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MIXED CROPPING OF GROUNDNUTS AND MAIZE IN EAST JAVA

Tumpangsari kacang tanah dan jagung
di Jawa Timur

Gemengde teelt van aardnoot en
mais in Oost-Java

W.C.H. van Hoof

MIXED CROPPING OF GROUNDNUTS AND MAIZE IN EAST JAVA

Proefschrift
ter verkrijging van de graad van
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Photographs on cover:

- Picking the pods from harvested groundnut plants
- Shelling the grains from maize ears by hand

STELLINGEN

1 Het voordeel van de stikstofbinding door de aardnoot is voor mais groter in relay-cropping (estafetteteelt) dan in gemengde teelt.

2 Door "on farm research" kunnen de mogelijkheden en beperkingen van gemengde teelt gemakkelijker en sneller vastgesteld worden dan door onderzoeksprogramma's op proefstations.

3 De LER (land equivalent ratio) is geen goede indicator voor het voordeel van gemengde teelt.
Rahman et al., 1982. Indian J. Agron. *27*, 1-6.

4 De optimale teeltmaatregelen voor enkelvoudige en voor gemengde teelt zijn meestal niet gelijk. In het onderzoek dient daar rekening mee gehouden te worden.
Dit proefschrift.

5 Opbrengsten in gemengde teelt zijn moeilijker te voorspellen dan het weer.

6 Wanneer de "leaf area index" van mais in gemengde teelt met aardnoot tijdens de groeiperiode hoger wordt dan 4, zal gemengde teelt niet produktiever zijn dan enkelvoudige teelt van aardnoot of mais.
Dit proefschrift.

7 Gemengde teelt heeft het meeste toekomst in erftuinen met meerjarige en overblijvende gewassen. Daar dient nodig aandacht aan besteed te worden.

8 *Rhizobium* is belangrijker voor de plantaardige produktie in de wereld dan de ureumfabrieken.

9 De verantwoordelijkheid van ontwikkelingswerkers ligt in de eerste plaats naar het ontwikkelingsland toe, en pas in de tweede plaats naar de uitzendende instantie.

10 Door de vertaling "morgen" van het Indonesiche woord "besok", verliest het alle nuances die de Javaan er aan toekent.

11 De afstammelingen van de koningin van Sheba aan de oostzijde van de Rode Zee zijn beter af met hun qat-cultuur dan haar nazaten aan de westzijde met hun drankprobleem.

12 De agrarische hogescholen dienen sterk op de landbouwpraktijk gericht te blijven, om ruimte over te laten voor de landbouwuniversiteit.

13 De positieve correlatie tussen de toename in lichaamslengte van de Nederlandse jeugd na 1970 en de opkomst van de bio-industrie, behoeft niet op toeval te berusten.

14 De ideaalbeleving van voetbalsupporters en bedevaartgangers vertoont grote overeenkomsten: het verschil zit hem vooral in de gevolgen van de uitingen van enthousiasme.

15 Begraven is natuurlijker, milieuvriendelijker en energetisch voordeliger dan cremeren.

16 Om echt te kunnen genieten van zwart-witte videoclips heb je kleurentelevisie nodig.

Liselore.

Proefschrift W.C.H. van Hoof
Mixed cropping of groundnuts and maize in East Java
Wageningen, 21 oktober 1987

CONTENTS

1 INTRODUCTION

1.1 CROPPING SYSTEMS

Growing one annual crop in sole stand means a restricted utilization of the available growth resources for at least an important part of the growing period. By growing more than one crop in a field in the course of one year, named multiple cropping, a more efficient use of growth resources can be obtained. Dalrymple (1971) has collected worldwide information on the importance of multiple cropping, defined as a regular sequence of annual crops in a field in the course of a twelve month period. An increase in the area under irrigation and the introduction of early-maturing cultivars of rice during the sixties have favoured multiple cropping in many Asian countries. The agricultural land on Java showed a cropping index of 120 (meaning an average of 1.2 crops per year on each field), and a cropping index of 185 was reported for Taiwan. In mixed cropping of annual crops, the utilization of the available growth factors can be higher than in sequential cropping. No figures on the extent of mixed cropping in Asian countries have been found.

1.2 MIXED CROPPING

Mixed cropping is a centuries-old technique of intensive farming, most prevalent in areas of the tropics with year-round crop production. Systems in use today have evolved largely from experience and in response to high food demand in densely populated areas (Papendick et al., 1976). Terminology in connection with mixed cropping is explained in chapter 2. Several interesting studies on mixed cropping have been published during the last ten years (Sanchez, 1976; Monyo et al., 1976; Papendick et al., 1976; Kass, 1978; Willey, 1979; ICRISAT, 1981; Steiner, 1984; Beets, 1982; Keswani and Ndunguru, 1982; Gomez and Gomez, 1983; Francis, 1986). Mixed cropping patterns used in tropical Asia were listed by Harwood and Price (1976), such as tree crops with annuals, complex mixtures of trees in home gardens, intensive vegetable production systems and mixed cropping of annual field crops.

Mixed crops can be compared with sole crops by expressing the yield of the associated crops as fractions of the corresponding sole crops and summing the fractions. It is also important to compare the energy contents, market values, and consistency of yield (under various growing conditions) of sole and mixed crops.

1.3 RESEARCH ON MIXED CROPPING IN EAST JAVA

Although rice is by far the most important food crop in Indonesia as a whole, it is less so in East Java, with its pronounced dry season (fig. 3.2). In large areas of East Java maize is a more important part of the staple diet than rice. Maize is often grown in association with other crops, such as groundnuts, mungbeans, cowpeas, soyabeans, common beans, cassava, sweet potatoes or vegetables.

Experimenting with mixed cropping of annual food crops in Indonesia started in the seventies (Syarifuddin et al., 1974; Thahir, 1975; Suryatna Effendi Sastrawinata, 1976). The crop association of groundnuts and maize has been studied for several years at the Faculty of Agriculture of Brawijaya University, Malang, East Java.

Several aspects of mixed cropping of groundnuts and maize have been examined in field and pot experiments by graduate students of the Faculty of Agriculture, such as plant density, relative sowing time, fertilizer application and nutrient use efficiency, water use efficiency, light use efficiency, effect of the mixed crop on weed growth and effect of genotype. A survey was conducted on farming practices of growing groundnuts and maize. The author of this thesis co-ordinated this research program and conducted a number of field experiments himself. Some results of the field research conducted from 1978 to 1980, are reported in this thesis.

1.4 AIMS OF THE RESEARCH

The aims of the research on mixed cropping of groundnuts and maize in East Java were to investigate the effect of cultural practices on growth and yield of groundnuts and maize in mixed crops and to compare mixed cropping with sole crops. Only aspects relevant for the farming practice and not requiring extra farm inputs, were selected to be presented in this thesis. The results of the study are considered in relation to their economic and social aspects.

In the next chapter the literature on mixed cropping of groundnuts and maize is reviewed. In chapter 3 the results of the survey on farming practices in growing groundnuts and maize are reported. Chapter 4 contains a description of the materials and general methods that were used in the research. The results of two field experiments on different sowing times of maize in mixed crops are reported in chapter 5. Chapter 6 shows the results of two field experiments on plant density of maize in mixed crops, and the results of one field experiment on the arrangement and density of maize plants in mixed crops with groundnuts. The combined effects of plant density and relative sowing time of maize in two experiments on mixed cropping are shown in chapter 7. In chapter 8, observations and calculations on light use efficiency are presented to clarify the results of the mixed cropping experiments. Social and economic implications of mixed cropping of groundnuts and maize are presented in chapter 9. Chapter 10 contains a general discussion of the experimental results and the conclusions and recommendations on possible improvements to mixed cropping practice in East Java.

2 REVIEW OF THE LITERATURE ON MIXED CROPPING OF GROUNDNUTS AND MAIZE

2.1 TERMINOLOGY IN CONNECTION WITH MIXED CROPPING

Mixed cropping of groundnuts (*Arachis hypogaea* L.) and maize (*Zea mays* L.) has been studied in different parts of the world, but the literature has not been reviewed before.
Growing crops together in the same field has been indicated by various terms. The most usual terms are 'mixed cropping' (Finlay, 1975; Holliday, 1976; Sanchez, 1976), 'intercropping' (Evans, 1960; Willey, 1979) and 'associated cropping' (Francis and Sanders, 1978). According to several authors, mixed cropping implies a thorough mixing of the crops in the field and intercropping implies that the crops are grown in separate rows (Andrews and Kassam, 1976; Willey, 1979; Westphal, 1981; Ferwerda, 1984). Others do not indicate any specific plant arrangement for mixed cropping or for intercropping (Ruthenberg, 1980; Fisher, 1979). Unfortunately, the term 'associated cropping' has not been widely adopted. Most studies on plant arrangement of crops grown together in a field, have not shown substantial differences between different plant arrangements (Herrera et al., 1976; Didi Suardi et al., 1976; De et al., 1978). Therefore, for studies on biological productivity of crop mixtures it is not very important to make a distinction between mixed cropping and intercropping, but for crop management the distinction is required. In this study, the term mixed cropping will be used for growing two or more crops together in a field, regardless of plant arrangement.

Yields of the associated crops in mixed cropping are compared with the yields of the sole crops. Sole crops used as checks in mixed cropping experiments have to be grown at the usual plant density and with the usual crop management. The yield of a crop in mixed cropping expressed as fraction of the yield of its sole crop is called relative yield, and abbreviated to RY. Summing up the relative yields of the associated crops gives the relative yield total of the mixed crop, abbreviated to RYT (De Wit and Van den Bergh, 1965). The term RYT is used for mixed cropping situations where part of the one crop has been replaced by the other crop in such a way that the total plant density of the mixed crop is 100% of that of the respective sole crops. The term RYT is considered to be incorrect in the case of addition of a crop to another crop in such a way that the total plant density of the mixed crop is higher than 100% of the respective sole crop densities. In mixed crops of groundnuts and maize, addition is much more usual than replacement (table 2.1). The term 'land equivalent ratio' (LER) for the summed RY values of the associated crops can be used regardless of replacement or addition situations. The term LER is widely used in the literature on mixed cropping (IRRI, 1974; Willey, 1979) and will be used is this study. RY and LER are used for marketable yield, as well as for total dry matter yield. A LER value higher than 1 indicates that the mixed crop has been more productive than the respective sole crops.

If the associated crops have a different growth duration, and if the land can be used for growing another crop during the remaining part of the growing season, the time factor has to be incorporated in the RY and LER. If the RY and LER are calculated from the average yield per day of field occupation, the time factor is included in RY and LER. The term 'area-time equivalent ratio' (ATER) has been introduced by Hiebsch (1978).

One way to compare productivity of the associated crops and the total mixed crop with each of the sole crops is to calculate the energy yield (Joules per hectare).

Mixed crops and sole crops can also be compared by calculating the economic revenues of the yields. In this study, the revenues of the sole and mixed crops will be expressed in US dollars per hectare, or as a percentage of the highest valuable sole crop.

Table 2.1 Experimental results on mixed cropping of groundnut and maize in three areas of the world

Area and reference	Plant density					Marketable yield				
	Sole crops (plants per 1,000 ha)		Mixed crop (% of sole crop density)			Sole crops (kg/ha)		Mixed crop (fraction of sole crop)		
	G	M	G	M	total	G	M	RY G	RY M	LER
a) West Africa										
Azab, 1968	111	37	67	100	167	2964	2206	0.56	0.42	0.98
Koli, 1975	111	37	67	100	167	1834	2764	0.50	0.65	1.15
Baker, 1978	48	25	92	16	108	2441	3000*	0.93	0.21	1.14
Mutsaers, 1978	250	42	100	33	133	1714	3200	0.67	0.52	1.19
Baker, 1980	48	25	100	32	132	951	1500*	0.84	0.22	1.06
b) India										
De et al., 1978	167*	67*	53	100	153	1500*	1310	0.24	1.31	1.55
Nair et al., 1979	220*	75	60	100	160	1000*	4230	0.20	1.02	1.22
Gangwar and Kalra, 1982	150*	53	60	100	160	2000*	1405	0.54	1.15	1.69
Rahman et al., 1982	150*	75*	60	100	160	1620	4320	0.37	1.09	1.46
Farah, 1983	150*	53*	60	100	160	2020	4500	0.22	1.00	1.22
c) South-East Asia										
Syarifuddin et al., 1974	250	75	100	40	140	1456	2653	0.77	0.40	1.17
Herrera et al., 1976	320	60	100	50	150	2290	4300	0.65	0.88	1.53
Liboon et al., 1976	200	50	100	40	140	2930	3320	0.67	0.42	1.09
Didi Suardi et al., 1976	250	50*	100	50	150	2000*	5000*	0.68	0.84	1.52
Aziz Azirin et al., 1976	200	100	75	100	175	1400	4700	0.57	0.85	1.42
Suyuthi et al., 1977	200	67	75	75	150	522	1389	0.70	0.89	1.59
Imam Muslim, 1977	333	63	100	33	133	1287	2431	0.85	0.54	1.39
Suwasik et al., 1978	250	71	100	60	160	1462	2196	0.60	0.50	1.10
Isgiyanto et al., 1980	400	100	50	50	100	3912	5871	0.54	0.53	1.07
Utami, 1981	200	100	88	50	138	1643	7000	0.65	0.41	1.06

Data followed by an asterisk (*) were estimated.

2.2 MIXED CROPPING OF GROUNDNUTS AND MAIZE IN THE WORLD

In three areas of the world mixed cropping of groundnuts and maize is important: West Africa, India and South-East Asia (West Africa: Azab, 1968; Buntjer, 1971; Palmer, 1971; Baker, 1974; Koli, 1975; Mutsaers, 1978; India: De et al., 1978; Nair et al., 1979; Gangwar and Kalra, 1982; Pandey et al., 1981; South-East Asia: Van der Veer, 1948; IRRI, 1973; Herrera et al., 1976; Ismail et al., 1975; Isgiyanto et al., 1980). From other parts in the world (such as East Africa and America) only incidental publications on this subject have been found (Evans, 1960; Akhanda, 1979; Edje, 1982). The way of growing groundnuts and maize in mixed cropping varied widely for the three areas. In West Africa groundnuts were the main crop and maize was added at a low plant density to give an additional yield. Sometimes sole maize was not included in the research (Baker, 1978). In India the maize was the main crop, some groundnuts were added to give an additional yield. Sole groundnuts were usually not included in research experiments (Gangwar and Kalra, 1982). In South-East Asia both groundnuts and maize were important in mixed cropping. The density of groundnut plants in mixed crops was usually similar to that in sole crops, and the density of maize plants less than the sole maize density (Syarifuddin et al., 1974; Herrera et al., 1976; Suwasik et al., 1978).

2.3 FACTORS AFFECTING MIXED CROPS

2.3.1 General

The research results and the state of knowledge on mixed cropping of groundnuts and maize are described in this section. The information has been grouped by factors affecting mixed cropping results.

- Plant density: ratio between groundnuts and maize as well as total plant density of the mixed crop.
- Plant arrangement.
- Different sowing times: difference in sowing dates for groundnuts and maize in mixed crops.
- Effects on weeds.
- Nutrient use efficiency and application of fertilizer (mainly nitrogen).
- Water use efficiency and water requirements.
- Effects of genotype.
- Effects on incidence of pests and plant diseases.
- Economic and social implications.
- Yield stability.

2.3.2 Plant density

Plant density of sole groundnuts varied from 40,000 to 400,000 plants per hectare, with the lowest densities in Africa (Evans, 1960; Koli, 1975; Baker, 1978 and 1980) and the highest in Asia (Syarifuddin et al., 1974; Herrera et al., 1976; Gopalaswamy et al., 1979; Isgyanto et al., 1980). The spreading Virginia type of groundnuts that is common in Nigeria is sown at a lower plant density than the Spanish bunch type of groundnuts that is usual in Indonesia. Pod yield of sole groundnuts varied from 522 to 3912 kg/ha.

Maize in sole cropping had a density between 20,000 and 150,000 plants per hectare, with low densities in Africa (Evans, 1960; Koli, 1975) and moderate or high densities in Asia (Syarifuddin et al., 1974; Herrera et al., 1976; Nair et al., 1979; Ishag, 1970; Isgiyanto et al., 1980). Improved maize cultivars with a long growth duration were sown at lower plant densities than traditional cultivars with a short growth duration. Moreover, traditional cultivars were often sown with two or more plants per hill, which usually resulted in a very high plant density. Grain yield for sole maize ranged from 1310 to 7000 kg/ha. LER values for mixed crops of groundnut and maize ranged from as low as 0.83 (Azab, 1968) to as high as 1.72 (Akanda and Quayyum, 1982).

Plant density in mixed crops is more complex to study than plant density in sole crops (Willey, 1979). In some mixed cropping experiments both groundnuts and maize were sown at 50% of their sole crop density, or at other ratios, with a total density of the mixed crop of 100% of the corresponding sole crop densities (Herrera et al., 1976; Mutsaers, 1978; Isgiyanto et al., 1980). This is the replacement type of mixed cropping. The addition type of mixed cropping, with a total plant density of the mixed crop higher than 100% of the corresponding sole crop densities, was more usual (table 2.1). Total plant density of the mixed crop was often between 100% and 200% (Evans, 1960; Syarifuddin et al., 1974; Herrera et al., 1976; Didi Suardi et al., 1976; Mutsaers, 1978; Nair et al., 1979).

The common African practice of growing groundnuts and maize together, was to sow groundnuts at the normal density of 48,000 plants/ha and to intersow widely spaced rows of maize at a low plant density (4,000 plants/ha). Total density of the mixed crop was about 120% (Buntjer, 1971; Baker, 1978).

The normal practice in India was to sow maize at the usual plant density (53,000 plants/ha) and to intersow groundnuts at a moderate density (89,000 plants/ha) with one row of groundnuts between each two maize rows. The total density of the mixed crop was about 160% (Gangwar and Kalra, 1976).

In South-East Asia groundnuts were often sown at the usual plant density (200,000 plants/ha) in mixed crops and the maize at a moderate density (50,000 plants/ha). The total density of the mixed crop was about 150% (Herrera et al., 1976; Didi Suardi et al., 1976; Suyuthi et al., 1977).

The results of mixed cropping experiments of groundnuts and maize in Nigeria (Baker, 1978) lead to an estimation of the relative yield (RY) of groundnuts in mixed crops of 0.93, a RY of 0.21 for maize and a LER of the mixed crop of 1.14 (0.93 + 0.21). Nair et al. (1979) in India reported a maize yield (RY of 1.02) in mixed cropping with groundnuts, that was similar to that of sole maize with an additional yield of groundnuts. For India, maize yield (RY of 1.15) in mixed crops often was higher than the sole maize yield (Gangwar and Kalra, 1982). Herrera et al. (1976) reported RY and LER values of 0.64 + 0.68 = 1.32 for $G_{0;50}$-$M_{0;50}$ (replacement type of mixed cropping) and 0.65 + 0.88 = 1.53 for $G_{0;100}$-$M_{0;50}$ (addition type of mixed cropping). LER values were similar with different proportions of groundnuts and maize, at the same total plant density in the mixed crop. Mutsaers (1978) found RY and LER values of 0.24 + 0.82 = 1.06 for $G_{0;33}$-$M_{0;67}$ (replacement), 0.57 + 0,53 = 1.10 for $G_{0;67}$-$M_{0;33}$ (replacement with more groundnut plants and less maize plants), 0,67 + 0.52 = 1.19 for $G_{0;100}$-$M_{0;33}$ (addition) and 0.61 + 0.77 = 1.38 for $G_{0;100}$-$M_{0;67}$ (addition with higher total density). Groundnut yield was lower and maize yield higher with an increasing proportion of maize plants in the mixed crop.

Spitters (1983) has developed a model on partitioning of dry matter over the plant parts for associated crops, using results from field experiments on mixed cropping of groundnuts and maize in East Java.

2.3.3 Plant arrangement

Didi Suardi et al. (1976) sowed maize at a density of 25,000 plants per hectare in mixed cropping with a normal density of groundnuts (250,000 plants/ha), arranged as 1, 2, 3 and 4 maize plants per hill in 2 meter wide rows. At 56 DAS, there was no significant difference in total dry matter weight of maize and groundnuts for the different plant arrangements. Orientation of the maize rows in a north-south or in an east-west direction did not show a significant difference either.

Herrera et al. (1976) found that groundnut yield was somewhat lower and maize yield higher in a mixed crop with maize arranged in 1-meter wide rows compared to 2-meter wide rows at the same density. The LER of the two mixed crops was similar. RY and LER were 0.65 + 0.88 = 1.53 for $G_{0;100}$-$M_{0;50}$ (1-meter wide rows) and 0.70 + 0.80 = 1.50 for $G_{0;100}$-$M_{0;50}$ with 2-m wide rows. Sowing groundnuts in the same rows as the maize or in separate rows did not have any effect on the yields.

A row width of 90 cm for maize in mixed cropping with groundnuts gave better results than 75 cm (De et al., 1978), though this difference in row width did not affect the yield of sole maize. The effect of plant arrangement on yields was small compared with the effect of plant density of maize in mixed crops with groundnuts (Reddy and Reddy, 1981).

2.3.4 Effects of different sowing times

Sowing maize earlier or later than groundnuts changed the proportion of both crops in the total yield of the mixed crops. Azab (1968) presented the results of mixed crops of groundnuts and maize in Ghana, with the maize sown 4 weeks earlier than the groundnuts, at the same time, or 4 weeks later than the groundnuts. RY and LER values were 0.19 + 0.67 = 0.86 for $G_{0;67}$-$M_{-28;100}$, 0.56 + 0.42 = 0.98 for $G_{0;67}$-$M_{0;100}$ and 0.93 + 0.12 = 1.05 for $G_{0;67}$-$M_{28;100}$. The pod yield of sole groundnuts was 2964 kg/ha and the grain yield of sole maize was 2206 kg/ha. The LER seemed to be slightly higher with later sowing of the maize than with earlier sowing. Yields of groundnuts and maize were most in balance when the maize was sown at the same time as the groundnuts.

Suyuthi et al. (1977) compared mixed crops of groundnuts and maize in Sulawesi, Indonesia, with sowing time of maize 10 days earlier than groundnuts, at the same time as groundnuts and 10 days later than groundnuts. RY and LER values were 0.66 + 0.85

= 1.51 for $G_{0;75}$-$M_{-10;75}$, 0.70 + 0.89 = 1.59 for $G_{0;75}$-$M_{0;75}$ and 0.82 + 0.71 = 1.53 for $G_{0;75}$-$M_{10;75}$. Pod yield of sole groundnuts was 522 kg/ha. Grain yield of sole maize was 1389 kg/ha. Groundnut yield in mixed crops was higher with later sowing of the maize. From the research results, the effect of sowing time of maize on maize yield and on total productivity of the mixed crop is not clear.

2.3.5 *Effects on weeds*

In the Philippines, weed growth was studied in sole groundnuts, sole maize and in mixed crops of groundnuts and maize at different levels of nitrogen supply (Gomez, 1973). At a low level of nitrogen supply the total dry matter weight of weeds in a sole crop of groundnuts was 900 kg/ha, in sole maize also 900 kg/ha and in a mixed crop of groundnuts and maize 700 kg/ha. At a high level of nitrogen supply the total dry matter weight of weeds was 3400, 1000 and 1800 kg/ha in sole groundnuts, sole maize and mixed crops, respectively. Apparently, the groundnuts failed to suppress weed growth at high levels of soil fertility. In mixed crops of groundnuts and maize, weed growth depended to an important extent on plant density and plant arrangement of the maize: the total dry matter weight of weeds was 1800, 1500, 1000 and 500 kg/ha for maize densities of 10,000 plants/ha (100 x 100 cm), 10,000 plants/ha (200 x 50 cm), 20,000 plants/ha (200 x 25 cm) and 60,000 plants/ha (100 x 17 cm), respectively.

A series of experiments on weed growth (mainly grasses) and the effect of weed control in groundnuts and maize was carried out in East Java in 1977 and 1978 (Suwasik et al., 1978). No weeding, weeding once at 20 DAS and clean weeding were compared. The average total dry matter weight of weeds in the unweeded and once weeded plots at 50 DAS was 1088 kg/ha in sole groundnuts, 1920 kg/ha in sole maize and 1575 kg/ha in a mixed crop of groundnuts and maize.

Sunardi et al. (1979) compared no weeding, hand weeding, hoeing and herbicide application in sole groundnuts, sole maize and in a mixed crop of groundnuts and maize (addition type of mixed cropping). The total dry matter weight of weeds without weed control was 2165 kg/ha in sole groundnuts, 4058 kg/ha in sole maize and 1650 kg/ha in the mixed crop. A single hand weeding, hoeing or herbicide application were all effective methods of weed control. With weed control, the total dry matter weight of weeds at the final harvest was 240 kg/ha in sole groundnuts, 1896 kg/ha in sole maize and 144 kg/ha in the mixed crop. The pod yield of sole groundnuts was 1821 kg/ha with weed control and the grain yield of sole maize was 3553 kg/ha, and RY and LER values for the mixed crop were 0.83 + 0.56 = 1.39. Compared with the corresponding weeded crops, the reduction in marketable yield of the unweeded crops was 21% for sole groundnuts, 56% for sole maize and 17% and 49%, respectively, for groundnuts and maize in the mixed crop.

2.3.6 Nutrient use

Aziz Azirin et al. (1976) compared the effect of different rates of application of nitrogen fertilizer on the yields of groundnuts and maize in sole and mixed crops. The applied rates of nitrogen were 0, 45, 90, 135 and 180 kg/ha. The pod yield of sole groundnuts without nitrogen fertilizer was 1400 kg/ha, and application of fertilizer did not increase the yield. There was a strong response of the maize to nitrogen fertilizer. Sole maize yield was higher with increasing rates of nitrogen fertilizer up to an optimum rate of 135 kg/ha. At this rate, the grain yield was 4700 kg/ha, while the yield without fertilizer was only 1400 kg/ha. In mixed cropping the groundnut yield was lower and the maize yield higher with increasing rates of nitrogen fertilizer. LER values were higher at high rates of nitrogen. The revenues of the mixed crop, expressed as a percentage of the revenues of the corresponding sole crops, was not increased by application of nitrogen fertilizer. A high yield, a high revenue and a reasonable balance between the associated crops was attained with a nitrogen rate of 90 kg/ha; the RY and LER values were 0.57 + 0.74 = 1.31, and the gross revenue of the mixed crops was 106% of the highest valued sole crop.

Nair et al. (1979) compared nitrogen rates of 0, 40, 60 and 120 kg/ha applied to sole maize and to a mixed crop of maize and groundnuts. There was a moderate effect of nitrogen fertilizer on maize yield. The highest sole maize yield (4950 kg/ha) was attained with a nitrogen rate of 60 kg/ha. Maize yields in the mixed crops were higher with increasing rate of nitrogen fertilizer and were not different from the sole maize yields. Groundnuts gave an additional yield on top of the maize yield. Wheat sown as a winter (rabi) crop after sole maize had a lower yield (917 kg/ha) than after the mixed crop (1080 kg/ha), due to the effect of residual nitrogen in the soil.

Kalra and Gangwar (1980) compared nitrogen rates of 40, 80 and 120 kg/ha to maize in sole and in mixed crops. The optimum nitrogen rate was 80 kg/ha. The response to nitrogen application was only moderate. Sole maize yield, averaged over the 3 rates of nitrogen application, was 1405 kg/ha; average maize yield in the mixed crops was 1615 kg/ha. An additional yield of 1080 kg/ha of groundnut pods was produced in the mixed crops. The mixed crop gave spectacular results compared to sole maize, but the sole maize yield was low.

Nitrogen application to maize in mixed crops inhibited nitrogen fixation by the groundnut plants, both directly by increasing soil nitrogen and indirectly by stimulating maize growth and shading the groundnut plants (Searle et al., 1981). Nodulation and nitrogen fixation of groundnut plants at 70 DAS were adversely affected in a mixed crop with maize, when the maize received nitrogen fertilizer (Nambiar and Dart, 1980). When no nitrogen fertilizer was applied to the maize, weight of nodules and nitrogen fixation of the groundnut plants were not affected. Only 67% of the incoming radiation reached the groundnut canopy in the mixed crop without nitrogen fertilizer and only 43% in the mixed crop with 100 kg/ha of nitrogen applied to the maize.

No data on the transfer of biologically fixed nitrogen from groundnut plants to maize plants in mixed crops have been reported, and it is unlikely that such transfer is of any practical significance (Palmer, 1971). Higher productivity of mixed crops of groundnuts and maize compared to the corresponding sole crops was not due to transfer of biologically fixed nitrogen from groundnuts to the associated maize crop, and groundnut plants in mixed crops showed less nitrogen fixation than in the sole crops (Nambiar et al., 1983).

Groundnuts in sole crops and in mixed crops with maize had a favourable residual effect on subsequent crops. The residual effect of a mixed crop of maize and groundnuts on a subsequent maize crop was equal to a nitrogen fertilizer application of 100 kg/ha of nitrogen to sole maize (Searle et al., 1981). More stable yields were obtained on the long term than with continious growing of sole maize in the same field.

2.3.7 Water use

In a pot experiment with limited water supply, Syamsulbahri (1979) found a water use of 325 l/kg dry matter for sole groundnuts, 172 l/kg dry matter for sole maize and 224 l/kg dry matter for a mixed crop of groundnuts and maize. Total dry matter yield of sole groundnut plants was 2879 kg/ha and of sole maize 4279 kg/ha. The RY and LER values for total dry matter yield of the mixed crop were 0.56 + 0.65 = 1.21. With limited water supply, the amount of water used in the mixed crops was 2% less than expected according to the water use efficiency in the sole crops. However, with adequate water supply the amount of water used in the mixed crop was 3% more than expected. With adequate water supply, the water use was 515 l/kg dry matter for sole groundnuts, 216 l/kg dry matter for sole maize and 297 l/kg dry matter for the mixed crop of groundnuts and maize. It should be noted that maize had a more efficient water use than groundnuts, but that maize failed more easily than groundnuts under conditions of water stress. Water use figures in field conditions were considerably higher than in pot experiments.

During the dry season of 1977 in East Java, Imam Muslim (1977) found a high productivity of mixed crops of groundnuts and maize compared with the corresponding sole crops. The highest LER value obtained was 0.80 + 0.90 = 1.70. The pod yield of sole groundnuts was 1287 kg/ha and the grain yield of sole maize 2487 kg/ha. During the growing season there was only 551 mm of effective rainfall. The high productivity of the mixed crops was an indication of a more efficient use of the available water by the mixed crops than by the corresponding sole crops.

2.3.8 Effects of genotype

Syarifuddin et al. (1974) compared three maize cultivars that took 110, 85 and 75 days to maturity, respectively, in mixed crops with groundnuts that took 105 days to maturity. The maize cultivar with the longest growth duration was an improved cultivar with a higher productivity than the traditional cultivars of maize with a short growth duration. The optimal plant density of the improved cultivar in mixed cropping was lower than of the traditional cultivars. The improved maize cultivar, sown at a low plant density (40% of the sole maize density) between the groundnuts, gave a high yield and the highest mixed crop revenue. RY and LER values were 0.87 + 0.57 = 1.44. The revenue of the mixed crop was 25% higher that that of the most valuable sole crop. When the density of the improved maize cultivar was high, groundnut yield was severely reduced. The maize cultivars with a short growth duration gave a high yield in mixed crops when they were sown at high plant densities (80% of the sole density) between the groundnuts, but the LER and the revenues were lower than for the mixed crop with the improved maize cultivar.

No differences in productivity and revenues were reported by Imam Muslim (1977) between mixed crops of groundnuts with a maize cultivar of 110 days to maturity and mixed crops with a maize cultivar of 85 days to maturity. For both cultivars a plant density of 67% of the sole maize density was optimal in mixed crops with groundnuts. However, this meant a lower absolute plant density for the improved maize cultivar (34,000 plants/ha) than for the traditional cultivar (42,000 plants/ha). The labour requirement for harvesting the mixed crop with the traditioncal cultivar was better spread out over time than with the improved maize cultivar.

Akhanda (1979) in California found that early and medium maturing maize cultivars were better suited for mixed cropping with groundnuts than late maturing cultivars. Sole crop yields were very high: 7000 kg/ha for sole maize and 3360 kg/ha for sole groundnuts. The yield of maize in the mixed crops did not differ from that of sole maize. RY of groundnuts in the mixed crops was only 0.18. At these levels of productivity, the use of mixed cropping is of doubtful value. The leaf canopy of the taller plant species intercepted nearly all incoming radiation during an important part of the growing period and hardly transmitted any light for the shorter species. Relay cropping or sequential cropping (double cropping) would have been more appropriate.

Isgiyanto et al. (1980) found no differences in productivity and revenues between a mixed crop with a maize cultivar of 85 days to maturity and one with a maize cultivar of 75 days to maturity (using the replacement type of mixed cropping). The treatment $G_{0;50}$-$M_{0;50}$ gave a higher revenue than $G_{0;25}$-$M_{0;75}$ and $G_{0;75}$-$M_{0;25}$. The LER was around 1.00, so the productivity of the mixed crop was similar to that of the corresponding sole crops.

Maize yield in a mixed crop in Malawi was hardly lower than the corresponding sole crop yield, but groundnut yield was strongly reduced compared with the corresponding sole crop, when a high yielding maize cultivar with a long growing duration was used

at the standard plant density (Edje, 1982); $G_{0;100}-M_{0;100}$ gave RY and LER values of 0.28 + 0.95 = 1.23. It should be noted that the sole maize check had a yield of 5850 kg/ha and the sole groundnut check 2320 kg/ha. It is understandable that with a LAI of 4 for maize in the mixed crop, the yield of the associated groundnuts was low.
No information was found in the influence of groundnut genotype on its performance in mixed crops with maize.

2.3.9 Effects on pests and plant diseases

A lower incidence of the maize borer (*Ostrinia furnacalis*) was found in sole maize at low plant density than at high plant density, and the lowest incidence was found in mixed crops of groundnuts and maize (Suryatna Effendi, 1976). There was less attack of downey mildew disease (*Peronosclerospora maydis*) on maize in mixed crops with a low maize density than in sole maize, when the disease incidence of the downy mildew was moderate.
Koli (1975) observed that the fungus disease *Sclerotium rolfsii* reduced the crop stand of sole groundnuts more than the crop stand of groundnuts in mixed crops with maize, when the groundnut and maize plants were sown alternating in the same rows. On the other hand, damage by rosette virus disease was minimized by sowing the groundnuts early and closely spaced in sole cropping.
Liboon et al. (1976) found a higher flexibility to compensate for crop damage in a mixed crop of groundnuts and maize than in a sole maize crop.

