Mkumba 2002). All yields are expressed in g m^{-2}. For a definition of nearby and far away from the maize station, see text.

For Experiments III and V, partial LER-values for both maize and sesame were calculated to evaluate the performance of both crops in intercropping (Table 5.3). For maize, two partial LER-values were calculated. First, the pure stand yield obtained with the corresponding number of maize plants per station was used as a reference. This figure indicates to which extent yield in intercrop was affected by the presence of sesame. Second, the pure stand yield obtained with three maize plants per station, being the configuration with the highest grain yield, was used as a reference. LER-values for dry matter and marketable yield largely followed the same trend, and for that reason only the result of the marketable yield is described. In Experiment III, with an average sesame density of only 6.3 plants m^{-2}, the introduction of sesame caused yield reductions between 2 and 23%. Partial LER-values typically followed an optimum curve, with maximum values at 2-4 plants per station, and lower values at both ends. This response closely resembles the yield response of maize in pure stand, indicating that for maize in this experiment intra-specific competition of maize was more important than inter-specific competition of sesame. Partial LER for sesame was around 0.50, except for the intercrop with one maize plant per station, were a value of

Table 5.3 Land Equivalent Ratio (LER) and partial LER (pLER) for shoot biomass and marketable yield of maize-sesame intercrops as influenced by number of maize plants per station in Experiment III (Mkumba 2001) and Experiment V (Mkumba 2002). Both pure stand yield obtained with an identical number of maize plants per station (Mi) and maximum yield of maize in pure stand obtained by optimum number of maize plants per station (M3) were used as reference for calculating pLER of maize.

Number of maize plants per station	pLER - Shoot biomass				pLER - Marketable yield			
	Maize		Sesame	LER	Maize		Sesame	LER
Experiment III	Mi	M3		M3	Mi	M3		M3
M1S*	0.99	0.77	0.33	1.10	0.83	0.68	0.32	1.00
M2S	0.98	0.96	0.49	1.45	0.98	0.92	0.46	1.38
M3S	0.96	0.96	0.52	1.48	0.80	0.80	0.47	1.27
M4S	0.98	0.98	0.53	1.51	0.94	0.88	0.48	1.36
M5S	0.85	0.83	0.55	1.38	0.77	0.70	0.51	1.21
Experiment V								
M1S	0.36	0.38	0.33	0.71	0.42	0.43	0.33	0.76
M3S	0.38	0.38	0.52	0.90	0.41	0.41	0.55	0.96
M5S	0.52	0.33	0.55	0.88	0.57	0.40	0.56	0.96
M7S	0.63	0.36	0.59	0.95	0.66	0.41	0.63	1.04

* For an explanation of treatment abbreviations see Table 5.1.

0.32 was obtained. In Experiment V, with a sesame density of about 22.2 plants m^{-2}, the effect of sesame on maize was much stronger, and maize only yielded about 40% of the highest pure stand yield. Partial LER based on pure stands with an identical number of maize plants per station indicated that the inter-specific competition of sesame became less pronounced at a higher number of maize plants per station. The partial LER based on a pure stand of maize with three plants per station showed however that maize production in all intercropping situations was nearly identical. This indicates that at a higher number of maize plants per station an increased level of intra-specific competition cancelled out the benefit from a reduced level of inter-specific competition from sesame. Partial LER of sesame increased with a higher number of maize plants per station and ranged from 0.33 with one plant per station to 0.63 with seven plants per station. In Experiment III, LER clearly exceeded one, except for the intercrop with one maize plant per station, where LER was exactly one. In Experiment V, LER-values of around one were obtained for all configurations, except for one maize plant per station, were LER was only 0.76.

Discussion

The experiments described were conducted in 2001 and 2002. In 2001, all experiments suffered from waterlogging shortly after sowing, resulting in poor emergence and seedling mortality of sesame. Because of the poor establishment of the sesame crop, Experiment I was re-sown, density of Experiment III was well below the intended density (6.3 versus 22.2 plants m^{-2}) and for Experiment IV only pure stand maize plots were taken into account. Maize survived this stress factor and was not severely affected. These observations clearly illustrate the risks associated with growing sesame in pure stand. For farmers this risk is an important motive for adding sesame to maize, rather than growing it in pure stand (Chapter 2). In case of waterlogging, sesame in intercrop is as severely affected as in pure stand. However, in intercrop the main crop maize survives and will be able to partly compensate for the lesser performance of sesame. This is clearly illustrated when comparing the partial LER of maize obtained in the experiment with the poor establishment of sesame (Experiment III; pLER ≈ 0.80) with the values obtained in the other experiments that were sown early January and had a good establishment of sesame (Experiments II and V; pLER ≈ 0.45).

In Southeast Tanzania, row sowing of sesame is recommended because it facilitates field operations such as obtaining the proper plant density, weeding and insect-pest control. The study showed that the method of sowing, either row or broadcast, did not have an effect on sesame yield. This was observed both in pure stand as well as in the intercrop with maize. For pure stand sesame these observations confirm earlier findings in Southeast Tanzania (e.g., Taylor and Chambi, 1986; Katinila *et al.*, 1995). In the intercrop, in contrast to sesame, grain yield of maize was affected by the method of sowing sesame. When broadcast sown, sesame caused reductions in grain yield of 53% (Marambo 2001) and 69% (Mkumba 2002). These reductions were significantly higher than the yield reductions of 19% and 55% obtained with row sowing. It seems that with broadcast sowing, sesame puts a stronger inter-specific competitive stress on maize. As sesame produced an identical yield as with row sowing, the resource exploitation of the system as a whole dropped, which is reflected in the lower LER-values obtained with broadcast sowing. Still, farmers introduce sesame through broadcast sowing, mainly because this is perceived a labour-saving practice. Broadcast sowing allows for a quick introduction of the sesame crop, particularly because this practice can be easily combined with the first-weeding operation. However, for subsequent weeding operations broadcast sowing might bring about a higher labour demand, as care is required not to damage the crop.

