AVRDC
The World Vegetable Center

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Intercropping with Legumes in the Tropics

by

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Contents

1. Introduction

Intercropping is the oldest technique of growing plants for human needs. Legumes are likely to be a component of a large variety of systems which have been developed throughout the tropics.

With main emphasis on the legume crop, this manuscript covers an intercropping system of hot pepper, maize, and snapbean to analyse complex interactions between crops and thereby identify a suitable method for comparing outputs of monocrops and intercrops.

An introductory literature review presents an overview over several aspects which has to be considered carefully when looking at intercropping and its role in traditional agriculture.

2. Literature review

2.1. Overview

Fast growing population in many tropical countries is reason for enormous increasing demand for food but leads at the same time to mostly irrevocable loss of arable lend due to increasing urbanisation (PCARRD, 1984). Higher production on decreasing agricultural areas can only be achieved by either (1) opening up new land for cultivation, or (2) increasing productivity on existing land (GOVINDEN et al., 1984). It is known that the cost-benefit ratio of bringing new land under cultivation is smaller than that of increasing production on already cultivated land and, therefore, increasing production per unit area seems to be more reasonable.
The so-called "green revolution" was associated with high-yielding varieties which were able to increase productivity but a critical reflection can also come to the conclusion that it were mainly improvements of input factors (irrigation. fertilisation, plant protection), and environmental conditions (infrastructure, markets) which were the true reasons for achieved results (ANDREWS & KASSAM, 1976). In contrast, since the 1960s, agricultural research has recognised that the ability to expand world food supply would depend on small farmers in the tropics, most of which are growing crop mixtures and have only limited access to mechanisation (KASS, 1978). Observations in Indonesia have shown that even though new varieties have been introduced, semi-subsistence farmers still prefer to grow traditional landraces because they are performing better under present farming practices (VAN DEN BOSCH, 1987). In this respect, 14 out of 20 commercial varieties for monocultures performed poorer than one landrace in traditional farming systems in India (SHARMA & MEHTA, 1988).

From the very beginning of cultivating plants several 10,000 years ago, countless farming systems have developed in tropical regions (PLUCKNETT & SMITH, 1986) in which a large part of foodstuff is produced mainly in mixed cultures (GOVINDEN ET AL., 1984). Similar to (West-) Africa, origins of these cropping systems in Central America can be found in associations of root crops and in mixtures of maize, bean, and cucurbits, whereas in Asia also tree crops play an important role (PLUCKNETT & SMITH. 1986).

Most of farms where crops are grown in mixtures are small sized: agriculture in tropical Asia consists of small farms with intensive production, where a variety of crops is grown in mixtures (HARWOOD & PRICE. 1976). The overwhelming part of farms in tropical America is smaller than 10 ha, their areas have traditionally (Maya culture) been used intensively and 50-85 % of the farming land is used growing mixtures (PINCHINAT et al., 1976). In tropical Africa, it is reported that 13 crops are grown largely in mixtures on farms 55 % smaller than one ha (OKIGBO & GREENLAND. 1976).

Traditional tropical agriculture, therefore, demands not only considering a large number of crops (REHM & ESPIG, 1984) but also the dimensions of time and space in selecting cropping systems (Table 1). The combination of the dimensions time and space make intercropping systems of great intensity (GOVINDEN et al., 1984).

Table 1. Definitions of cropping systems (VANDERMEER, 1989; FRITZ & STOLZ. 1989)

Sole cropping: Growing one crop on a field

Monoculture: Growing one crop on the same land for longer than one year

Sequential cropping: Growing more than one crop on the same land in one year

Intercropping, mixed cropping, polyculture: Two or more crops grown for a definite part of their life cycle simultaneously on the same land

Relay intercropping: The maturing first crop interplanted with a second crop

Full intercropping: Two or more crops grown simultaneously on the same land

Mixed intercropping: Two or more crops are intercropped with no row arrangement

Strip intercropping: More than one row of the first crop is intercropped with more than one row of a second crop

Row intercropping: Two crops are grown in alternate, single rows

2.2. Biological factors

2.2.1 Ecological factors

Growing more than one crop in one place results in interactions which are discussed on basis of two theories (VANDERMEER, 1986):