2.3.10 Economic and social implications

Under a high level of crop management (water supply, soil fertility, crop protection), mixed crops of groundnuts and maize did not give a higher return over variable costs than the sole crops. Under a low level of crop management, however, the total

return over variable costs was higher for mixed crops than for sole crops (IRRI, 1974). Mixed cropping was attractive in land-limiting, labour-surplus situations.
Farmers in Ghana practised mixed cropping of groundnuts and maize to save on land cultivation efforts in the beginning of the rainy season and to get an early supply of maize for food after the long dry season (Azab, 1968). Azab compared the revenue of 1 acre of a mixed crop of groundnuts and maize with the revenues of half an acre of sole groundnuts and half an acre of sole maize. By this method of calculation he arrived at a higher revenue for the mixed crop than for the corresponding sole crops. However, if the mixed crop was compared with the most valuable sole crop (groundnuts), the mixed crop did not give a higher revenue.
Syarifuddin et al. (1974) reported a high revenue for a mixed crop of groundnuts and a late maturing maize cultivar. The return/cost ratio (R/C) of the mixed crop was similar to that of sole groundnuts and higher than that of sole maize.
Isgiyanto et al. (1980) mentioned a high revenue for mixed crops of groundnuts and early maturing maize cultivars.
Even when the LER was considerably higher than 1, in many cases the revenue of the mixed crop was lower than that of the most valuable sole crop (Syarifuddin et al., 1974; Isgiyanto et al., 1980). However, more food was produced, there was a better spreading of the required labour over the growing period, less weed growth and more stable yields than with sole cropping.

2.3.11 Yield stability

The effect of mixed cropping on yield stability over long periods (e.g. 20 years) have not been studied. Nevertheless, maintenance of soil fertility, prevention of soil erosion and avoidance of crop failure have been mentioned as important advantages of mixed cropping (Aiyer, 1949). A wheat crop following a mixed crop of groundnuts and maize had a 17% higher yield than after a sole maize crop (Nair et al., 1979).

Mutsaers (1978) reported indications that a mixed crop of groundnuts and maize under severely limiting nitrogen availability, had less risk of a supra-optimal plant density of maize than a sole maize crop.

Suryatna Effendi (1976) mentioned that damage by the maize borer was less catastrophic in mixed crops of groundnuts and maize than in sole maize.

The degree of compensation by groundnuts and maize in sole and mixed crops for artificial damage to the plants was studied in the Philippines (Liboon et al., 1976). The crop stand and leaf area were reduced to simulate insect damage. The sole maize yield was seriously affected by damage to the crop, the sole groundnut yield much less: groundnuts compensated better for damage than maize. In mixed crops, besides the intraspecific compensation for damage, maize gave a modest compensation for damage to groundnuts and groundnuts gave a strong compensation for damage to maize. Damage to maize decreased the shading of the groundnut plants.

Total yields in mixed crops were more stable over a long period than yields of the respective sole crops. However, the contribution of the individual associated crops to the total yield of the mixed crop was as variable or even more variable than the yields of the corresponding sole crops. The higher stability can be explained by the residual effect of biological nitrogen fixation by groundnut plants (Nambiar et al., 1981), by risk spreading over the two associated crops and by the possibility of compensation by one of the associated crops for damage to the other crop.

3 SURVEY OF FARMING PRACTICE

3.1 PROCEDURE

The survey was carried out from November 1979 to April 1980 in two districts of East Java: Wagir, 6 km south-west of Malang, situated at an altitude of 540 m above sea level, and Purwosari, 25 km north of Malang, at an altitude of 450 m (fig. 3.1). A questionnaire was used. In each district 20 farmers, selected in consultation with the village head, were interviewed. The interviewers were graduate students of the Faculty of Agriculture of Brawijaya University (fig. 3.3). The survey data were supplemented with observations and measurements in the field. At harvest time, crop samples were taken and their dry matter yields were calculated.

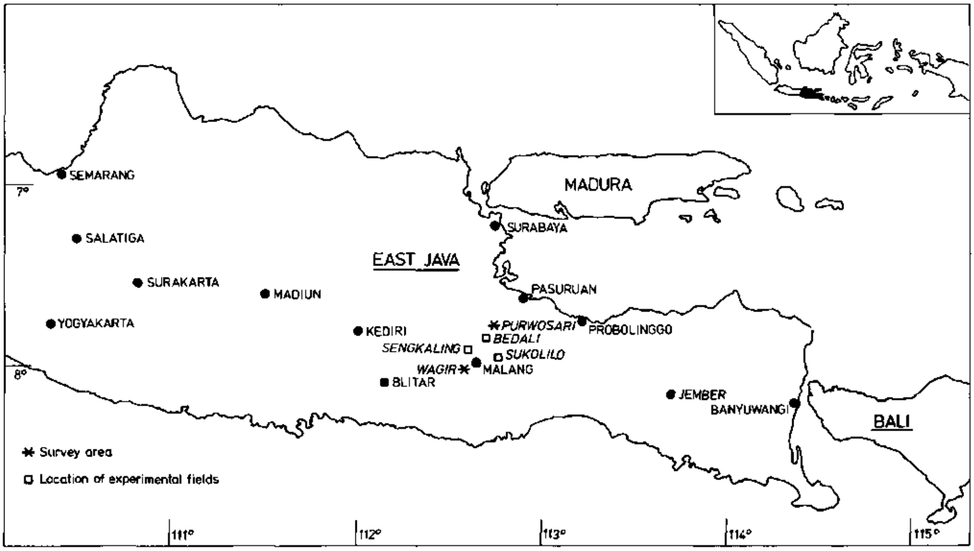

Fig. 3.1 Map of East Java

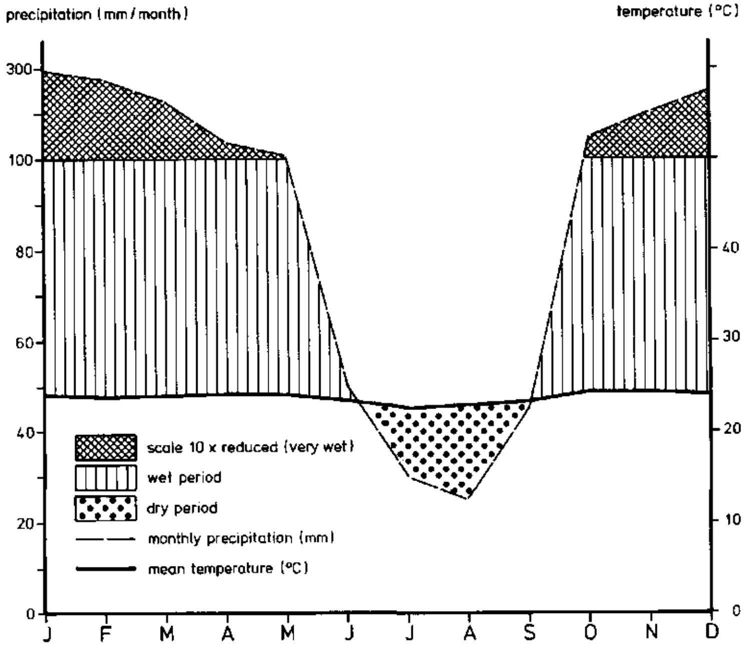

Fig. 3.2 Climate diagram for Malang
(after Walter and Lieth, 1967)

3.2 RESULTS

The average farm size was 0.81 ha, including the home garden. At least half of the land was double cropped every year. The average area of groundnuts and maize per year and per farm was 0.70 ha. The area of groundnuts consisted of 40% sole cropping and 60% mixed cropping, and the area of maize consisted of 51% sole cropping and 49% mixed cropping.
The soil in the district Wagir was a loamy sand soil and in the district Purwosari it was a clay soil.
In the district Wagir, sowing of groundnuts and maize took place the year round. The peak period for growing groundnuts and maize was from November to February, during the rainy season (fig. 3.2), under rainfed conditions, as upland crops (in Indonesian: tegalan). Growing groundnuts and maize as sole crops was more usual than growing the two crops in association.

A common practice in Wagir was planting cassava as a relay crop between groundnuts and between maize.

In the district Purwosari, groundnuts and maize were mainly grown from July-August to October-November, during the dry season (fig. 3.2), as irrigated crops after rice, known as second crops (in Indonesian: palawija). In Purwosari groundnuts and maize were mainly grown in mixed cropping.

The spacing of groundnuts was somewhat closer in the district Purwosari than in the district Wagir and the spacing of maize wider (table 3.1).

There were 2 maize plants per hill in both districts. Groundnuts had on average 1.5 plants per planting hole in Wagir, and 1 plant per planting hole in Purwosari. In both districts, the plant density of groundnuts in mixed crops was similar to that in sole crops. The plant density of maize in mixed crops was about half of that in sole crops. The summed plant density in mixed crops was considerably higher than the plant density in sole crops.

No fertilizer was applied to the groundnuts in sole or in mixed crops. Maize was side-dressed with urea (46% nitrogen) in both sole and mixed crops. In sole crops the fertilizer was usually applied in two equal doses at 20 DAS and 40 DAS. In mixed crops it was more usual to apply the fertilizer once at 30 DAS.

Maize was mostly used for home consumption. Most of the groundnuts were sold, usually while still standing in the field (in Indonesian: tebasan). The fresh maize haulms were used as fodder for the farmers' own livestock and for the cattle of other farmers. Sometimes it was sold. Maize stubble was collected to be used as fuel for cooking.

The tender parts (tops) of the groundnut haulms were used as fodder for the farmers' own livestock and for the cattle of other farmers, and the rest was left in the field.

Table 3.1 Results from the survey of farming practice of growing groundnuts and maize

District	Wagir	Purwosari
a) Average farm size (ha)	0.89	0.72
b) Area cultivated annually to groundnuts and to maize (ha/farm)		
Sole groundnuts	0.27*	0.07
Sole maize	0.35	0.19
Mixed crop of groundnuts and maize	0.11	0.41
c) Spacing (cm x cm)		
Sole groundnuts	30 x 29	26 x 17
Sole maize	78 x 28	84 x 40
Groundnuts in mixed crops	31 x 29	26 x 18
Maize in mixed crops	90 x 44	120 x 54
d) Plant density (number of plants/ha)		
Sole groundnuts	172,000	226,000
Sole maize	92,000	60,000
Groundnuts in mixed crops	167,000	214,000
Maize in mixed crops	50,000	31,000
e) Plant density (as % of sole crop)		
Groundnuts in mixed crops	97	95
Maize in mixed crops	54	52
Total mixed crop	151	147
f) Fertilizer application (kg/ha of urea)		
Sole maize	96	87
Maize in mixed crops	38	35
g) Marketable yield (kg/ha)		
Sole groundnuts	1465	1368
Sole maize	2284	1991
Groundnuts in mixed crops	1084	1203
Maize in mixed crops	936	896
h) RY and LER		
RY of groundnuts in mixed crops	0.74	0.88
RY of maize in mixed crops	0.41	0.45
LER of mixed crops	1.15	1.33

* Sole groundnuts in the district Wagir were usually relay-cropped with cassava.

A S L I

GUBERNUR KEPALA DAERAH TINGKAT I
JAWA TIMUR

SURAT KETERANGAN

untuk melakukan survey / research

Nomor : 1700 /Sur/Res/Um. 033/19 79.

Membaca	:	1.Srt.Rektor UNIBRAW Malang, 23 Oct. 1979 No.FP.102/C.1/79. 2.Srt.Rektor UNIBRAW Malang,7 Nop.1979 No.6269/C.1/79. 3.Srt.Kep.Dinas Pertanian Prop.Jatim, 10 Nop. 1979 No.Birad/2219/I-a
Mengingat	:	1. Instruksi Menteri Dalam Negeri No. 3 Tahun 1972 2. Surat Gubernur Kepala Daerah Tk. I Jawa Timur tgl. 17 Juli 1972. No. Gub. / 187 / 1972

dengan ini menyatakan TIDAK KEBERATAN dilakukan survey / research oleh :

Nama Penanggung Jawab	:	DR. SOETONO. Dekan Fak.Pertanian UNIBRAW Malang.
Alamat	:	Jl. Mayjen Haryono 169 Malang.
Thema / Acara survey / research	:	Bercocok tanam kacang tanah dan jagung pada sistim tumpang sari di Jawa Timur.
Daerah / Tempat dilakukan survey / research	:	Kab. Malang, Probolinggo dan Pasuruan.
Lamanya survey / research	:	3 (tiga) bulan mulai tgl.15 Nopember 1979.
Pengikut / peserta survey / research	:	

Ir.WC. H.Van Hoof (Belanda), supervisi.
Dan 5 orang surveyor lapangan.
Daftar nama nama terlampir.

DAFTAR PESERTA SURVAI

No.	Nama	Nrp.	Keterangan
1.	Achijad M. Djamhari	4771500-Agr	Surveyor lapang
2.	Santosa	4741138-Agr	Surveyor lapang
3.	Soegito	4600008-Agr	Surveyor lapang
4.	Soeyitno	4751247-SE	Surveyor lapang
5.	Bambang Soetedjo	4751169-SE	Surveyor lapang

Surabaya, 14 NOV 1979

GUBERNUR KEPALA DAERAH TINGKAT I
JAWA TIMUR.
Sekretaris Wilayah/Daerah
u.b.
Kepala Direktorat Sospol,

SOEKARSONO
NIP.010000923

TEMBUSAN disampaikan kepada :

1. Yth. Pangdam VIII/Brawijaya
2. „ Kadapol X/Jawa Timur
3. „ Ketua Bappeda Prop. Daerah Tk. I Jawa Timur
4. „ Kepala Direkt. Khusus Prop. Daerah Tk. I Jawa Timur
5. „ Dinas / Jawatan : ybs.
6. „ Pembantu Gubernur di Malang.
7. „ Bupati Kepala Daerah Tk. II : ybs.
8. „ Walikotamadya Kepala Daerah Tk. II : –
9. Rektor UNIBRAW.

Fig. 3.3 Authorization of the Governor of East Java Province for a survey on mixed cropping of groundnuts and maize

3.3 DISCUSSION AND CONCLUSIONS

A considerable part of the groundnuts and maize in the districts Wagir and Purwosari was produced in mixed cropping.
The total marketable yield of the mixed crops of groundnuts and maize expressed in land equivalent ratio, was 15% higher than the yield of the corresponding sole crops in the district Wagir and 33% higher in the district Purwosari (table 3.1). However, the LER values calculated from the survey results need to be considered with caution, because in many cases different maize cultivars were used for sole crops and for mixed crops. 'Harapan' (growth duration 110 days) was a typical maize cultivar for sole crops and 'Kretek' (85 days) for mixed crops.

Plate 1: Observations in a farmer's field with a mixed crop of groundnuts and maize in the district Purwosari

Plate 2. Bundles of groundnut haulms for sale as fodder

4 *MATERIALS AND GENERAL METHODS*

4.1 LOCATION, TIME AND CLIMATE

All field experiments were conducted from 1978 to 1980 in the surroundings of Malang in East Java. Malang is situated at an altitude of about 500 m above sea level, at 7°57'S and 112°37'E (see fig. 3.1). The daylength at this latitude varies from 11 h 55 min to 12 h 45 min over the year.
The meteorological data for Malang are presented in table 4.1. There is a dry season from May to September (east monsoon) and a rainy season from November to March (west monsoon). The onset of the rains and the duration of the rainy season are variable over the years, so that dryland farming often is upset by drought.
Meteorological observations at the Meteorological Station of Brawijaya University are presented for the individual experiments in the chapters 5, 6 en 7.

Table 4.1 Meteorologocial data of Malang, average over the period 1974 to 1980

	Temperature (°C)			Soil temperature 50 cm (°C)	Precipitation (mm)	Class A pan evaporation (mm)	Relative humidity (%)	Incoming radiation (J/cm2 per day)
	mean	maximum	minimum					
January	24.0	28.8	19.9	27.2	295	112	82	1525
February	23.8	28.9	20.0	27.0	277	102	83	1560
March	23.9	28.9	20.1	27.1	227	118	84	1568
April	24.1	29.4	19.5	27.4	137	126	80	1765
May	24.0	29.2	19.2	27.6	107	136	80	1641
June	23.3	28.5	18.4	27.4	51	135	79	1622
July	22.6	28.2	17.5	26.9	30	149	79	1741
August	22.9	28.6	17.8	27.1	25	158	77	1824
September	23.3	28.9	18.5	27.5	45	150	78	1857
October	24.2	29.7	19.6	28.0	151	146	79	1791
November	24.3	29.5	19.7	27.8	204	120	81	1663
December	24.2	29.0	19.8	27.3	254	121	82	1609
Total					1803	1573		
Mean	23.7	29.0	19.2	27.4			80	1680

The data were obtained from the Meteorological Station of Brawijaya University, Malang, situated at an altitude of 505 m above sea level.

The results of 7 field experiments on mixed cropping of groundnuts and maize are reported. Experiment 1 was carried out in 1978 at a seed production farm of the Agricultural Extension Service at Bedali, 15 km north of Malang, situated at an altitude of 420 m above sea level. Experiment 2 was carried out in the same year on a farmer's field at Sengkaling, 9 km north-west of Malang, situated at an altitude of 600 m. The experiments 3, 4, 5, 6 and 7 were carried out in 1979 and 1980 on farmers' fields at Sukolilo, 13 km north-east of Malang, situated at 520 m altitude.
Various soil types are found in the Malang area (Peta Tanah Tinjau, Lembaga Penelitian Tanah, 1964; Soil Map of the World, FAO-Unesco, 1974). The soil type is a Luvisol at Bedali, an Andosol at Sengkaling and a Regosol at Sukolilo. The parent material of all three soil types is volcanic tuff.
Analysis of soil samples from the experimental fields was carried out at the Department of Soil Science, Faculty of Agriculture, Brawijaya University. Characteristics of the analysed soils are shown in table 4.2. The soil class at all three locations was loam.

Table 4.2 Characteristics of some soils in the Malang area

Location	Clay (%)	Silt (%)	Sand (%)	Organic mat. (%)	C/N ratio	Total N (%)	P (ppm)	K (ppm)	Ca (%)	pH (water)
Bedali	13	35	52	1.8	13	0.08	5	220	0.08	6.2
Sengkaling	24	34	42	2.4	11	0.12	21	290	0.22	6.7
Sukolilo	15	36	49	2.2	12	0.09	7	260	0.12	6.8

An evaluation of soil characteristics is given in table 4.3. The organic matter content of all soils was rather low. The C/N ratio was fair. Total nitrogen content was low. Phosphate availability (Bray II) was from medium to very low. Potassium content was good. Calcium content (NH4-acetate extraction) was from good to low. The pH of all soils was between 6 and 7 (1:1 soil-water), suitable for groundnuts and maize. At Sengkaling the soil was more fertile than at Bedali and Sukolilo.

Table 4.3 Indicatory values of soil characteristics (after Agricultural Compendium, 1981)

	Organic matter content (%)	C/N ratio	Total N (%)	P (ppm)	K (ppm)	Ca (%)	pH (water)
High	5	20 (bad)	0.3	30	300	0.30	7.5 (alkaline)
Medium	3	13 (fair)	0.2	20	150	0.15	6.5 (neutral)
Low	1	10 (good)	0.1	15	100	0.05	5.5 (acid)

4.2 PLANT MATERIAL

Only one cultivar of groundnuts ('Gajah') and one of maize ('Kretek') were used in the experiments. 'Gajah' is the most common groundnut cultivar in East Java. It is a Spanish bunch type, that takes about 105 days from sowing to maturity. 'Kretek', an improved selection of the traditional cultivar 'Kediri', is a yellow flint maize with a growing period of about 85 days.

4.3 CULTURAL PRACTICES

The cultural practices adopted for the experiments were the ones used in the local farmers' fields. The soil was prepared by ploughing and hoeing. During soil preparation a basal dressing was carried out of 40 kg/ha of phosphorus pentoxide in the form of triple superphosphate and of 23 kg/ha of nitrogen in the form of urea. Sowing was done with a planting stick, and the planting holes were closed by foot. Groundnuts were sown at a spacing of 25 x 25 cm. The plant density of groundnuts was 160,000 per hectare. Maize was sown at a spacing of 80 x 20 cm, with 3 seeds per planting hole. Two weeks after sowing, the maize was thinned to 2 plants per hill, resulting in a plant density of 125,000 per hectare. The plant density in experiments 1 and 2 followed the practice at the seed production farm of the Agricultural Extension Service at Bedali.

Three weeks after sowing, the maize rows were ridged with a hoe. In mixed crops, maize rows were not ridged. Weeding of groundnuts and of mixed crops was done with a small hoe, three weeks after sowing.

Maize in sole crops received a side dressing of 45 kg/ha of nitrogen, in the form of urea, at the time of ridging. No top dressing was applied to maize in mixed crops. Groundnuts were not top-dressed.

When insect damage was observed in maize, the plants were sprayed with diazinon at a dose of 300 ml active ingredient per hectare. A fence of transparent plastic sheet, 50 cm high, was placed around the experimental fields against rats. Baits with zinc phosphide crimidine were used for rat control. No other chemical control of pests and diseases was carried out.

Harvesting was done by hand. Maize plants were cut with a sickle at 20 cm above soil level. Maize ears were picked and dried in the sun. Groundnut plants were uprooted and the mature pods were picked by hand. The pods were dried in the sun for about one week.

4.4 EXPERIMENTAL DESIGNS

4.4.1 Randomized complete block design

Experiments 1 and 3 were laid out as randomized complete block designs, with four replicates each. The gross plot size was 48 m^2. Two rows for groundnuts, and one row for maize were taken as border rows. Samples were taken every 15 days during the growing period. The sampling areas in the experimental plots of experiment 3 were 1.5 m^2 for groundnuts, comprising 24 groundnut plants, and 1.6 m^2 for maize, comprising 20 maize plants (see fig. 4.1). The net plot size for the final harvest was 8 m^2, comprising 128 groundnut plants and/or 100 maize plants.

At other plant densities of groundnuts and maize (experiment 1) the number of sample plants varied accordingly. In experiment 1, the spacing of groundnuts was 30 x 20 cm, with two seeds per planting hole, and the spacing of maize was 80 x 30 cm, with two plants per hill.

The data for each sampling date were submitted to an analysis of variance for groundnuts and for maize separately. The LER values of the mixed crop treatments were also analysed statistically.

4.4.2 Systematic designs

Systematic designs were used to study relative sowing time, plant density and plant arrangement in mixed crops, as in experiments 2, 4, 5, 6 and 7. Border rows were needed for each replicate of the experiment. Some plants were selected for non-destructive measurements every 15 days during the growing period (plant height, length and width of the leaves, number of leaves). The experimental plots were replicated four times.

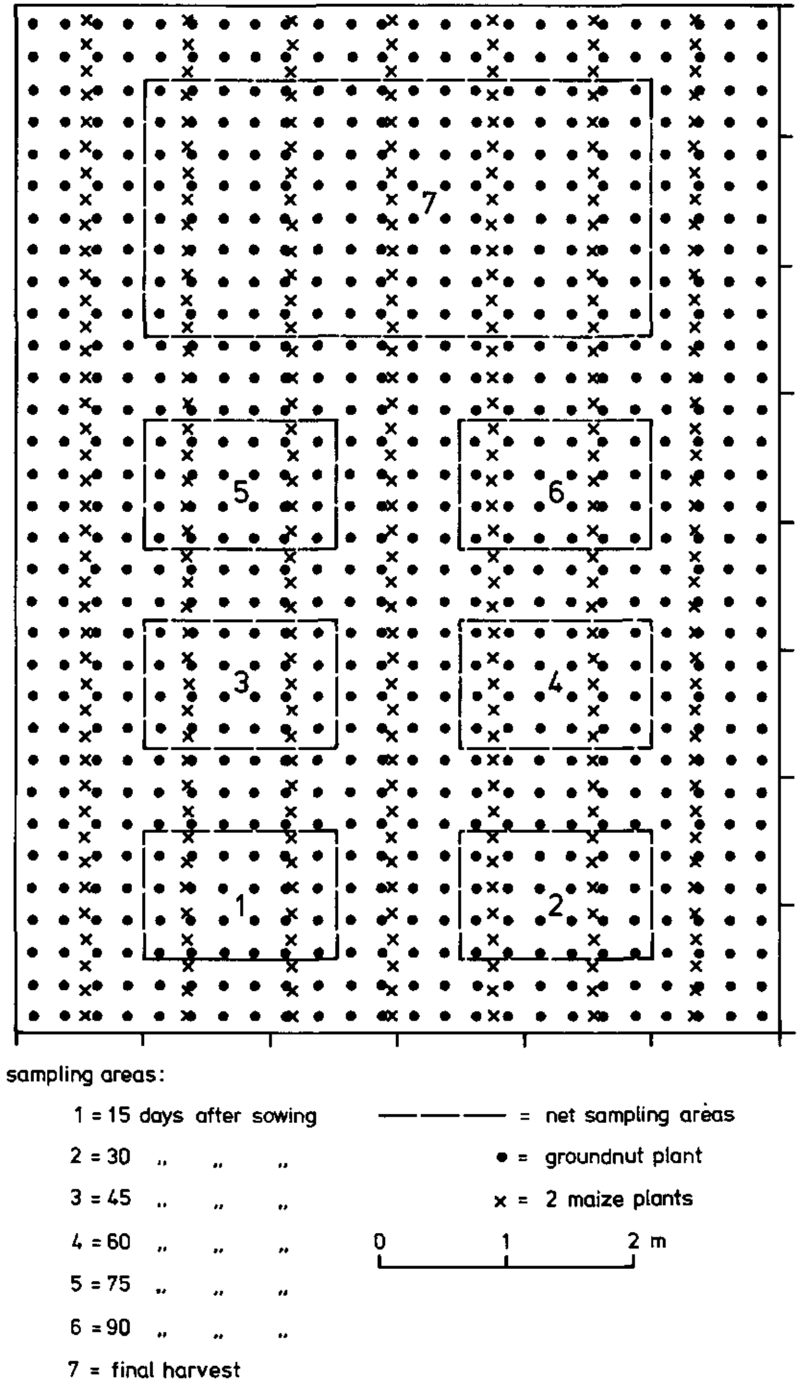

Fig. 4.1 Lay-out of an experimental plot with a mixed crop of groundnuts and maize in experiment 3.

In experiment 2, the sowing time of maize in mixed crops with groundnuts was changed systematically along the rows. The sowing time interval was six days over a period of one month. Each sowing date occupied a three meter row length. Spacing of groundnuts was 30 x 20 cm, with two seeds per planting hole, and the spacing of maize was 80 x 30 cm, with two plants per hill. Maize in sole crops was also sown on different dates. No sowing time effect was observed for maize in sole crops. The average yield of sole maize for the 3 sowing dates was used as a control to evaluate the results of the mixed crops.

The fan design, a systematic spacing design described by Nelder (1962), was used to cover a wide range of plant densities of maize between groundnuts. The maize plants gradually got more space without changing their arrangement, each position in the row corresponding to a different plant density. The plant density of groundnuts was constant over the field (fig. 4.2). At harvest time the fan was divided into 9 segments of 1-meter row length. The fan design has been used in the experiments 4, 6 and 7.

Linear and quadratic regression analysis were used to establish the relationship between the experimental data and the variables (plant density or sowing time) in the systematic designs. With regression analysis, trends in yields were shown within a series of plant density steps (experiments 4, 5, 6 and 7) or sowing dates of maize (experiment 2), which was more appropriate than testing the differences between individual treatments within the series. Regression analysis has been worked out for linear or quadratic trends, depending on the correlation coefficient (R). A low correlation coefficient for the linear regression analysis and a higher one for the quadratic regression analysis meant that the relationship was presented better with a curved line. The regression equations were calculated for the mean yields of the treatments over the four replicates within each series of plant density steps or sowing dates of maize.

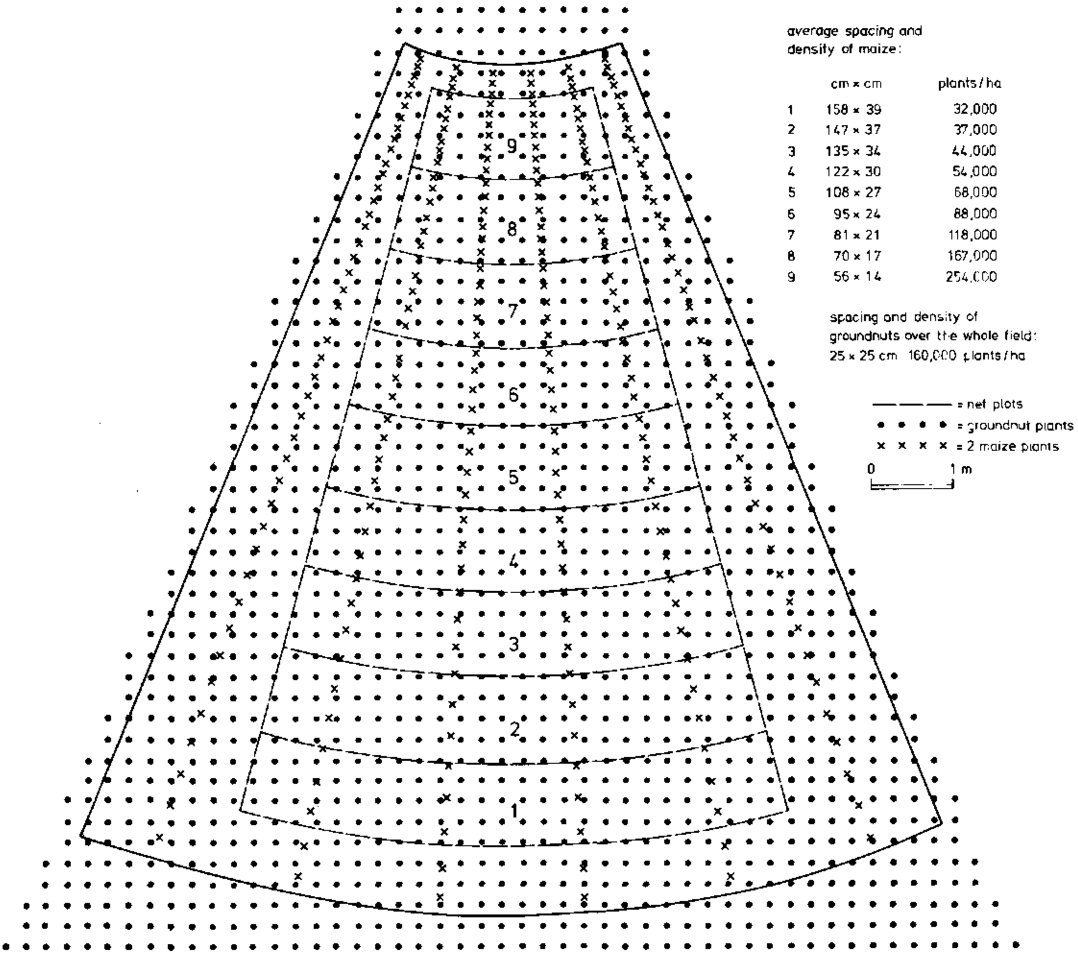

Fig. 4.2 Lay-out of a systematic spacing design (fan design) of maize in mixed cropping with groundnuts.

In experiment 5, the density and arrangement of maize plants in mixed cropping with groundnuts were varied systematically by keeping the row spacing constant and varying the distance between maize plants in the row stepwise (arrangement 1), or by varying the row spacing and keeping the distance between plants in the row constant (arrangement 2). Each row corresponded to a different plant density and plant arrangement (see fig. 4.3).

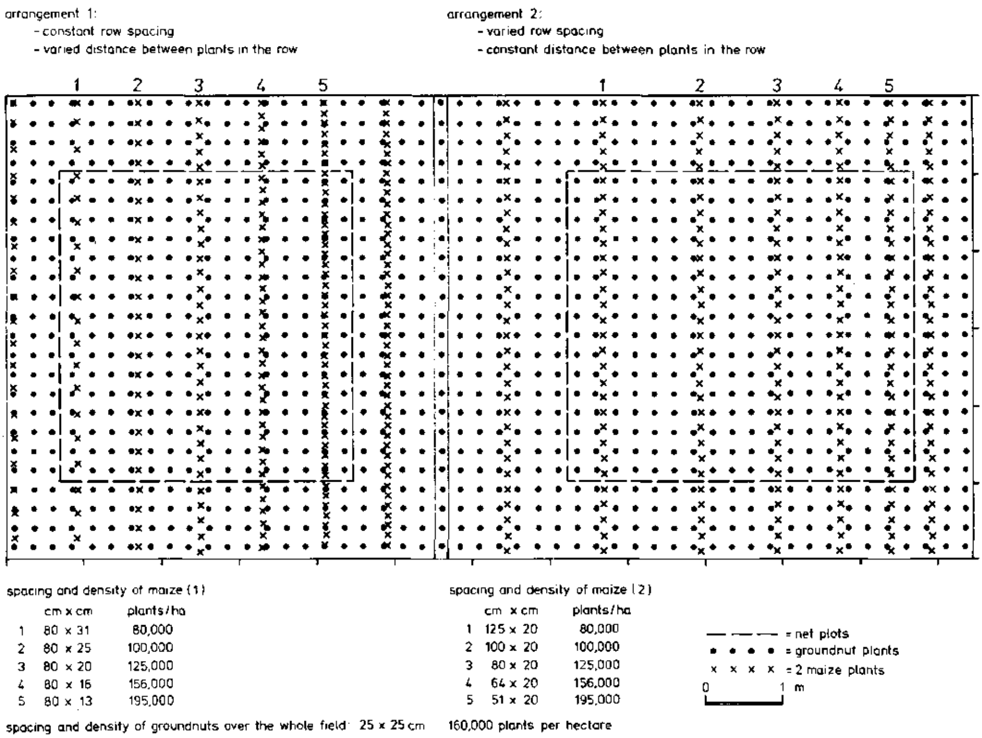

Fig. 4.3 Lay-out of a systematic spacing design with two plant arrangement series of maize plants in experiment 5.

4.5 OBSERVATIONS AND CALCULATIONS

4.5.1 Plant height

The height of groundnut plants was measured from soil level to the top of the last unfolded leaf. The height of maize plants was measured from soil level to the highest point of the plant after straightening out the bent-down leaf blades. A 2.5 m long measuring stick of bamboo was used.