In 1987, the Tanzanian Agricultural Research Organization (TARO) reported the results of various studies on the effect of number of maize plants per station on maize grain yield in pure stand. They reported that at a constant overall density of 4.4 plants m^{-2}, there was no significant difference in grain yield between one (75 cm × 30 cm), two (75 cm × 60 cm) and three (75 cm × 90 cm) maize plants per station. Based on these results one maize plant per station was adopted as the general recommendation for the whole of Tanzania (TARO, 1987a; Bisanda *et al.*, 1998; Mafuru *et al.*, 1999; Katinila *et al.*, 1998). In the current study, a range of number of maize plants per station at a constant density of 6.7 plants m^{-2} was examined both in pure stand and in intercrop. Based on all three experiments combined, 2-3 maize plants per station was found to be the optimum. For each experiment separately, a trend analysis was conducted. As the research was aimed at identifying the optimum, rather than at detecting significant differences between individual treatments, trend analysis is considered a more suitable method than multiple comparison procedures (Gomez and Gomez, 1984). The current results confirm the validity of this statement, as also in the current experiments the use of a multiple comparison procedure did not result in detecting a significant difference in grain yield among one, two and three plants per station.

In the intercropping system, two distinct situations could be discerned. First, in Experiment V, with an average pLER of maize of 0.41, grain yield of maize was independent of number of maize plants per station (range: 1-7 plants per station). In pure stand, yields obtained with five and seven plants per maize station were clearly lower than the yields obtained with one and three maize plants per station. In this situation, the more even distribution of maize plants caused less intra-specific competition, resulting in a higher crop yield. In intercrop this advantage disappeared, as inter-specific competition of sesame on maize also started to play a major role. A more even distribution of maize then implies a strong interference between maize and sesame, as more plants of both species are situated in one another's sphere of influence. Consequently, the presence of sesame resulted in a higher level of inter-specific competition of sesame on maize. The lower level of intra-specific competition was, thus, a higher level of inter-specific competition resulting in nearly identical maize yields independent of the number of maize plants per station. For sesame, a steady increase in seed yield with increasing maize plants per station was observed. This reflects the lower level of interference between maize and sesame at a higher aggregation level of maize plants. Figure 5.4 further confirms these findings as it illustrates that with a higher number of maize plants sesame plants nearby a maize station suffered stronger from inter-specific competition. At the same time, the sesame plants away from the station profited to an even larger extent, resulting in a higher overall sesame yield.

In Experiment III, where maize was far less affected by sesame (average pLER of maize of 0.80) grain yield of maize followed an optimum curve, with a maximum yield at around three plants per station. The shape of this response curve was nearly identical to the response function of maize in pure stand, indicating that in this situation the intra-specific competition of maize was far more influential than the inter-specific competition of sesame. Sesame seed yield was on average 5.7 g m^{-2}, except for the intercrop with one maize plant per station, where a yield of 3.9 g m^{-2} was obtained. Farmers in Southeast Tanzania are primarily interested in securing their basic food requirement (Chapter 2). For this reason, priority is given to the maize crop and only intercrops in which maize yield is not severely reduced by sesame are considered acceptable. In the current experiments, sesame was introduced simultaneously with maize, though most farmers inter-seed sesame into the maize crop at around two weeks after sowing of the maize. The reason for introducing sesame simultaneously with maize was the use of the improved sesame variety *Nal-92*, which has a superior yield and apart from that a white seed colour, a characteristic which is strongly promoted because of a high demand in the international market (Kamwela, 1993). At the same time, the genetic uniformity of such an improved variety is far higher than that of the more commonly used local sesame varieties, and particularly for experimentation this is considered an advantage. As variety *Nal-92* is known to be less competitive than the local sesame varieties, it was decided to introduce sesame simultaneous with maize. The average partial LER of maize obtained in the experiments with a sesame density of 22.2 plants m^{-2} (Experiments I, II and IV) was 0.48 (range 0.81-0.31), demonstrating that even for the less competitive variety *Nal-92*, simultaneous introduction seems too early. Partial LER of maize in Experiment III, with a poor establishment of sesame resulting in a density of only 6.3 plants m^{-2}, was on average 0.80. Unintentionally, this experiment thus gave a better representation of an intercrop as desired by farmers, in which a substantial maize yield is assured. The results from this experiment demonstrate that in situations were competition from sesame is marginal, the response of maize grain yield to the number of maize plants per station is largely identical to the response in pure stand. At the same time, sesame yield was hardly affected by number of maize plants per station in this situation. Consequently, it is concluded that in the maize-sesame intercrop, given the objective of the farmers, two to three plants per maize station is the optimum configuration.

In Southeast Tanzania, research on maize and sesame crops has been conducted for more than 20 years. Farmers do not follow recommendations related to spatial arrangements developed for maize and sesame based on pure stands. The current study confirmed that two to three maize plants per station, as adopted by farmers, was superior to institutional recommendation of one maize plant per station. This demonstrates that farmers have valuable knowledge, and that scientists should tap creative abilities of farmers to reveal the relevance of farmers' practice and refine agricultural research recommendations (URT, 1997). In line with this, Bentley and Andrews (1992) noted that there exist knowledge gaps between farmers and researchers. They concluded that better technologies could be developed if the two would amalgamate. The present research findings confirm these conclusions.

CHAPTER 6

General discussion

General discussion

In this study, the maize-sesame production system in Southeast Tanzania was studied. Ssurveys were conducted to understand farmers' motives for intercropping maize and sesame and to be aware of the socio-economic background. Additionally, the influence of various factors, such as sowing time, fertilization and spatial arrangement, on performance and interplant competition within a maize-sesame intercropping system was studied experimentally and data were quantitatively analysed using descriptive models. This chapter discusses the results of the different chapters in this thesis in relation to each other and gives future perspectives.