1. Competitive production principle

Besides interactions between organisms of the same species (intraspecific interactions), interspecific interactions (interactions between different species) influence mixed cropping systems (HART, 1986). Intraspecific competition can be measured relatively easy in monocultures through systematic variation of plant densities (HUXLEY & MAINGU, 1978; VANDERMEER et al., 1984; VEEVERS & ZAFAR-YAB, 1980), whereas measuring interspecific competition depends on planting density, proportion, and planting design of the individual crops grown in mixture (RADOSEVICH & WAGNER, 1986). In this respect, possible mechanisms of interactions between species include (GLIESSMAN, 1986; RADOSEVICH & WAGNER, 1986): (1) coexistence (no interactions), (2) one-side interactions (one crop facilitates/inhibits the performance of the second crop), (3) antagonism (two-way negative influence), and (4) symbiosis (two-way positive influence).

2. Competitive exclusion principle

According to this theory, two species with identical demands on growth factors cannot exist side by side. In other words, two populations can coexist when they do not use the same resources (ROSSET et al., 1984). Through formation and occupation of different ecological niches, interspecific competition is avoided (GEISSLER et al., 1981), and according to the "environmental modification principle" (VANDERMEER. 1986) two species are interacting through "interference" which means modification of environmental conditions for one crop by another (HALL, 1974). Competition can only be regarded as a part of this theory. With reference to mixed cultures, the "interference production principle" (VANDERMEER. 1981) states that a polyculture is more productive than the monocultures of their crops if one crop does not modify the growth factors of the other crop too extensively or in other words if interspecific competition is smaller than intraspecific competition. Examples for avoidance of interspecific competition by use of different niches and superior productivity of mixed cultures over monocrops are:

- Use of different nitrogen sources (CABAHUG & PAVA, 1984)
- Use of different soil depths (ANDREWS & NEWMAN, 1970; ASHOKAN et al., 1985)
- Use of growth factors at different times (GOVINDEN et al., 1984)
- Use of different plant heights (HARWOOD & PRICE, 1976; RAO, 1986)

Examples for active modification of environmental conditions of one species by another are:

- Weed suppression (ALTIERI & LIEBMAN, 1986; DAHIYA & RAO, 1985)
- Protection for wind (BARKER & FRANCIS. 1986; RADKE & HAGSTROM, 1976)
- Modification of micro climate (ALTIERI et al., 1977; CHAVEZ & MENDOZA, 1986)
- Modification of pest and disease potential (AKBOOLA & FAYEMI, 1971; BHATNAGAR & DAVIES, 1981)
- Modification of nutrient supply (ALLEN & OBURA, 1976; HAYSTEAD, 1983)
- Modification of water supply (GOVINDEN et al., 1984; SUWANARIT et al., 1984)
- Modification of soil structure (UNGER & STEWART, 1976; SIDDOWAY & BARNETT, 1976)

2.2.2 Growth factors

Light

Light intensity within a plant canopy decreases exponentially (KRUG, 1991). For use in crop mixtures this implies the importance of combining a tall crop with effective use of high light intensity (e.g. C_4 plants such as maize), and a determinate, shade tolerant second crop. Many early-closing crops are able to achieve high light absorption in sole stands, but cannot maintain this rate over their whole life cycle. In this respect, relay intercropping or intercropping is a route to more efficient use of available resources.

Water

Many crop mixtures show higher productivity compared with their monocrop counterparts in dry regions (KASS, 1978; REJU et al., 1986). There is reason to believe that available water has either been used more efficient, or as result of interference, more water has been made available (e.g. because of deeper penetrating roots of one crop). Many *Fabaceae* are relatively drought resistant because of their strong, deeply penetrating root system (FRITZ & STOLZ, 1989; KRUG, 1991) and this is particularly true for soybeans in mixed cultures (ALLEN & OBURA, 1976). Intercropping maize with mungbeans (SUWANARIT et al., 1984) or cowpeas (AYENI et al., 1984) led to lower evapotranspiration rates than sole stands of maize.

Soil cover is a key element for interaction between transpiration and evaporation. On the one hand, higher leaf area per ground area provided by a second crop can reduce water run off and facilitate water penetration from surface into ground in particular when heavy rainfall occurs (OLASANTAN, 1985). On the other, a higher leaf area index can facilitate higher transpiration rates (RADKE & HAGSTROM. 1976). Evaporation exceeds transpiration if leaf area is small and lower crop densities seem to be more suitable for dry seasons or regions with uneven distributed rainfalls. In regions with regular rainfall where evaporation is higher than transpiration (constant wet soil surface), higher crop densities are more favourable because reduced evaporation likely overcompensates higher transpiration (ROSSET et al., 1984; SUWANARIT et al., 1984).