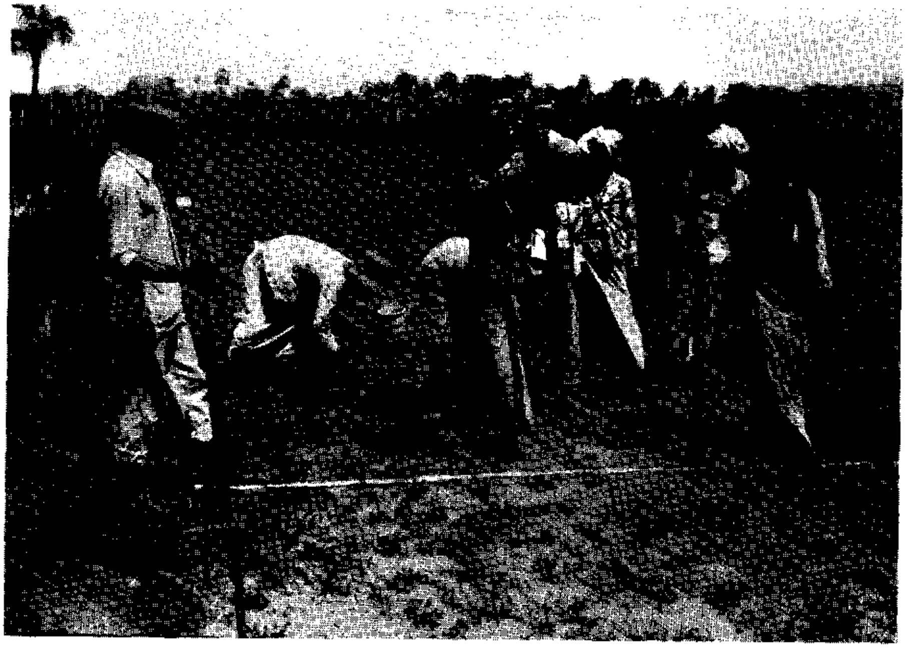

Plate 3. Sowing of maize between 10 days old groundnut plants in an experimental field at Sukolilo

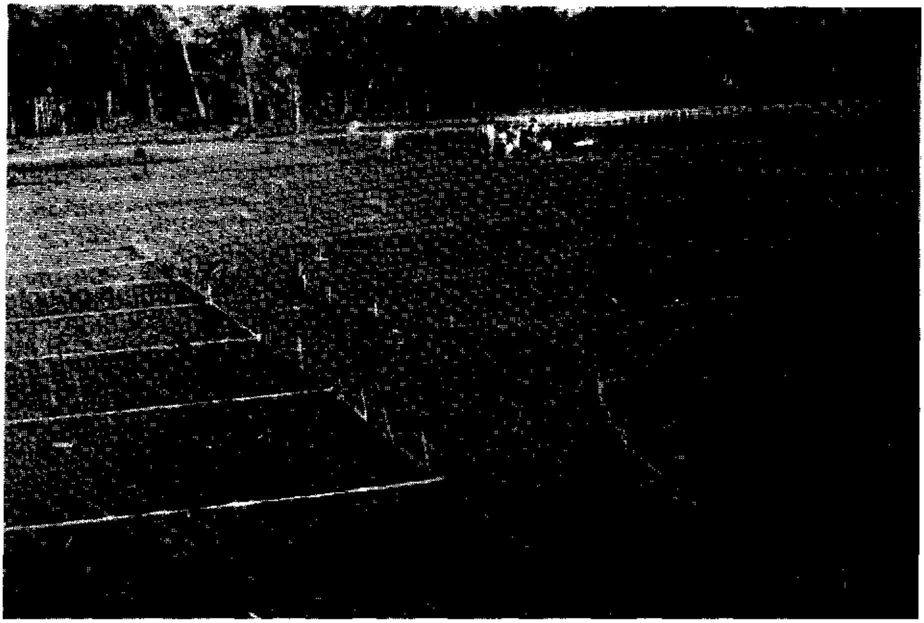

Plate 4. View of the lay-out of field experiment 6 at Sukolilo, for sowing maize in a fan design in mixed cropping with groundnuts

4.5.2 LAI

Leaf areas of the sampled plants were measured with an electronic area meter (Li-cor 3100), after harvesting of the sampling area. Leaf areas of groundnut plants in the field were calculated by measuring the lengths (2R) and widths (2r) of the leaflets and using the formula for calculating the area of an ellipse:

leaf area = 3.14 x R x r

For well-developed groundnut plants in the field, the area of some leaves was measured and multiplied by the total number of leaves per plant to calculate the approximate leaf area per plant. Leaf areas of maize plants in the field were determined by measuring the lengths (L) and maximum widths (W) of the leaf blades, using the formula:

leaf area = 0.7 x L x W

The factor 0.7 in the formula was found empirically by comparing the lengths and widths of leaf blades of sampled plants and measuring their areas with the electronic area meter. The factor 0.7 was in agreement with the findings of Williams, Loomis and Lepley (1964).

The leaf area index (LAI) was calculated by dividing the leaf area of the sampled plants by the area of ground sampled. The LAI for the mixed crop was calculated by summing the LAI values for groundnuts and maize in mixed crops for each observation date.

4.5.3 Time to flowering

The flowering time for groundnuts was taken to be the date when 50% of the plants in an experimental plot had begun to flower.

Time to flowering was the interval from sowing to 50% flowering. After the onset of flowering, the number of new flowers was counted daily on four selected groundnut plants per plot.

The flowering of maize was divided into tasseling and silking. The dates were recorded when the tassel had appeared in 50% of the maize plants and when in 50% of the plants silk was visible.

4.5.4 Yield and yield components

At each harvest, the groundnut plants were separated into leaves, stalks and pods. After the final harvest the total number of pods and the number of mature pods per sampled plant were counted. The dry weights of the groundnut stalks, leaves and pods were determined after drying to constant weight in a forced ventilated oven at 85°C. After drying the pods, the number of seeds was counted and seeds were weighed. The harvest index (H.I.) of groundnuts was the dry weight of mature pods divided by the total dry weight of stalks, leaves and pods. Root weight was not included in the total dry matter yield.

Maize plants were separated into (pseudo-)stem, leaf blades and ears. After drying at 85°C and weighing, the grain was removed from the ears, weighed and counted. The H.I. of maize was the dry grain weight divided by the dry weight of all the aboveground plant parts.

The dry weights of both groundnuts and maize were converted into kilograms per hectare. Total dry matter yield included all oven-dried plant parts except the roots. The pod yield of groundnuts and the grain yield of maize were adjusted to 12% moisture content to obtain the marketable yield.

4.5.5 Yield calculations in the mixed crops

The relative yields (RY) of groundnuts and maize in mixed crops were calculated as the proportions of the corresponding sole crops. By summing the relative yield of groundnuts and maize, the land equivalent ration (LER) of the mixed crop was calculated (IRRI, 1974).

The energy yield of groundnuts and maize was calculated. The average energy content of dry organic matter was assumed to be 16,700 joules (J) per gram of sugar, starch, protein and fibre and 37,600 J per gram of fat. Energy content of groundnut pods was 23,280 J per gram, based on a fat content of 45% in the seeds and assuming 30% shell weight. The energy content of maize grains with 4.5% fat content was 17,640 J per gram.

The economic value of the yield was also calculated. The selling price of groundnut pods in Indonesian rupiah (Rp) was Rp 300 per kg. The selling price of maize grain was Rp 75 per kg. The costs of the original sowing seeds were subtracted from the gross revenue of the yield. Sowing seed was more expensive per kilogram than the selling prices for groundnuts and maize. The price for sowing seed of groundnuts was Rp 400 per kg of pods. The price for sowing seed of maize was Rp 100 per kg. To sow one hectare of groundnuts at a spacing of 25 x 25 cm and a plant density of 125,000 plants per hectare, 100 kg of pods were needed. For one hectare of maize at a spacing of 80 x 20 cm with two plants per hill and a plant density of 125,000 plants per hectare, 25 kg of sowing seed was needed. Fertilizer prices were Rp 100 per kg for urea and for triple superphosphate. Prices from 1980 were used for the calculations. The economic values of the yield was also converted to US$ per ha, based on the 1980 exchange rate of Indonesion Rp 625 = US$ 1.

4.5.6 Light interception by the crops and light use efficiency

In some experiments the light intensity above the crop and beneath the canopy was measured every 15 days with a nickel-cadmium light meter. In the mixed crops, the light intensity was measured at three levels: above the maize crop, above the groundnut crop (beneath the maize canopy) and beneath the groundnut canopy. Light measurements were made between 3 and 4 p.m. The difference between the light intensity above the crop and beneath the canopy was considered as the fraction of light intercepted by the crop (Monteith, 1972). The total percentage of light intercepted by a mixed crop was calculated from the difference between the light intensity above the maize crop and beneath the groundnut canopy.

The relationship between LAI and light interception by the crop was determined for groundnuts and for maize from preliminary experiments (fig. 4.4).

Calculations of light interception based on LAI values were less variable than calculations based on light measurements in the field. The total amount of light intercepted by groundnuts and maize during the growing period was estimated by interpolation, based on the LAI curves over the growing period and the empirically established relationship between LAI and light interception by the crops. Total light interception of mixed crops was calculated by summing the percentages of light intercepted by groundnuts and by maize during the growing period.

The energy content of the intercepted light was calculated based on the average amount of incoming radiation per day measured at the Meteorological Station of Brawijaya University, Malang (table 4.1). This was on average 1680 J/cm^2 per day. The light use efficiency of the crops was calculated by dividing the energy content of the total dry matter yield by the energy content of the intercepted light.

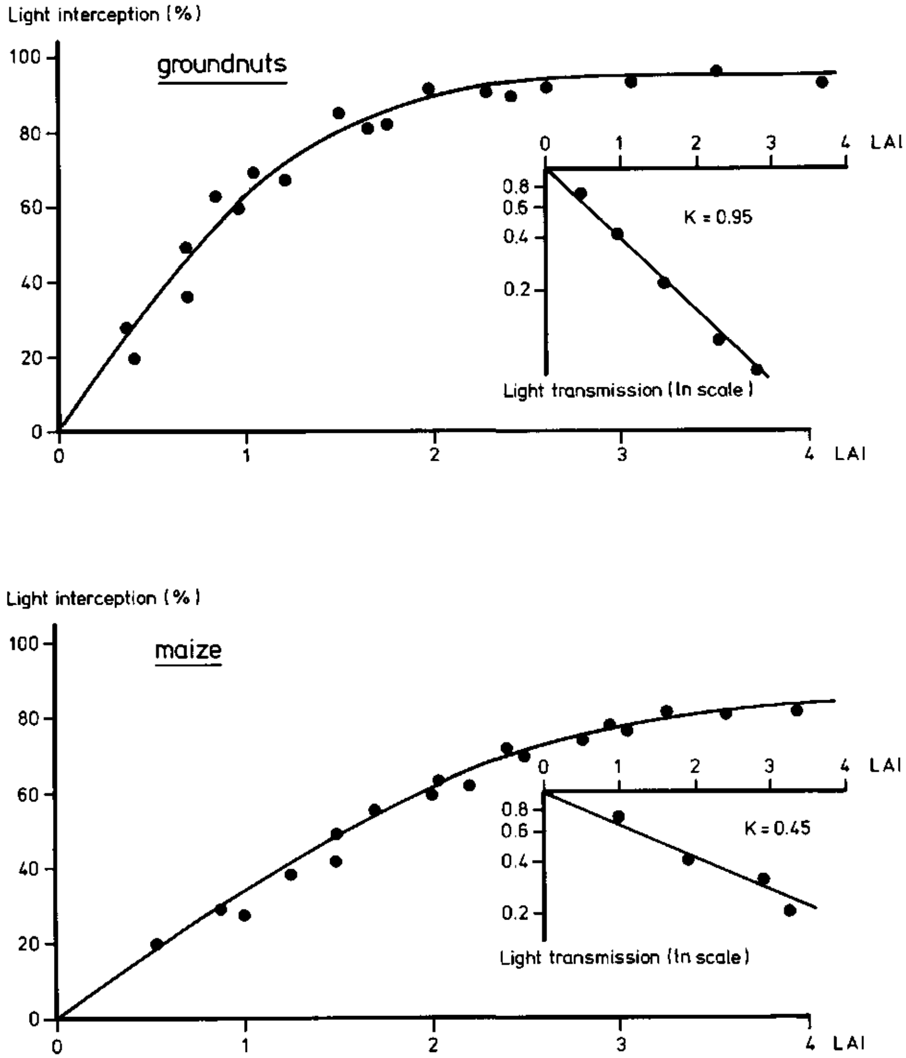

Fig. 4.4 Relationship between LAI and intercepted light (as % of incoming radiation) for groundnuts and for maize.

5 *THE EFFECTS OF DIFFERENT SOWING TIMES*

5.1 INTRODUCTION

Competition between crops in mixed cropping can be strongly influenced by changing the sowing time of one of the crops.
The farming practice in East Java of sowing groundnuts and maize at the same time in mixed crops causes the groundnut crop to suffer severe competition from the maize.

In the following experiments, the effect of later sowing of the maize on the results of the mixed crop was compared with simultaneous sowing of groundnuts and maize.

5.2 MATERIALS AND METHODS

Experiment 1

Experiment 1 was carried out from 3 April until 17 July 1978 on a seed production farm of the Agricultural Extension Service at Bedali, 15 km north of Malang (fig. 3.1). The graduate student S.M. Sitompul carried out the experiment. Sowing was done at the end of the rainy season and harvesting during the dry season. The previous crop was upland rice. No irrigation was practised. Rainfall and open pan evaporation during the growing period are shown in fig. 5.1. The mean temperature during this period was 23.7°C.

Characteristics of the loam soil at Bedali are shown in paragraph 4.1, table 4.2. The water availability in the soil profile was studied six times during the growing period by sampling to a depth of 60 cm with an auger. Four samples per drillhole were taken; 0-15 cm, 15-30 cm, 30-45 cm and 45-60 cm, respectively. The soil samples were dried at 105°C to constant

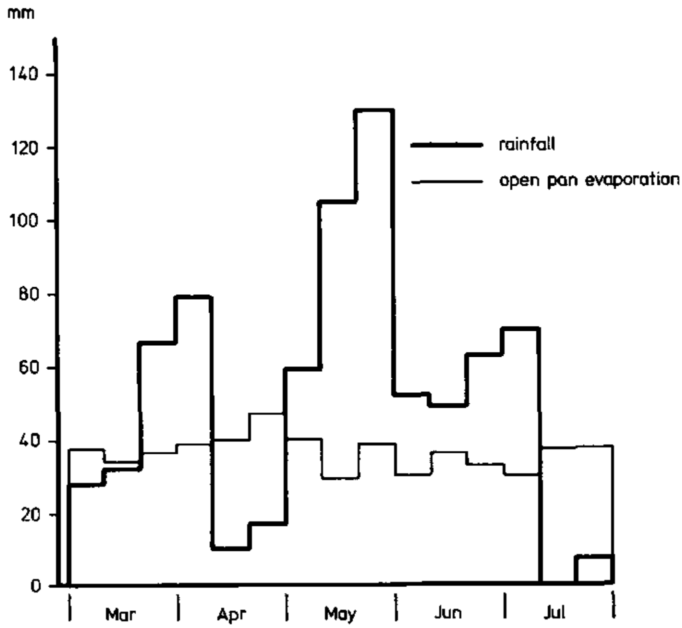

Fig. 5.1 Rainfall and open pan evaporation in mm per period of 10 days from March to July 1978.

weight and their water content was calculated. The soil at Bedali had a field capacity of 45% water. The permanent wilting point was reached at a water content of 10%. Thus the maximum amount of water available for plant growth in the soil was 35%. Information on water content of the soil is shown in table 5.1.

Around 15 days after sowing (DAS) of the groundnuts, the top soil was dry. From 30 to 60 DAS the subsoil was extremely wet.

Table 5.1 Water content (%) in different layers of the soil at Bedali during the growing period of groundnuts and maize.

Depth of soil layer (cm)	Sampling time (days after sowing)					
	0	15	30	45	60	75
0-15	25	18	37	36	31	22
15-30	29	19	43	43	41	38
30-45	33	22	46	47	42	40
45-60	36	24	50	49	43	41

The experiment was laid out as a randomized complete block design, replicated 4 times. Treatments were:

- Sole G: Sole groundnuts, sown at 3 April, 1978
- Sole M: Sole maize sown 0, 10 and 20 days later than groundnuts
- $G\text{-}M_{0;100}$: Mixed crop of groundnuts and maize, sown at the same date
- $G\text{-}M_{10;100}$: Mixed crop, with maize sown 10 days later than groundnuts
- $G\text{-}M_{20;100}$: Mixed crop, with maize sown 20 days later than groundnuts

Spacing of groundnuts was 30 x 20 cm, with 2 seeds sown per hill. There were 167,000 groundnut hills per hectare. It did not make a difference in yield at the final harvest whether two groundnut plants developed per hill or only one (Sitompul et al., 1981). Spacing of maize was 30 x 80 cm, with 2 plants per hill. The plant density of maize was 83,000 plants per hectare. These plant spacings were the normal practice on the seed production farm at Bedali.

Basal fertilizer application was 23 kg/ha of N in the form of urea and 40 kg/ha of phosphorus pentoxide in the form of triple superphosphate. The top dressing to sole maize was 92 kg/ha of nitrogen and 69 kg/ha of nitrogen in the form of urea to maize in the mixed crops. This fertilizer rate was higher than the usual farming practice. No top dressing was given to groundnuts.

Experiment 2

Experiment 2 was carried out from 5 April to 23 July, 1978 on a rented farmer's field at Sengkaling, 9 km north-west of Malang (fig. 3.1). The graduate student Juliar Dicky Hartono carried out the experiment. The previous crop was maize. The field was watered once after sowing. Climatic conditions were the same as reported for experiment 1. Characteristics of the loam soil at Sengkaling are shown in section 4.1, table 4.2.

The experiment was laid out in a systematic sowing time design, replicated 4 times. Treatments were:

- Sole G: Sole groundnuts, sown at 5 April, 1978
- Sole M: Sole maize, sown 0, 6, 12, 18 and 24 days after groundnuts
- $G\text{-}M_{0;100}$: Mixed crop of groundnuts and maize, sown at the same date
- $G\text{-}M_{6;100}$: Mixed crop, with maize sown 6 days later than groundnuts
- $G\text{-}M_{12;100}$: Mixed crop, with maize sown 12 days later than groundnuts
- $G\text{-}M_{18;100}$: Mixed crop, with maize sown 18 days later than groundnuts
- $G\text{-}M_{24;100}$: Mixed crop, with maize sown 24 days later than groundnuts.

In each replicate, the sowing time of the maize in the mixed crop varied consistently along the row. Border rows were present around the replicates. No guard plants were observed between the successive plots within the replicates. Spacing of groundnuts and maize and fertilizer application were the same as in experiment 1.

5.3 RESULTS

5.3.1 Plant height

Groundnuts

In experiment 1 no differences in plant height of groundnuts were found between mixed crop treatments (fig. 5.2). Groundnut plants reached a height of about 60 cm. The mean height of the groundnut plants in G-$M_{0;100}$ was higher than in the sole crop. The height of the groundnut plants was increased by shading and was negatively correlated with LAI and total dry matter and marketable yield. In experiment 2 there were hardly any differences in the heights of groundnut plants between the treatments.

Maize

Maize plants grown in mixed crops were shorter than those in sole crops (fig. 5.2). In mixed crops, delaying the sowing time of maize resulted in shorter plants. Maximum heights of sole maize plants was 181 cm. Maximum height of maize plants in G-$M_{20;100}$ was 147 cm. Sole maize plants in experiment 2 were taller than in experiment 1. The taller the maize plants, the higher the LAI and the higher the total dry matter yield and the marketable yield. The sowing time effect on height of maize plants in mixed crops was stronger in experiment 2 than in experiment 1.

5.3.2 *LAI*

Groundnuts

The maximum LAI of groundnuts was reached around 60 DAS (fig. 5.3). In experiment 1, LAI of groundnuts in G-$M_{0;100}$ was higher than in G-$M_{20;100}$. The LAI of groundnuts in mixed crops was

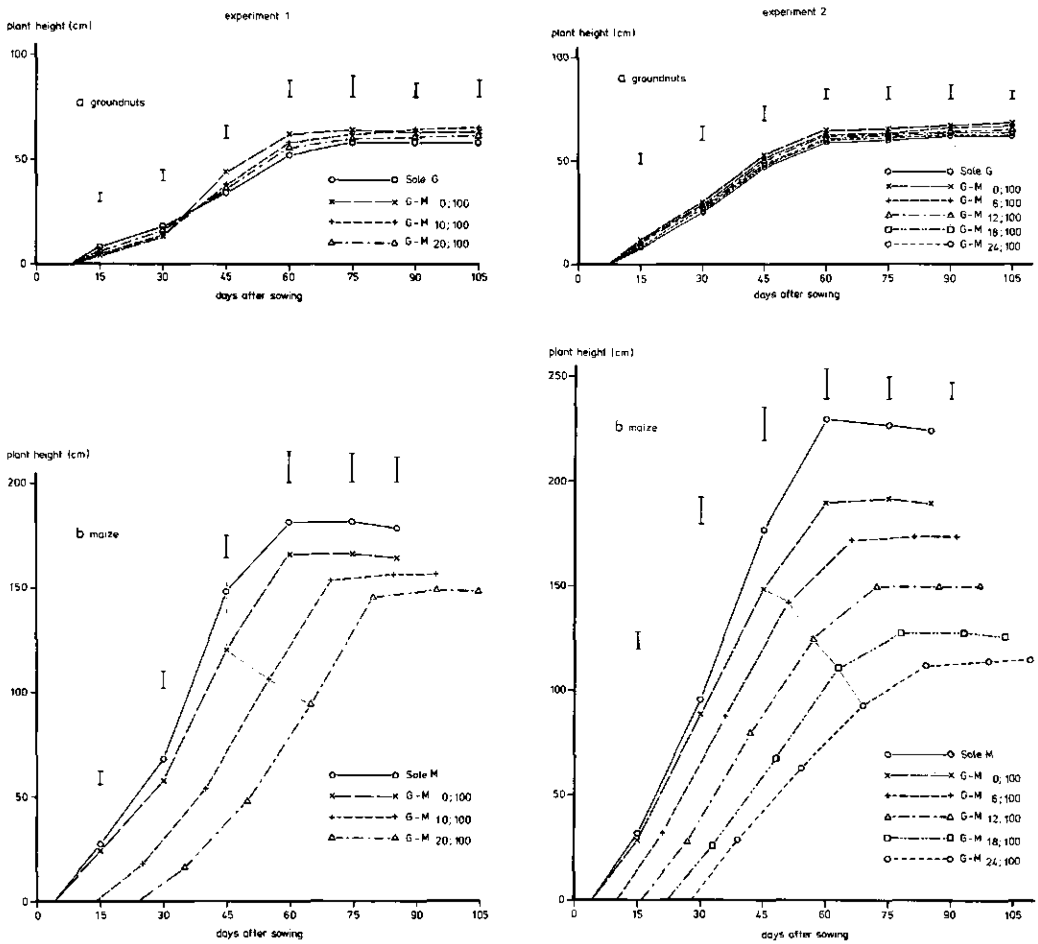

Fig. 5.2 Height of groundnut plants and maize plants during the growing period in experiments 1 and 2.

higher with delaying the sowing of maize (experiment 2). The sowing time effect on the LAI of groundnuts was stronger in experiment 2 than in experiment 1.

Maize

A delay in sowing time of maize in mixed crops resulted in a lower LAI of maize. The sowing time effect on LAI of maize was stronger in experiment 2 than in experiment 1.

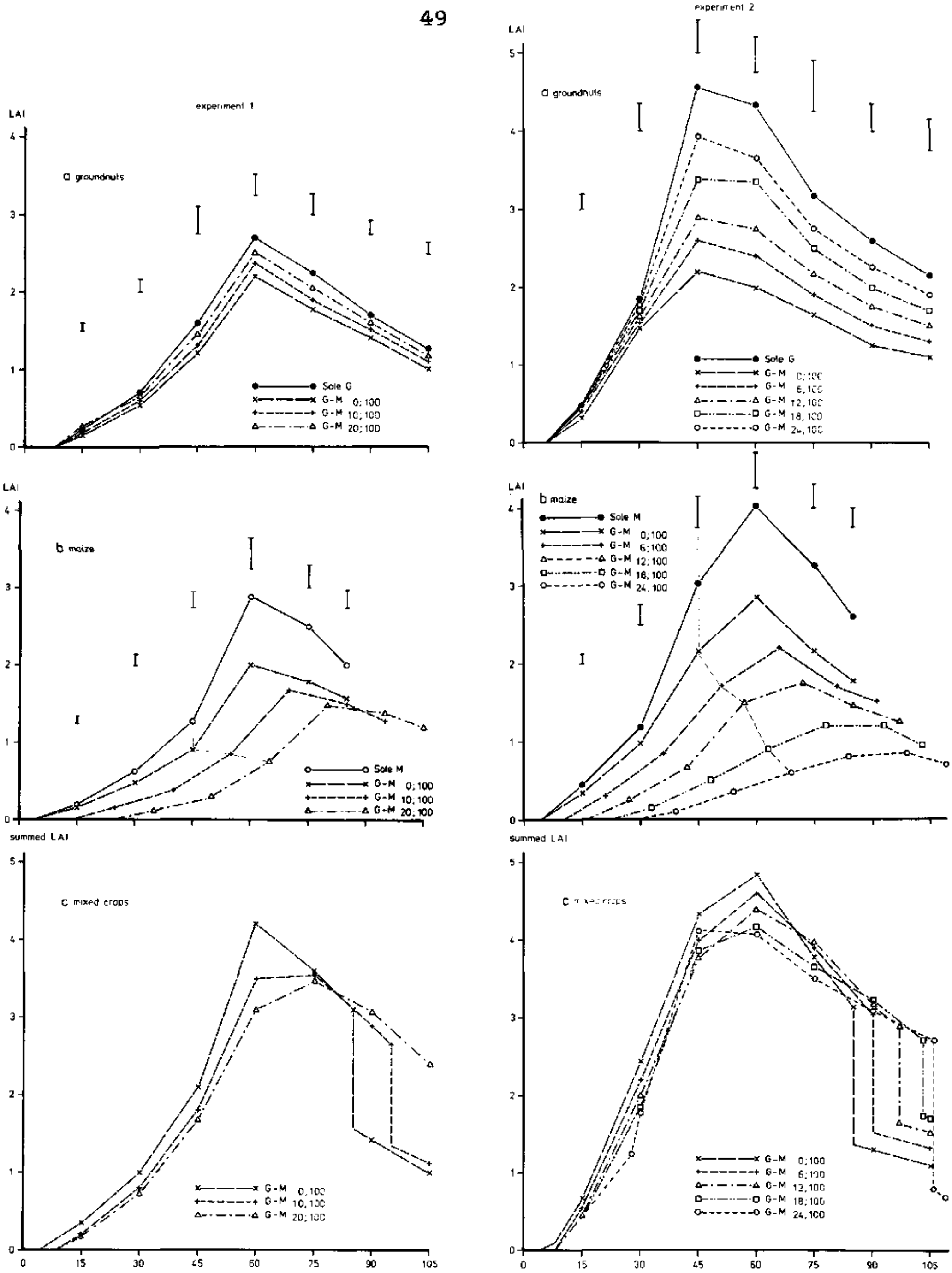

Fig. 5.3 LAI of groundnuts maize and the summed LAI of groundnuts and maize in mixed crops during the growing period in experiments 1 and 2.
DAS = days after sowing of the groundnuts.

Total mixed crop

The summed LAI of groundnuts and maize in mixed crops was higher than that of the respective sole crops (fig. 5.3). The accumulated LAI over the growing period was similar for the mixed crop treatments. The maximum value of the summed LAI was higher with simultaneous sowing of maize than with delayed sowing, causing stronger shading of the groundnut plants. The summed LAI was more evenly distributed over the growing period with later sowing of the maize. The LAI values and the summed LAI values of corresponding treatments (sole groundnuts, sole maize and mixed crops) in experiment 2 were higher than in experiment 1, and the maximum LAI values were reached sooner (fig. 5.3). Plant development was much stronger in experiment 2 than in experiment 1.

5.3.3 Time to flowering

The flowering time was the date when 50% of the plants had begun to flower. The time to flowering was the time interval between sowing and 50% flowering (see 4.5.3).

Groundnuts

In experiment 1, groundnuts in $G\text{-}M_{0;100}$ started to flower later than in the sole crop and in $G\text{-}M_{20;100}$. In experiment 2, groundnuts in mixed crops started to flower earlier with later sowing of the maize. There was no difference in time to flowering between $G\text{-}M_{24;100}$ and sole groundnuts.

Maize

Tasseling and silking of maize in mixed crops started later than in the sole crops. In experiment 1, differences between mixed crop treatments were not significant. In experiment 2, delaying the sowing time of maize in the mixed crops resulted in later tasseling and silking.

Table 5.2 Time (days) to flowering of groundnuts and maize in experiments 1 and 2.

	Flowering of groundnuts		Tasseling of maize		Silking of maize		Interval between tasseling and silking (days)
Experiment 1							
Sole G	31.3	a					
Sole M			39.7	a	43.5	a	3.9
$G\text{-}M_{0;100}$	33.6	b	42.4	ab	46.2	b	4.0
$G\text{-}M_{10;100}$	32.2	ab	42.9	b	46.8	b	3.9
$G\text{-}M_{20;100}$	31.9	a	43.1	b	47.3	b	4.2
LSD (0.05)	1.4		2.7		2.5		
CV (%)	3.2		5.1		4.3		
Experiment 2							
Sole G	29.7	a					
Sole M			38.6	a	42.8	a	4.2
$G\text{-}M_{0;100}$	32.4	c	39.5	ab	44.7	ab	5.2
$G\text{-}M_{6;100}$	31.3	bc	40.3	ab	44.9	b	4.6
$G\text{-}M_{12;100}$	30.9	b	41.1	b	45.9	b	4.8
$G\text{-}M_{18;100}$	31.0	b	43.6	c	48.7	c	5.1
$G\text{-}M_{24;100}$	29.7	a	45.4	c	50.9	d	5.5
LSD (0.05)	1.1		1.8		2.0		
CV (%)	2.4		3.1		2.8		

Data in each column followed by the same letter are not different at the 0.05 probability level. This is similar for the other tables.

5.3.4 Total dry matter yield and yield components

In experiment 1, from 30 DAS onwards, groundnuts in $G\text{-}M_{0;100}$ had a lower total dry matter weight than in the corresponding sole crop and in $G\text{-}M_{20;100}$ (table 5.3). In the mixed crops, the total dry matter weight of groundnuts was higher with delayed sowing of the maize.

Table 5.3 Total dry matter yield (kg/ha) of groundnuts during the growing period in experiment 1

	Days after sowing													
	15		30		45		60		75		90		105	
Sole G	81	a	476	b	1318	b	2815	b	3416	c	3582	c	3543	c
$G\text{-}M_{0;100}$	72	a	362	a	905	a	1811	a	2291	a	2491	a	2508	a
$G\text{-}M_{10;100}$	78	a	416	ab	1138	b	2324	ab	2709	ab	2927	ab	2988	b
$G\text{-}M_{20;100}$	82	a	442	b	1198	b	2610	b	3124	bc	3146	bc	3154	b
LSD (0.05)	12		65		226		523		436		454		216	
CV (%)	14.6		8.2		10.7		15.8		8.9		9.3		5.1	

At 15 DAS, the total dry matter weight of maize in the sole crop was higher than that in $G\text{-}M_{10;100}$ and $G\text{-}M_{20;100}$ but similar to that in $G\text{-}M_{0;100}$ (table 5.4). Starting from 30 DAS, sole maize had a higher total dry matter weight than maize in the mixed crops. From 60 DAS onwards the total dry matter weight of maize in $G\text{-}M_{0;100}$ was consistently higher than in $G\text{-}M_{20;100}$.

Table 5.4 Total dry matter yield (kg/ha) of maize during the growing period in experiment 1.

	Days after sowing											
	15		30		45		60		75		85	
Sole M	28	b	222	b	1114	b	3095	c	5353	c	6157	c
$G\text{-}M_{0;100}$	27	b	145	a	645	a	2308	b	4237	bc	4441	b
$B\text{-}M_{10;100}$	19	a	105	a	556	a	1975	ab	3640	ab	4058	ab
$G\text{-}M_{20;100}$	15	a	100	a	491	a	1660	a	3054	a	3413	a
LSD (0.05)	5		57		294		482		1663		685	
CV (%)	15.5		23.0		23.9		8.6		17.7		9.4	

Total dry matter yield of groundnuts was higher when sowing time of the maize was delayed (table 5.5), but total dry matter yield of maize was much lower.

The weight of the groundnut stalks increased until 75 DAS (fig. 5.4). The weight of the groundnut leaves was initially about half of the total dry matter weight, but decreased sharply from 60 DAS onwards. The pods started to be formed around 45 DAS and their weight increased until the final harvest. Partitioning of the dry matter weight over the plant parts was similar for groundnuts in the sole and the mixed crops.

Partitioning of the dry matter weight of maize over (pseudo-)-stem, leaf blades and ear in the sole crop (fig. 5.4) was similar to that in the mixed crops. Ear filling was slower in the mixed crops than in the sole crops, which might be expected from the later flowering.

Table 5.5 Total dry matter yield (kg/ha) of groudnuts and maize at the final harvest in experiment 2.

	Groudnuts	Maize
Sole G	5005 e	
Sole M		10558 e
$G\text{-}M_{0;100}$	2089 a	7821 d
$G\text{-}M_{6;100}$	2450 ab	5654 c
$G\text{-}M_{12;100}$	2811 bc	4378 b
$G\text{-}M_{18;100}$	3326 c	2667 a
$G\text{-}M_{24;100}$	3980 d	1925 a
LSD (0.05)	618	1043
CV (%)	6.9	11.2

A delay in sowing time of maize resulted in a higher number of groundnut pods per plant and a lower number of seeds per maize ear (table 5.6). The harvest index (H.I.) for groundnuts was similar in the sole and the mixed crops. In experiment 2, a longer delay in sowing time of maize resulted in a lower number of ear per maize plant. The H.I. and 100-seed weight of maize were lower with a delay of more than 12 days in sowing time of maize. Severe competition during flowering of the maize in the treatments G-$M_{12;100}$, G-$M_{18;100}$ and G-$M_{24;100}$ resulted in a low H.I.