Intercropping systems: Farmers benefits

Intercropping, which can be defined as growing two or more crops on the same piece of land (Willey, 1979a, b; Papendick *et al.,* 1976) is a widespread practice in subsistence farming all over the tropics. The most commonly used systems are: (1) mixed intercropping, where two or more crops are grown simultaneously, without a specific spatial arrangement; (2) row or strip intercropping, where two or more crops are grown simultaneously, with one or more crops planted in rows or strips; (3) relay intercropping, where two or more crops are grown simultaneously with only a partial overlap of their growing cycle (Kropff and Goudriaan, 1994). Intercropping systems are used in Africa, India, and other parts of Asia and in South and Central America (Petersen, 1994). Mead and Riley (1981), in a review on intercropping research, pointed out that 98% of cowpea in Africa, 90% of the beans in Columbia, 73% of the beans in Guatemala, 80% of the beans in Brazil, and 60% of the maize in Latin America are produced in an intercropping situation. A lot of research on intercropping systems has focused on identifying reasons for farmers to practice mixed cropping systems. Increased land productivity (Minae *et al.,* 1998; Grisley and Mwesigwa, 1994; Jiang *et al.,* 1994; Rhoades and Bebbington, 1990), demand for extra food and fluctuating or unpredictable prices of cash crops (Onsongo, 1997), reduced risk of crop failure (de Wit, 1960; Cowell *et al.*, 1989; Lynam *et al.*, 1986; Minae *et al.,* 1998), increased labour utilization efficiency (Rhoades and Bebbington, 1990), crop diversification (Minae *et al.,* 1998; Innis, 1997; Lynam *et al.,* 1986), soil and water conservation practice (Michael, 1998; Kebede-Asrat *et al.*, 1996; Innis, 1997; Rhoades and Bebbington, 1990) and control of insect pests, diseases and weeds (Innis, 1997) are the major reasons for intercropping. These production systems tend to be low input, risk reducing approaches that enable crop diversification and the fulfilment of subsistence objectives. Fornage *et al.* (1986) pointed out that the diversity of mixed cropping strategies is a measure of the heterogeneous nature of the environment. Furthermore, the selected mixed cropping strategy also reflects farmers' objectives and production possibilities. Poor farmers produce mainly annual crops, use traditional farming techniques and market only a limited proportion of their products. Wealthy and innovative farmers, on the other hand, produce either a mixture of perennial and annual crops or exclusively perennial crops, employ a fairly high level of technology and market a large proportion of their products. Masae *et al.* (1995) stated that research into alternative management practices needs to account for the place of intercropping within the overall farming system and the trend towards greater commercialization of intercropping. Therefore an extensive socio-economic survey was conducted in this study (Chapter 2).

Intercropping research relevant to smallholder farmers requires understanding of farmers' needs and priorities and this is a good starting point for technical research to identify relevant researchable areas. Therefore, farmer involvement in research is important because the acceptance or rejection of a new intercropping technology is the farmers' decision. Waddington (1989) enlightens that a major aim of diagnosis of intercropping systems is to learn the farmers' objectives in intercropping, which are often more than a desire to maximize output (Willey, 1985; Byerlee and Tripp, 1988). In some situations farmers prefer monocropping to intercropping. However, in many situations intercropping is practiced because a multiplicity of objectives prevail (Jodha, 1979).

Quite often socio-economic and technical studies are not linked; this may result into improper recommendations to farmers. In view of this shortfall, before experimental agronomic research started, multi-visit surveys were carried out in this study in South-east Tanzania to understand farmers' motives for intercropping maize and sesame (Chapter 2). The study revealed that arable cropping is the main occupation, responsible for 75% of the mean annual household income. Only 14% of the annual household income is generated through off-farm activities, resulting in low-opportunity cost for labour. Consequently, nearly all labour in the maize-sesame system is provided through family and exchange labour. After the cash crop cashew, maize and sesame were found the second and third most important crops. Most farmers (90%) intercropped maize and sesame, but in nearly all cases, one or more crops were included. Pigeon pea, pumpkins and cassava were most frequently added to a maize-sesame intercrop. In an intercrop, maize is considered a main crop, as it is a major source of food for the household. On average almost 70% of the maize produced was used for home consumption. Sesame complements maize in achieving the household objectives, and 98% of sesame produced is sold to traders to obtain cash, shortly after harvest. Sesame is considered secondary to maize, as maize should secure the basic food requirement of the household. The maize-sesame system therefore is a typical example of the first intercropping situation described by Willey (1979a), where intercropping should give almost full yield of the main crop and any additional yield of a second crop is considered a benefit.

In an intercrop, sesame is added to a maize crop, as growing sesame in pure stand is not considered an option, because of the risks associated to this practice. During early stages sesame is reported to be prone to seedling mortality due to water logging. This was confirmed in chapter 3 and 5 where the experiments suffered from water logging shortly after sowing, resulting in poor emergence and seedling mortality of sesame. In addition, sesame might be completely wiped out by sesame flea beetle especially during the first six weeks after emergence (Simons, 1982; Mponda and Temu, 1992). These problems are equally likely to occur in an intercrop, however, in that situation a maize crop is left unaffected and even part of the yield loss of sesame is compensated for by maize. This is clearly illustrated in Chapter 5 when comparing the partial land equivalent ratio (pLER) of maize obtained in the experiment with the poor establishment of sesame following water logging (Experiment III; pLER≈0.80) with the values obtained in other experiments that were sown early January and had a good establishment of sesame (Experiments II and V; pLER ≈0.45). Furthermore, sesame is associated with risk of drought, particularly with sowing beyond late January (Chapter 3 and 5). Soil moisture limitations during the last part of the growing cycle are then even stronger, resulting in poor performance of sesame and this explains the sensitivity of sesame to late planting.

All farmers consider adding sesame to maize as a more efficient use of labour. Studies elsewhere show that intercropping may give low returns to labour (Reddy, 1988; Mwania, 1988) but other sources cite more efficient use of labour (Wood, 1984; Lightfoot and Tayler, 1987). Around 33% of the respondents reported that scarcity of fertile land was a main motive for them to combine both crops in an intercrop. The maize-sesame intercrop was also mentioned to contribute to the replenishment of soil fertility (74% of the respondents). This may contribute to the perception of farmers that their fields are fertile enough and application of fertilizers is not required. Some farmers also mentioned that intercropping minimizes weed problems. Moreover, farmers perceive that maize and sesame are good companion crops. This perception is in line with observed niche differentiation indices of the intercrop of around four, indicating that the component crops are at least partially complementary in resource use (Chapter 4).