Soil

Already in 1966, soil losses due to erosion in intensive monocrops in the USA have been estimated at 7 t/ha·year (SIDDOWAY & BARNETT, 1976). Large field sizes and intensive mechanisation are some of the reasons for deterioration of soil fertility in maize monocultures whereas legumes have a positive long-term effect in mixtures with maize (AKBOOLA & FAYEMI, 1971; KASS, 1978).

To a minimum reduced tillage and a permanent crop cover provided by continuously interplanting of crops into existing stands has positive effects on water penetration and soil conservation (GOVINDEN et al., 1984), soil temperature, soil compaction and erosion by water and wind (UNGER & STEWART, 1976). Intensive rooting in different soil depths and continuous growth of new roots throughout the life cycle are effects of polycultures to use soil factors entirely and protect them for losses caused by erosion and leaching (ASHOKAN et al., 1985). In this respect, legume polycultures have proofed to be particularly advantageous on light, sandy soils (KASS, 1978).

Pests and diseases

According to the "natural enemy hypothesis" and "resource concentration hypothesis" the stability of many populations protects an ecosystem from damage by a single population which is getting out of control. In contrast, concentrated stimulus enhances growth of a small number of positively reacting populations (ALTIERI & LIEBMAN, 1986). Therefore, it is likely that in contrast to possibly explosive growth of pathogen populations in sole or monocultures, polycultures are less susceptible to damage and more ecologically stable. Analysis confirms that a polyculture has actually never been damaged more than a monocrop (ALTIERI & LIEBMAN, 1986) and that increases in pathogen potential due to newly established monocultures could be substantially reduced by re-establishment of old intercropping farming practices (LITSINGER & MOODY, 1976).

There are at least 2 factors which can restrict the severity of crop damages in polycultures: (1) even if one component in polyculture is damaged to the same extent than in its monoculture, it is likely that the second crop compensates or overcompensates for yield losses (BHATNAGAR & DAVIES, 1981). (2) One specialised pathogen can heavily damage a monocrop but in polyculture a higher number of pathogens and, at the same time, a higher number of beneficial species will reduce the total damage.

Which factors can lead to lower infestations in polycultures? Tall growing crops may have an effect as physical barrier and protect smaller crops from pathogens (ALTIERI et al, 1977; ALTIERI & LIEBMAN, 1986; AVRDC, 1992). Colour and texture of backgrounds can be a hindrance for pathogens to find a suitable host plant (ALTIERI & LIEBMAN, 1986). In this respect, uniform monocultures with long-term uncovered soil are particularly susceptible to pathogens (ALTERI et al., 1977) whereas dense crop cover of uneven colour and texture in polycultures can reduce infestations (AKBOOLA & FAYEMI, 1971).

Mechanisms of biological disturbance include (1) trap crops which can distract pathogens (GOVINDEN et al., 1984), (2) excretions of active anti-pathogen substances (many grass species; LITSINGER & MOODY, 1976) and (3) dilution of pathogen-attracting substances (ALTIERI & LIEBMAN. 1986). Use of synthetic pesticides in polycultures is difficult (concentrations, drift, timing; GOVINDEN et al., 1984; PINCHINAT et al., 1976). Therefore, optimised cropping system including choice of suitable crops, crop combinations, and planting geometry to protect for outbursts of specialised pathogens, and maintain long-term productivity of planting sites.

Weeds

With regard to polycultures, there are at least three effects of weeds on crop yield:

- Yield reduction through competition for growth factors
- Yield increase through reduction of pathogens
- Modification of yield proportions

Weeds can cause significant yield losses (PRASAD et al., 1985) whereas in weed-free systems yield losses due to pathogens might be increased (ALTIERI et al., 1977). In case weed control favours one crop component more than the other, it is possible that yields of the more susceptible crop are reduced due to better competitive ability of the less susceptible crop (ALTIERI et al., 1977). In areas with high pathogen potential, it is advantageous to tolerate a certain amount of weeds if there is scope that yield losses due to weed competition might be overcompensated by reduced biotic plant damages. Mechanical weed control is superior to use of selective herbicides (DAH IA & RAO, 1985; PRASAD et al., 1985). Particularly legumes with ability for early developing a dense canopy are suitable to reduce weeds in long-term crops such as sugarcane, and bring additional income without affecting yield of the main crop (PRASAD et al., 1985).