Table 5.6 Yield components of groundnuts and maize in experiments 1 and 2.

	Groundnuts				Maize			
	No of mature pods hill	No of seeds per pod	100-seed weight (g)	H.I.	No of ears per plant	No of seeds per ear	100-seed weight (g)	H.I.
<u>Experiment 1</u>								
Sole G	10.4	1.88	38.2 b	0.49 b				
Sole M					0.91	241	16.4 a	0.49 a
G-$M_{0;100}$	6.0	1.83	37.2 ab	0.38 a	0.89	178	15.8 a	0.47 a
G-$M_{10;100}$	7.2	1.86	36.7 ab	0.38 a	0.92	150	15.8 a	0.45 a
G-$M_{20;100}$	8.2	1.84	36.6 a	0.41 a	0.90	131	15.5 a	0.44 a
LSD (0.05)			1.5	0.06			2.0	0.07
CV (%)			6.7	9.0			8.3	8.2
<u>Experiment 2</u>								
Sole G	11.7	1.82	39.6 c	0.39 ab				
Sole M					0.77	271	20.7 d	0.34 c
G-$M_{0;100}$	5.0	1.81	36.4 ab	0.37 ab	0.79	218	19.7 cd	0.36 c
G-$M_{6;100}$	6.1	1.82	34.8 a	0.36 a	0.78	164	17.7 bc	0.33 c
G-$M_{12;100}$	6.6	1.83	37.0 b	0.37 ab	0.76	103	17.0 b	0.25 b
G-$M_{18;100}$	9.1	1.81	35.8 ab	0.41 b	0.68	80	13.5 a	0.23 ab
G-$M_{24;100}$	9.9	1.82	36.5 ab	0.39 ab	0.57	61	12.5 a	0.19 a
LSD (0.05)			1.8	0.04			2.6	0.05
CV (%)			5.5	10.3			7.4	12.5

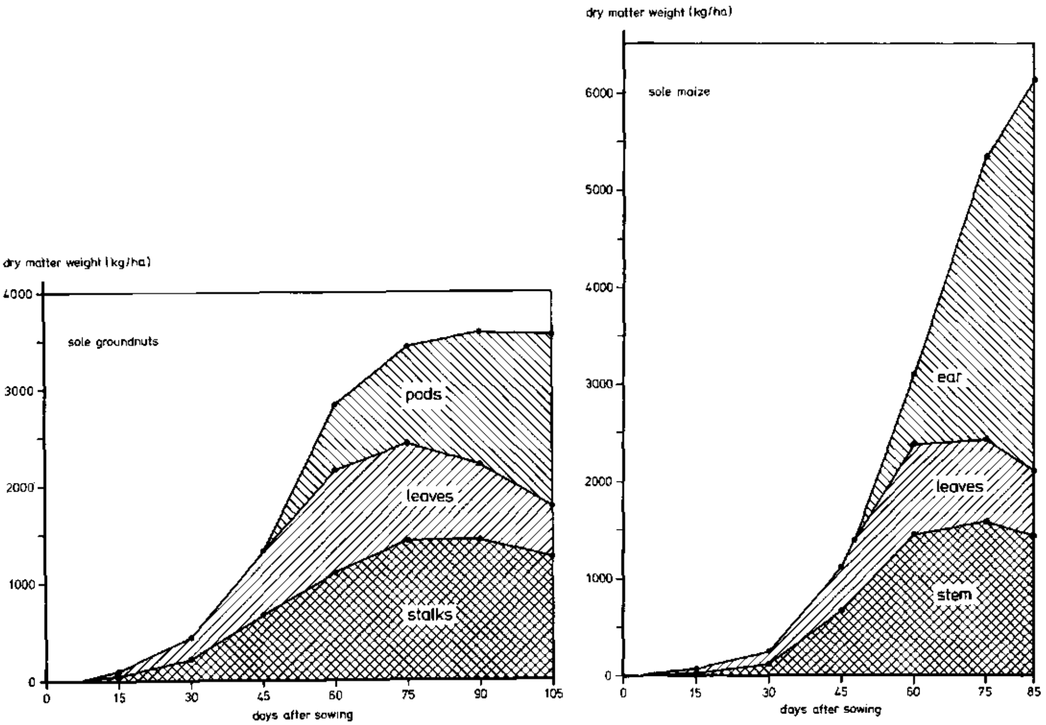

Fig. 5.4 Partitioning of total dry matter weight during the growing period in experiment 1
a: stalks, leaves and pods of groundnuts
b: (pseudo-)stem, leaf blades and ear of maize

5.3.5 Marketable yield

With delayed sowing of maize in the mixed crops, groundnut yield was higher but the grain yield of maize was lower (table 5.7). Statistical analysis showed significant differences in marketable yields of groundnuts and maize between treatments, in both experiments.

The relationship between marketable yield of groundnuts and sowing time of the maize was linear in experiment 2. The relationship between marketable yield of maize and relative sowing time was parabolic.

Table 5.7 Marketable yield (kg/ha) of groundnuts and of maize in experiments 1 and 2.

	Pod yield of groundnuts	Grain yield of maize
Experiment 1		
Sole G	1981 c	
Sole M		3403 c
$G\text{-}M_{0;100}$	1078 a	2365 b
$G\text{-}M_{10;100}$	1281 ab	2072 ab
$G\text{-}M_{20;100}$	1486 b	1725 a
LSD (0.05)	358	438
CV (%)	15.2	11.3
Experiment 2		
Sole G	2208 c	
Sole M		4088 e
$G\text{-}M_{0;100}$	883 a	3230 d
$G\text{-}M_{6;100}$	1016 a	2167 c
$G\text{-}M_{12;100}$	1170 a	1267 b
$G\text{-}M_{18;100}$	1546 b	695 ab
$G\text{-}M_{24;100}$	1744 b	409 a
LSD (0.05)	294	760
CV (%)	9.5	8.4

Groundnuts : $y = 821 + 37.5\,x$ $r = 0.98$

Maize : $y = 3245 - 208\,x + 3.74\,x^2$ $R^2 = 0.99$

y = marketable yield (kg/ha)

x = delay in sowing time of maize (days)

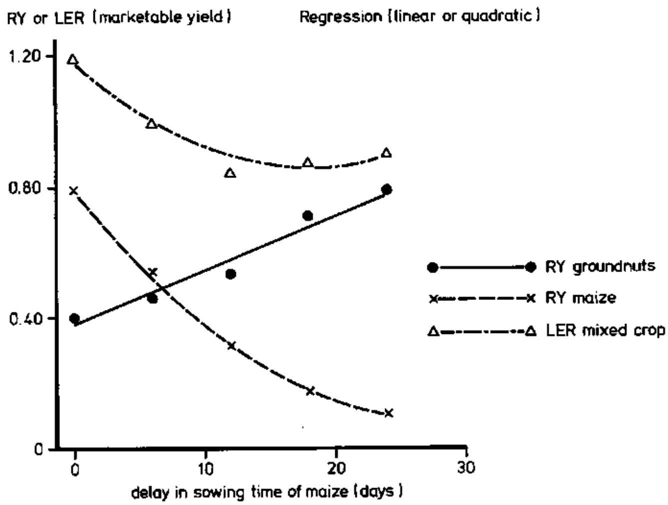

Fig. 5.5 Relationship between relative marketable yields (RY) of groundnuts and maize and sowing times of maize, and the corresponding LER curve in experiment 2.

5.3.6 RY and LER

The RY of groundnuts was higher and the RY of the maize was lower with later sowing of the maize. In experiment 1, the LER of the mixed crops was similar for the different sowing dates of the maize. In experiment 2, the LER was lower with later sowing of the maize (table 5.8 and fig. 5.5).

In experiment 1, the LER for the total dry matter yield was higher than the LER for marketable yield (table 5.8). The partitioning of the total dry matter yield over the plant parts in the mixed crops was different from that in the sole crops (see H.I. in table 5.6).

Table 5.8 RY of groundnuts and maize and LER of the mixed crop for marketable yield and total dry matter yield in experiments 1 and 2.

	Values for marketable yield			Values for total dry matter yield		
	RY of groundnuts	RY of maize	LER	RY of groundnuts	RY of maize	LER
Experiment 1						
Sole G	1.00			1.00		
Sole M		1.00			1.00	
G-$M_{0;100}$	0.55	0.70	1.25 a	0.63	0.72	1.35 a
G-$M_{10;100}$	0.65	0.61	1.26 a	0.72	0.66	1.38 a
G-$M_{20;100}$	0.75	0.50	1.25 a	0.77	0.55	1.32 a
LSD (0.05)			0.07			0.06
CV (%)			9.2			4.3
Experiment 2						
Sole G	1.00			1.00		
Sole M		1.00			1.00	
G-$M_{0;100}$	0.40	0.79	1.19 c	0.42	0.75	1.17 c
G-$M_{6;100}$	0.46	0.53	0.99 b	0.49	0.54	1.03 b
G-$M_{12;100}$	0.53	0.31	0.84 a	0.56	0.42	0.98 an
G-$M_{18;100}$	0.70	0.17	0.87 a	0.66	0.26	0.92 a
G-$M_{24;100}$	0.79	0.10	0.89 a	0.80	0.18	0.98 a
LSD (0.05)			0.09			0.08
CV (%)			6.7			4.1

5.4 DISCUSSION AND CONCLUSION

In mixed cropping, both groundnuts and maize showed a lower productivity than in sole cropping, because of the competition between them. By delaying the sowing of the maize in mixed cropping up to 24 days, the groundnuts got a start on the maize and became more competitive towards the maize. Groundnut yield in mixed crops was higher and maize yield was lower with later sowing of the maize (table 5.7). Initially there was no shading of the groundnut plants, and later in the growing period the shading was less severe because of the smaller size of the maize plants.

The effect of later sowing of the maize was stronger on the maize plants than on the groundnut plants. This can be seen clearly in the development of the plant height (fig. 5.2), the LAI (fig. 5.3) and the development of the total dry matter yield (tables 5.3, 5.4 and 5.5). In experiment 1, at the final harvest, the effect of the sowing time of the maize on marketable yield and on total dry matter yield, expressed in relative yield and LER, was similar for groundnuts and for maize (table 5.8). In experiment 2, the sowing time effect on maize was stronger than on groundnuts during growth and at the final harvest.

The time to flowering for groundnuts in the mixed crops was later than for sole groundnuts. This explains in part the lower H.I. values for the groundnut in the mixed crops in experiment 1. Heavy leaf drop in sole groundnuts during the last part of the growing period resulted in an increased H.I. value. In experiment 2 the growth of groundnuts in the sole crop was very abundant and the H.I. was similar to that in the mixed crops.

Competition from groundnuts towards maize was stronger in late sown maize than in early sown maize. This resulted in a retarded development of the maize. Time to tasseling and silking of the maize was delayed. In experiment 2 in particular, the H.I. was low in late sown maize.

Total dry matter yields of sole groundnuts and sole maize were higher in experiment 2 than in experiment 1. The soil in Sengkaling was more fertile than in Bedali (see chapter 4, table

4.2). In experiment 1, the topsoil was too dry around 15 days after sowing for the young plants of groundnut and maize (G-$M_{0;100}$ and G-$M_{10;100}$, see table 5.1). In experiment 2, the plants were watered in the young stage and did not suffer from water stress. Sole maize plants in experiment 2 were taller than in experiment 1 (see fig. 5.2). LAI values for sole groundnuts and sole maize in experiment 2 were considerably higher than in experiment 1, resulting in severe intraspecific competition and in low H.I. values. Maximum LAI values were reached earlier during the growing season in experiment 2 (45 DAS for sole maize) than in experiment 1 (60 DAS for sole maize), which can be seen in figure 5.3. The high LAI values were not maintained in the second half of the growing period. This was caused by the strong competition between the plants, in particular heavy mutual shading, and also by the heavy rains during that period (fig. 5.1). Groundnut plants especially suffered from the excess of water in the soil (table 5.1). Ridging protected the sole maize crop from damage to the roots caused by excess of water. The wet weather in the middle of the growing period favoured the development of fungal diseases, which caused premature leaf drop. The LER of the mixed crops in experiment 1 was higher than in experiment 2. Apparently, total LAI of groundnuts and maize in mixed cropping was supra-optimal in experiment 2, resulting in a very strong interspecific competition, low H.I. values and low LER values. The maximum LAI of maize in mixed cropping (G-$M_{0;100}$) in experiment 2 was 2.9 at 60 DAS, resulting in an interception of 76% of the incoming radiation by the maize canopy (fig. 5.3 and fig. 4.4). During that stage of the growing period less than 25% of the incoming radiation was available for the groundnut. The strong competition affected the 100-seed weight, in particular that of maize (table 5.6). Most mixed crop treatments in experiment 2 were less productive than the corresponding sole crops.

In experiment 1, a delay of 10 days in sowing time of maize resulted in a mixed crop with about equal relative yields for each of the associated crops, both above 60% of the respective sole crop yields (with groundnuts slightly higher). In experiment 2 the same situation could be achieved with a delay of 6-12 days in sowing time of maize, with yields for the associated crops of about 50% of the respective sole crop yields. Time from sowing to emergence was about 8 days for groundnuts and 4 days for maize. So when maize was sown 10 days later than groundnuts, groundnut plants emerged about one week before the maize plants.

Overall conclusion from the sowing experiments:
A delay of about 10 days in sowing time of maize in mixed crops was positive compared to simultaneous sowing or a longer delay, because competition for groundnuts was not too severe, the summed LAI for the mixed crop maintained a high level over the longest part of the growing period, labour peaks for sowing and harvesting were avoided (see chapter 9), and the duration of land occupation by the mixed crop did not exceed that of sole groundnuts (105 days).

6 *THE EFFECTS OF PLANT DENSITY AND PLANT ARRANGEMENT*

6.1 INTRODUCTION

The productivity of bunch type groundnuts in Indonesia was little affected by plant density over the range 150,000 to 400,000 plants per hectare, or even higher (Sitompul et al., 1981).

Maize cultivars in Indonesia with a short period to maturity showed optimal plant densities of between 80,000 and 140,000 plants per hectare, depending on season and level of crop management (Meddy Sugiharto and Soetono, 1978; Tohir Bachri and Soetono, 1978; Ariffin et al., 1980).

The effects of plant density in mixed crops are more complex to study than in sole crops (Willey, 1979). Some results have been published on the effect of plant density on productivity in mixed crops of maize and groundnuts (Ishag, 1970; Didi Suardi and Sri Haryono, 1976; Isgiyanto et al., 1980). Information on plant density in mixed crops of groundnuts and maize was collected in section 2.3.2 of the literature review.

It may be expected that both plant density and the ratio between plant species in mixed crops have an important effect on the contribution of each crop to the final yield. In the field experiments groundnuts at the normal sole crop density (160,000 plants/ha) were combined with a range of plant densities of maize. The normal sole crop density for the maize cultivar 'Kretek' was about 125,000 plants/ha (80 x 20 cm, 2 plants per hill). Mixed crops in local farmers' fields had groundnuts at about the same plant density and maize at about 50% the plant density as in the sole crops (survey of farming practice, chapter 3).

The sowing time of maize in the experiments on plant density was 10 days later than that of groundnuts. In the sowing time experiments described in chapter 5, this delay was found to give a good balance between groundnut yield and maize yield in the mixed crops.

The amount and quality of light available for groundnuts in mixed crops with maize, is influenced not only by the plant density, but also by the arrangement of the maize. A greater distance between the maize rows means less shading for the groundnut plants in between. It may be expected that the effect of plant arrangement will be strongest at high plant densities of maize. Therefore, in the experiment on density and arrangement of the maize in mixed cropping with groundnuts (experiment 5), extremely high maize densities have been included.

6.2 MATERIALS AND METHODS

Experiment 3

Experiment 3 was carried out from 19 February until 3 June, 1980 on a rented farmer's field at Sukolilo, 13 km north-east of Malang, situated at an altitude of 520 m above sea level (see fig. 3.1). Sowing was done during the rainy season, and harvesting during the dry season. The previous crop was irrigated rice. No irrigation was practised. Rainfall and open pan evaporation during the growing period are shown in fig. 6.1. Characteristics of the loam soil at Sukolilo were shown in section 4.1, table 4.2.

Experiment 3 was laid out in a randomized complete block design, replicated 4 times. Spacing and plant density of groundnuts and maize are shown in table 6.1.

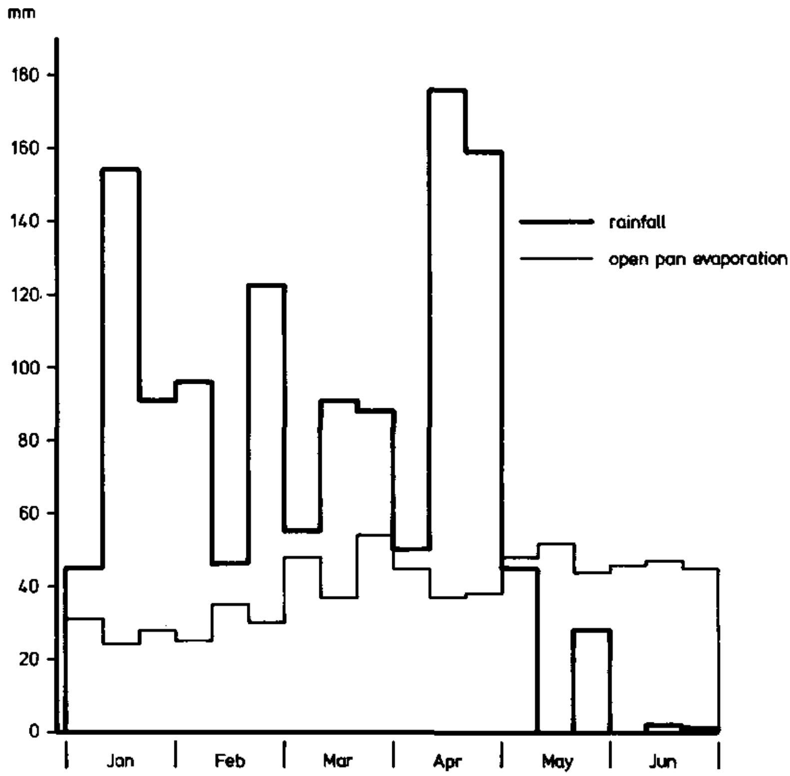

Fig. 6.1 Rainfall and open pan evaporation in mm per period of 10 days from January to June 1980.

Experiment 4

Experiment 4 was carried out from 22 February until 6 June, 1980 at Sukolilo, in the same field as experiment 3.
The experiment was laid out in a systematic spacing design, replicated 5 times. The maize was sown in a fan shape, in a field with a constant plant density of groundnuts (see description of the fan design in section 4.4.2). At the final harvest 1-meter segments from each of the maize rows were taken together to form a plot (see fig. 4.2). Spacing and plant density of groundnuts and maize are shown in table 6.2.

Table 6.1 Spacing and plant density of groundnuts and maize in experiment 3.

	Groundnuts		Maize		Total density of mixed crop (as
	Spacing (cm x cm) (plants per ha)	Plant density 2 plants per hill)	Spacing (cm x cm, (plants per ha)	Plant density % of sole crops)	
Sole G	25 x 25	160,000			
Sole M			80 x 20	125,000	
G-M$_{10;50}$	25 x 25	160,000	113 x 28	63,000	150
G-M$_{10;75}$	25 x 25	160,000	92 x 23	94,000	175
G-M$_{10;100}$	25 x 25	160,000	80 x 20	125,000	200

The groundnuts were sown on 19 February, and the maize on 29 February, 1980.

For maize in the mixed crops the indicated plant density was the average plant density in each 1-meter long segment of the row that constituted the experimental plot.

The groundnuts were sown on 22 February, and the maize on 3 March, 1980 (10 days later).

Table 6.2 Spacing and plant density of groundnuts and maize in experiment 4.

	Groundnuts		Maize		Total density of mixed crop (as % of sole crops)
	Spacing (cm x cm)	Plant density (plants per ha)	Spacing (cm x cm, 2 plants per hill)	Plant density (plants per ha)	
Sole G	25 x 25	160,000			
Sole M			80 x 20	125,000	
G-M$_{10;43}$	25 x 25	160,000	122 x 30	54,000	143
G-M$_{10;54}$	25 x 25	160,000	108 x 27	68,000	154
G-M$_{10;70}$	25 x 25	160,000	95 x 24	88,000	170
G-M$_{10;92}$	25 x 25	160,000	82 x 21	118,000	192
G-M$_{10;123}$	25 x 25	160,000	70 x 17	167,000	223

Experiment 5

Experiment 5 was conducted from 22 February until 6 June, 1980 at Sukolilo, in the same field as the experiments 3 and 4.

Experiments 5 was laid out in a systematic spacing design with two series of plant arragements, replicated 4 times. Eache maize row corresponded to a different plant density and arrangement of the maize. In arrangement series 1, spacing between the maize rows was kept constant and the distance between the plants in the row was different in each row (see fig. 4.3). In arrangement 2 the spacing between the successive maize rows was different and the distance between the plants in the row was kept constant for all rows. Each series of plant arrangements consisted of 5 maize densities in 5 different plant arrangements. The spacing and plant arrangement of groundnuts and maize in experiment 5 are shown in table 6.3.

Table 6.3 Spacing and plant density of groundnuts and maize in experiment 5.

	Groundnuts		Maize		Total density of mixed crop (as % of sole crops)
	Spacing (cm x cm)	Plant density (plants per ha)	Spacing (cm x cm, 2 plants per hill)	Plant density (plants per ha)	
Sole G	25 x 25	160,000			
Sole M			80 x 20	125,000	
Arrangement 1					
$G\text{-}M_{10;64}$	25 x 25	160,000	80 x 31	80,000	164
$G\text{-}M_{10;80}$	25 x 25	160,000	80 x 25	100,000	180
$G\text{-}M_{10;100}$	25 x 25	160,000	80 x 20	125,000	200
$G\text{-}M_{10;125}$	25 x 25	160,000	80 x 16	156,000	225
$G\text{-}M_{10;256}$	25 x 25	160,000	80 x 13	195,000	256
Arrangement 2					
$G\text{-}M_{10;64}$	25 x 25	160,000	125 x 20	80,000	164
$G\text{-}M_{10;80}$	25 x 25	160,000	100 x 20	100,000	180
$G\text{-}M_{10;100}$	25 x 25	160,000	80 x 20	125,000	200
$G\text{-}M_{10;125}$	25 x 25	160,000	64 x 20	156,000	225
$G\text{-}M_{10;156}$	25 x 25	160,000	51 x 20	195,000	256

The groundnuts were sown on 22 February, and the maize on 3 March, 1980 (10 days later).

Plate 5. Young groundnut and maize plants in experiment 5, arranged in a systematic spacing design

Plate 6. The farmer Pak Ali and the author of this thesis in a groundnut field at Sukolilo

6.3 RESULTS

6.3.1 Plant height

Experiments 3 and 4

Groundnuts

In experiment 3, groundnut plants in the sole crop were shorter than in the mixed crops at 45, 60 and 75 DAS (fig. 6.2). The height of the groundnut plants in the mixed crops (with different densities of maize) was not different. The maximum height of sole groundnut plants was 59 cm. The maximum height of the groundnut plants in G-$M_{10;50}$, G-$M_{10;75}$ and G-$M_{10;100}$ was 62, 63 and 65 cm, respectively. In experiment 4, the heights of groundnut plants were not very different for the different treatments. From 25 DAS onwards, the groundnut plants in the mixed crops were slightly taller than the groundnut plants in the sole crop. The maximum height of sole groundnut plants 62 cm. The groundnut plants in the mixed crops were taller with increasing plant density of maize.

Maize

In experiment 3, the heights of the maize plants were not different in the sole crops and the mixed crops (fig. 6.2). The maximum heights of sole maize plants was 184 cm. The maximum height of maize in G-$M_{10;50}$, G-$M_{10;75}$ and G-M_{10-100} was 179, 177 and 174 cm, respectively. In experiment 4, sole maize plants were slightly taller than plants in the mixed crops. The maximum height of sole maize plants was 182 cm. Maize plants in the mixed crops were shorter with increasing maize density.

Experiment 5

Groundnuts

Sole groundnut plants reached 61 cm and groundnut plants in mixed crops 64-70 cm (table 6.4). The height of groundnut

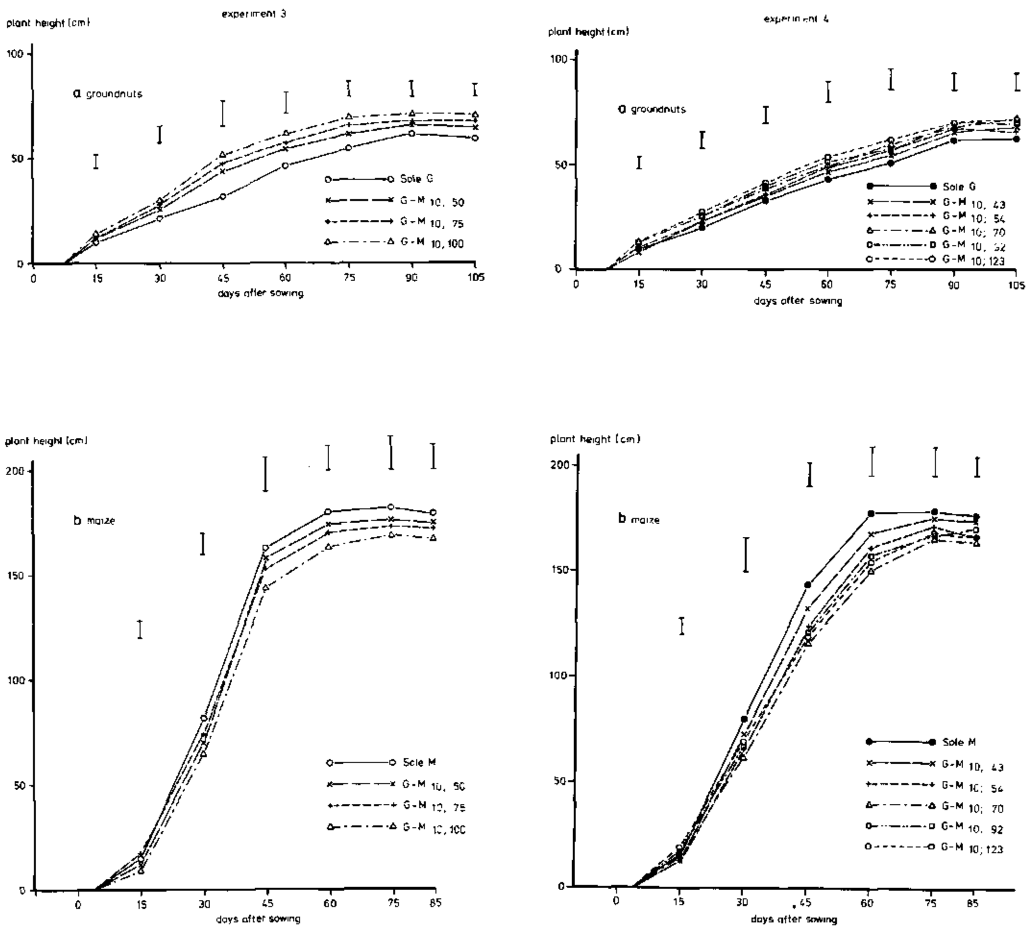

Fig. 6.2 Height of groundnut plants and maize plants during the growing period in experiments 3 and 4.

plants was slightly taller where maize densities were higher. They were similar in height to the groundnut plants in the experiments 1, 2, 3 and 4. There was no substantial difference between the heights of groundnut plants in the two series of plant arrangements, but in arrangement series 1 (constant row spacing of 80 cm), the height of the groundnut plants was less affected by maize density than in arrangement series 2 (constant spacing of 20 cm in the row).

Maize

Maize plants reached a height of 176 cm in the sole crop, but only 145-159 cm in the mixed crops, and their heights decreased with increasing plant density. The height of maize plants in arrangement 1 was not significantly different from that in arrangement 2.

Table 6.4 Height of fully grown groundnut and maize plants in experiment 5.

	Spacing of maize (cm x cm)	Height of groundnuts (cm)	Height of maize (cm)
Sole G		61 a	
Sole M	80 x 20		176 d
Arrangement 1			
$G\text{-}M_{10;64}$	80 x 31	66 bcd	157 bc
$G\text{-}M_{10;80}$	80 x 25	67 bcd	155 abc
$G\text{-}M_{10;100}$	80 x 20	67 bcd	154 abc
$G\text{-}M_{10;125}$	80 x 16	68 bcd	151 abc
$G\text{-}M_{10;156}$	80 x 13	69 cd	145 a
Arrangement 2			
$G\text{-}M_{10;64}$	125 x 20	65 abc	159 c
$G\text{-}M_{10;80}$	100 x 20	64 ab	157 bc
$G\text{-}M_{10;100}$	80 x 20	66 bcd	155 abc
$G\text{-}M_{10;125}$	64 x 20	67 bcd	150 abc
$G\text{-}M_{10;156}$	51 x 20	70 d	147 ab
LSD (0.05)		4	10
CV (%)		8.9	11.2

6.3.2 LAI

Experiments 3 and 4

In experiment 3, from 40 DAS onwards, the LAI for sole groundnuts was higher than that for groundnuts in the mixed crops (fig. 6.3), and reached a maximum of 2.74. The LAI for groundnuts in the mixed crops was slightly lower with increasing maize density, with maximum values of 2.54, 2.30 and 2.10 for $G\text{-}M_{10;50}$, $G\text{-}M_{10;75}$ and $G\text{-}M_{10;100}$ respectively. From 30 DAS onwards, the LAI for sole groundnuts in experiment 4 was slightly higher than that for groundnuts in the mixed crops, with a maximum value of 3.04. The maximum LAI values for groundnuts in the mixed crops were lower with increasing maize density.

Maize

In experiment 3, the LAI for sole maize was higher than that for maize in the mixed crops (fig. 6.3), with a maximum value of 2.61. The maximum LAI for maize in the mixed crops was 1.69, 2.06 and 2.37 for $G\text{-}M_{20;50}$, $G\text{-}M_{10;75}$ and $G\text{-}M_{10;200}$, respectively. In experiment 4, the maximum LAI for sole maize was 2.52. The LAI for maize in the mixed crops was higher with increasing maize density, with maximum values from 1,54 to 2.26.

Total mixed crop

The maximum summed LAI values for the mixed crops in experiment 3 were 4.25, 4.35 and 4.50 for $G\text{-}M_{10;50}$, $G\text{-}M_{10;75}$ and $G\text{-}M_{100}$, respectively (fig. 6.3). The maximum summed LAI values for the mixed crops in experiment 4 were 4.20, 4.05, 4.20, 4.25 and 4.15 for $G\text{-}M_{10,43}$, $G\text{-}M_{10,54}$, G-M10;70, $G\text{-}M_{10;92}$ and $G\text{-}M_{10;123}$, respectively.

Experiment 5

The maximum LAI values for the treatments in experiment 5 during the growing period are shwon in table 6.5.

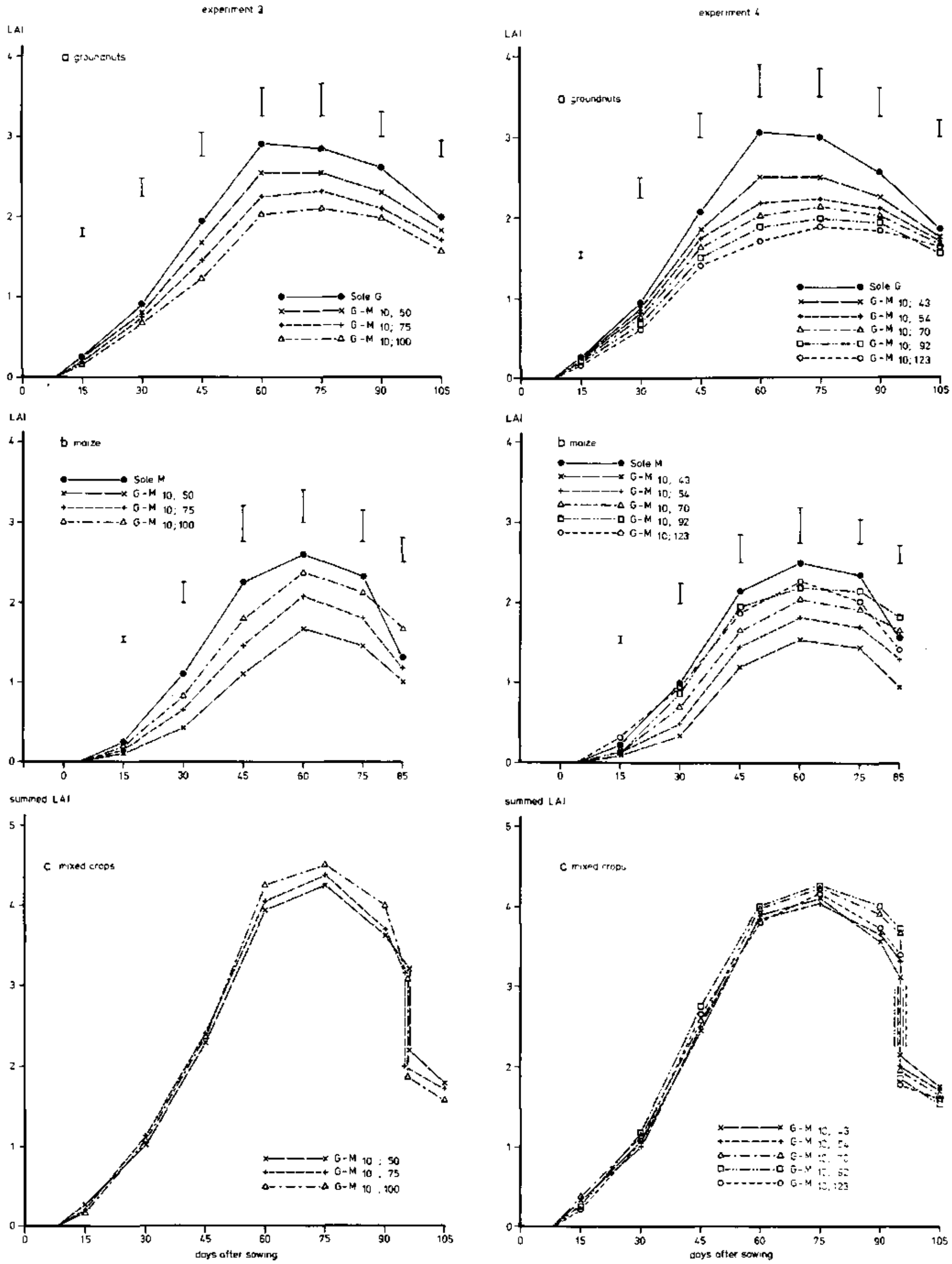

Fig. 6.3 LAI of groundnuts, maize and the summed LAI of the mixed crops during the growing period in experiments 3 and 4.
DAS: days after sowing of the groundnuts in a and c, and after sowing of the maize in b.