Intercropping systems: Factors determining system performance

Although intercropping has been practiced for many years, research on this farming system is difficult because of the complexity of handling more than one crop in a single field, the difficulty of introducing machinery into the system, and the difficulty of assessing the results of the research (Petersen, 1994). In addition, factors under study in intercropping systems such as spacing, spatial arrangement, sowing time, varietal choice and fertilizer rates have an effect in pure stands but may also affect competitive relations between component crops in intercropping systems. Depending on management factors, optimal conditions in intercrop situations might be different from pure stand. Optimizing crop performance in an intercropping system is a question of maximizing complementarity and minimizing competition between the two component crops (Willey, 1979a). Intercrop performance can be improved with respect to temporal and spatial complementarity and also by improving the compatibility of genotypes used as component crops in the intercrop (Willey, 1979b). Staggering the relative planting time of the crops would be an example to account for temporal differences in resource use by the crops. Baumann *et al.* (2001) reported that staggered planting could improve leek-celery intercrop performance, as the temporal resource requirement of the crops is very similar. However, planting times would have to differ substantially, which would make it impossible to plant and harvest the crop mechanically and hence would reduce the acceptability of the system in practice. In contrast, early inter-seeding of a secondary crop may reduce the yield of the main crop. Sodsai-Changsaluk *et al.* (1993) found that yield and yield components of baby corn (*Zea mays* L.) were reduced by early introduction of cotton (*Gossypium hirsutum*) in a maize-cotton relay cropping system. Akanvou *et al.* (2002) found that, in contrast to later inter-seeding, rice biomass and grain yield were significantly reduced when legumes (*Cajanus cajan* and *Stylosanthes hamata* Taub.) were introduced between 0 and 28 days after rice sowing. On the other hand, late inter-seeding might give a poorly yielding secondary crop. In Southeast Tanzania, Taylor (1986) showed the importance of early inter-seeding of sesame into a crop of local sorghum (*Sorghum bicolor* (L.) Moench). Compared to sowing both crops simultaneously, sesame yield was only 47%, 32% and even 0% with delays of ten days, two weeks and four weeks, respectively.

With respect to fertilizer management in intercropping, Baumann *et al.* (2001) pointed out that neither nitrogen uptake nor yield of the mixture was greater than that of celery in pure stand. Whereas the N-uptake of celery was proportional to plant density, the uptake of leek was very low, probably due to the retarded development of the plants. When additional nitrogen was applied, leek could hardly profit because it was out-competed by celery. The results showed that in intercropping system higher nitrogen rates could not compensate for inter-specific competition, particularly with respect to the effects on leek. For maize-sesame intercropping it was observed that adding nitrogen led to increased competitiveness of maize (Chapter 4). This demonstrates that the availability of nutrients does not only affect yield level but also affects the competitive relations between the component crops. These examples clearly demonstrate that recommendations based on pure stands cannot simply be extrapolated to intercropping situations.

Research institutions released improved varieties for farmers in Southeast Tanzania. Recommended maize varieties are Ilonga, Tuxpeno, Staha, Kilima, TMV 1, CH1, CH3, Kito-ST and Katumani-ST, whereas for sesame Lindi white, Morada, Morada-2, SSBS-4, SSBS-7, Bora, Nal-92, Ziada-94 and Zawadi-94 are recommended. Developed varieties have been selected based on high yield in pure stand. In addition, market requirements like white seed colour was incorporated in most sesame varieties. Despite all breeding efforts, adoption of these varieties is still poor. Farmers mentioned that the improved varieties are not readily available, too expensive or farmers were simply not aware of their existence (Chapter 2). Our research further demonstrated that efforts for breeding improved sesame varieties should not only consider characteristics such as yield, seed colour and seed oil content, but should also take into account characteristics such as competitive ability and growth duration, that determine the suitability of sesame in intercropping systems (Chapter 3).

Maize-sesame intercropping systems: biological or economic benefit?

Several criteria have been used to evaluate the efficiency of intercropping systems. These criteria are generally focusing on identification of benefit from an ecological point of view (yield benefit). However, if the objective of the intercropping research is to make recommendations for farmers, the trials should be evaluated in the manner a farmer would use the information to make decisions. The criteria used in evaluation must be consistent with that of the target group of farmers to whom the recommendation is to be made. This study clearly demonstrated that fertile land suitable for maize-sesame intercropping is limited in supply in Southeast Tanzania. For this reason, evaluating return to investment in land is important to farmers. A number of measures have been suggested for assessing the output of intercropping systems. Among these, the measure that has received the widest adoption is the land equivalent ratio (LER), proposed by Willey and his associates (Willey and Osiru, 1972; Willey, 1979a, b; Mead and Willey, 1980). LER is a standard index that is defined as the relative land area under sole crops that is required to produce the same yield achieved by intercrops. The LER represents the increased biological efficiency achieved by growing two crops together in a specific environment. In many studies, the LER was much higher than one, because plant density in pure stand was below optimal. Even in pure stands a yield gain would have been obtained by simply adding plants.

Farmers in Southeast Tanzania are primarily interested in securing their basic food requirements (Chapter 2). For that reason, the priorities that farmers are giving to both crops are not identical, and LER is not the most appropriate decisive factor for evaluation of the intercrop. In case of the maize-sesame intercropping system, a first consideration should be whether the reduction in maize yield following the addition of sesame is acceptable. Partial LER could be used to show reductions of maize grain yield following the addition of sesame. Simultaneous sowing caused significant reductions in maize grain yield. This yield reduction was highly variable and accordingly, partial LER-values for maize ranged from 0.31 to 0.96 (Chapters 3, 4 and 5). In Southeast Tanzania, where farmers consider securing their basic food requirement as one of their main objectives, risks of encountering such low maize yields may not be acceptable.

Institutional recommendations and farmers' adoption

In Tanzania, research on maize and sesame crops has been conducted for more than twenty years. Most agronomic recommendations related to choice of variety, plant spacing, time of planting, plant density, fertilizer rate, weeding regime, and pesticide use have been developed for both crops based on pure stands (TARO, 1987a, b). Recommended time of planting for both maize and sesame is between December and end of January depending on the onset of the first rains. Also recommended densities (maize, 4-7 plants m^{-2}; sesame, around 20 plants m^{-2}), fertilizer rates (maize, 20 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}; sesame, 45 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}) and spatial arrangement (sowing maize in rows at one plant per station, sowing sesame in rows) are based on research in pure stands.