2.2.3 Special effects of legumes in polyculture

Symbiosis with Rhizobium bacteria

The effectiviness of legumes to fix atmospheric nitrogen through their root nodules depends on several factors (CABAHUG & PAVA, 1984): (1) low soil nitrogen but high soil phosphorous contents favour nodulation. (2) A suitable preceding legume crop leaving active bacteria in the soil is advantageous as well as (2) greater pH and (3) lower soil temperature. Similar to monocultures, air nitrogen fixation rates in polycultures are ranging from 100 kg/ha in Germany (KRUG, 1991) to 100-130 kg/ha for soybeans in the tropics (REHM & ESPIG, 1984; CHANDEL et al., 1989). Inoculation of legumes can increase these values and this is particularly true for legumes in polycultures under low soil nitrogen levels (CABAHUG & PAVA, 1984).

Besides fixation of atmospheric nitrogen, the possibility of direct N-transport from a legume to a non-legume crop is of special interest. Experimental results have shown no advantage for the non-legume crop (AKBOOLA & FAYEMI, 1971; ALLEN & OBURA, 1976) or that release of N by root nodules is not greater than a few kg/ha, being of no use for the non-legume crop (MAHMUD et al., 1985). On the other hand, soybeans have been described being suitable to provide nitrogen to adjacent sorghum crops in the range of 30 and 40-80 kg/ha, respectively (SINGH et al., 1985; SINGH et al., 1986; CHANDEL et al., 1989).

Gaseous transfer within canopies

Transport of ammonia from an evolving legume to an uptaking non-legume through gaseous transfer within canopies has been proofed under artificial conditions, but seems unlikely significant under field conditions (HAYSTEAD, 1983).

Beneficial effects for succeeding crops

Legumes may be of no direct advantage for intercropped species but play an important role within crop sequences. Compared to monocrops of non-legumes, mixed systems with legumes have significant positive effects on succeeding crops: in a sugarcane-based intercropping system, pulses increased organic carbon, total N and available P content but had no effect on cane yields (YADAV et al., 1987). Soybeans and blackgram in mixture with maize increased yields of succeeding wheat significantly (SINGH & SINGH, 1984) and soybean used as green manure in mixture with maize favoured corn yields (PANDEY & PENDLETON, 1986). These long-term effects of making air nitrogen available for non-legumes depend on the rapidity of rotting legume roots and nodules which, in turn, depends on climatic conditions (soil water and temperature; ROSSET et al., 1984). In this respect, a slower release of nitrogen from legume biomass can avoid N-leaching (HAYSTEAD, 1983).

2.3. Economic factors

2.3.1 Conditions and objectives for production

Indigenous conditions which determine production in a small holder's polyculture system include (1) environmental conditions of high variability (climate, soil, pathogens; LYNUM et al., 1986), (2) restricted market conditions (marketing channels), (3) problematic labour input (rising labour costs, shortage of labour), (4) restricted capital, (5) limited availability of production factors (e.g. technology) and (6) shortage of land (HARWOOD & PRICE. 1976).

In this environment of adverse conditions, a majority of tropical small farmers do not only produce for subsistence but also have commercial purposes (HARWOOD & PRICE. 1976; OELSLIGLE et al., 1976). Particularly in smallholdings, the need for satisfying nutritional needs has first priority and at this level, polycultures are grown at higher intensity than monocrops on larger farms (LYNAM et al., 1986). The probability of changing from a mixed to a sole cropping system increases with a shift towards exclusive commercialization of products, increasing availability of means to control adverse environmental conditions (irrigation, fertilizers and pesticides) and increasing labour costs.

Important reasons for the dominance of polycultures not only on small farms are:

Profits should preferably be related to the most limiting factor. Limiting factors include (HILDEBRAND, 1976; NORMAN, 1974; PARKHURST & FRANCIS, 1986):

- water
- seeds
- land
- labour (particularly in seasons of critical availability, e.g. before the onset of the rainy season)

Empirical results of farms in Nigeria (NORMAN, 1974; NORMAN, 1977) show that profits/unit area can be 62 % greater, profits/work-hour 15 % less, profits/scarce work-hour (June-July: labour peak) 20 % greater, and total net return 60 % greater than in comparable monocultures.