Groundnuts

The maximum LAI value for sole groundnuts during the growing period was 3.01, and was slightly higher than that for groundnuts in the mixed crops. The LAI for groundnuts in the mixed crops was higher with increasing maize density, but was not different for the corresponding maize densities in the plant arrangement series 1 and 2. The LAI values for groundnuts were comparable to the values in the experiment 3 and 4.

Maize

The LAI for sole maize was higher than that for maize in the mixed crops. The effect of plant density on the LAI was significant, but the effect of plant arrangement not (table 6.5).

Table 6.5 Maximum LAI values for groundnuts and maize during the growing period and maximum summed LAI values for the mixed crops in experiment 5.

	Spacing of maize (cm x cm)	LAI of groundnuts	LAI of maize	Summed LAI of mixed crop
Sole G		3.01 e		
Sole M	80 x 20		2.71 c	
Arrangement 1				
$G\text{-}M_{10;64}$	80 x 31	2.16 cd	1.56 a	3.80
$G\text{-}M_{10;80}$	80 x 25	2.08 cd	1.96 ab	4.02
$G\text{-}M_{10;100}$	80 x 20	1.85 bcd	2.17 abc	4.06
$G\text{-}M_{10;125}$	80 x 16	1.73 abc	2.43 bc	4.18
$G\text{-}M_{10;156}$	80 x 13	1.57 ab	2.76 c	4.29
Arrangement 2				
$G\text{-}M_{10;64}$	125 x 20	2.17 cd	1.58 a	3.87
$G\text{-}M_{10;80}$	100 x 20	2.11 cd	1.82 ab	3.95
$G\text{-}M_{10;100}$	80 x 20	1.86 bcd	2.18 abc	4.09
$G\text{-}M_{10;125}$	64 x 20	1.63 ab	2.59 c	4.20
$G\text{-}M_{10;156}$	51 x 20	1.38 a	2.88 c	4.25
LSD (0.05)		0.43	0.72	
CV (%)		7.6	9.4	

Table 6.6 Time (days) from sowing to flowering of groundnuts and maize in experiments 3, 4 and 5.

	Flowering of ground-nuts	Tasseling of maize	Silking of maize	Interval between tasseling and silking (days)
Experiment 3				
Sole G	0.3 a			
Sole M		40.1 a	45.3 a	5.2
G-M$_{10;50}$	31.7 b	42.6 b	48.6 b	6.0
G-M$_{10,75}$	32.4 b	43.3 bc	49.5 bc	6.2
G-M$_{10;100}$	33.3 c	43.8 c	50.3	6.5
LSD (0.05)	0.8	0.8	0.9	
CV (%)	4.2	3.1	3.9	
Experiment 4				
Sole G	30.8 a			
Sole M		40.4 a	45.7 a	5.3
G-M$_{10;43}$	32.0 b	42.5 b	47.7 b	5.2
G-M$_{10;54}$	32.3 b	42.7 b	48.0 b	5.3
G-M$_{10;70}$	32.7 bc	43.2 bc	48.6 bc	5.4
G-M$_{10;92}$	33.4 cd	43.7 cd	49.3 cd	5.6
G-M$_{10;123}$	33.9 d	44.3 d	50.2 d	5.9
LSD (0.05)	0.9	0.8	1.1	
CV (%)	3.8	4.2	4.7	
Experiment 5				
Sole G	31.3 a			
Sole M		40.1 a	45.6 a	5.5
Arrangement 1				
G-M$_{10;64}$	32.5 abc	42.4 b	47.4 b	5.0
G-M$_{10;80}$	32.8 bcd	42.8 bc	47.9 bc	5.1
G-M$_{10;100}$	33.2 cd	43.5 bcd	48.7 bcd	4.2
G-M$_{10;125}$	33.8 de	44.1 cd	49.5 cd	5.4
G-M$_{10;156}$	34.4 e	44.7 d	50.3 d	5.6
Arrangement 2				
G-M$_{10;64}$	31.8 ab	42.8 bc	47.9 bc	5.1
G-M$_{10;80}$	32.3 abc	42.9 bc	48.3 bc	5.4
G-M$_{10;100}$	33.0 bcd	43.3 bcd	48.7 bcd	5.4
G-M$_{10;125}$	34.0 de	44.0 cd	49.2 cd	5.2
G-M$_{10;156}$	34.7 e	44.1 cd	49.5 cd	5.4
LSD (0.05)	1.2	1.4	1.6	
CV (%)	5.3	4.9	6.2	

Total mixed crop

The summed LAI values for the mixed crops were similar for the two series of plant arrangements.

6.3.3 Time to flowering

The time from sowing to flowering of groundnuts and maize was longer in the mixed crops, without hardly any exception, and was later with increasing maize density (table 6.6). In experiment 5, the effect of plant arrangement on time to flowering was negligible compared to the plant density effect.

6.3.4 Total dry matter yield and yield components

In experiment 3, from 30 DAS onwards the total dry matter weight of groundnuts in the mixed crops was lower than in the sole crop, and was lower with increasing maize density (table 6.7).

Table 6.7 Total dry matter yield (kg/ha) of groundnuts during the growing period in experiment 3

	Days after sowing						
	15	30	45	60	75	90	105
Sole G	103 a	694 c	2037 c	3024 d	3212 c	3353 c	3407 c
G-$M_{10;50}$	102 a	621 bc	1628 b	2296 c	2441 b	2517 b	2540 b
G-$M_{10;75}$	105 a	556 ab	1496 b	2120 b	2257 a	2305 a	2349 a
G-$M_{10;100}$	99 a	490 a	1281 a	1873 a	2126 a	2228 a	2306 a
LSD (0.05)	28	105	146	134	148	166	184
CV (%)	10.2	9.1	7.3	8.4	9.6	6.0	7.7

At 15 DAS, the total dry matter weights of maize differed significantly between some treatments, proportional to the different maize densities (table 6.8), in experiment 3. From 30 DAS onwards, the differences between the total dry matter

Table 6.8 Total dry matter yield (kg/ha) of maize during the growing period in experiment 3.

	Days after sowing					
	15	30	45	60	75	85
Sole M	40 b	242 d	1418 c	2840 d	4449 d	4702 d
$G\text{-}M_{10;50}$	18 a	113 a	829 a	1701 a	2798 a	2881 a
$G\text{-}M_{10;75}$	24 ab	141 b	945 ab	1963 b	3261 b	3433 b
$G\text{-}M_{10;100}$	37 b	179 c	1035 b	2244 c	3651 c	4103 c
LSD (0.05)	6	21	187	229	241	311
CV (%)	9.8	7.3	11.0	8.5	6.1	7.9

weights of maize in different treatments were more pronounced, and were no longer proportional to the maize density, but depended also on cropping system. Sole maize was consistently higher in total dry matter weight than maize in the mixed crops from 30 DAS onwards.

In experiments 4 and 5, the total dry matter yield of groundnuts in the mixed crops was lower than in the sole crops, and was lower with increasing maize density (table 6.9). The total dry matter yield of maize was higher with increasing density.

Total dry matter yield of maize in $G\text{-}M_{10;156}$ was similar to that in sole maize, but in most other mixed crops it was lower. The effect of plant arrangement on total dry matter yield of maize was very small compared with the plant density effect.

Partitioning of the dry matter weight over the plant parts during the growing period is shown in fig. 6.4 for sole groundnuts and sole maize in experiment 3. For groundnuts and maize in the mixed crops the partitioning over the plant parts was similar, as shown for the sole crops.

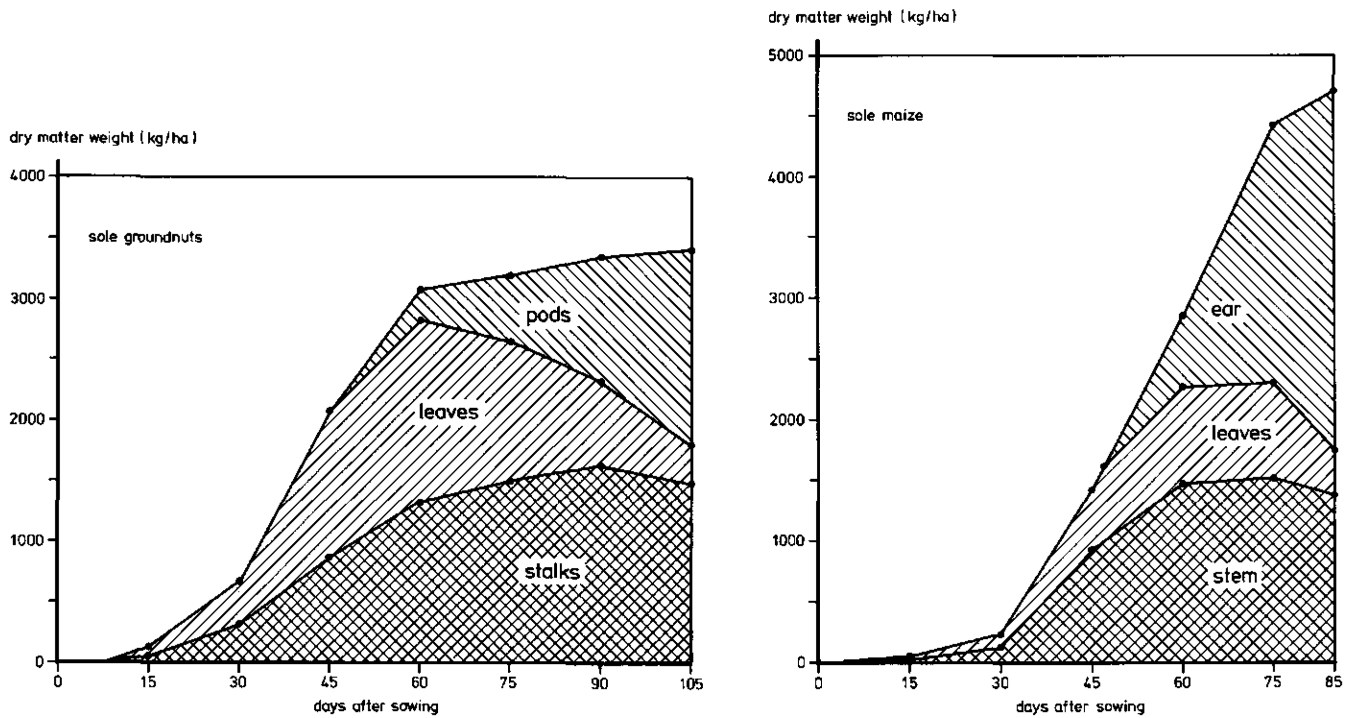

Fig. 6.4 Partitioning of total dry matter weights during the growing period in experiment 3
a: over stalks, leaves and pods of sole groundnuts
b: (pseudo-)stem, leaf blades and ear of sole maize

Table 6.9 Total dry matter yields (kg/ha) of groundnuts and maize at the final harvest in experiments 4 and 5.

	Groundnuts	Maize
<u>Experiment 4</u>		
Sole G	3649 d	
Sole M		4274 c
$G\text{-}M_{10;43}$	2293 c	2523 a
$G\text{-}M_{10;54}$	2199 bc	2771 a
$G\text{-}M_{10;70}$	2131 abc	3292 b
$G\text{-}M_{10;92}$	2029 ab	3585 b
$G\text{-}M_{10;123}$	1930 a	3608 b
LSD (0.05)	241	465
CV (%)	6.8	9.2
<u>Experiment 5</u>		
Sole G	3608 g	
Sole M		4308 e
<u>Arrangement 1</u>		
$G\text{-}M_{10;64}$	2164 e	2889 a
$G\text{-}M_{10;80}$	2081 e	3456 bc
$G\text{-}M_{10;100}$	1845 d	3681 cd
$G\text{-}M_{10;125}$	1731 cd	3929 cde
$G\text{-}M_{10;156}$	1566 bc	4240 e
<u>Arrangement 2</u>		
$G\text{-}M_{10;64}$	2386 f	2697 a
$G\text{-}M_{10;80}$	2105 e	3081 ab
$G\text{-}M_{10;100}$	1862 d	3691 cd
$G\text{-}M_{10;125}$	1519 b	4175 de
$G\text{-}M_{10;156}$	1238 a	4418 e
LSD (0.05)	204	514
CV (%)	7.0	9.7

In table 6.10 several yield components are listed for groundnuts and maize in the experiments 3, 4 and 5. Sole groundnuts had more pods per plant than plants in the mixed crops. The number of maize ears per plant was lower with increasing plant density, and was lower in sole maize than in some of the mixed crop treatments with a low maize density. The 100-seed weight of maize and the number of seeds per ear were lower in the

Table 6.10 Yield components for groundnuts and maize in experiments 3, 4 and 5.

	Groundnuts				Maize			
	No of mature pods per hill	No of seeds per pod	100-seed weight (g)	H.I.	No of ears per plant	No of seeds per ear	100-seed weight (g)	H.I.
Experiment 3								
Sole G	9.6	1.90	36.2 b	0.45 b				
Sole M					0.78	115	18.5 b	0.44 a
$G\text{-}M_{10;50}$	7.0	1.92	34.8 ab	0.41 ab	0.96	122	18.7 b	0.48 a
$G\text{-}M_{10;75}$	6.3	1.90	34.2 a	0.39 a	0.89	108	18.0 b	0.47 a
$G\text{-}M_{10;100}$	5.8	1.88	33.7 a	0.36 a	0.85	106	15.5 a	0.46 a
LSD (0.05)			1.4	0.05			2.0	0.04
CV (%)			7.1	9.0			8.3	8.2
Experiment 4								
Sole G	9.9	1.92	36.3 a	0.43 a				
Sole M					0.71	116	19.2 b	0.46 a
$G\text{-}M_{10;43}$	6.6	1.91	35.8 ab	0.45 a	0.90	129	19.1 b	0.48 a
$G\text{-}M_{10;54}$	6.4	1.89	35.8 ab	0.45 a	0.85	121	18.7 b	0.47 a
$G\text{-}M_{10;70}$	6.2	1.88	35.4 ab	0.44 a	0.83	115	18.2 b	0.47 a
$G\text{-}M_{10;92}$	5.8	1.86	35.1 ab	0.43 a	0.74	106	17.4 b	0.45 a
$G\text{-}M_{10;123}$	5.6	1.83	34.7 b	0.42 a	0.63	93	16.1 b	0.43 a
LSD (0.05)			1.3	0.06			1.8	0.06
CV (%)			5.7	3.7			6.3	3.2
Experiment 5								
Sole G	6.6	1.89	36.7 cd	0.41 a				
Sole M					0.71	116	19.6 c	0.47 d
Arrangement 1								
$G\text{-}M_{10;64}$	4.1	1.90	37.3 d	0.44 a	0.79	113	19.3 bc	0.48 d
$G\text{-}M_{10;80}$	3.8	1.89	37.1 cd	0.42 a	0.74	110	19.4 bc	0.46 cd
$G\text{-}M_{10;100}$	3.5	1.85	37.2 d	0.43 a	0.72	97	19.1 abc	0.45 cd
$G\text{-}M_{10;125}$	3.3	1.79	36.4 bcd	0.40 a	0.66	83	18.8 abc	0.41 b
$G\text{-}M_{10;156}$	3.2	1.75	34.8 a	0.41 a	0.61	70	18.2 a	0.36 a
Arrangement 2								
$G\text{-}M_{10;64}$	4.5	1.86	37.0 cd	0.42 a	0.83	101	19.0 abc	0.47 d
$G\text{-}M_{10;80}$	4.0	1.84	37.2 d	0.43 a	0.77	99	18.9 abc	0.47 d
$G\text{-}M_{10;100}$	3.6	1.85	36.6 c	0.43 a	0.74	97	18.8 abc	0.46 d
$G\text{-}M_{10;125}$	3.0	1.81	36.2 bc	0.42 a	0.70	92	18.7 abc	0.45 cd
$G\text{-}M_{10;156}$	2.5	1.80	35.5 ab	0.42 a	0.65	79	18.4 ab	0.42 bc
LSD (0.05)			0.9	0.04			1.0	0.03
CV (%)			3.7	4.4			4.8	5.8

mixed crops than in the sole crops for treatments with normal and high maize densities, but depended more strongly on plant density than on cropping system. The H.I. for sole groundnuts was significantly higher than the H.I. values for groundnuts in the mixed crops in experiment 3, but not in the experiments 4 and 5. There were no significant differences between H.I. values of groundnuts in the mixed crop treatments, but H.I. values tended to be lower with increasing maize density. The H.I. for sole maize and maize in the mixed crops was not significantly different in experiments 3 and 4, but was higher than the H.I. for maize in some mixed cropping treatments with extremely high maize densities in experiment 5. There were no significant differences between H.I. values of groundnuts in the mixed crop treatments in experiment 4, but H.I. values tended to be lower with increasing maize density. In experiment 5, when maize plants were grown at high densities, their arrangement affected the H.I. The H.I. for maize in treatment $G\text{-}M_{10;156}$ in arrangement series 1 was significantly lower than for the same plant density in arrangement series 2.

6.3.5 Marketable yield

In the mixed crops, the marketable yield of groundnuts was lower with increasing maize density, but the maize yield was higher, except at extremely high maize densities (table 6.11). Statistical analysis showed significant differences between the marketable yield of both groundnuts and maize for different plant densities. In the experiments 4 and 5, regression analysis was carried out of marketable yields of groundnuts and maize on maize density. The relationship between pod yield of groundnuts and maize density was linear, and the relationship between grain yield of maize and plant density parabolic. The marketable yield figures of groundnuts and maize showed the same trend for the different maize densities in the plant arrangement effect was small compared with the plant density effect.

Table 6.11 Marketable yields of groundnuts and maize in experiments 3, 4 and 5.

	Pod yield of groundnuts (kg/ha)	Grain yield of maize (kg/ha)
Experiment 3		
Sole G	1742 d	
Sole M		2350 c
$G\text{-}M_{10;50}$	1197 c	1565 a
$G\text{-}M_{10;75}$	1041 b	1837 b
$G\text{-}M_{10;100}$	954 a	1986 b
LSD (0.05)	71	183
CV (%)	12.6	14.7
Experiment 4		
Sole G	1796 c	
Sole M		2235 c
$G\text{-}M_{10;43}$	1171 b	1366 a
$G\text{-}M_{10;54}$	1126 b	1484 a
$G\text{-}M_{10;70}$	1072 ab	1741 b
$G\text{-}M_{10;92}$	990 ab	1839 b
$G\text{-}M_{10;123}$	920 a	1768 b
LSD (0.05)	189	230
CV (%)	10.7	8.8
Experiment 5		
Sole G	1685 f	
Sole M		2306 f
Arrangement 1		
$G\text{-}M_{10;64}$	1077 de	1566 ab
$G\text{-}M_{10;80}$	998 cd	1799 bc
$G\text{-}M_{10;100}$	895 bc	1886 cde
$G\text{-}M_{10;125}$	789 b	1826 bcd
$G\text{-}M_{10;156}$	726 b	1725 abc
Arrangement 2		
$G\text{-}M_{10;64}$	1131 e	1434 a
$G\text{-}M_{10;80}$	1024 d	1635 abc
$G\text{-}M_{10;100}$	908 c	1930 cde
$G\text{-}M_{10;125}$	728 b	2140 ef
$G\text{-}M_{10;156}$	591 a	2103 def
LSD (0.05)	108	297
CV (%)	7.3	11.2

Linear regression analysis was carried out of marketable yield of groundnuts on maize density in experiment 4. For maize regression analysis showed a parabolic relationship between marketable yield and plant density.

Groundnuts: $y = 1297 - 3.16\ x$ $\quad r = -0.99$

Maize: $y = 289 + 31.4\ x - 0.157\ x^2$ $\quad R^2 = 0.99$

y = marketable yield (kg/ha)

x = maize density (in thousands of plants/ha)

These relationships, transformed to the RY of groundnuts and maize, are shown by graphs in fig. 6.5. Summing of the RY values for groundnuts and maize at different maize densities, resulted in the LER curve for the mixed crop.

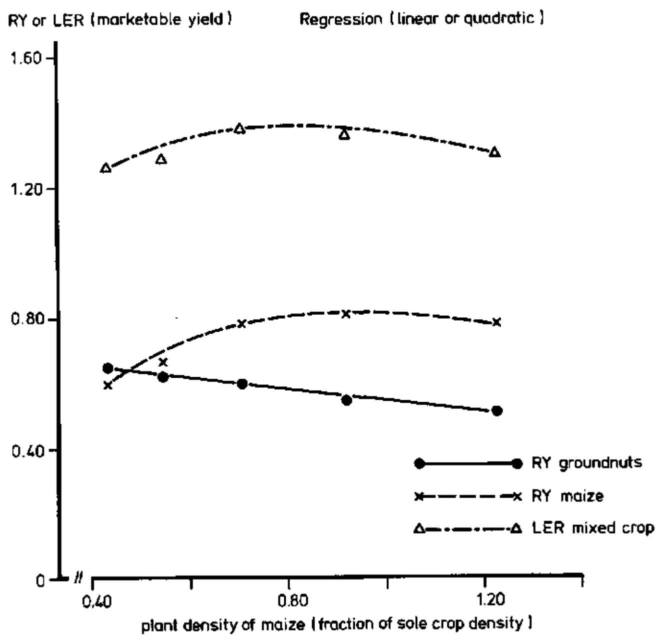

Fig. 6.5 Relationship between relative marketable yields of groundnuts and maize and maize densities, and the corresponding LER curve in experment 4.

The regression equations for the relationship between marketable yields of groundnuts and maize and maize densities are given below for the plant arrangement series 1 and 2 of experiment 5. For groundnuts the best fitting was obtained with linear regression, for maize the trend was parabolic.

Arrangement 1

Groundnuts:	$y = 1306 - 3.90\,x$	$r = -0.98$
Maize :	$y = 423 + 25.4\,x - 0.110\,x^2$	$R^2 = 0.88$

Arrangement 2

Groundnuts:	$y = 1503 - 6.08\,x$	$r = -0.99$
Maize :	$y = -317 + 34.8\,x - 0.123\,x^2$	$R^2 = 0.99$

y = marketable yield (kg/ha)
x = maize density (in thousands of plants/ha)

These relationships, transformed to the RY of groundnuts and maize, are shown by graphs in fig. 6.6. Summing gave the corresponding LER curves for the plant arrangement series 1 and 2. The linear regression line for the groundnut yields in arrangement series 2 had a stronger slope than that for arrangement series 1. The quadratic regression curve for maize yields in arrangement series 1 had its maximum at a density of about 145,000 maize plants per hectare. In arrangement series 2 the maximum maize yield was reached at a density of about 175,000 maize plants per hectare (fig. 6.6).

6.3.6 RY and LER

In experiment 3, the LER for marketable yield was highest at 100% density of the maize in the mixed crop (table 6.12). In experiment 4, the relationship between the LER for marketable yield of the maize and plant density was parabolic (see figure 6.5). In experiment 3, the LER for total dry matter yield was higher with increasing maize density. In experiment 4, the relationship between the LER for total dry matter yield and maize density was parabolic. At high densities of maize, the LER for

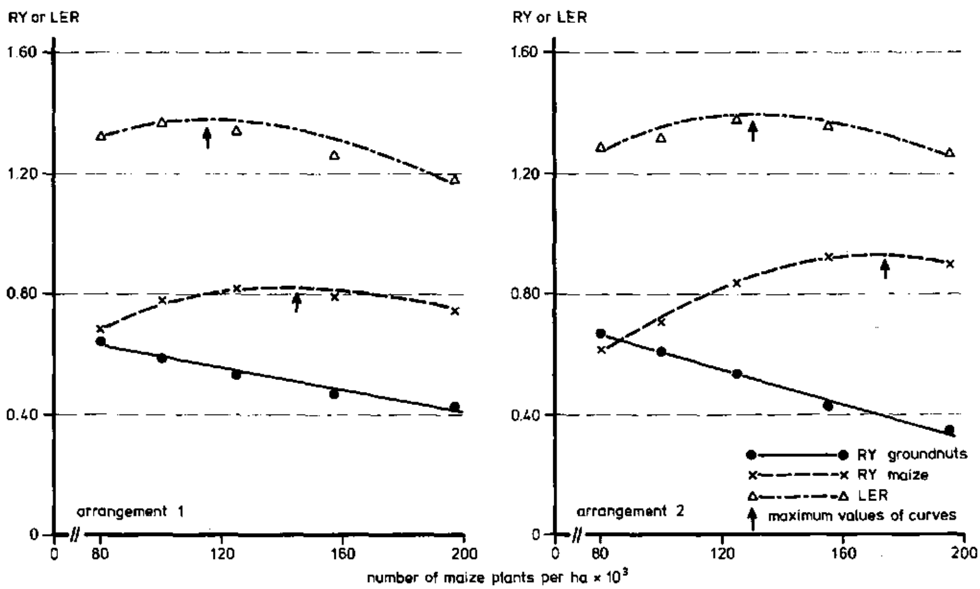

Fig. 6.6 Relationship between relative marketable yields (RY) of groundnuts and maize and maize densities, and the corresponding LER curves for the plant arrangement series 1 and 2 of experiment 5.

total dry matter yield was considerably higher than the LER for marketable yield.

In experiment 5, the maize densities for maximum LER values were considerably lower than for maximum maize yield. The highest LER value for marketable yield in plant arrangements series 1 was reached at a density of about 115,000 maize plants per hectare (about 90% of the sole crop denisty). In arrangement series 2, the highest LER value was reached at a higher maize density of about 130,000 plants per hectare (about 105%, see fig. 6.6). The maximum LER values for total dry matter

Table 6.12 Relative marketable yields (RY) and total dry matter yields (RY) of groundnuts and maize and corresponding LER values for the mixed crops in experiments 3, 4 and 5.

	Values for marketable yields			Values for total dry matter yields		
	RY of groundnuts	RY of maize	LER	RY of groundnuts	RY of maize	LER
Experiment 3						
Sole G	1.00 d			1.00 c		
Sole M		1.00 c			1.00 d	
$G\text{-}M_{10;50}$	0.69 c	0.67 a	1.36 a	0.75 b	0.61 a	1.36 a
$G\text{-}M_{10;75}$	0.60 b	0.78 b	1.38 ab	0.69 a	0.73 b	1.42 b
$G\text{-}M_{10;100}$	0.55 a	0.85 b	1.41 b	0.68 a	0.87 c	1.55 c
LSD (0.05)	0.04	0.07	0.03	0.05	0.06	0.05
CV (%)	12.6	14.7	6.2	7.7	7.9	2.9
Experiment 4						
Sole G	1.00 c			1.00 d		
Sole M		1.00 c			1.00 c	
$G\text{-}M_{10;43}$	0.65 b	0.61 a	1.26 a	0.63 c	0.59 a	1.22 a
$G\text{-}M_{10;54}$	0.63 b	0.66 a	1.29 a	0.60 bc	0.65 a	1.25 a
$G\text{-}M_{10;70}$	0.60 ab	0.78 b	1.38 b	0.58 abc	0.77 b	1.35 b
$G\text{-}M_{10;92}$	0.55 ab	0.82 b	1.37 b	0.56 ab	0.84 b	1.40 b
$G\text{-}M_{10;123}$	0.51 a	0.79 b	1.30 a	0.53 a	0.84 b	1.37 b
LSD (0.05)	0.10	0.10	0.04	0.06	0.10	0.06
CV (%)	10.7	8.8	2.4	6.8	9.2	3.2
Experiment 5						
Sole G	1.00 f			1.00 g		
Sole M		1.00 f			1.00 e	
Arrangement 1						
$G\text{-}M_{10;64}$	0.64 de	0.68 ab	1.32 bc	0.60 e	0.67 e	1.27 a
$G\text{-}M_{10;80}$	0.59 cd	0.78 bc	1.37 bc	0.58 e	0.80 bc	1.38 c
$G\text{-}M_{10;100}$	0.53 bc	0.82 cde	1.35 bc	0.51 d	0.85 cd	1.36 bcd
$G\text{-}M_{10;125}$	0.47 b	0.79 bcd	1.26 ab	0.48 cd	0.91 cde	1.39 d
$G\text{-}M_{10;156}$	0.43 b	0.75 abc	1.18 a	0.43 bc	0.98 e	1.41 d
Arrangement 2						
$G\text{-}M_{10;64}$	0.67 e	0.62 a	1.29 abc	0.66 f	0.63 a	1.29 ab
$G\text{-}M_{10;80}$	0.61 d	0.71 abc	1.32 bc	0.58 e	0.72 ab	1.30 abc
$G\text{-}M_{10;100}$	0.54 c	0.84 cde	1.38 c	0.52 d	0.86 cd	1.38 cd
$G\text{-}M_{10;125}$	0.43 b	0.93 ef	1.36 bc	0.42 b	0.97 d	1.39 d
$G\text{-}M_{10;156}$	0.35 a	0.91 def	1.26 ab	0.34 a	1.03 bcd	1.37 bcd
LSD (0.05)	0.06	0.12	0.11	0.05	0.11	0.08
CV (%)	7.3	11.2	6.1	7.0	9.7	5.3

yield were reached at higher maize densities than the ones giving maximum LER values for marketable yield (table 6.12). Total dry matter yields in plant arrangement series 1 were similar to those in arrangement series 2. The effect of arrangement of maize plants on marketable yield was more pronounced than on total dry matter yield. At high maize densities, plant arrangement influenced the H.I. of maize (see table 6.10).

6.4 DISCUSSION

From germination onwards the maize plants sufferend from competition by the groundnut plants, because the maize was sown 10 days after the groundnuts. This explains why maize plants in the mixed crops were shorter than those in the sole crops, had a lower LAI and longer time to flowering (fig. 6.2, fig. 6.3, tables 6.4, 6.5 and 6.6). In the mixed crops, both groundnuts and maize showed a lower productivity than in the sole crops, because of the competition between them. Groundnut yield in mixed crops was lower and maize yield was higher with increasing maize density (table 6.11).

By a delay of 10 days in sowing time, the maximum maize yield in the mixed crops was reached at higher maize densities (145%-175% of the sole crop density, see fig. 6.6) than might be expected to give the maximum for the mixed crops were obtained at considerably lower maize densities (90%-105% of the sole crop density, see fig. 6.6) because of the higher contribution from the groundnuts, and highest revenues of the mixed crops were obtained at low maize densities (see chapter 9).

In experiment 5, the plant arrangement effect on total dry matter yield and marketable yield was small compared to the plant density effect. Only at extremely high maize densities (in $G\text{-}M_{10;125}$ and $G\text{-}M_{10;156}$), was it substantial. At high maize densities, an even distribution of maize plants over the field (arrangement series 2) resulted in a higher HI than a more uneven distribution (arrangement series 1) did. The intraspecific competition between the maize plants was severe at high densities. Groundnut plants in arrangement series 1 received more light than in arrangement series 2 for the mixed cropping treatments with extremely high maize densities. The maize density range from $G\text{-}M_{10;64}$ to $G\text{-}M_{10;100}$ was of practical relevance for mixed cropping in East Java (see survey on farming practice, chapter 3). In this range, maize density has influenced the mixed crop yields considerably, but the effect of plant arrangement was negligible.

Overall conclusion from the experiments on maize density: Maximum marketable yield of maize was reached in treatments $G\text{-}M_{10;100}$, $G\text{-}M_{10;92}$, $G\text{-}M_{10;100}$ and $G\text{-}M_{10;125}$ from experiments 3, 4, 5-1 and 5-2 respectively. Because the groundnut yields were highest in the lowest density treatments, the maximum LER values were reached at lower maize densities, in treatments $G\text{-}M_{10;100}$, $G\text{-}M_{10;70+92}$, $G\text{-}M_{10;80+100}$ and $G\text{-}M_{10;100}$, respectively. For a maximum mixed crop yield of groundnuts and maize (sown 10 days later), maize density should be in the range of 70% to 100% of the sole crop density, or lower for maximum revenues from the mixed crop (chapter 9).

7 *THE COMBINED EFFECTS OF PLANT DENSITY AND SOWING TIME*

7.1 INTRODUCTION

Farmers in East Java usually sow groundnuts and maize in mixed crops simultaneously. In chapter 5 it was shown that delaying the sowing time of maize in mixed crops gave a start to the groundnuts. A low maize density in mixed crops resulted in a higher proportion of groundnuts in the total yield of the mixed crop (chapter 6). It may be expected that the optimum plant density of maize in mixed crops will be higher it the sowing time of the maize is further delayed. To test this hypothesis, in the following experiments maize was sown on different dates after the groundnuts at a range of densities.

7.2 MATERIALS AND METHODS

Experiment 6

Experiment 6 was conducted from 18 August until 1 December, 1979 on a rented farmer's field at Sukolilo, 13 km north-east of Malang, situated at an altitude of 520 m above sea level. Characteristics of the loam soil at Sukolilo are shown in section 4.1, table 4.2. Sowing was done during the dry season. Harvesting was done during the rainy season. The previous crop was sugar cane. Rainfall and open pan evaporation during the growing period are shown in fig. 7.1.