Farmers often are neglecting these recommendations. Our research showed that 90% of the farmers grow maize and sesame in intercropping systems. Most farmers use two to three maize plants per station, which was found to be optimal in pure stand as well as in intercrop with sesame present at low density. In intercrop, sesame is introduced into a maize crop through broadcast sowing as this method has the advantage of being easy and fast so that the time required to introduce sesame into a maize crop is much shorter as compared to row sowing. This study showed that sesame seed yield in intercrop was independent of the spatial arrangement of sesame. Maize grain yield however suffered to a larger extent from the presence of sesame when this crop was broadcast sown. Farmers secure maize yield by introducing sesame two weeks after maize. This study demonstrated the importance of this practice. Farmers are not using fertilizers, mainly because they perceive their soils to be fertile enough. Besides that, our research demonstrated that nitrogen is far more limiting than phosphorus, particularly at the valley bottoms. This demonstrates that agricultural sciences should focus on a proper analysis of the socio-economic and biological system before the initiation of research programs and the development of recommendations.

Bentley and Andrews (1992) are of the opinion that a knowledge gap exists between farmers' and scientific knowledge and that better technologies could be developed if the two could be married together. Moreover, farmers are interested in improving the productivity of maize-sesame intercropping, but other factors limit their ability to do so. Farmers reported that with respect to the use of inputs (improved varieties, pesticides, fertilizer) unavailability, high costs and unawareness were the main constraints. Agricultural research policy in Tanzania emphasizes the need of farmer oriented and problem solving research, which must take place with full farmer support, as they best know the problems confronting them.

Recommendations and future research for improving maize-sesame intercrop performance

In this research, the improved sesame variety *Nal-92* was used, because of its good performance in pure stand and its white seed colour, a characteristic which is strongly promoted, because of the high demand for white-seeded sesame in the international market. As this variety is far less competitive than the commonly used farmers' varieties, it was decided to sow sesame simultaneously with maize, whereas farmers introduce sesame at one to four weeks after maize sowing. For *Nal*-92, later introduction did not show to be a good alternative, as sesame seed yield was reduced by 87% and 96% with introduction at two and four weeks after maize sowing, respectively. Simultaneous sowing however also demonstrated to have major disadvantages. With this practice, average maize yield reduction was 27%. However, yield reduction was highly variable, with percentages ranging from 4%-69%. Furthermore, simultaneous sowing was associated with risk of seedling mortality due to water logging as well as the risk of sesame attaining physiological maturity before the end of the rains. Farmers prefer to harvest their sesame crop from the end of May because this is the beginning of the dry season, which will provide favourable conditions for drying the crop in the field. This demonstrates that sesame has some very specific requirements associated to the fact that the crop is mainly grown in an intercrop. For this reason, it is recommended that breeding of improved sesame varieties should not only focus on characteristics such as yield, seed colour and seed oil content, but should also take into account characteristics such as competitive ability and growth duration, that determine the suitability of sesame in intercropping systems.

Based on earlier research findings in Tanzania, one maize plant per station in pure stand was adopted as the general recommendation for the country. This research demonstrated that two to three maize plants per station, as practiced by farmers, was better in pure stand as well as in intercropping. In intercropping systems, this spatial configuration increased sesame yield. This demonstrates that farmers have valuable knowledge and that scientists have to use this knowledge to refine agricultural research recommendations.

Broadcast sowing of sesame into a maize crop reduced maize yield between 53% to 69%, and this reduction was only 19% to 55% when row sown. On the other hand, sesame yield in intercrop was independent of sowing method. It is recommended that farmers should adopt row sowing of sesame in order to secure the food requirements of the households.

The study also demonstrated that an external input such as fertilizer is hardly used. About 92% of respondents reported that their soils are fertile enough. Lack of cash and the fact that fertilizers are not readily available were reported by about 25% of the respondents. Our research demonstrated that in this area, N is the major limiting factor for crop production. At the low fertility site, application of nitrogen fertilizer resulted in 2.5 and 3.5 fold increases in pure stand yield of maize and sesame, respectively. At the more fertile site, there was no significant crop response to nitrogen fertilization. However, continuous cropping without fertilization in the long run may lead to nutrient mining. Therefore, integrated approaches of increasing soil fertility using locally available resources and chemical fertilizers should be encouraged. Because of the high variability in soils, it is important to develop soil specific fertilizer recommendations. For this reason, there is a need to conduct in-depth characterization of the major soils type in the maize-sesame belt. Detailed studies on phosphorus and nitrogen requirements of maize and sesame in intercrop is recommended as well as studies on the economics of fertilizer use, especially now that input and output markets have been liberalized.

Adding sesame to maize was reported by 83% of respondents as an option to avoid risk of total crop failure due to water logging, snails and sesame flea beetle. Nearly all respondents reported sesame flea beetle to be the most devastating insect pest of sesame. None of the households used pesticides to control the insect pest because they are unaware of their existence (35% of respondents) or insecticides are simply not available (42% respondents). The extension service and research organizations are charged with extending information about these technologies, but their low rates of contact with farmers constrain the use of these technologies.

All farmers consider adding sesame to maize as a more efficient use of labour. To some extent this is surprising as an estimated labour requirement of the intercrop was on average 42% higher than that of the pure stands. There is a need to identify appropriate labour saving technologies, which also favour a more balanced time-pattern of labour demand. For this purpose, appropriate tools such as animal driven implements could be experimented in future in collaboration with farmers.

Some farmers also mentioned that intercropping minimizes weed problems. The most common weeds mentioned were *Panicum alata*, *Commelina benghalensis* and *Rottboellia cochinchenensis*. Therefore, it is recommended to study the competitive effect in a maize-sesame intercropping system with weeds and use knowledge to optimize the intercropping system with respect to crop performance and weed suppressive ability.

Given the complexity of the maize-sesame intercropping systems, and the many factors that have an influence on their performance, it would be useful in future to develop a generic tool (e.g., a simulation model), that is able to integrate all of these factors. In that way, alternative management options can be explored, without having to conduct large multi-factorial experiments. However, developing these models, particularly for low-input conditions, would require a major research effort in the first place.

Finally, the complementary roles of the survey and experimental methods that were used in this research were useful to amalgamate farmers' knowledge and scientific knowledge for better insight into the maize-sesame intercropping systems, something that could not have been possible if the research would have used only one approach. Intercropping research relevant to smallholder farmers requires our understanding of farmers' needs and priorities and this is a good starting point for technical research to identify relevant researchable areas. Therefore, farmer participation in research is important because the acceptance or rejection of a new intercropping technology is the farmers' decision. Therefore, socio-economic scientists and technical scientists should develop research programs in the framework of the needs and priorities of the farmers so that they can develop a process of co-innovation.