Dependability of return can be assured by diversity of production in polyculture but also through compensation of yield losses of a damaged crop by the non-damaged intercrop (BHATNAGAR & DAVIES, 1981; GOVINDEN et al., 1984; LYNAM et al., 1986). Dependability refers to stability of satisfying nutritional needs of the farmer's family or stability of family income

(GOMEZ & GOMEZ, 1983). Calculations on basis of historical data (PEARCE & EDMONDSON, 1982), linear optimisations on basis of yield statistics (GOMEZ & GOMEZ, 1983), and literature reviews (BHATNAGAR & DAVIES, 1981; KASS, 1978) can proof that polycultures are in fact less affected by total losses, and that there is a smaller danger that their yields are falling below critical limits. Therefore, polycultures are able to avoid risks and ensure stable production (NORMAN, 1974).

Use of labour

Although polycultures require more total labour input per unit area, they require less work-hours in periods of labour peak (GOVINDEN et al., 1984; OELSLIGLE et al., 1976) and are, therefore, helpful to alleviate labour peaks and seasonality of production (BORAH et al., 1984). Particularly under conditions where facilities for storage are absent and a well distributed income is important, polycultures seem to be more preferable than sole cropping practices. A series of further examples of socio-cultural factors, such as tradition, which play an important role in a farmer's decision can be found in BRADFIELD (1986).

If intercropping is the best alternative for growing crops under indigenous low-input conditions, the question arises what will happen under improved technological conditions: it is possible that a farmer adopts sole cropping techniques (GOVINDEN et al., 1984) or polycultures remain preferable (NORMAN, 1974; NORMAN, 1977). If polycultures are only efficient under low-input conditions (HARWOOD & PRICE, 1976), it is not certain that a farmer is interested in mechanisation (KASS, 1978). In terms of environmental protection but also for economic reasons, substitution of more and more expensive inorganic fertilisers and chemical sprayers may be reasonable techniques for conserving resources (HARWOOD & PRICE, 1976).

2.3.2 Economy of legume polycultures

The following economic characteristics of polycultures with legumes are widespread:

(1) In polyculture with long-term crops, yields of the primary crop are likely to be not affected but yields of the legume provides additional income for a farmer. This is particularly true for polycultures with sugarcane (PRASAD & PARASHAR, 1989) and rice (GOSH et al., 1986; MANDAL et al., 1990).

(2) In regions with adverse climatic conditions, many legumes are able to compensate for yield losses of a damaged primary crop. Examples include polycultures with different legumes in semi-arid regions of India (BISHNOI et al., 1987; RAJU et al., 1986).

(3) Individual crop yields in polyculture might be smaller than in monocultures but the combined total yield exceeds yields of monocrops.

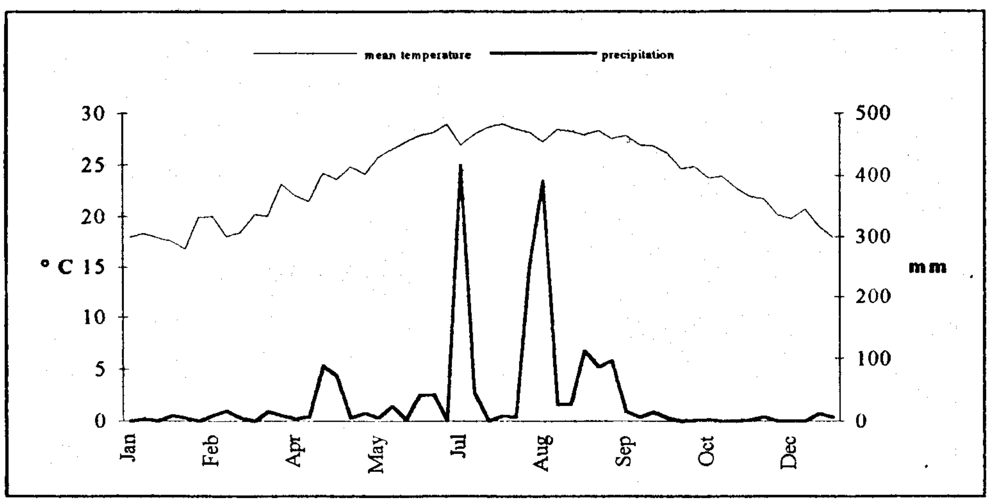
3. Material and methods

3.1 Location

An intercropping experiment with hot pepper (*Capsicum annuum* L.), sweet corn (*Zea mays* L. convar. *saccharata*), grain corn (*Zea mays* L.), and snapbean (*Phaseolus vulgaris* var. *nanus*) was undertaken on the AVRDC experimental farm, Shanhua close to Tainan (latitude 23° N, longitude 120° E) in Taiwan from 11th, July 1991 to 4th, March 1992.