Before soil preparation, the field was irrigated by flooding. During the early stages of growth the field was irrigated three times by flooding: on 28 August, 10 September, and 8 October. At soil preparation 50 kg/ha of N, phosphorus pentoxide and potassium oxide in the form of NPK 15-15-15 compound fertilizer was applied as basal fertilizer. A side dressing of 58 kg/ha of

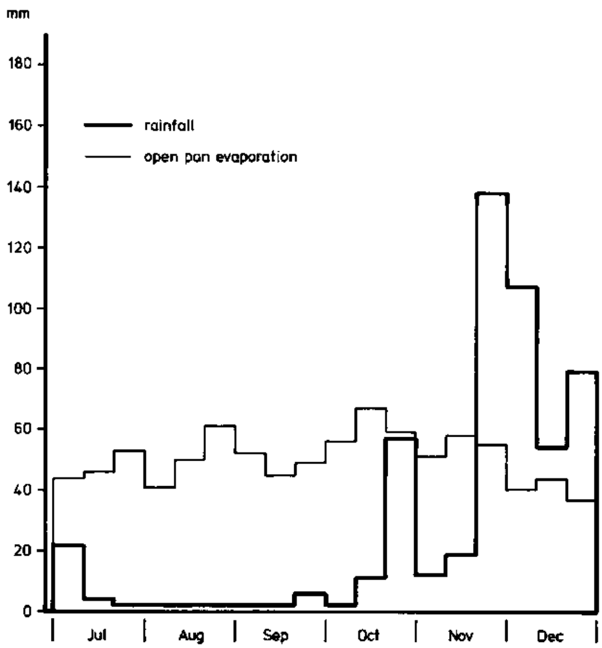

Fig. 7.1 Rainfall and open pan evaporation in mm per period of 10 days from July to December 1979.

nitrogen, as urea, was applied to sole maize, 25 days after sowing. Maize in the mixed crops received a side dressing of 36 kg/ha of nitrogen.

The experiment was laid out in a split-plot design, with 3 sowing dates of maize in the main plots (the fans) and a wide range of plant densities of maize in the sub-plots (segments of the fan). The experiment was in 4 replicates. Sole maize was sown on 3 dates, at the standard density of 125,000 plants per hectare. Groundnuts in the sole crop and the mixed crops was sown on one date, at the standard density of 160,000 plants per hectare. The maize in the mixed crops was sown in a fan shape, in a field with a constant plant density of groundnuts. The lay-out of the experiment is presented in fig. 7.2. At the final harvest, 1-meter segments from each of the maize rows were taken together to form a plot (see section 4.4.2, fig. 4.2).

The average yield of sole maize for the three sowing dates was used as a control to evaluate the mixed cropping results. For the mixed crops, the results of the part of the fan with a maize density range of 37,000 to 88,000 plants per hectare are presented in this chapter.

Spacing and plant density of groundnuts and maize are shown in table 7.1.

Table 7.1 Spacing and plant density of groundnuts and maize in experiments 6 and 7.

	Groundnuts		Maize		Total density of mixed crops (as % of sole crops)
	Spacing (cm x cm)	Plant density (plants per ha)	Spacing (cm x cm) 2 per hill	Plant density (plants per ha)	
Sole G	25 x 25	160,000			
Sole M			80 x 20	125,000	
$G\text{-}M_{0;30}$	25 x 25	160,000	147 x 37	37,000	130
$G\text{-}M_{0;35}$	25 x 25	160,000	135 x 35	44,000	135
$G\text{-}M_{0;43}$	25 x 25	160,000	122 x 30	54,000	143
$G\text{-}M_{0;54}$	25 x 25	160,000	108 x 27	68,000	154
$G\text{-}M_{0;70}$	25 x 25	160,000	95 x 24	88,000	170

Identical spacing and plant densities were used for the mixed crop treatments with 10 days later sowing ($G\text{-}M_{10;x}$) and with 20 days later sowing ($G\text{-}M_{20;x}$) of the maize.

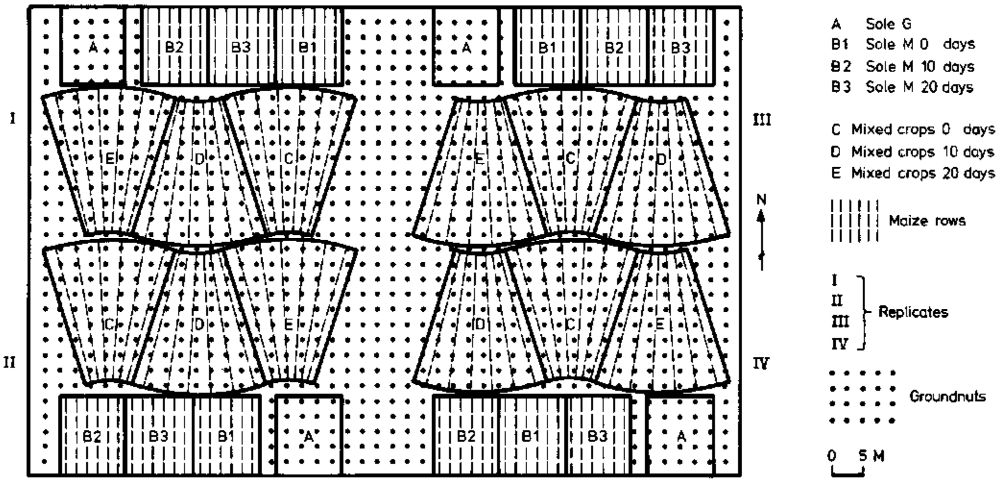

Fig. 7.2 Lay-out of experiments 6 and 7, with different sowing times and plant densities of maize in mixed cropping with groundnuts.
Days: delay in sowing time of maize.

For maize in the mixed crops, the plant density shown was the average density in each 1-meter segment of the maize rows that constituted the sub-plot (see fig. 4.2).

The number of mixed crop treatments was 15, consisting of the 5 above mentioned plant densities for each of the 3 sowing dates of maize. The main plots were designated by the sowing dates of the maize.

The groundnuts were sown on 18 August, 1979. The first sowing date of maize was on 18 August 1979, the second on 28 August (10 days later) and the third on 7 September (20 days later). The last sown maize showed a heavy infestation of downy mildew, caused by the fungus *Peronosclerospora maydis*.

Experiment 7

Experiment 7 was conducted from 16 February to 31 May, 1980, on a rented farmer's field at Sukolilo, close to the site of experiment 6. Sowing was done during the rainy season, and harvesting during the dry season. The previous crop was irrigated rice. Rainfall and open pan evaporation during the growing period are shown in chapter 6, figure 6.1.

The experimental design and the lay-out of experiment 7 were identical to those of experiment 6. The number of mixed crop treatments was 15, consisting of 5 plant densities on 3 sowing dates of the maize. Sole crops of groundnuts and maize were added as controls in the experimental field (see fig. 7.2).

Cultural practices were similar to those in experiment 6, except that the crop was not irrigated and no basal fertilizer was applied. Sole maize reived a side dressing of 46 kg/ha of nitrogen in the form of urea, and maize in the mixed crops received 23 kg/ha of nitrogen.

The groundnuts were sown on 16 February, 1980. The first sowing date of maize was on 16 February, 1980, the second on 26 February (10 days later) and the third on 7 March (20 days later). No sowing time effect was observed for sole maize. The average yield of sole maize for the 3 sowing dates was used as a control to evaluate the results of the mixed crops.

7.3 RESULTS

7.3.1 Plant height

In this section, plant height means the maximum height during the growing period for each treatment.

Table 7.2 Height (cm) of fully grown groundnut and maize plants in sole and mixed crops.

	Experiment 6		Experiment 7	
	Groundnuts	Maize	Groundnuts	Maize
Sole G	63 a		71 a	
Sole M		205 e		201 d
$G\text{-}M_{0;30}$	65 abc	197 de	73 abc	198 cd
$G\text{-}M_{0;35}$	67 abcd	194 d	73 abc	198 cd
$G\text{-}M_{0;43}$	69 bcd	195 de	76 c	195 cd
$G\text{-}M_{0;54}$	70 cd	192 cd	75 bc	194 cd
$G\text{-}M_{0;70}$	71 d	190 bcd	76 c	194 cd
$G\text{-}M_{10;30}$	64 ab	193 cd	72 ab	197 cd
$G\text{-}M_{10;35}$	65 abc	190 bcd	73 abc	197 cd
$G\text{-}M_{10;43}$	66 abcd	185 bcd	74 abc	193 cd
$G\text{-}M_{10;54}$	67 abcd	181 bcd	75 bc	192 bcd
$G\text{-}M_{10;70}$	68 abcd	178 b	75 bc	190 bc
$G\text{-}M_{20;30}$	63 a	164 a	72 ab	183 ab
$G\text{-}M_{20;35}$	64 ab	161 a	72 ab	180 a
$G\text{-}M_{20;43}$	64 ab	158 a	73 abc	178 a
$G\text{-}M_{20;54}$	65 abc	156 a	73 abc	176 a
$G\text{-}M_{20;70}$	65 abc	155 a	74 abc	177 a
LSD (0.05)	5	12	3	9
CV (%)	6.8	5.3	7.2	6.1

Groundnut plants grew taller in experiment 7 than in experiment 6. The height of groundnut plants in the sole crop was 63 cm in experiment 6 and pl cm in experiment 7, and was similar for most treatments (table 7.2). The height of groundnut plants in the mixed crops tended to be greater than in the sole crop. The later the sowing time of maize, the smaller the effect on the height of groundnut plants. In experiment 6 only groundnut plants in $G\text{-}M_{0;43}$, $G\text{-}M_{0,54}$ and $G\text{-}M_{0;70}$ were significantly taller than the groundnut plants in the sole crop. In experiment 7 also, groundnut plants in $G\text{-}M_{0,54}$ and $G\text{-}M_{0,70}$ were taller than the sole groundnut plants. The lower the density of the maize, the smaller the effect on the height of the groundnut plants.

The height of maize plants in the sole crops in experiment 6 was similar to that in experiment 7, slightly over 2 m, but in the mixed crops less than 2 m. The effect of sowing time on the height of maize plants in the mixed crops was stronger in experiment 6 than in experiment 7. The effect of density on height of maize plants was negligible.

7.3.2 *LAI*

In this section, LAI means the highest LAI value for each crop during the growing period in each treatment. The summed LAI is the highest values of the summed LAI of groundnuts and maize during the growing period for each mixed crop treatment.

The LAI for groundnuts was higher in experiment 6 than in experiment 7, and in mixed crops was higher with later sowing of the maize. The effect of maize density in the mixed crops on the LAI for groundnuts was smaller in the treatments with 20 days delay in sowing time of maize ($G\text{-}M_{20;x}$), than in the treatments with maize sown at the same date as the groundnuts ($G\text{-}M_{0;x}$) or 10 days later ($G\text{-}M_{10;x}$).

The LAI values for maize in experiment 6 were similar to those in experiment 7, and in the mixed crops they were lower with later sowing of maize. The LAI for maize was higher with increasing plant density.

The summed LAI value for the mixed crops was higher in experiment 6 than in experiment 7. In both experiments, the summed LAI for the mixed crops was higher than the LAI for the sole crops. The summed LAI values were similar for the different sowing dates. The summed LAI was higher with increasing maize density, in particular in ($G\text{-}M_{20;x}$).

Table 7.3 Highest LAI values for groundnuts and maize during the growing period and the highest summed LAI values for the mixed crops.

	Experiment 6			Experiment 7		
	LAI for groundnuts	LAI of maize	Summed LAI for mixed crops	LAI for groundnuts	LAI for maize	Summed LAI for mixed crops
Sole G	3.49 h			2.82 i		
Sole M		3.21 i			2.98 h	
$G\text{-}M_{0;30}$	2.56 ef	1.50 bc	4.12	1.78 def	1.77 c	3.59
$G\text{-}M_{0;35}$	2.22 bcde	1.95 de	4.19	1.68 cde	1.91 cd	3.62
$G\text{-}M_{0;43}$	2.07 bcd	2.23 ef	4.28	1.39 abc	2.31 def	3.68
$G\text{-}M_{0;54}$	1.79 ab	2.63 g	4.37	1.34 ab	2.57 fgh	3.89
$G\text{-}M_{0;70}$	1.55 a	2.86 h	4.35	1.15 a	2.82 gh	3.96
$G\text{-}M_{10;30}$	2.86 fg	1.52 bc	4.40	2.00 fgh	1.40 ab	3.48
$G\text{-}M_{10;35}$	2.62 ef	1.83 d	4.43	1.88 efg	1.64 bc	3.56
$G\text{-}M_{10;43}$	2.52 def	2.19 ef	4.67	1.77 def	1.96 cde	3.76
$G\text{-}M_{10;54}$	2.27 cde	2.64 g	4.88	1.65 bcde	2.36 ef	4.03
$G\text{-}M_{10;70}$	1.94 abc	2.97 h	4.88	1.48 bcd	2.46 fg	3.92
$G\text{-}M_{20;30}$	3.25 gh	0.91 a	4.20	2.30 h	1.17 a	3.51
$G\text{-}M_{20;35}$	3.08 gh	1.03 ab	4.15	2.14 gh	1.41 ab	3.57
$G\text{-}M_{20;43}$	2.91 fg	1.27 b	4.22	2.03 fgh	1.64 bc	3.65
$G\text{-}M_{20;54}$	2.90 fg	1.61 b	4.41	1.93 efg	1.92 cd	3.89
$G\text{-}M_{20;70}$	2.79 fg	1.94 de	4.63	1.88 efg	2.22 def	4.08
LSD (0.05)	0.47	0.29		0.31	0.42	
CV (%)	9.2	11.1		11.7	12.6	

7.3.3 Time to flowering

In experiment 6, the flowering of the groundnut plants was later in the mixed crops than in the sole crop. The later the sowing of the maize in the mixed crop, the smaller the delay in flowering of the groundnuts (table 7.4). The higher the maize density in the mixed crops, the greater the delay in flowering of the groundnuts. The time to flowering of groundnuts in the different treatments of experiment 7 was comparable to that in experiment 6, but the time from sowing to flowering was later. The time from sowing to tasseling and silking was later in ex-

Table 7.4 Time (days) to flowering of groundnuts and maize in experiments 6 and 7.

	Flowering of groundnuts	Tasseling of maize	Silking of maize	Interval between tasseling and silking (days)
Experiment 6				
Sole G	30.9 a			
Sole M		41.9a	46.7 abc	4.8
$G\text{-}M_{0;30}$	32.2 cdf	41.6 a	46.2 a	4.8
$G\text{-}M_{0;35}$	32.6 efd	41.7 a	46.5 ab	4.8
$G\text{-}M_{0;43}$	32.9 fg	42.1 ab	47.0 abcd	4.9
$G\text{-}M_{0;54}$	33.3 gh	42.5 abc	47.4 abcd	4.9
$G\text{-}M_{0;70}$	33.9 h	42.9 abc	48.0 bcde	5.1
$G\text{-}M_{10;30}$	31.8 bcd	41.8 a	46.7 abc	4.9
$G\text{-}M_{10;35}$	32.1 bcde	42.0 ab	46.9 abc	4.9
$G\text{-}M_{10;43}$	32.5 def	42.4 abc	47.4 abcd	5.0
$G\text{-}M_{10;54}$	32.9 fg	42.8 abcd	47.9 bcde	5.1
$G\text{-}M_{10;70}$	33.3 gh	43.2 bcde	48.4 def	5.2
$G\text{-}M_{20;30}$	31.4 ab	43.2 bcde	48.9 ef	5.7
$G\text{-}M_{20;35}$	31.7 bc	43.5 cde	49.1 ef	5.6
$G\text{-}M_{20;43}$	32.0 bcd	43.6 cde	49.3 ef	5.7
$G\text{-}M_{20;54}$	32.2 cdef	43.9 de	49.6 f	5.7
$G\text{-}M_{20;70}$	32.6 efg	44.3 e	49.9 f	5.6
LSD (0.05)	0.7	1.3	1.5	
CV (%)	2.6	3.5	3.4	
Experiment 7				
Sole G	32.8 a			
Sole M		42.8 ab	47.8 ab	5.0
$G\text{-}M_{0;30}$	34.5 ef	42.5 a	47.2 a	4.7
$G\text{-}M_{0;35}$	34.8 ef	42.6 a	47.9 a	4.8
$G\text{-}M_{0;43}$	35.1 fg	42.9 ab	47.8 ab	4.9
$G\text{-}M_{0;54}$	35.5 gh	43.3 abcd	48.2 abc	4.9
$G\text{-}M_{0;70}$	36.1 h	43.7 bcde	48.8 bcd	5.1
$G\text{-}M_{10;30}$	33.6 bc	42.6 a	47.4 a	4.8
$G\text{-}M_{10;35}$	33.8 cd	42.8 ab	49.0 bcde	5.2
$G\text{-}M_{10;43}$	34.3 de	43.1 abc	48.3 abc	5.2
$G\text{-}M_{10;54}$	34.8 ef	43.5 abcd	48.8 bcd	5.3
$G\text{-}M_{10;70}$	35.1 fg	44.0 cde	49.4 cde	5.4
$G\text{-}M_{20;30}$	33.0 ab	43.2 ab	48.1 ab	4.9
$G\text{-}M_{20;35}$	33.2 abc	43.8 bcde	48.8 bcd	5.0
$G\text{-}M_{20;43}$	33.5 bc	44.0 cde	49.2 cde	5.2
$G\text{-}M_{20;54}$	33.8 cd	44.3 de	49.7 de	5.4
$G\text{-}M_{20;70}$	34.4 de	44.7 e	50.2 e	5.5
LSD (0.05)	0.6	1.0	1.2	
CV (%)	2.0	2.7	3.2	

periment 7 than in experiment 6, and the interval between tasseling and silking was greater. The time to tasseling and to silking was similar in sole and mixed crops, in both experiments. In the mixed crops, tasseling and silking started later with higher density. Later sowing of maize in the mixed crops resulted in a sligh delay in tasseling and silking.

7.3.4 Total dry matter yield and yield components

The total dry matter yield of groundnuts in the mixed crops was much lower than in the sole crop, lower at higher maize density, and higher with later sowing of the maize (table 7.5). The total dry matter yield of maize in the mixed crops was lower with later sowing, and higher with increasing density.

Table 7.5 Total dry matter yield (kg/ha) of groundnuts and maize at the final harvest

	Experiment 6		Experiment 7	
	Groundnuts	Maize	Groundnuts	Maize
Sole G	4842 h		3247 l	
Sole M		5796 i		4792 k
$G\text{-}M_{0;30}$	3767 de	3178 cd	1844 hi	3095 ef
$G\text{-}M_{0;35}$	3481 d	3702 e	1651 def	3548 gh
$G\text{-}M_{0;43}$	2958 c	4218 fg	1529 cd	3972 ij
$G\text{-}M_{0;54}$	2510 ab	5107 h	1361 ab	4141 ij
$G\text{-}M_{0;70}$	2272 a	5331 h	1222 a	4250 j
$G\text{-}M_{10;30}$	3913 ef	3065 cd	1944 ij	2394 bc
$G\text{-}M_{10;35}$	3726 de	3467 de	1821 ghi	2834 de
$G\text{-}M_{10;43}$	3441 d	3821 ef	1684 efg	3245 fg
$G\text{-}M_{10;54}$	2898 bc	4629 g	1546 cde	3572 gh
$G\text{-}M_{10;70}$	2560 abc	5217 h	1460 bc	3837 hi
$G\text{-}M_{20;30}$	4403 g	1681 a	2268 k	1583 a
$G\text{-}M_{20;35}$	4310 fg	1790 a	2239 k	1772 a
$G\text{-}M_{20;43}$	3919 ef	2242 b	2016 j	2206 b
$G\text{-}M_{20;54}$	3690 de	2941 c	1823 ghi	2687 cd
$G\text{-}M_{20;70}$	3536 de	3472 de	1720 fgh	3259 fg
LSD (0.05)	398	426	141	332
CV (%)	8.1	8.3	5.7	7.5

Plate 7. Sampling in a farmers' field at harvest time

Plate 8. Harvesting groundnuts 10 days after the maize in a fan design

Table 7.6 Yield components for groundnuts in experiments 6 and 7.

	Experiment 6				Experiment 7			
	No of mature pods per plant	No of seeds per pod	100-seed weight	H.I.	No of mature pods per plant	No of seeds per pod	100-seed weight	H.I.
Sole G	11.2	1.93	39.3 ghi	0.40 a	8.7	1.85	37.1 ef	0.42 a
$G\text{-}M_{0;30}$	9.2	1.96	37.8 cde	0.41 a	5.2	1.82	35.3 bcd	0.41 a
$G\text{-}M_{0;35}$	8.7	1.95	37.3 bcd	0.42 a	4.9	1.80	34.8 abc	0.42 a
$G\text{-}M_{0;43}$	7.7	1.93	36.9 abc	0.43 a	4.5	1.79	34.3 ab	0.41 a
$G\text{-}M_{0;54}$	6.5	1,90	36.5 ab	0.41 a	4.2	1.77	33.9 a	0.43 a
$G\text{-}M_{0;70}$	6.2	1.87	35.9 a	0.42 a	3.9	1.75	33.7 a	0.43 a
$G\text{-}M_{10;30}$	9.3	1.94	38.6 efgh	0.41 a	5.4	1.87	35.9 cde	0.43 a
$G\text{-}M_{10;35}$	9.1	1.92	38.3 defg	0.41 a	5.3	1.83	35.3 bcd	0.43 a
$G\text{-}M_{10;43}$	8.5	1.93	38.0 cdef	0.42 a	4.9	1.80	35.4 bcd	0.43 a
$G\text{-}M_{10;54}$	7.3	1.91	37.6 bcde	0.42 a	4.5	1.79	34.7 abc	0.41 a
$G\text{-}M_{10;70}$	6.6	1.89	37.1 bc	0.41 a	4.4	1.77	34.3 ab	0.41 a
$G\text{-}M_{20;30}$	9.9	1.98	40.2 i	0.41 a	6.1	1.86	37.3 f	0.42 a
$G\text{-}M_{20;35}$	9.8	1.96	39.9 i	0.41 a	6.0	1.83	37.1 ef	0.40 a
$G\text{-}M_{20;43}$	9.2	1.95	39.7 hi	0.42 a	5.5	1.84	36.8 ef	0.42 a
$G\text{-}M_{20;54}$	8.5	1.94	39.4 ghi	0.40 a	5.1	1.81	36.6 def	0.42 a
$G\text{-}M_{20;70}$	8.2	1.91	39.1 fghi	0.40 a	4.8	1.79	36.2 def	0.41 a
LSD (0.05)			1.1	0.04			1.3	0.03
CV (%)			4.3	4.5			4.9	5.1

Groundnuts

The number of seeds per pod was lower in experiment 7 than in experiment 6, but was similar for all treatments within each experiment (table 7.6). The 100-seed weight was higher for sole groundnuts than for some of the mixed crop treatments. Later sowing of maize resulted in a higher 100-seed weight for groundnuts. The number of mature pods per plant was a good indicator for the marketable yield (see section 7.3.5). The harvest index values for groundnuts in experiments 6 and 7 were similar, and, in both experiments, no significant differences between the treatments were observed. In experiment 6 there was a tendency of higher H.I. values for groundnuts in the mixed crops than in the sole crop.

Maize

The number of seeds per ear was lower with increasing plant density and with later sowing of the maize, which was also the trend for the 100-seed weight (table 7.7). The H.I. for maize was lower in experiment 6 than in experiment 7. In experiment 6 the H.I. for sole maize showed a tendency to be lower than in some of the mixed crop treatments.

Table 7.7 Yield components for maize in experiments 6 and 7.

	Experiment 6				Experiment 7			
	No of ears per plant	No of seeds per ear	100-seed weight	H.I.	No of ears per plant	No of seeds per ear	100-seed weight	H.I.
Sole M	0.63	147	19.7 fg	0.39 a	0.76	117	19.4 cd	0.45 a
$G\text{-}M_{0;30}$	0.88	195	21.0 i	0.42 a	0.94	197	20.5 h	0.45 a
$G\text{-}M_{0;35}$	0.86	195	20.9 i	0.42 a	0.95	188	20.3 gh	0.44 a
$G\text{-}M_{0;43}$	0.84	183	20.3 ghi	0.40 a	0.91	186	19.9 efg	0.46 a
$G\text{-}M_{0;54}$	0.89	175	19.6 fg	0.41 a	0.95	145	19.6 de	0.45 a
$G\text{-}M_{0;70}$	0.83	154	19.1 ef	0.40 a	0.86	126	19.3 c	0.43 a
$G\text{-}M_{10;30}$	0.89	187	20.5 hi	0.41 a	0.97	154	20.4 h	0.47 a
$G\text{-}M_{10;35}$	0.90	174	20.6 i	0.41 a	0.97	151	20.1 fgh	0.46 a
$G\text{-}M_{10;43}$	0.88	165	19.8 fgh	0.41 a	0.94	150	19.7 def	0.46 a
$G\text{-}M_{10;54}$	0.90	159	19.3 f	0.40 a	0.88	143	19.4 cd	0.46 a
$G\text{-}M_{10;70}$	0.87	148	18.5 de	0.40 a	0.87	120	18.8 ab	0.45 a
$G\text{-}M_{20;70}$	0.69	133	16.8 a	0.39 a	0.89	98	18.5 a	0.44 a
$G\text{-}M_{20;30}$	0.55	168	18.3 cd	0.38 a	0.91	105	19.5 cde	0.44 a
$G\text{-}M_{20;35}$	0.59	157	18.0 bcd	0.41 a	0.90	101	19.4 cd	0.44 a
$G\text{-}M_{20;43}$	0.61	150	17.6 bc	0.39 a	0.91	102	19.3 cd	0.44 a
$G\text{-}M_{20;54}$	0.71	135	17.3 ab	0.38 a	0.90	99	19.1 bc	0.43 a
LSD (0.05)			0.7	0.05			0.4	0.06
CV (%)			10.3	5.7			8.6	6.3

7.3.5 Marketable yield

The groundnut yield in the mixed crops was higher with later sowing of maize and lower at increasing maize density (table 7.8). The groundnut yield in the sole crops was higher than in the mixed crops, except for the treatments G-$M_{20;30}$ and G-$M_{20;35}$ in experiment 6.

Table 7.8 Marketable yield (kg/ha) of groundnuts and maize, with different sowing times and plant densities of maize.

	Experiment 6		Experiment 7	
	Pod yield of groundnuts	Grain yield of maize	Pod yield of groundnuts	Grain yield of maize
Sole G	2202 i		1556 j	
Sole M		2590 i		2452 j
G-$M_{0;30}$	1765 efg	1517 d	863 fg	1597 ef
G-$M_{0;35}$	1650 def	1760 ef	785 de	1815 gh
G-$M_{0;43}$	1428 cd	1923 f	711 bc	2086 i
G-$M_{0;54}$	1168 ab	2356 h	659 b	2096 i
G-$M_{0;70}$	1079 a	2437 hi	593 a	2084 i
G-$M_{10;30}$	1808 efg	1427 cd	947 h	1281 c
G-$M_{10;35}$	1739 ef	1613 de	881 g	1466 de
G-$M_{10;43}$	1626 def	1770 ef	812 ef	1707 fg
G-$M_{10;54}$	1366 bc	2123 g	726 cd	1876 gh
G-$M_{10;70}$	1192 ab	2386 h	687 bc	1964 hi
G-$M_{20;30}$	2060 hi	717 a	1093 i	783 a
G-$M_{20;35}$	1990 ghi	829 ab	1059 i	885 a
G-$M_{20;43}$	1848 fgh	981 b	963 h	1105 b
G-$M_{20;54}$	1693 ef	1282 c	874 fg	1317 cd
G-$M_{20;70}$	1593 cde	1540 d	809 e	1618 ef
LSD (0.05)	227	188	63	173
CV (%)	9.9	8.0	5.5	7.7

The maize yield in the mixed crops was lower with later sowing, and higher at increasing plant density (table 7.8). The maize yield was higher in the sole than in the mixed crops, except for treatment G-$M_{20;70}$ in experiment 6.

7.3.6 RY and LER

The RY values for groundnuts in experiment 6 were higher than in experiment 7, both for pod yield and total dry matter yield (fig. 7.3). The RY values for maize in experiment 6 were similar to those in experiment 7. The LER values for corresponding treatments were higher in experiment 6 than in experiment 7, both for marketable yield and total dry matter yield. The relationship between the relative groundnut yields in fig. 7.3 are the result of linear regression analysis. In experiment 6, the RY values for groundnuts decreased more strongly with increasing maize density in G-$M_{0;x}$ than in G-$M_{20;x}$. For maize in mixed cropping, the relationship between the relative yields and plant density was parabolic for the first and second sowing dates (G-$M_{10;x}$), and linear for the third sowing date (G-$M_{20;x}$). With 20 days delay in sowing time of maize, the highest relative marketable yield for maize was reached at the highest density, and at lower densities for maize sown at the same date as the groundnuts (fig. 7.3). Summing the RY values for groundnuts and for maize at different maize densities, resulted in the LER curves for the different sowing time treatments. Maximum LER values were reached at lower plant densities for the first sowing date treatment (G-$M_{0;x}$) than for the second and third sowing dates. In experiment 6, maximum LER values of over 1.35 for G-$M_{0;x}$ were obtained at a total mixed crop density of about 150%, and similar maximum LER values for G-$M_{10;x}$ at slightly higher total densities. In experiment 7, maximum LER values for G-$M_{0;x}$ and G-$M_{10;x}$ were reached at similar plant densitis as in experiment 6, but the values were lower (1.20-1.30). In G-$M_{10;x}$, the maximum LER values for total dry matter yield were obtained at higher total plant densities than for marketable yield. Maximum LER values for G-$M_{20;x}$ were lower than for the first and second sowing time of maize, but a tendency was visible that a further increase of the maize density would have resulted in higher LER values.

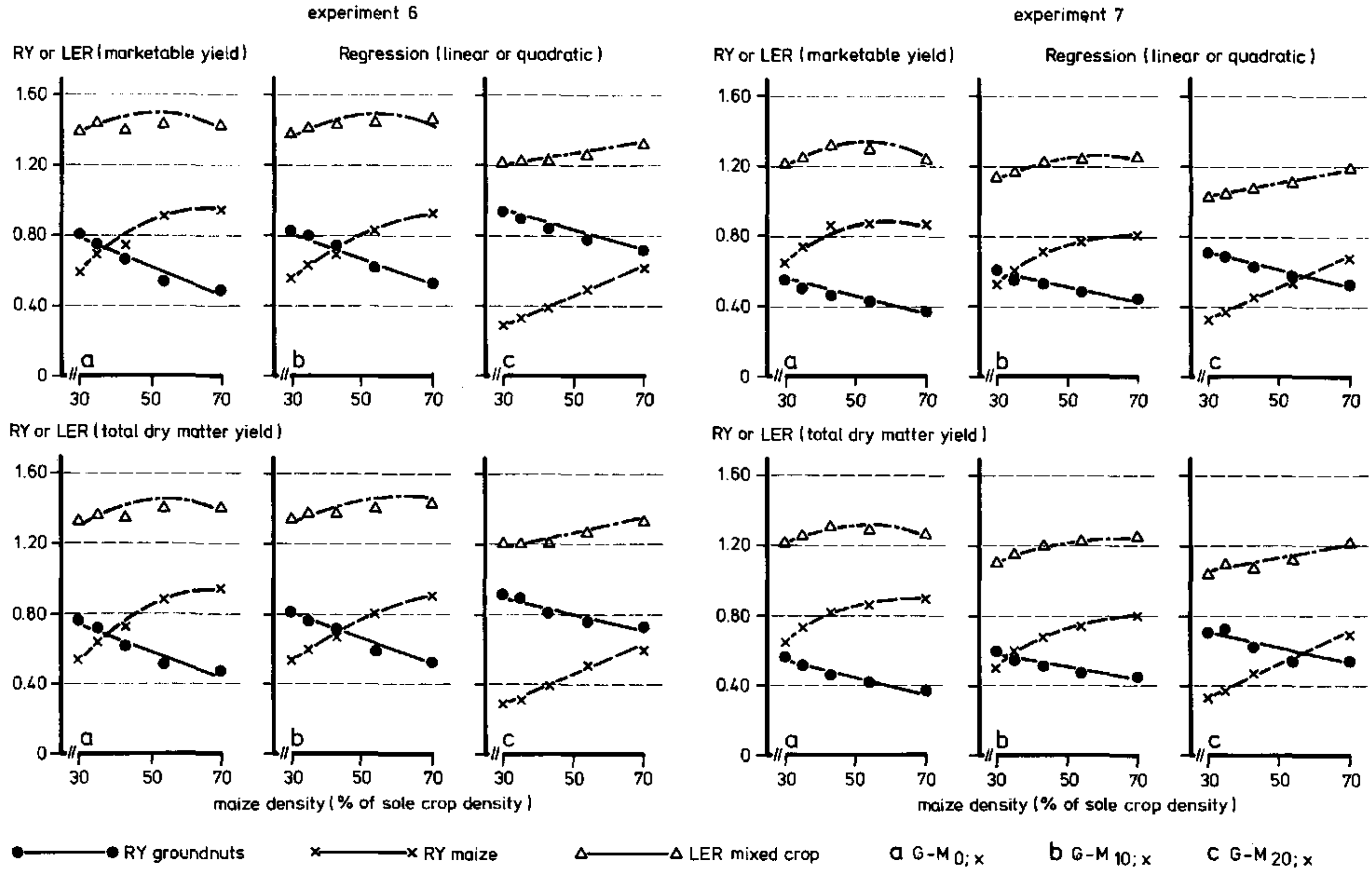

Fig. 7.3 Relationship between relative marketable and total dry matter yields (RY) of groundnuts and maize and maize densities, for the 3 sowing dates, and the corresponding LER curves, in experiments 6 and 7.

7.4 DISCUSSION AND CONCLUSIONS

The higher yield level of experiment 6 compared with experiment 7, is explained partly by the high rate of fertilizer that has been applied in experiment 6. Less fertilizer has been applied in experiment 7: no basal fertilizer application, and only a small amount of urea was applied as side dressing to maize.

The season has contributed to the difference in yield level between the experiments 6 and 7. In experiment 6 sowing took place during the dry season and the field was properly irrigated during the young stage of the crop. During the rainy part of the growing period the last sown maize plants have suffered severely from damage by the fungus disease *Peronosclerospora maydis* (downy mildew). The harvest took place during the rainy season. Experiment 2 started during the rainy season and there was excess of water after sowing of the crops. Harvesting was done during the dry season.

By delaying the sowing time of maize in the mixed crops, the plant density, resulted in a similar RY for groundnuts and for maize and a similar LER for the mixed crop, compared to simultaneously sown groundnuts and maize.

A delay in sowing time of maize, together with an increase in maize density, resulted in a similar RY for groundnuts and for maize and a similar LER for the mixed crop, compared to simultaneously sown groundnuts and maize. By delaying the sowing of maize in mixed crops, the plant density of maize could be increased without affecting the total dry matter yield and marketable yield groundnuts. With delaying the sowing time of maize 10 days, the maize density had to be increased to reach a similar yield level as with simultaneously sown maize. Later sowing of maize in the mixed crops resulted in a less abundant development of the individual maize plants. The shift in the balance between groundnut yield and maize yield in mixed crops, caused by a lower plant density and/or by later sowing of the maize, was very pronounced in experiments 6 and 7.