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Summary

In Southeast Tanzania, the major food crop maize is often inter-seeded with the cash crop sesame using an additive design. Farmers consider maize an essential crop for securing their basic food requirements, whereas sesame is added to generate cash. Even though most farmers grow maize and sesame in intercropping systems, there has been little research initiated to improve these systems. In this study, farmers' practices and farmers' motives for adopting the practice of intercropping maize and sesame were studied first. Concurrently, experiments were conducted to evaluate the performance of the maize-sesame intercropping systems and to explore options for improvement. These experiments were conducted using the improved maize variety Staha and the improved sesame variety *Nal-92*.

In Chapter 2, a baseline survey was carried out to understand farmers' basis for using maize-sesame intercropping systems. The survey revealed that in the study area arable cropping is the main occupation, responsible for 75% of the mean annual household income. Cashew, maize and sesame were found to be the most important crops contributing to the household income. Only 14% of the annual household income is generated through off-farm activities, resulting in low-opportunity cost for labour. Consequently, nearly all labour in the maize-sesame system is provided through family and exchange labour. External inputs, especially fertilizer, pesticides and improved planting materials are hardly used. About 90% of the farmers intercropped maize and sesame. Maize provides the main source of food for the household. On average almost 70% of the produced maize was left for domestic consumption, whereas the surplus produce is sold. To assure good maize production, the most fertile soils are allocated to maize, and sesame is only introduced at about two weeks after maize sowing. Sesame complements maize in achieving the household objectives, as it is a reliable source of cash, which comes available soon after harvest. Accordingly, income diversification was mentioned as one of the motives for growing this intercrop. Another reason for adding sesame to a maize crop is the risk of crop failure associated to growing sesame in pure stand, as a result of seedling mortality due to water logging. Additionally, the sesame crop can be wiped out by snails or sesame flea beetle, particularly during the seedling stage. Besides that, all respondents perceived that adding sesame to maize saves labour, whereas 33% practice intercropping due to scarcity of fertile land. Finally, maize and sesame were perceived to be good companion crops, which in addition contribute to restoration of soil fertility and weed suppression.

In Chapter 3, the influence of the relative sowing time of sesame on the

performance of the intercrop was studied. It was observed that simultaneous sowing of maize and sesame caused highly variable reductions in maize grain yield ranging from 12 to 60%. This reduction was considerably smaller (on average 14% and 8%) when sesame was introduced at two or four weeks, respectively. Conversely, delayed seeding led to significant reductions in dry matter and seed yield of sesame, caused by a direct effect of sowing time and an increased competitiveness of maize. Whereas with simultaneous sowing yield reduction in sesame seed yield compared to pure stand was 60%, the reduction in seed yield increased to 87% and 96% with introduction time of two and four weeks after maize sowing, respectively. A financial analysis revealed that the attractiveness of the intercrop relative to that of maize in pure stand, was strongly determined by the maize:sesame price ratio. Based on a long-term average price ratio of 1:3.5, simultaneous sowing turned out to be the option with the highest gross financial return. At the same time, simultaneous sowing was associated with risks of seedling mortality of sesame due to water logging and risk of obtaining a severe reduction in maize grain yield. Furthermore, sesame attained physiological maturity before the end of the rainy period, whereas farmers prefer to harvest sesame at the beginning of the dry season (May), which provides favourable conditions for drying the crop in the field. It was argued that this last problem could be overcome through more directed plant breeding efforts.

The objective of Chapter 4 was to study the nature of interaction between maize and sesame in intercropping systems. Experiments were conducted at two sites, differing in soil fertility. Pure stands and intercrops of maize and sesame were grown at various total densities and mixing ratios, following a row-based additive design. Data on final shoot biomass and marketable yield under non-fertilized conditions were analysed using an empirical regression model for quantification of intra-specific and inter-specific competition. Maize was found to be more competitive than sesame, and the experiments revealed niche differentiation indices varying from 2.8 to 4.5, indicating that maize and sesame were at least partially complementary in resource acquisition, which forms the basis for a yield advantage in intercropping. This quantitative observation was in line with the more qualitative perception of farmers, that maize and sesame are good companion crops that are not interfering too strongly. Additionally, the response to N, P and a combination of N and P-fertilization was determined at recommended densities of maize and sesame in a pure stand as well as in an intercrop. P/N ratios of shoot tissue of maize and sesame ranged from 1/1.5 to 1/6.4, indicating that nitrogen was a major limiting factor. Consequently, both maize and sesame in pure stand responded significantly to N and NP-fertilization at the low fertility site (Mkumba). At this site, the application of nitrogen fertilizer resulted in 2.5 and 3.6 fold increases in pure stand yield of maize and sesame, respectively. In intercrop, only

maize profited from N fertilization, as for sesame the advantage of additional N was counterbalanced by the presence of a more competitive maize crop. At both sites, fraction nitrogen recovery was highest in the intercropping situation.

In Chapter 5, the effect of row and broadcast sowing of sesame, as well as the effect of number of maize plants per station, on the performance of the maize-sesame intercrop were evaluated. The rationale of this study was that institutional recommendations for spatial arrangement based on pure stands, specifically sowing one maize plant per station and row sowing of sesame, do not match with farmers' practices in intercropping. Farmers use 2-3 maize plants per station, whereas sesame is introduced through broadcast sowing. The study showed that, both in pure stand and intercrop, sesame seed yield was independent of sowing method. In the intercrop, in contrast to sesame, grain yield of maize was affected by the method of sowing sesame. When broadcast sown, sesame caused reductions in grain yield of 53% (Marambo 2001) and 69% (Mkumba 2002). These reductions were significantly higher than the yield reductions of 19% and 55% obtained with row sowing. Two to three maize plants per station were found to be optimal in pure stands of maize. With sesame present at a low density, this optimum remained, whereas at high densities of sesame, maize yield was independent of the number of maize plants per station. For sesame, seed yield either remained the same (low density) or increased (high density) with increasing number of maize plants per station. It was concluded that farmers, given their priority for securing maize yield, will benefit most from a maize-sesame intercrop when using two to three maize plants per station, while introducing sesame through row-sowing.