The southern part of Taiwan is dominated by tropical to subtropical climatic conditions. Equatorial, hot, humid air masses in summer (SW monsoon) follow dry and cooler NE monsoon winds in winter. In 1990/91, mean annual temperatures reached 23.8° C (Berlin: 8.8° C) and accumulative yearly precipitation was 1916 mm.

Figure 1. Mean temperature and precipitation (Ø 1990/91) at AVRDC



The alluvial lowlands of western Taiwan are intensively used by industry and agriculture. Soils of northern and eastern parts in that area are loamy whereas in the coastal regions they have a more sandy structure with very low organic matter contents (WESTERMANN VERLAG, 1973).

Climate (heavy rainfalls in summer) and intensive land use (irrigation) put great demands on preservation of soil resources. However, already in 1973, WESTERMANN VERLAG warned of podzolization, erosion and acidification following excessive fertilisation in Taiwan's agriculture. A good example for the failure of agricultural research in introducing high yielding cultivars, but neglecting giving farmers advice on how to cultivate them with a minimum of destruction of the environment is given in HUNG et al. (1991): For cultivating vegetable soybean it is recommended to supply 30-40-30 kg/ha N-P-K and about 2-3 t/ha organic dung. A survey showed, however, that farmers actually used up to almost 10 times of that (75-208 kg/ha N, 42-321 kg/ha P, 72-226 kg/ha K) without any application of organic manure.

3.2 Layout and cultural practices

Sole and intercropping treatments of hot pepper with maize, and snapbean as succeeding crop for maize were tested in a randomised complete block design with three replications and three factors:

Cropping system

- Row intercropping (hot pepper and maice/snapbean intercropped on the same bed)
- Strip intercropping (hot pepper and maice/snapbean intercropped on alternate beds)

Corn type

- Sweet corn
- Grain corn

Corn harvest

- Plants removed at harvest
- Plants cut to pepper height at harvest

Control treatments were the following 4 sole crops:

- Hot pepper (2 rows per bed)
- Hot pepper (1 row per bed)
- Sequence grain corn and succeeding snapbean
- Sequence sweet corn and succeeding snapbean

A summary of experimental details is presented in Table 2, figure 2 and table 3.

Table 2. Experimental details

Treatment		**Spacing** *cm × cm*			**Population** *plants/ha*			
		hot pepper	**corn**	**bean**	**hot**	**corn**	**bean**	**total[1]**
sole crops								
1. hot pepper (1 row/bed)		100˙30	-	-	33,333	-	-	33,333
2. hot pepper (1row/bed)		50˙30	-	-	66,666	-	-	66,666
crop sequence								
3. grain corn - snapbean		-	100˙20	50˙20	-	50.000	100,000	50,000/ 100,000
4. sweet corn - snapbean		-	100˙20	50˙20	-	50.000	100.000	50,000/ 100,000
intercrops								
maize	**harvest**							
row intercropping								
5. grain corn	removed	100˙30	100˙20	100˙20	33,333	50,000	50,000	83,333/ 83,333
6. grain corn	cut down	"	"	"	"	"	"	"
7. sweet corn	removed	"	"	"	"	"	"	"
8. sweet corn	cut down	"	"	"	"	"	"	"
strip intercropping								
9. grain corn	removed	"	"	"	"	"	"	"
10. grain corn	cut down	"	"	"	"	"	"	"
11. sweet corn	removed	"	"	"	"	"	"	"
12. sweet corn	cut down	"	"	"	"	"	"	"