Overall conclusion:
The experiments have shown that maize and groundnuts in mixed crops sown simultaneously each at the normal corresponding sole crop density, resulted in sub-optimal groundnut yields (RY less than 0.50) and LER values (experiments 2, 6 and 7).

Better results for the mixed crop were achieved by either delaying the sowing time of maize with about 10 days and/or decreasing the plant density of maize.

RY values for groundnuts reached 0.60 and LER 1.38 at 10 days delay and with 70% to 75% of the sole crop maize density (experiments 3 and 4).

A decrease in maize density in mixed crops had a comparable effect on the ratio between RY of groundnuts and maize as a delay in sowing time of maize. Delaying the sowing time of maize was a safer way to obtain a high proportion of groundnuts in the total mixed crop yield than a decrease in plant density of simultaneously sown maize. Later sowing of maize at a moderate density, made the level of groundnut yield better predictable than sowing the maize at a low density simultaneously with groundnuts.

8 *LIGHT INTERCEPTION AND LIGHT USE EFFICIENCY*

8.1 INTRODUCTION

It may be expected that mixed crops of a tall C_4 species with a short C_3 species make a more complete use of the incoming radiation than the corresponding sole crops (Trenbath, 1981). A study of the light interception during the growing period, and of light use efficiency by groundnuts (C_3 species) and maize (C_4 species) in sole and mixed crops, may be helpful in explaining the differences in total dry matter yields that were found between treatments in the field experiments.

8.2 MATERIALS AND METHODS

At regular intervals during the growing period, measurements were made of the solar radiation above and beneath the canopy of the maize and groundnut plants. From these data, the percentage of light intercepted by the foliage was calculated. Only certain wavelengths of the light can be used for photosynthesis, which are called the photosynthetically active radiation (PAR), constituting about 50% of the total incoming radiation. The relationship between the percentage of light intercepted and the LAI was determined by plotting the calculated percentages of light intercepted by the foliage against the LAI values during the growing period (see fig. 4.4), in accordance with information mentioned by Monteith (1972). Calculations of light interception based on LAI values were less variable than calculations based on light measurements in the field. The penetration of light through the canopy approximately followed the Lambert-Beer law (Monsi and Saeki, 1953). The K value (extinction coefficient) in the formula was 0.95 for groundnuts, with horizontally-oriented leaves, and 0.45 for maize, with its more erect leaves.

The energy content of the solar radiation and the intercepted light was calculated, based on the average amount of solar radiation per day measured at the Meteorological Station of Brawijaya University, Malang (table 4.1). This was in average 1680 J/cm^2 per day, or 168 GJ/ha per day. The energy content of the dry matter, which consisted of carbohydrates such as sugars, starch and fibres, was treated as 16,700 J/g, that of fat as 37,600 J/g. Groundnut seeds contained 45% fat, and 30% of the pod weight was shell, so, the energy content of groundnut pods was 23,280 J/g. Maize grains contained 4.5% fat and had an energy content of 17,640 J/g. The light use efficiency of the crops was calculated by dividing the energy content of the total dry matter yield by the energy content of the intercepted light.
The light interception and the light use efficiency were calculated for all treatments in experiments 1 and 3.

8.3 RESULTS

8.3.1 Incoming radiation and light interception

For sole groundnuts and for the mixed crops the total amount of incoming radiation during the growing period of 105 days was 17,640 GJ/ha, and for sole maize with its 85 days growing period, it was 14,280 GJ/ha. Variation of daily incoming radiation over the year was not large and has not been taken into account in the calculations.
The percentage light intercepted by groundnut and maize plants and the summed percentage of light intercepted by the mixed crop during the growing period are shown in fig. 8.1. When the maize plants were tall and well developed, the light intensity above the groundnut canopy in the mixed crops was considerably reduced.
Light intercepted by sole groundnuts as percentage of the total incoming radiation during the growing period was more than that intercepted by sole maize. The energy content of the intercept-

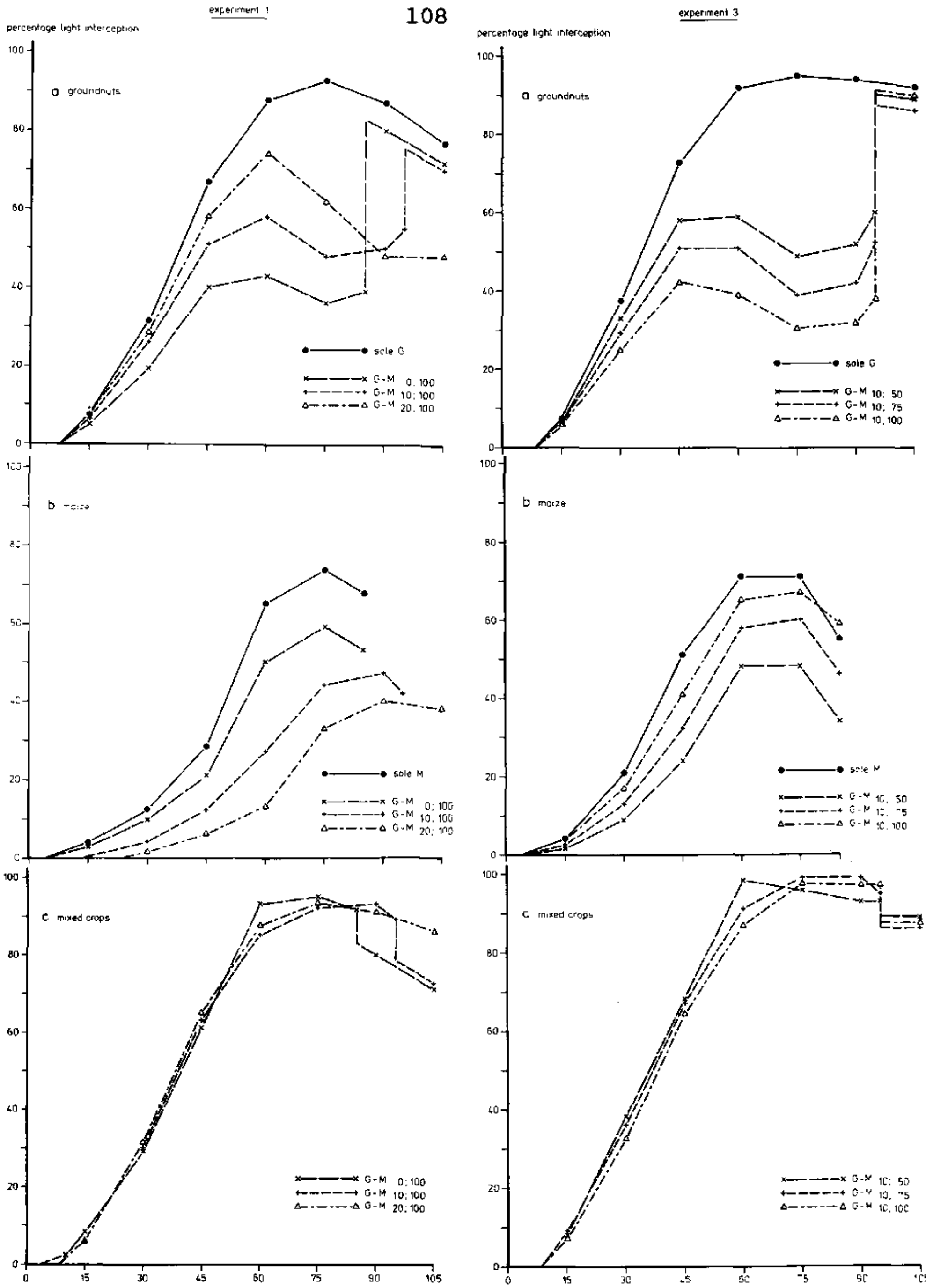

Fig. 8.1 Percentage light intercepted during the growing period by groundnut and maize plants and the summed percentage of light intercepted by the mixed crops in experiments 1 and 3.

ed radiation by sole groundnuts was about double that of sole maize. The amount of light intercepted by the mixed crops was similar to that of sole groundnuts.

Light intercepted by the mixed crops summed over the total growing period was divided as follows between groundnuts and maize: for G-$M_{0;100}$ light intercepted was 38% + 25% = 63%; for G-$M_{10;100}$ the figures were 43% + 21% = 64%; for G-$M_{20;100}$ it was 46% + 18% = 64%; for G-$M_{10;50}$ light intercepted was 48% + 22% = 70%; for G-$M_{10;75}$ the figures were 41% + 28% = 69% and for G-$M_{10;100}$ it was 35% + 33% = 68%, approximately.

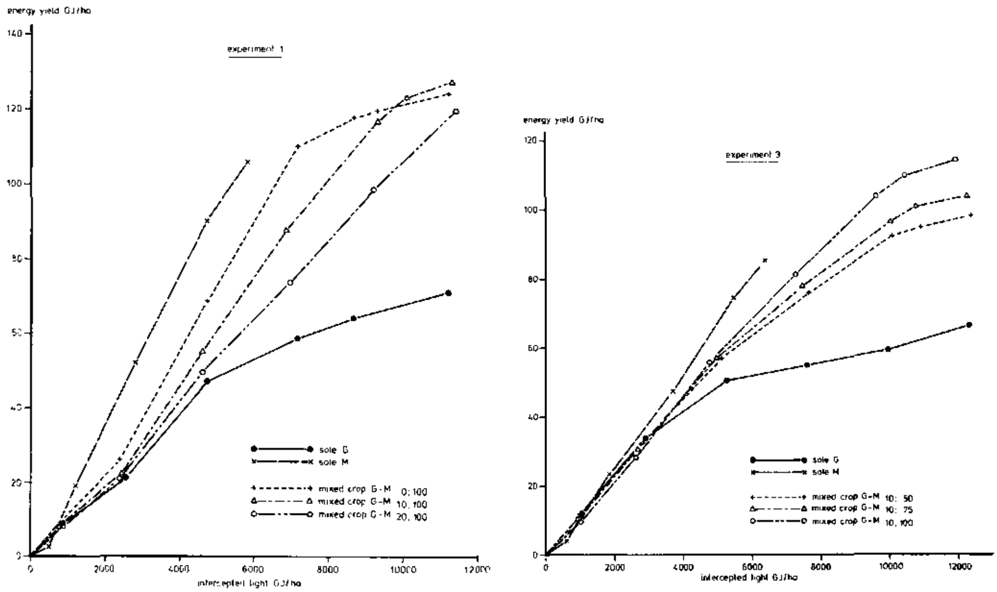

Fig. 8.2 Relationship between the amount of light intercepted and the energy yield of sole groundnuts, sole maize and the total mixed crops in experiments 1 and 3.

Table 8.1 Light intercepted and light use efficiency in experiments 1 and 3

	Light intercepted		Energy yield (GJ/ha)	Licht use efficiency (%)			Overall efficiency (%)
	GJ/ha	% of total incoming radiation		G	M	Total mixed crop	
Experiment 1							
Sole G	11,183	63.4	70.64	0.63			0.40
Sole M	5,785	40.5	105.64		1.83		0.75
G-M 0;100	11,107	63.0	124.26	0.73	1.70	1.12	0.70
G-M 10;100	11,283	64.0	126.80	0.75	1.89	1.12	0.72
G-M 20;100	11,354	64.4	119.72	0.76	1.79	1.05	0.68
Experiment 3							
Sole G	12,278	69.6	66.99	0.55			0.38
Sole M	6,358	44.5	80.47		1.27		0.56
G-M 10; 50	12,305	69.8	98.76	0.59	1.27	0.80	0.56
G-M 10; 75	12,217	69.3	104.12	0.62	1.20	0.85	0.59
G-M 10;100	11,937	67.7	114.21	0.72	1.21	0.96	0.65

8.3.2 Light use efficiency

The relationship between the amount of intercepted light and the energy content of the total dry matter yield of sole groundnuts, sole maize and the summed energy yield of the mixed crops are shown in fig. 8.2.

The energy content of the total dry matter yield as percentage of the total incoming radiation during the growing period (overall efficiency) was 0.39% for sole groundnuts, 0.66% for sole maize and 0.65% for the mixed crops, averaged over the experiments 1 and 3 (table 8.1).

8.4 DISCUSSION AND CONCLUSIONS

Light interception in mixed crops was higher than that in sole maize and similar to that in sole groundnuts. In both experiments 1 and 3, there were no differences in summed light interception figures between the mixed crop treatments. The light intercepted in the mixed crops was differently distributed over the growing period. The contribution of groundnuts and maize to the total amount of light intercepted in the mixed crops varied strongly between the mixed crop treatments.

The light use efficiency of groundnuts was higher in the mixed than in the sole crops. The light intensity above the gorundnut canopy in the mixed crops was reduced during part of the growing period due to the shading effect of the maize. The light use efficiency of maize tended to be lower in the mixed than in the sole crops. This can be explained by the competition for nutrients between the groundnut and maize plants.

The light interception by sole groundnut and sole maize plants was higher in experiment 3 than in experiment 1. Leaf drop from groundnut plants towards the end of the growing period was more severe in experiment 1 than in experiment 3, due to *Cercospora* leaf spot disease.
The light use efficiency of maize in experiment 1 was considerably higher than in experiment 3, due to the more abundant fertilizer application, and possibly to the lower plant density of sole maize in experiment 1.
The summed energy yield of the mixed crops was higher than that of sole maize because of their higher summed light interception, and higher thant that of sole groundnuts because of their higher average light use efficiency.

9 *ECONOMIC AND SOCIAL IMPLICATIONS*

9.1 INTRODUCTION

Instead of comparing the weight or energy yield figures of mixed and sole crops, their value in monetary units and the economic returns can be evaluated. Monetary value brings all crops and cropping systems to the same numerator. The economic and social implications of mixed cropping compared with sole cropping have been analysed for the experiments 1 and 3.

The gross revenue from crop production is the total value of main- and by-products of crops grown during the reference period. The main products consist of groundnut pods and maize grain, used for own consumption by the farmer's family or for sale. In East Java there is a limited market for green maize ears as a vegetable. The main by-products of groundnuts and maize are the haulms, used as cattle fodder or occasionally sold.

9.2 MATERIALS AND METHODS

Information on direct farm costs and labour requirements for growing groundnuts and maize in sole and mixed crops were provided by Mr. David, manager of the seed multiplication farm of the Agricultural Extension Service at Bedali and Mr. Ali, a farmer at Sukolilo.

Land rent, costs for farm equipment and interest have not been included in the economic analysis, because they were similar for the compared cropping systems.

In mixed cropping, it was difficult to divide certain costs such as labour costs for soil cultivation, fertilizer, weed control and pesticides between the two crops. Therefore, the allocations in table 9.2 and table 9.3 are approximative estimates only.

The prices of crop products, sowing seed and the official exchange rate used for the calculations were mentioned in chapter 4, section 4.5.5. The price for urea and triple superphosphate was US$ 0.17 per kg. For a labour's day work from 7 to 11 in the morning a male worker was paid US$ 0.64 and a female worker US$ 0.56. As pesticides, diazinon (300 ml per ha per application) was used to control insect damage and zinc phosphide crimidine was used in baits against rats. The cost of diazinon (3 applications) was US$ 2 per hectare and the cost for zinc phosphide crimidine was US$ 1 per hectare.

9.3 RESULTS

9.3.1 Material and labour costs

Labour requirements for groundnuts were higher than for maize. Slightly more work was done by women (53%) than by men (47%) in sole groundnut crops, but about three times more work was done by men (73%) than by women (27%) in sole maize crops.

Table 9.1 Labour requirements (days/ha) for sole crops of groundnuts and maize, and distribution of the required labour between men and women

	Sole groundnuts			Sole maize		
	Men	Women	Total labour days	Men	Women	Total labour days
1. Land preparation	70		70	70		70
2. Sowing	16	32	48	6	12	18
3. Side dressing of maize					12	12
4. Hoeing, ridging and weeding		28	28	38		38
5. Pesticide application	3		3	3		3
6. Harvesting	14	56	70	5	20	25
Total labour days	103	116	219	122	44	166
Labour costs (US$/ha)	66	65	131	78	25	103

Table 9.2 Labour requirements (days/ha) for mixed crops of groundnuts and maize, and distribution of the required labour between men and women

	Groundnut crop (estimated)		Maize crop (estimated)		
	Men	Women	Men	Women	Total labour days for mixed crop
1. Land preparation	36		36		72
2. Sowing	16	32	6	12	66
3. Side dressing of maize				12	12
4. Hoeing and weeding		16		12	28
5. Pesticide application	2		1		3
6. Harvesting	12	48	4	16	80
Total labour days	66	96	47	52	261
Labour costs (US$/ha)	42	54	31	30	157

Table 9.3 Farm costs (US$/ha) for growing groundnuts and maize in sole and mixed crops

	Sole groundnuts	Sole maize	Mixed crops		
			Groundnuts	Maize	Total mixed crop
Costs of materials					
1. Sowing seed	64	4	64	4	68
2. Fertilizer		17		9	9
3. Pesticides	3	3	2	1	3
Total	67	24	66	14	80
Costs of labour					
1. Land preparation	45	45	23	23	46
2. Sowing	28	11	28	11	39
3. Side dressing of maize		7		7	7
4. Hoeing,ridging and weeding	16	24	9	7	16
5. Pesticide application	2	2	1	1	2
6. Harvesting	40	14	35	12	47
Total	131	103	(96)	(61)	157
Total farm costs	198	127	(163)	(74)	237

Labour requirements for mixed crops were higher than for sole groundnuts and much higher than for sole maize. In mixed crops considerably more labour was done by women (57%) than by men (43%).

In table 9.3 farm costs have been listed for conditions that were similar to those in experiment 3. In experiment 3 with 160,000 groundnut plants per ha, 200 kg groundnut pods were needed as sowing seed, at US$ 0.64 per kg. For a plant density of 125,00 plants per ha, 25 kg sowing seed of maize were needed, at US$ 0.16 per kg. With different plant densities and a different rate of fertilizer application, the costs for sowing seed, fertilizer and some of the mentioned labour costs had to be modified accordingly (experiment 1, table 9.4).

Table 9.4 Marketable yield of groundnuts and maize, gross revenues, material costs and net revenues in experiments 1 and 3

	Marketable yield (kg/ha)		Gross revenues (US$/ha)	Material costs (US$/ha)	Net revenues (US$/ha)
	G	M			
Experiment 1					
Sole G	1981		951	157	794
Sole M		3403	408	66	342
G-$M_{0;100}$	1078	2365	801	186	615
G-$M_{10;100}$	1281	2072	864	186	678
G-$M_{20;100}$	1486	1725	920	186	734
Experiment 3					
Sole G	1742		836	67	769
Sole M		2350	282	24	258
G-$M_{10;50}$	1197	1565	762	73	689
G-$M_{10;75}$	1041	1837	720	77	643
G-$M_{10;100}$	954	1986	696	80	616

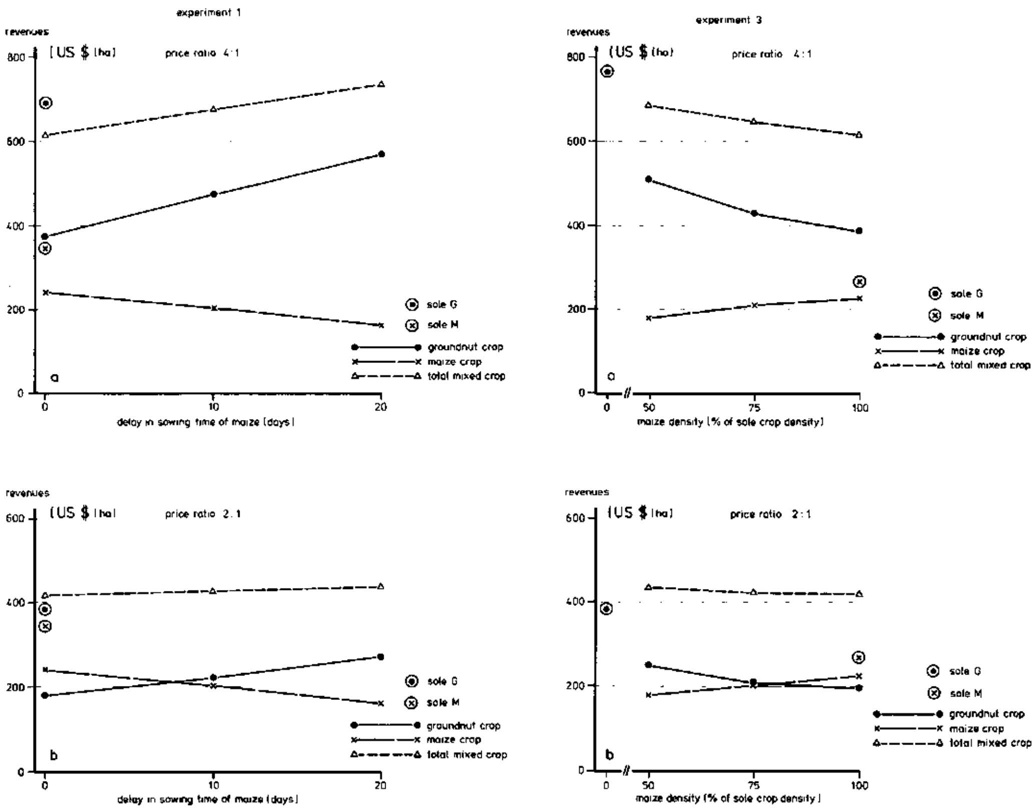

Fig. 9.1 Net revenues (US$/ha) of groundnuts and maize in sole crops and in mixed crops in experiment 1 and experiment 3, with the actual ratio of 4:1 between the price of groudnuts and maize and with an assumed price ratio of 2:1.

9.3.2 Revenues

In table 9.4 the value of the marketable yield of groundnuts and maize is shown. The costs for sowing seed, fertilizer and pesticides have been subtracted from the value of the yield. In experiment 1, these costs were higher than the amounts mentioned in table 9.1, because of the high fertilizer rate that was applied and the high sowing density of groundnuts, resulting in high costs for sowing seed. The costs for labour have not been subtracted from the gross revenue. In the normal farming practice the labour was provided by the farmer's family.
The effect of sowing time of maize and the effect of plant density of maize in the mixed crops on net revenues are shown graphically in fig. 9.1.

9.4 DISCUSSION AND CONCLUSIONS

Net revenues from the mixed crops were much higher than from sole maize and only slightly lower than from sole groundnuts. Delaying the sowing time of maize resulted in higher net revenues. Decreasing the maize density had the same effect.
In 1980 the groundnut price in East Java was four times as high as the price of maize. The ratio between groundnut and maize prices is likely to fluctuate from season to season and from year to year. The net revenues of the mixed crops compared with the sole crops show a different picture if a calculation is made with a groundnut price only twice the price of maize. The price ratio 2:1 corresponds better to the energy yield and the nutritional value of both crops than the actual ratio of 4:1 (see chapter 8). For the calculation in table 9.5, the assumption has been made that the selling price for groundnuts was US$ 0.24 per kg and the price of groundnut pods for sowing seed US$ 0.32 per kg.

Table 9.5 Marketable yield of groundnuts and maize, gross revenues, material costs and net revenues in experiments 1 and 3 with an assumed ratio of 2:1 between the price for groundnuts and maize

	Marketable yield (kg/ha)		Gross revenues (US$/ha)	Material costs (US$/ha)	Net revenues (US$/ha)
	G	M			
Experiment 1					
Sole G	1981		475	93	382
Sole M		3403	408	66	342
$G\text{-}M_{0;100}$	1078	2365	543	122	421
$G\text{-}M_{10;100}$	1281	2072	556	122	434
$G\text{-}M_{20;100}$	1486	1725	564	122	442
Experiment 3					
Sole G	1742		418	35	383
Sole M		2350	282	24	258
$G\text{-}M_{10;50}$	1197	1565	475	42	433
$G\text{-}M_{10;75}$	1041	1837	470	45	425
$G\text{-}N_{10;100}$	954	1986	467	48	419

With a ratio of 2:1 between groundnut and maize prices, the difference between the net revenues of sole groudnuts and sole maize will become smaller, and the net revenues of the mixed crops will be higher than that of the respective sole crops.

If the net revenues were completely attributed to the factor labour, and no revenues to land and other inputs, the remuneration per labour day was US$ 3.57 for sole groundnuts, US$ 1.81 for sole maize and US$ 2.54 for the mixed crops, averaged over the experiments 1 and 3. This was considerably higher than the wages for hired labour in East Java (US$ 0.64 per day for men and US$ 0.56 per day for women).

Recent developments in agriculture in Indonesia had as a consequence that labour opportunities for women decreased: in particular by harvesting of high yielding rice cultivars with the sickle (male workers) instead of the ani-ani (traditional knife for harvesting individual rice panicles used by women). Mixed crops of groundnuts and maize mean a shift to more work for women compared to the sole crops. This shift has to be attributed mainly to the substitution of ridging the rows in sole maize crops with a large hoe (male workers) by weeding with a small hoe (female workers) in the mixed crops.

Unripe maize ears were sold for US$ 0.012 per ear. Well developed ears were preferred for this purpose. It was very attractive to sell unripe maize ears, but the demand was limited.

The fresh haulms of groundnut plants and maize plants were used as livestock fodder. The nutritional value depended on the maturity of the plants at harvest time. Data on digestible value of crop residues were listed by Nell and Rollinson (1974). A bundle of groundnut haulms (about 25 kg fresh weight) was sold for US$ 0.48. The selling price for a bundle of maize haulms (about 175 plants and 25 kg fresh weight) was also US$ 0.48. In situations with a demand for cattle fodder, maize and groundnut haulms constituted an important contribution to the net revenues of these crops.

Agriculture in East Java is to an important extent subsistence oriented. Population density is extremely high (more than 600 inhabitants per square km: Statistical Yearbook of Indonesia, Biro Pusat Statistic, 1977-1978) and will continue to increase in the coming years.

Production of food and fodder from groundnuts and maize was about 25% higher in mixed crops than in the respective sole crops, without hardly any extra costs. Moreover, mixed crops of groundnuts and maize are better for the maintenance of soil fertility than sole maize crops. Improvement of mixed cropping practices is an inexpensive way to cope with the increasing food demand in East Java.

10 GENERAL DISCUSSION AND CONCLUSIONS

10.1 GENERAL DISCUSSION

The survey of farming practices of growing groundnuts and maize in sole and mixed cropping in East Java made it possible to compare the experimental results with the usual production practices. Recommendations for improved cultural practices were made for local farming conditions.

The most suitable time for sowing mixed crops of groundnuts and maize is at the end of the rainy season. During the dry season more light is available for the groundnuts in the mixed crops than during the rainy season. At the beginning of the dry season with its unreliable rainfall, the risk of crop failure is less with mixed crops of groundnuts and maize than with the sole crops.

The advantages of mixed crops were more pronounced in situations with marginal growth conditions (low soil fertility, inadequate water supply, poor weed control, incidence of diseases and pests) than in those with good growth conditions. In fields with a bad soil structure, caused by heavy rainfall, groundnut yield was less affected than maize yield (experiments 3, 4, 5 and 7). Because of the reduced risk of crop failure, mixed crops had a higher stability in energy yield than the respective sole crops, which is extremely important in subsistence agriculture.

The results of experiment 2 were not included in the forthcoming evaluation, because soil fertility in Sengkaling, where experiment 2 was conducted, was higher than in the other experimental sites (table 4.2). Fertilizer application was high and water supply was adequate in experiment 2, which resulted in high LAI values and high sole crop hields. The mixed crop, therefore, did not utilize the available light better than the sole crops, and the LER values were around 1.

10.2 GROUNDNUTS IN MIXED CROPPING

Growth and yield of groundnuts were both depressed by the presence of maize. Compared to sole groundnuts, groundnuts in mixed cropping had:

a) lower LAI and longer time to flowering;

b) fewer pods per plant and lower 100-seed weight, total dry matter yield and marketable yield.

The average RY value for marketable yield in the experiments ranged from 0.53 to 0.72. In the survey of farming practice, the RY of groudnuts was 0.74 and 0.88 for Purwosari and Wagir, respectively, with maize densities of about 50% of the sole crop density.

Corresponding maize densities in the field experiments (experiments 3, 4, 5, 6 and 7) gave RY values from 0.64 to 0.69. RY values from the literature for groundnuts combined with about 50% maize density $G\text{-}M_{0;50}$ ranged from 0.54 t0 0.70.

The yield in the field experiments was higher than in the surveyed farmers' fields, but more fertilizer was used in the experiments.

Delaying the sowing time of maize in mixed crops, resulted in better development and yield of groundnuts, as shown by:

a) higher LAI and shorter time to flowering;

b) more pods per plant and higher 100-seed weight (though not in experiment 1), total dry matter yield and marketable yield.

A 10-day delay in the sowing of maize resulted in a higher pod yield: the RY increased by +0.06 to +0.10. A 20-day delay in sowing of maize resulted in a higher RY for groundnuts of +0.16 to +0.20. In the literature an increase of RY value was found of +0.12 for 10 days delay and +0.37 for 28 days delay.

For groundnuts in mixed cropping this trend was found, the longer the delay in sowing time of maize, the higher the pod yield. The average increase in RY for groundnuts was about +0.01 per day delay in the sowing time of maize.

A low plant density of maize in mixed crops also resulted in a better development and yield of groundnuts, as shown by:

a) higher LAI and shorter time to flowering;
b) more pods per plant and higher total dry matter yield and marketable yield.

With maize density decreased from 100% to 70/75%, the RY for groundnuts increased by +0.05 to +0.07. With a decrease in maize density from 70/75% to 50/54%, the RY for groundnuts increased by +0.03 to +0.09. A decrease in maize density from 123/125% to 92/100% resulted in a RY increase for groundnuts of +0.04 to +0.08. In the literature a decrease in maize density from 67% to 33% resulted in a RY increase for groundnuts of +0.06 (Mutsaers, 1978).
A 10% decrease in plant density of maize resulted in an average increase in RY of groundnuts by +0.02.

Groundnut plants in mixed crops with maize were taller than in the sole crop for several treatments in experiments 3, 5, 6 and 7. A delay in sowing time and/or decrease in plant density of maize resulted in plants similar in height to sole groundnut plants. More shading resulted in taller plants with fewer pods per plant.
No data were found in literature on the height of groundnut plants in mixed crops.
The height of fully grown groundnut plants and their total dry matter yield were negatively correlated.

The arrangement of maize plants had only a slight effect on yield of groundnuts at extremely high maize densities (experiment 5). The ratio between row distance and plant distance in the row constitutes the rectangularity of the plant arrangement. The lower the rectangularity, the higher the RY of groundnuts (at the same extremely high maize density). A more even distribution of the maize plants over the field (rectangularity close to 1) resulted in a lower RY of groundnuts. This was in accordance with the results of Herrera et al. (1976) who compared a

1-meter row distance with a 2-meter row distance for a similar plant density of maize in mixed crops with groundnuts.

The number of seeds per pod was not a good indicator of groundnut yield in mixed crops, and also H.I. values were not conclusive. When heavy competition occurred in the early stages of growth, the development of individual groundnut plants was restricted and the H.I. usually remained high. When severe competition occurred during flowering and pod setting, competition did not affect plant development, but did affect pod formation and, therefore, the H.I. was low.

10.3 MAIZE IN MIXED CROPPING

The development and yield of maize were both depressed by the presence of groundnuts in mixed crops. Compared to sole maize, maize in mixed crops with 100% maize density had:

a) shorter plants, lower LAI and longer time to flowering;
b) fewer seeds per ear and lower total dry matter yield and marketable yield.

The RY values for maize ranged from 0.61 to 0.87. In the literature from South-East Asia, a RY value of 0.85 was reported for maize at 100% of the corresponding sole crop density (Aziz Azirin et al., 1976).

A delay in sowing time of maize in mixed crops had a negative effect on development and yield of maize. Late sown maize plants were less developed and yielded less than maize plants sown at the same time as groundnuts. Compared with sole maize, they had:

a) shorter plants and lower LAI values;
b) fewer seeds per ear and lower total dry matter yield and marketable yield.

With a delay of 20 days, the number of ears per plant, 100-seed weight and H.I. were lower than with simultaneous sowing. In some experiments time to flowering was later when the maize

was sown later. A 10-day delay in sowing time resulted in a decrease in the RY of maize grain of -0.05 to -0.11, and a 20-day delay resulted in a decrease of -0.20 to -0.36. In the literature, 10 days delay in sowing time resulted in a decrease of -0.18 in RY of maize and 28 days delay in a decrease of -0.30 in RY.
The average depression in RY of maize was -0.01 per day delay in sowing time of maize (range -0.005 to -0.018).

At low maize densities, the individual plants were better developed than at high densities. Maize at low plant densities had:

a) taller plants, a shorter time to flowering and a slightly shorter time interval between tasseling an silking;
b) fewer plants without an ear, more seeds per ear and a higher 100-seed weight.

A low maize density had a negative effect on development and yield of the total maize crop (lower LAI, lower total dry matter yield and lower marketable yield) in the range from 37,000 to 94,000 maize plants per hectare. At higher plant densities (between 80% and 150% of the sole crop density), the RY of maize reached a maximum value. The plant densities giving maximum yield were calculated from the quadratic regression equations presented in section 6.3.5.
Delaying the sowing of maize in mixed crops resulted in ashift of the maximum grain yield of maize towards the higher plant densities. With 10 days delay, a decrease of 10% in plant density of maize (in the low plant density range) resulted in a depression in the RY from -0.04 to -0.09.
The average decrease in the RY of maize was -0.06 per 10% decrease in plant density.

The plant arrangement had a slight effect on the H.I. and marketable yield of maize in mixed crops only at extremely high plant densities. A higher rectangularity, meaning a wider distance between the rows compared to the distance between the plants in the row, resulted in a lower H.I. and a lower marketable yield. The effect of plant arrangement on total dry matter yield of maize was not significant. This experimental result was in accordance with the results in literature of Herrera et al. (1976).

The H.I. was not a good indicator for evaluating the maize yield in mixed cropping.

The interdependence of relative sowing time and plant density of maize was mentioned before. In experiments 6 and 7 this interdependence was studied systematically. With a longer delay in sowing time, the relationship between plant density and maize yield became more linear (figure 7.3) and the maximum grain yield was reached at higher plant densities. In experiment 6 the effect of maize density on groudnut yield was less pronounced with increasing delay in sowing time of maize: with 20 days delay in the sowing time of maize, the groundnut yield was less affected by maize density than in simultaneously-sown treatments.