In the final chapter, the experiments with the maize-sesame intercropping systems were evaluated in the light of farmers' practices and motives for intercropping both crops. Additionally, the role of institutional recommendations for farmers' adoption was discussed. Finally, it was recommended that future projects should put emphasis on participatory research in teams of social scientists, technical scientists and farmers in the process of co-innovation to improve the well being of farmers and rural households.

Samenvatting

In Zuidoost Tanzania is maïs het belangrijkste voedselgewas. Maïs wordt veelal verbouwd in een mengteeltsysteem met sesam. Terwijl maïs dient om de basis voedselvoorziening van het gezin veilig te stellen, heeft sesam vooral tot taak de financiële armslag te vergroten. Hoewel maïs en sesam veelal in mengteelt worden verbouwd, is er maar weinig onderzoek specifiek gericht op verbetering van dit teeltsysteem. Het in dit proefschrift gepresenteerde onderzoek vormt hierop een uitzondering. Via een sociaal-economische studie, waarin boeren geïnterviewd werden, zijn de gangbare praktijk en de motieven van boeren om dit mengteeltsysteem toe te passen in kaart gebracht. Tegelijkertijd zijn verschillende experimenten uitgevoerd om het biologisch inzicht in het mengteeltsysteem te vergroten. In deze experimenten werd steeds gewerkt met maïs-ras *Staha* en sesam-variëteit *Nal-92*.

In Hoofdstuk 2 worden de resultaten van de interviews met boeren besproken. In het gedeelte van Zuidoost Tanzania waarop het onderzoek betrekking heeft, is akkerbouw de belangrijkste activiteit. Hiermee wordt gemiddeld 75% van het gezinsinkomen verdiend. Cashew, maïs en sesam zijn hierbij de belangrijkste gewassen. Slecht 14% van het totale gezinsinkomen wordt buiten het bedrijf verdiend, simpelweg omdat er maar weinig mogelijkheden zijn om buitenshuis geld te verdienen. Bijna alle arbeid op het bedrijf wordt dan ook geleverd door het gezin. Van kunstmest, bestrijdingsmiddelen en genetisch verbeterd plant materiaal wordt nauwelijks gebruik gemaakt. Ongeveer 90% van de boeren verbouwt maïs en sesam in mengteelt. Maïs wordt hierbij als het belangrijkste gewas gezien, omdat dit gewas het basisvoedsel vormt en daarmee de belangrijkste garantie voor overleving. Gemiddeld genomen wordt 70% van de geproduceerde maïs door het gezin geconsumeerd, terwijl het overige deel verkocht wordt. Om verzekerd te zijn van een goede maïsoogst wordt maïs meestal op de meer vruchtbare percelen verbouwd. Sesam wordt gemiddeld genomen twee weken later gezaaid dan maïs om een al te sterke concurrentie te voorkomen. Dit gewas vormt een betrouwbare bron van inkomsten. Kort na de oogst wordt het zaad opgekocht door handelaren, die met grote vrachtauto's van dorp naar dorp trekken. Het geld dat op deze wijze beschikbaar komt, zorgt voor financiële armslag vlak na de oogst, in een tijd waarin de maïsprijzen nog bijzonder laag zijn. Inkomensdiversificatie wordt dan ook als één van de redenen opgegeven voor toepassing van het mengteeltsysteem. Daarnaast zien boeren er geen heil in om sesam alleen te verbouwen. Dan bestaat er namelijk een gerede kans dat er van de oogst van een heel perceel niets terechtkomt. Zo zorgt een overmaat aan water in het begin van het groeiseizoen voor een slechte opkomst. Ook slakken en aardvlooien kunnen aan

het begin van het seizoen gemakkelijk een heel gewas vernietigen. In een mengteelt met maïs blijft er in zo'n geval ten minste nog één gewas over. Ook geven boeren aan dat een mengteelt relatief weinig arbeid vraagt. Daarnaast wordt een gebrek aan vruchtbare grond genoemd als reden voor het toepassen van een mengteelt. De boeren ervaren maïs en sesam verder ook als gewassen die goed bij elkaar passen en elkaar niet al te veel in de weg zitten.

In Hoofdstuk 3 is de invloed van het relatieve zaaitijdstip van sesam op de opbrengst van het mengteeltsysteem bestudeerd. Het gelijktijdig zaaien van maïs en sesam leidde tot wisselende resultaten. Ten opzichte van een monocultuur werd de maïsopbrengst verlaagd met percentages variërend van 12 tot 60%. Het introduceren van sesam op een later tijdstip resulteerde in een aanmerkelijk lagere daling van gemiddeld 14% bij een introductie na twee weken en van gemiddeld 8% bij introductie op vier weken na de zaai van maïs Vanzelfsprekend leidde de latere zaai tot een lagere opbrengst van sesam. Bedroeg de opbrengstverlaging ten opzichte van een monocultuur bij gelijktijdige zaai nog 60%, bij een verlate zaai liep deze op tot 87% (zaai na 2 weken) of zelfs tot 96% (zaai na 4 weken). Een financiële analyse maakte duidelijk dat de aantrekkelijkheid van het mengteeltsysteem ten opzicht van een monocultuur van maïs vooral bepaald wordt door de prijsverhouding tussen maïs en sesam. Op basis van historische gegevens bleek deze verhouding gemiddeld 1:3.5 te bedragen. Uitgaande van dit gemiddelde, kwam gelijktijdige zaai gemiddeld genomen als financieel meest aantrekkelijke optie uit de bus. Hierbij moet wel worden opgemerkt dat deze optie de nodige risico's met zich meebrengt. Vroege zaai betekent een verhoogde kans op een slechte opkomst van sesam door een te veel aan water aan het begin van het regenseizoen. Daarnaast kan in een ongunstig geval de maïsopbrengst ten gevolge van concurrentie door sesam behoorlijk laag uitvallen. In het specifieke geval van *Nal-92*, bleek bovendien dat bij gelijktijdige zaai sesam al voor het einde van het regenseizoen tot rijpheid kwam. Dit maakt het drogen van het geoogste product op het veld onmogelijk. Overigens is dit laatste probleem wellicht op te lossen door een meer gerichte veredeling.

In Hoofdstuk 4 is gekeken naar de aard van de interactie tussen maïs en sesam. Voor dit doel werden zowel monoculturen van maïs en sesam als ook mengculturen van beide gewassen in diverse dichtheden aangelegd. Gegevens van de bovengrondse biomassa en de korrelopbrengst (voor maïs) en zaadopbrengst (voor sesam) werden geanalyseerd met behulp van een empirisch regressiemodel. Op deze wijze werden zowel intraspecifieke als interspecifieke concurrentie gekwantificeerd. Onder onbemeste omstandigheden bleek maïs beduidend concurrentiekrachtiger dan sesam. Bovendien bleken maïs en sesam gedeeltelijk complementair te zijn in het gebruik van hulpbronnen, wat duidt op de mogelijkheid om in een mengteelt een meeropbrengst te realiseren. Deze waarneming komt goed overeen met de waarneming van boeren dat maïs en sesam elkaar goed verdragen. Voor maïs en sesam verbouwd in de geadviseerde dichtheden werd bovendien de respons op stikstof- en fosfaatbemesting bestudeerd. De P/N verhouding in het bovengrondse plantmateriaal van maïs en sesam varieerde tussen 1/1.5 en 1/6.4. Dit duidt op een gebrek aan stikstof en het was dan ook niet verwonderlijk dat in monocultuur er een sterke reactie waargenomen werd op het toedienen van N-bemesting. Op de locatie met de laagste bodemvruchtbaarheid werd gemiddeld zelfs een verdrievoudiging van de opbrengsten waargenomen. In mengteelt bleek slechts maïs te profiteren van de extra stikstof. Voor sesam was er nauwelijks een respons waar te nemen, doordat de betere beschikbaarheid van stikstof te niet gedaan werd door de toegenomen concurrentiekracht van maïs. Overigens bleek in alle gevallen de opname van de toegediende stikstof in de mengteelt hoger te zijn dan in de monoculturen.

In Hoofdstuk 5 werd de invloed van de ruimtelijke rangschikking van beide gewassen op de opbrengst in mengteelt bepaald. Aanleiding tot dit onderzoek vormde de waarneming dat de aanbevelingen die hieromtrent door de onderzoeksinstellingen worden verstrekt, door de praktijk nauwelijks worden opgevolgd. Zo wordt voor maïs geadviseerd om per plantgat één maïsplant te plaatsen, terwijl in de praktijk, bij een en dezelfde plantdichtheid, de planten veel meer geclusterd worden geplaatst, met veelal 2-3 planten per plantgat. Voor sesam wordt geadviseerd de planten in rij-verband te zaaien, terwijl de praktijk breedwerpig zaaien verkiest. De studie maakte duidelijk dat zowel in monocultuur als in mengteelt, de wijze van zaaien van sesam geen invloed had op de opbrengst. In de mengteelt bleek de wijze van zaaien echter wel degelijk invloed te hebben op de maïsopbrengst. Breedwerpig zaaien van sesam leidde tot opbrengstverminderingen in maïs van gemiddeld 61%, terwijl bij zaai in rijen de maïsopbrengst met slechts 37% bleek te verminderen. Voor wat betreft het aantal maïsplanten per plantgat, bleek twee tot drie optimaal voor het behalen van de hoogste opbrengst in monocultuur. Ditzelfde resultaat werd gevonden in een mengteelt met een relatief lage dichtheid van sesam. Bij een hoge dichtheid van sesam bleek de maïsopbrengst onafhankelijk van het aantal planten per plantgat. Voor sesam bleef de opbrengst gelijk (in lage dichtheid), of werd een toename in opbrengst bij een toenemend aantal maïsplanten per plantgat gevonden (bij hoge dichtheid). Omdat boeren veel belang hechten aan het behalen van een goede maïsopbrengst verdient het aanbeveling in de mengteelt te werken met twee-drie maïsplanten per plantgat, terwijl voor sesam rijenzaai de voorkeur verdient boven breedwerpig zaaien.

In het laatste hoofdstuk worden de experimenteel gevonden resultaten nogmaals geëvalueerd tegen het licht van de gangbare boerenpraktijk. Bovendien wordt het spanningsveld tussen aanbevelingen en boerenpraktijk nader bediscussieerd. Ten slotte wordt geconcludeerd dat in toekomstige projecten de nadruk dient te liggen op participatief onderzoek. In dergelijk onderzoek dient er een goede wisselwerking te zijn tussen sociaal-economische en technische onderzoekers en boeren. Deze wisselwerking zal moeten leiden tot co-innovatie gericht op de algehele verbetering van de leefomstandigheden van boeren en plattelandsgemeenschap.

Curriculum vitae

Geoffrey Suleiman Mkamilo was born on 30 June 1964 in Kilosa, Tanzania. In 1991, he obtained the degree of BSc in Agriculture from Sokoine University in Morogoro. After graduating, he was employed by the Ministry of Agriculture and Food Security of Tanzania, as an agricultural research scientist and he joined the National Sisal Research Program in Tanga. In October 1992, he was transferred to Naliendele Agricultural Research Center (ARC) in Mtwara, where he joined the Socio-economics/Farming Systems Research (FSR) Team as an agronomist. In 1996, he was awarded a Government scholarship for graduate studies at Wageningen University in The Netherlands. In 1998, he successfully completed this study and obtained an MSc-degree in Crop Science (specialization Crop Production). Soon after his graduation, Wageningen University awarded him a PhD-sandwich fellowship on a project proposal entitled: 'Designing options for sustainable improvement of productivity of maize-sesame intercropping systems in Southeast Tanzania'. He started this thesis research in February 1999, after his institute agreed to support the research programme. The research, of which this thesis is the final result, was conducted in collaboration with the Crop and Weed Ecology Group of Wageningen University.

Funding

This PhD thesis contains the results of research conducted within a Sandwich Programme, which involved the Wageningen University and Research Centre in The Netherlands and the Tanzanian Agricultural Research Project Phase Two.

Financial support for the printing of this thesis was obtained from the Dr Judith Zwartz Foundation, Wageningen, The Netherlands.

Printing of this thesis within the Tropical Resource Management Papers series was financially supported by 'Het Fonds Landbouw Export Bureau 1916-1918' (LEB-fonds).