10.4 EVALUATION OF THE TOTAL MIXED CROP

The normal farming practice in East Java was to sow groundnuts and maize in mixed crops at the same time, with plant densities of approximately 100% of the sole groundnut density and 50% of the sole maize density (survey, chapter 3).

In the normal farming practice, the RY value for groundnuts was higher and the RY value for maize lower, compared to the experimental results. But pod yield of sole groundnuts in the normal farming practice (1400 kg/ha) was lower than in the experiments (1550 to 2200 kg/ha). Sole maize yield in the normal farming practice was also lower than in the experiments. Yields of maize in mixed crops were much lower in the normal farming practice than in the field experiments, but it must be remembered that more fertilizer was applied to maize in the field experiments.

Maximum LER of marketable yields

The normal farming practice to sow groundnuts in mixed crops at about 100% of the usual sole crop density and maize at approximately 50% of the usual sole crop density, was correct. With 10 days delay in sowing time of maize, the increase in groundnut yield was proprtional to the decrease in maize yield, resulting in similar LER values to those for mixed crops of simultaneously-sown groundnuts and maize (table 10.1). Delaying the sowing time of maize in mixed crops resulted in a higher and more precitable groundnut yield than could be expected for simultaneously-sown groundnuts and maize. Later sown maize plants remained smaller because of the stronger competition from the groundnut plants and, therefore, had to be sown at higher plant densities than the simultaneously-sown maize.

Table 10.1 Average RY and LER values in normal farming practice and in field experiments

	RY of groundnuts	RY of maize	LER of mixed crop
Normal farming practice			
$G\text{-}M_{0;50}$	0.81	0.43	1.24
Experimental results			
$G\text{-}M_{0;54}$	0.48	0.87	1.35
$G\text{-}M_{10;75}$	0.54	0.80	1.34
$G\text{-}M_{20;100}$	0.70	0.53	1.23

Because the value of groundnuts was higer than that of maize, a 10-day delay in sowing the maize resulted in higher revenues per hectare. With 10 days delay in sowing time of maize, the highest average LER for marketable yield was obtained with a maize density of 75% of the sole crop density (LER of 1.34). Delaying the sowing time of maize longer than 10 days resulted in higher groundnut yields (chapters 5 and 7) and, consequently, higher returns at the price ratio between groundnuts and maize at that time (chapter 9).

The total energy yield of the mixed crops was higher than that of the sole crops. Summed LAI values were positively correlated to total energy yield. Light interception of the mixed crops was as high as that of sole groundnuts (67%) and higher than that of sole maize (43%). The light use efficiency of the mixed crop (1.0%) was lower than that of sole maize (1.6%), but higher than that of sole groundnuts (0.6%).
With a higher proportion of maize in the mixed crop, the light use efficiency of the mixed crop was higher.

Maximum return/cost ratio (R/C ratio) at the high price ratio of 4:1 for groundnuts against maize, as higher when the maize density was less than the usual sole crop density (chapter 9). This was in accordance with the normal farming practice to sow nearly 100% groundnuts and 50% maize in mixed crops. Delaying the sowing time of maize by 10 days resulted in higher revenues of the mixed crop. At 20 days delay and 100% maize density, revenues were still higher, but maize yields were low. The highest R/C ratios were recorded in mixed crops with maize sown 10 days later than the groundnuts, at a density of 35% to 70% of the sole maize density. A strong reduction of the groundnut yield in mixed cropping resulted in a sharp decrease of the R/C ratio, partly because of the high cost of groundnut seed. The groundnut harvest was usually sold. A strong reduction of the maize yield compared to the sole maize crop hardly had any effect on the R/C ratio, because of the low cost of maize seed. However, the farmers were interested in a good maize yield in mixed crops, because they needed the maize as food for their families and their labourers. When the only purpose of growing groundnuts and maize was to sell the entire yield, the highest

proportion of groundnuts would give the highest revenues and the highest R/C ratio.
The value of the haulms of maize and groundnuts as livestock fodder was another factor in favour of mixed cropping compared to sole cropping.

Labour distribution

Mixed crops required more labour, mainly for sowing and harvesting, than sole crops, but a more even distribution between men and women. With simultaneous sowing of groundnuts and maize, harvesting was spread over two periods: first the maize harvest and 20 days later the groundnut harvest. With 10 days delay in sowing time of maize, the labour peak for sowing was spread out, but with 20 days delay the harvesting periods for groundnuts and maize coincided. So, the most even labour distribution was attained with 10 days delay in sowing time of maize.

10.5 OVERALL CONCLUSIONS AND RECOMMENDATIONS

Mixed cropping compared to sole cropping gave:
- LER values considerably higher than 1;
- higer energy yields;
- a more even distribution of labour between men and women;
- revenues intermediate between those of the respective sole crops.

A delay of 10 days in sowing time of maize in mixed cropping resulted in:
- better development and higher yield of groundnuts, at the expense of maize;
- higher revenues per hectare than with simultaneous sowing of groundnuts and maize;
- better spreading of labour over the growing period.

The optimum density of maize plants in mixed crops, for maximum LER and for a high RY of maize, was higher with delayed sowing of maize than with simultaneous sowing of groundnuts and maize. The highest revenues in mixed crops were obtained at lower maize densities than for maximum LER. With the price ratio between groundnuts and maize at that time, the maximum revenues were obtained with the lowest possible competition of maize against groundnuts.

Recommendations for mixed cropping of groundnuts and maize in East Java, with sowing at the end of the rainy season, are as follows:

1. When groundnuts are sown at the usual sole crop density (160,000 to 250,000 plants per hectare), maize should be sown 10 days later than groundnuts, with a density of about 75% of the usual sole crop density (which is 80,000 to 125,000 plants per hectare) to obtain the maximum LER and the highest food production.
2. For highest possible revenues, the maize density should be lower or the delay in sowing time of maize later.
3. It should be remembered, however, that on fertile and highly fertilized soils, mixed crops may be less productive than sole maize (see experiment 2). On such soils, relay cropping is a better choice than mixed or sole cropping, to make the best use of all the growth factors.

ANNEX 1 KEY TO ABBREVATIONS

ATER	area-time equivalent ratio
°C	degree Celsius
C_3	C_3 photosynthetic pathway
C_4	C_4 photosynthetic pathway
Ca	calcium
cm	centimetre
C/N ratio	carbohydrate/nitrogen ratio
CV (%)	coefficient of variation (percentage)
DAS	days after sowing
e.g.	for instance
et al.	et alii = and others
g	gramme
GJ	gigajoule = 10^9 J
H.I.	harvest index
ha	hectare
hrs	hours
J	joule
K	extinction coefficient (law of Lambert-Beer)
K	potassium
kg	kilogramme
km	kilometre
LAI	leaf area index
LER	land equivalent ratio
ln	natural logarithm (with base e)
LSD (0.05)	least significant difference, at a probability level of 95%
m	metre
N	nitrogen
P	phosphorus
p.m.	post meridiem
PAR	photosynthetically active radiation
pH	soil reaction (acidity or alkalinity)
r	linear correlation coefficient
R^2	multiple regression correlation coefficient
R/C	return/cost ratio
Rp	Indonesian rupiah (1980 exchange rate US$ 1 = Rp 625)
RY	relative yield
RYT	relative yield total
US$	United States of America dollar

KEY TO EXPERIMENTAL TREATMENTS

G	groundnuts
M	maize
Sole G	groundnut crop grown alone in a field
Sole M	maize crop grown alone in a field
$G_{t;d}$-$M_{t;d}$	mixed crop of groundnuts and maize, with t = sowing time (days interval between sowing dates of G and M) and d = plant density (% of sole crop density)
G-$M_{t;d}$	mixed crop of groundnuts and maize, with G = $G_{0;100}$ and $M_{t;d}$ as indicated above; e.g. G-$M_{10;75}$ = $G_{0;100}$-$M_{10;75}$

ANNEX 2

LIST OF REPORTS BY GRADUATE STUDENTS ON SUBJECTS RELATED TO MIXED CROPPING OF GROUNDNUTS AND MAIZE

Faculty of Agriculture, Brawijaya University
Malang, Indonesia
Department of Tropical Crop Science, Agricultural University
Wageningen, The Netherlands

Hadiwahyono, 1978. Pengaruh tumpangsari kacang tanah dengan jagung terhadap produksi bahan kering, penyerapan nitrogen dan pospat (Influence of mixed cropping of groundnuts and maize on dry matter yield and uptake of nitrogen and phosphate). 85 pp.

Sudarmadi Purnomo, 1980. Pengaruh waktu tanam jagung di antara kacang tanah pada tumpangsari kacang tanah dan jagung terhadap pertumbuhan dan produksi (Influence of sowing time of maize between groundnuts on growth and yield). 46 pp.

Sitompul, S.M., 1979. Pengaruh waktu tanam jagung terhadap pertumbuhan dan produksi kacang tanah dan jagung dalam sistem tumpangsari (Influence of sowing time of maize on growth and yield of groundnuts and maize in mixed cropping). 113 pp.

I Made Suwetja, 1979. Pengaruh kombinasi populasi tanaman dan pupuk N (urea) pada jagung terhadap pertumbuhan serta produksi tumpangsari kacang tanah dan jagung (Combined effects of plant density and nitrogen fertilizer application to maize on growth and yield of groundnuts and maize in mixed cropping). 64 pp.

Dewa Nyoman Suarta, 1979. Pengaruh populasi kacang tanah dan jagung terhadap pertumbuhan dan produksi pada pertanaman tumpangsari (Influence of plant density of groundnuts and maize on growth and yield in mixed cropping). 83 pp.

Sunardi, 1981. Pengaruh berbagai cara pengendalian gulma terhadap pertumbuhan dan produksi kacang tanah dan jagung dalam dua sistem tanam (Influence of different methods of weed control on growth and yield of groundnuts and maize in two cropping systems). 91 pp.

Juliar Dicky Hartono, 1979. Pengaruh waktu penanaman jagung (Kultivar Kretek) di antara kacang tanah (Kultivar Gajah) terhadap pertumbuhan dan produksi jagung dan kacang tanah (Influence of sowing time of maize between groundnuts on growth and yield of groundnuts and maize). 90 pp.

Achijad Moechson Djamhari, 1980. Pengaruh waktu tanam jagung pada pola tanam tumpangsari dan sisipan tanaman kacang tanah dan jagung terhadap pertumbuhan dan produksi kedua tanaman (Influence of sowing time of maize in mixed cropping and relay cropping of groundnuts and maize on growth and yield of both crops). 101 pp.

Santosa, 1980. Pengaruh waktu naungan terhadap produksi kacang tanah (Influence of time of shading on groundnut yield). 32 pp.

Santosa, 1980. Pengaruh populasi dan waktu tanam pada jagung terhadap pertumbuhan dan produksi tumpangsari kacang tanah dan jagung (Effects of plant density and sowing time of maize on growth and yield of groundnuts and maize in mixed cropping). 101 pp.

Eko Widaryanto, 1980, Pengaruh populasi dan jumlah tanaman per lubang terhadap pertumbuhan dan produksi kacang tanah (Influence of plant density and number of plants per hole on growth and yield of groundnuts). 29 pp.

Syamsulbahri, 1979. Pengaruh pemberian air terhadap pertumbuhan dan produksi kacang tanah dan jagung sistem tunggal serta kacang tanah dengan jagung sistem tumpangsari (Influence of water supply on growth and yield of groundnuts and maize in sole and mixed cropping). 121 pp.

Utami, 1981. Pengaruh pemberian air terhadap pertumbuhan dan hasil tanam jagung (Influence of water supply on growth and yield of maize). 40 pp.

Utami, 1981. Pengaruh varietas jagung terhadap pertumbuhan dan produksi kacang tanah dan jagung dalam sistem tunggal dan tumpangsari (Influence of maize cultivars on growth and yield of groundnuts and maize in sole and mixed cropping). 84 pp.

Muharso, 1980. Pengaruh pemupukan nitrogen terhadap pertumbuhan dan produksi kacang tanah dan jagung dalam sistem tumpangsari dengan kacang tanah sistem tunggal serta jagung sistem tunggal (Influence of nitrogen fertilizer application on growth and yield of groundnuts and maize in sole and mixed cropping). 91 pp.

Bosch, F. van den, 1981. De invloed van schaduw op de groei en ontwikkeling van aardnoot, soja en mungbean (Influence of shading on growth and development of groundnuts, soya beans and mung beans). 58 pp.

Gielen, J., 1983. Aspekten van standdichtheid in enkelvoudige en gemengde teelt van mais en aardnoot (Aspects of plant density in sole and mixed cropping of maize and groundnuts). 34 pp.

Beus, J. de, 1983. De stikstofhuishouding bij intercropping van mais (*Zea mays*) en cowpea (*Vigna unquiculata*), met name in West-Afrika (Nitrogen economy in intercropping of maize and cowpeas, with special reference to West Africa). 39 pp.

Maaswaal, C. van, and A. Linnemann, 1982. Invloed van beschaduwing op de ontwikkeling en opbrengst van pinda (*Arachis hypogaea* L.) (Influence of shading on development and yield of groundnuts). 50 pp.

Hoogland, E., 1982. De invloed van perioden van watertekort op de groei, ontwikkeling en opbrengst van aardnoot (*Arachis hypogaea* L.) (Influence of periods of water stress on growth, development and yield of groundnuts). 43 pp.

Oey, T.K. and J.B.P. de Loor, 1983. Nutriëntenbenutting door aardnoot en mais in enkelvoudige en gemengde teelt (Nutrient utilization by groundnuts and maize in sole and mixed cropping). 62 pp.

SUMMARY

Mixed cropping of groundnuts and maize in East Java was studied by means of a survey of farming practice and by field experiments. The influence of different sowing times and plant density of maize on the development and yield of groundnuts and maize were the main topics in this thesis. Plant arrangement, light use efficiency, and economic aspects were also investigated.

The normal farming practice in East Java for mixed cropping of groundnuts and maize was to sow the crops simultaneously at the end of the rainy season. The average plant densities used were: 190,000 plants per hectare (167,000-214,000) for groundnuts (95% of the plant density of the sole crop) and 40,000 plants per hectare (31,000-50,000) for maize (53% of the sole crop density). Average yields were 1140 kg/ha of groundnuts (80% of the sole crop yield) and 900 kg/ha of maize (43% of the sole maize yield). The average LER of the mixed crops was 1.23, which means a 23% higher productivity than the sole crops of groundnuts and maize.

In the field experiments, the density of groundnuts was 160,000 plants per hectare, and the density of sole maize was 125,000 plants per hectare (80 x 20 cm, 2 plants per hill). In each of the experiments 3 to 7, the plant density of maize in the mixed crops was varied. In experiments 1 and 2 , however, the maize density was 83,000 plants per hectare (80 x 30 cm, 2 plants per hill), both in sole and mixed crops.

In experiments 1 and 2, the sowing date of maize (sown at 100% density) in the mixed crop was varied. Later sown maize plants were less developed and gave lower yields than simultaneously-sown maize. Groundnuts in the mixed crops showed a better development and yield when maize was sown later, but not as good as sole groundnuts.

In experiment 2, the sole crop yields were much higher, and the response to a delay in sowing time of the maize was much stronger than in experiment 1. The higher yield was due to better nutrient availability and freedom from water stress in the beginning of the growing period.
The most equal yield distribution between groundnuts and maize in mixed crops was reached when maize was sown about 10 days later than groundnuts.

In experiments 3 to 5 the plant density of maize in the mixed crop was varied, with maize sown 10 days later than the groundnuts. At higher plant densities, the development and yield of the groundnut crop and of the individual maize plants was less than at lower maize densities.
When maize was sown 10 days later than the groundnuts (100% density), maximum maize yields in mixed crops were obtained at maize densities between 80% and 150% of the sole crop density, but the highest LER values for the mixed crop were reached with slightly lower maize densities between 70% and 100%. This was higher than the usual maize density in farmers' fields of about 50% in mixed crops with simultaneously-sown groundnuts and maize.

The effect of the arrangement of maize plants in mixed crops was small compared with the effect of plant density. Only at extremely high maize densities, plant arrangement had a substantial effect (experiment 5).

The interaction of sowing time effect and plant density effect, studied in experiments 6 and 7, showed that the longer the delay in sowing time of the maize, the higher the plant density of maize had to be, to reach maximum LER values for the mixed crop.

The higher productivity of the mixed crops compared to sole maize can be explained by the higher percentage of intercepted light (67% against 43%), and compared to sole groundnuts by the better utilization of the intercepted light (1.0% against 0.6%).

The revenues from the mixed crops were much higher than from sole maize and only slightly lower than from sole groundnuts. Delaying the sowing of maize in the mixed crop resulted in higher revenues. A change in the price ratio between groundnuts and maize from 4:1 to 2:1 would result in higher revenues for the mixed crop than for each of the sole crops (chapter 9).

In mixed crops, a higher share of the work was done by women (57%) than in sole groundnuts (53%) and sole maize (27%). A 10-day delay in the sowing time of maize resulted in a better spreading of the labour demand over the growing period.

Sowing maize 10 days later than groundnuts at a density of 75% of the normal sole crop density can be an improvement of the normal farming practice to sow maize at 50% density simultaneously with the groundnuts. In mixed crops with 10 days delay in sowing time of maize and 70% to 100% maize density, the marketable yield was 1070 kg/ha of groundnuts and 1840 kg/ha of maize, averaged over the 7 field experiments. The groundnut yield in the experiments was similar to that in the farmers' practice with simultaneous sowing and 50% maize density, and the maize yield was twice as high.

In experiment 2, with its high fertility level and its adequate water supply, the LAI of sole maize was higher than 4, and sole maize yield was over 4 tons per hectare. In mixed crops with LAI values of maize higher than 4, the shading of the groundnut crop is too heavy, and no yield advantage can be expected from the mixed crop compared to the sole maize crop. Relay cropping can be a proper practice of intensive crop production when high yield levels are obtained with sole crops. Mixed crops are more secure than sole crops in situations of marginal farming, low soil fertility, unreliable water supply and low input level. Improvements in mixed cropping techniques are a cheap way to increase the food production in East Java.

RINGKASAN

Dalam rangka proyek kerjasama di bidang pendidikan agronomi antara Fakultas Pertanian Universitas Brawijaya, Malang, dan Departemen Ilmu Tanaman Tropis Universitas Pertanian Wageningen (Proyek NUFFIC LHW-14) sekitar 20 mahasiswa sarjana Indonesia dan Belanda melaksanakan penelitian tentang sistem tumpangsari kacang tanah dan jagung. Judul laporan penelitiannya terdaftar dalam appendiks 1. Hasil-hasil beberapa percobaan lapang yang dilaksanakan oleh mahasiswa tingkat sarjana, sudah diterbitkan dalam majalah Agrivita. Penulis tesis ini adalah pembimbing penelitian tersebut bersama beberapa orang staf Indonesia atau Belanda lainnya. Sistem tumpangsari adalah suatu cara bercocok tanam yang tradisionil di Indonesia. Seorang yang mendorong penelitian tumpangsari tanaman pangan di Jawa Timur adalah almarhum prof.dr. H. Soetono M.Agr. yang telah wafat awal tahun 1984.

Dalam tesis ini diuraikan terutama pengaruh kepadatan tanaman dan waktu tanam jagung dalam sistem tumpangsari kacang tanah dan jagung. Survey tentang cara bercocok tanam kacang tanah dan jagung menghasilkan informasi bahwa petani di Jawa Timur menanam jagung dengan kepadatan 40.000 tanaman per hektar bersamaan dengan kacang tanah yang ditanam dengan kepadatan 190.000 tanaman per hektar. Hal itu merupakan 95% dari kepadatan tanaman tunggal kacang tanah dan 53% dari kepadatan yang normal tanaman tunggal jagung. Hasil rata-rata adalah 1140 kg/ha polong kacang tanah (80% dari tanaman tunggal) dan 900 kg/ha jagung (43% dari tanaman tunggal). 'Land equivalent ratio' (LER) 1,23, berarti bahwa hasil dari sistem tumpangsari ini menjadi 23% lebih tinggi dari hasil sistem tanaman tunggal.

Dalam percobaan lapang, kepadatan tanaman kacang tanah pada sistem tumpangsari dan tunggal adalah 160.000 per hektar dan kepadatan tanaman jagung pada sistem tunggal berjumlah 125.000 per hektar (80 x 20 cm, 2 tanaman per lubang). Dalam percobaan 3 sampai 7, kepadatan tanaman jagung pada sistem tumpangsari divariasikan. Pada percobaan 1 dan 2, kepadatan jagung adalah

83.000 tanaman per hektar (80 x 30 cm, 2 tanaman per lubang) yang berlaku maupun untuk sistem tunggal ataupun untuk sistem tumpangsari.

Pada percobaan 1 dan 2, waktu tanam jagung dalam sistem tumpangsari divariasikan. Pengunduran waktu tanam jagung, menyebabkan tanaman jagung menjadi lebih pendek dan hasilnya lebih rendah dibandingkan dengan tanaman jagung yang ditanam bersamaan kacang tanah, sedangkan tanaman kacang tanah lebih baik perkembangannya dan lebih tinggi hasilnya.

Hasil-hasil percobaan 2 pada sistem tanaman tunggal lebih tinggi letaknya dari hasil-hasil percobaan 1 dan pengaruh daripada pengunduran waktu tanam jagung lebih besar. Hasil yang tinggi ini disebabkan karena tingkat kesuburan tanah yang lebih tinggi serta persediaan air yang cukup pada waktu permulaan pertumbuhan.

Distribusi hasil kacang tanah dan jagung yang paling serata adalah apabila jagung ditanam 10 hari sesudah kacang tanah.

Dalam percobaan 3, 4 dan 5, kepadatan tanaman jagung pada sistem tumpangsari divariasikan, dengan memperbedakan waktu tanam jagung selama 10 hari sesudah kacang tanah. Dengan kepadatan tanaman jagung yang tinggi, perkembangan tanaman kacang tanah dan tanaman jagung secara individuil menjadi kurang kuat, dibandingkan dengan kepadatan jagung yang rendah. Hasil maksimum dari jagung dicapai pada tingkat kepadatan antara 80% dan 150% dari kepadatan yang biasa tanaman jagung tunggal, kalau saat tanam jagung dilakukan 10 hari sesudah kacang tanah, namun nilai LER yang paling tinggi dicapai dengan kepadatan jagung yang lebih rendah, yaitu antara 70% dan 100%. Kepadatan tanaman jagung pada sistem tumpangsari ini lebih tinggi daripada di lapang petani, di mana kepadatannya adalah sekitar 50% dari jagung tunggal yang ditanam bersamaan kacang tanah.

Pengaruh jarak tanam jagung dalam sistem tumpangsari ini adalah kecil dibandingkan dengan pengaruh kepadatan tanaman. Hanya pada kepadatan tanaman jagung yang sangat tinggi, pengaruh jarak tanam menjadi signifikan (percobaan 5).

Interaksi pengaruh waktu tanam dan kepadatan tanaman jagung, yang diteliti dalam percobaan 6 dan 7, memperlihatkan bahwa makin diundurkan waktu tanam jagung, makin tinggi kepadatannya yang harus dipergunakan untuk mencapai nilai LER yang maksimum.
Produktifitas yang lebih tinggi pada sistem tumpangsari dibandingkan dengan sistem tanaman tunggal jagung, dapat dejelaskan oleh penyebab intersepsi cahaya yang lebih tinggi (67% lawan 43%), dan dibandingkan dengan sistem tanaman tunggal kacang tanah oleh penyebab penggunaan yang lebih effisien dari cahaya yang terintersep (1,0% lawan 0,6%).
Pendapatan (uang) dari sistem tumpangsari lebih besar daripada pendapatan hasil jagung dalam sistem tunggal dan agak kurang daripada kacang tanah tunggal, apabila perhitungan ini didasarkan atas perbandingan harga 4:1 yang sedang berlaku antara kacang tanah dan jagung. Pengunduran saat tanam jagung dalam sistem tumpangsari, menaikkan pendapatan. Perubahan hipotetis perbandingan harga kacang tanah dan jagung dari 4:1 menjadi 2:1, menyebabkan pendapatan pada sistem tumpangsari lebih tinggi dari pendapatan pada sistem tanaman tunggal yang bersangkutan (bab 9).
Pada sistem tumpangsari, persentase kerja yang dilakukan oleh wanita lebih tinggi (57%) dibandingkan dengan persentase kerja pada sistem tanaman tunggal kacang tanah (53%) dan jagung (27%). Pengunduran waktu tanam jagung pada sistem tumpangsari dengan 10 hari, menyebbabkan distribusi kebutuhan kerja lebih serata selama masa tumbuh.
Menanam jagung 10 hari sesudah kacang tanah dengan kepadatan tanaman 75% dari kepadatan jagung tunggal, dapat merupakan perbaikan dari sistem tumpangsari yang tradisionil pada petani, di mana jagung ditanam bersamaan dengan kacang tanah, dengan kepadatan sekitar 50% dari jagung tunggal. Dengan mengundurkan saat tanam jagung selama 10 hari dan menanam jagung dengan kepadatan 70% sampai 100% dari kepadatan jagung tunggal, hasil kacang tanah menjadi 1070 kg/ha dan hasil jagung 1840 kg/ha, sesuai nilai rata-rata dari hasil perlakuan bersangkutan dalam ke-7 percobaan lapang. Dalam percobaan-percobaan ini hasil ka-

cang tanah sama dengan hasil petani dan hasil jagung, dua kali lebih tinggi daripada hasil yang dicapai oleh petani.

Dalam percobaan 2, dengan kesuburan tanahnya yang tinggi dan persediaan air yang mencukupi, nilai 'leaf area index' (LAI) tanaman tunggal jagung di atas 4, dan hasilnya lebih tinggi daripada 4 t/ha. Dalam keadaan tingkat produksi demikian, naungan bagi tanaman kacang tanah terlampau berat, sehingga sistem tumpangsari tidak dapat melebihi produktifitas tanaman tunggal jagung. Kalau tingkat produktifitas pada sistem tanaman tunggal sedemikian tingginya, maka sistem bercocok tanam 'relay-cropping' (penanaman sisipan) merupakan suatu cara yang sesuai untuk mengintensifkan produksi tanaman. Sistem tumpangsari adalah cara bercocok tanam yang lebih aman daripada sistem tanaman tunggal dalam situasi pertanian yang marginal, kesuburan tanah yang rendah, persediaan air yang tidak menentu dan tingkat input yang rendah.

Dengan perbaikan tehnik bercocok tanam sistem tumpangsari merupakan suatu cara yang murah untuk menambah produksi pangan di Jawa Timur.

SAMENVATTING

In het kader van een NUFFIC-onderwijsproject aan de Landbouwfaculteit van de Brawijaya Universiteit in Malang, Oost-Java, is door een twintigtal Indonesische en Nederlandse studenten onderzoek uitgevoerd aan gemengde teelt van aardnoot en mais. De titels van de onderzoeksverslagen en literatuurstudies over dit onderwerp en verwante onderwerpen, die zijn begeleid door de projectuitvoerder voor agronomie samen met Indonesische stafleden of met stafleden van de vakgroep Tropische Plantenteelt van de Landbouwuniversiteit Wageningen, zijn als bijlage 1 in dit proefschrift opgenomen. De resultaten van verschillende door de studenten uitgevoerde veldproeven zijn gepubliceerd in het Indonesische tijdschrift Agrivita. De projectuitvoerder voor agronomie en schrijver van dit proefschrift heeft zelf actief meegedaan aan het onderzoek over gemengde teelt van aardnoot en mais, door het opzetten en coördineren van een survey bij boeren in Oost-Java en door het uitvoeren van een vijftiental veld- en potproeven. In dit proefschrift worden de resultaten gepresenteerd van de survey en van 7 veldproeven, uitgevoerd in de periode 1978-1980, aangevuld met literatuurgegevens over gemengde teelt van aardnoot en mais.

De invloed van de plantdichtheid en van verschillende zaaitijden op de ontwikkeling en de opbrengst van aardnoot en mais vormen de belangrijkste onderwerpen van onderzoek die besproken zijn in dit proefschrift. Verder is aandacht geschonken aan plantverband, lichtbenutting en economische aspecten.

De normale praktijk van boeren in Oost-Java was aardnoot en mais tegelijkertijd in gemengde teelt uit te zaaien aan het einde van de regentijd. De gemiddelde dichtheid van aardnoot in gemengde teelt was 190.000 planten per hectare (95% van de gebruikelijke dichtheid in enkelvoudige teelt) en van mais 40.000 planten per hectare (53% van de gebruikelijke dichtheid in enkelvoudige teelt). De gemiddelde opbrengst was 1140 kg/ha aardnoten (80% van de enkelvoudige teelt) en 900 kg/ha mais (43% van de enkelvoudige teelt). De 'land equivalent ratio' (LER)

van de gemengde teelt was 1,23, wat duidt op een 23% hogere opbrengst dan bij enkelvoudige teelt van aardnoot en mais.
In de veldproeven was de dichtheid van aardnoot 160.000 planten per hectare in enkelvoudige en gemengde teelt en van mais in enkelvoudige teelt 125.000 planten per hectare (80 x 20 cm, 2 planten per plantgat). In elk van de proeven 3 tot en met 7 varieerde de plantdichtheid van de mais in gemengde teelt. In de proeven 1 en 2 was de dichtheid van mais 83.000 planten per hectare (80 x 30 cm, 2 planten per plantgat), zowel in enkelvoudige als in gemengde teelt.
In de proeven 1 en 2 werd de zaaitijd van mais in de gemengde teelt gevarieerd. Vergeleken met tegelijkertijd uitzaaien van aardnoot en mais, gaf later tussenzaaien van mais minder ontwikkelde maisplanten en een lagere maisopbrengst, maar beter ontwikkelde aardnootplanten met een hogere aardnootopbrengst.
In proef 2 waren de opbrengsten veel hoger dan in proef 1 en was de invloed van later tussenzaaien van mais op de opbrengst veel sterker. De hogere opbrengst in proef 2 was toe te schrijven aan de hogere vruchtbaarheid van de bodem en de betere watervoorziening in het begin van de teeltperiode.
De meest evenwichtige verdeling tussen aardnoot en mais in gemengde teelt werd bereikt bij 10 dagen later tussenzaaien van de mais.
In de proeven 3, 4 en 5 werd de plantdichtheid van de mais gevarieerd, bij 10 dagen later tussenzaaien. Hoge plantdichtheden van mais veroorzaakten minder ontwikkelde aardnootplanten met een lagere opbrengst en minder ontwikkelde individuele maisplanten. De maximum maisopbrengst werd bereikt bij plantdichtheden van mais tussen 80% en 150% van die in enkelvoudige teelt, maar de maximum LER van de gemengde teelt werd bereikt bij dichtheden tussen 70% en 100% van die van mais in enkelvoudige teelt. Deze dichtheden van mais waren hoger dan de gebruikelijke plantdichtheid van mais in gemengde teelt bij de boeren, die ongeveer 50% was van de dichtheid in enkelvoudige teelt, bij tegelijkertijd uitzaaien van aardnoot en mais.

De invloed van het plantverband van mais in gemengde teelt was klein, vergeleken met de invloed van de plantdichtheid. Slechts bij extreem hoge dichtheden van de mais was de invloed van het plantverband van belang (proef 5).
In de proeven 6 en 7, waarin de gecombineerde invloed van plantdichtheid en verschillende zaaitijden werd onderzocht, bleek dat naarmate de zaaitijd van mais langer werd uitgesteld, de dichtheid van de mais hoger moest zijn om maximum LER-waarden te bereiken voor de gemengde teelt.
De hogere opbrengsten van de gemengde teelt, vergeleken met de enkelvoudige teelt van mais waren te verklaren door de hogere lichtonderschepping (67% tegenover 43%) en vergeleken met de enkelvoudige teelt van aardnoot, door de efficiëntere lichtbenutting (1,0% tegenover 0,6%).
Gemengde teelt leverde meer op in geldswaarde dan mais in enkelvoudige teelt en iets minder dan aardnoot in enkelvoudige teelt, bij de geldende prijsverhouding van 4:1 voor aardnoot en mais. Later tussenzaaien van mais in gemengde teelt leverde een opbrengst op met een hogere geldswaarde dan gelijktijdig uitzaaien van aardnoot en mais. Bij een veronderstelde prijsverhouding tussen aardnoot en mais van 2:1 zou de opbrengst van de gemengde teelt hogere inkomsten opleveren dan aardnoot of mais in enkelvoudige teelt.
Bij gemengde teelt werd een groter aandeel in het werk (57%) door vrouwen geleverd dan bij enkelvoudige teelt van aardnoot (53%) en mais (27%). Door de mais 10 dagen later te zaaien dan de aardnoot, werd de arbeidsbehoefte regelmatiger over de teeltperiode gespreid.
Een verbetering van de gangbare teeltwijze in Oost-Java, waarbij mais in een dichtheid van ongeveer 50% van die in enkelvoudige teelt tegelijkertijd met aardnoot wordt uitgezaaid, kan worden bereikt door de mais 10 dagen later tussen te zaaien in een dichtheid van ongeveer 75%. In de 7 veldproeven werd hiermee een gemiddelde aardnootopbrengst (1070 kg/ha) gehaald, gelijk aan die bij de boeren en een dubbel zo hoge maisopbrengst (1840 kg/ha) als bij de boeren.

In proef 2 met zijn hoge bodemvruchtbaarheid en zijn goede watervoorziening, was de 'leaf area index' (LAI) van mais in enkelvoudige teelt hoger dan 4 en de opbrengst meer dan 4 ton per hectare. Bij dergelijke opbrengstniveaus ondervindt de aardnoot te sterke schaduw om een hogere produktiviteit te kunnen verwachten van gemengde teelt. In dergelijke situaties kan 'relay-cropping' (estafette-teelt) een goede vorm van teeltintensivering zijn. Gemengde teelt is veiliger dan enkelvoudige teelt onder marginale omstandigheden, lage bodemvruchtbaarheid, onzekere watervoorziening en schaarste aan kunstmest en andere produktiemiddelen.

Door verbeterde teelttechnieken voor gemengde teelt kan in Oost Java op een goedkope manier een hogere voedselproduktie bereikt worden.

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Van 1983 tot 1986 werd onderwijs verzorgd in de tropische landbouw aan de Tropencursus voor Kader in Ontwikkelingswerk.

In 1981, 1984, 1985 en 1987 werden korte uitzendingen uitgevoerd voor DGIS naar landbouwprojecten in de Arabische Republiek Jemen.