[1] maize / snapbean

Figure 2. Layout and randomisation

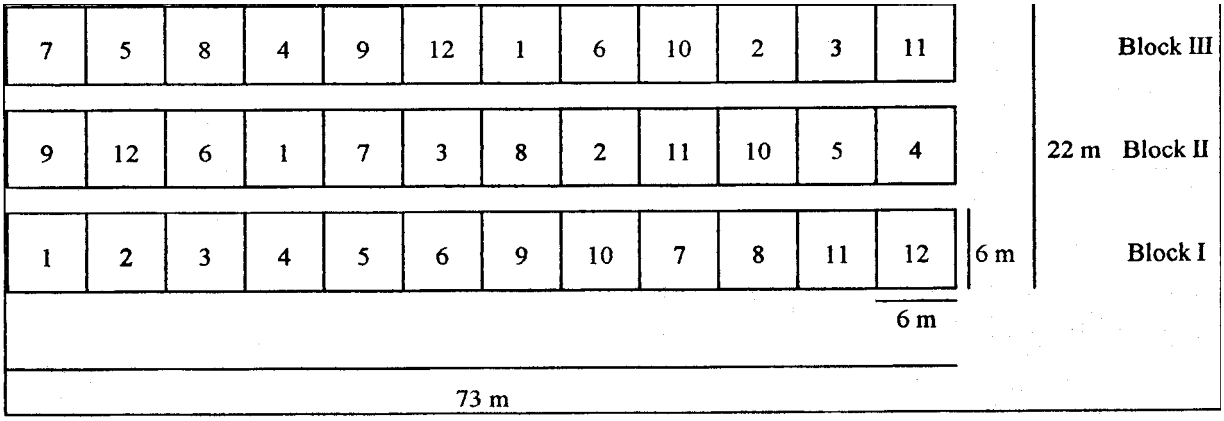


Table 3. Cultural practices

Days after sowing/planting Pepper	Maize	Bean	Date	Practices
			11.07.	Sowing Capsicum
			14.08.	Fertilizer 200:120:120 kg/ha N:P:K
0			15.08.	planting Capsicum
1			16.08.	Mulching with rice straw
6	0		21.08.	Sowing maize
7	1		22.08.	Plant protection Capsicum (insecticide + fungicide)
13	7		28.08.	Plant protection Capsicum + maize (Fungicide) Biological plant protection maize Fertilizer 500 g/plot carbamide
18	12		02.09.	Plant protection Capsicum (Fungicide)
26	20		10.09.	Plant protection Capsicum (Fungicide)
34	28		18.09.	Biological plant protection maize
35	29		19.09.	Fertilizer 0.9:0.8:0.2 kg/plot N:P:K
41	35		25.09.	Plant protection Capsicum (Fungicide)
45	39		29.09.	Irrigation
50	44		04.10.	Biological plant protection maize
53	47		07.10.	Fertilizer 1.1:0.8:0.2 kg/plot N:P:K
62	56		16.10.	Biological plant protection maize Irrigation
69	63		23.10.	Plant protection Capsicum (Fungicide)
78	72		01.11.	Irrigation
83	77		06.11.	Removal/cut down sweet corn
85	79		08.11.	Fertilizer (over leaf) 0.4 % urea
99		0	22.11.	Removal/cut down grain corn Sowing snapbean
103		4	26.11.	Plant protection Capsicum (Fungicide)
113		14	06.12.	Plant protection Capsicum (Fungicide)
117		18	10.12.	Thinning snapbean
118		19	11.12.	Fertilizer 1.0:1.0:0.2 kg/plot N:P:K
123		24	16.12.	Plant protection Capsicum (Fungicide)
124		25	17.12.	Irrigation
134		35	27.12.	Plant protection Capsicum (Fungicide)
195		96	26.02.	Removal snapbean
202			04.03.	Removal Capsicum

Some cultural practices such as intensive use of inorganic fertilizers, plant protection measures, use of varieties adapted to sole cropping did not match traditional intercropping techniques. Furthermore, a density of 50,000 plants/ha seems to be too low for a sole corn crop.

3.3. Data collection and processing

Data for (1) yields and (2) final plant biomass was collected in areas of 12, 8, and 4 m^2 according to treatment. (3) Absolute growth parameters for plant growth analysis of snapbean were taken from six plants per plot including:

- height of main stem from soil level to highest node
- fresh/dry weight of root, stem, leaf, and pods
- leaf area (2 plants per plot)

(4) Light interception data for snapbean was collected with a LICOR LI-1000 radiometer. Table 4 summarises data collection procedures.

Table 4. Data collection

Days after sowing/transplanting			Date	Procedure
Pepper	Corn	Bean		
34	28		18.09.	Light interception measurement
53	47		07.10.	Light interception measurement
68	62		22.10.	Light interception measurement
78	72		01.11.	Harvesting hot pepper
81	75		04.11.	Harvesting sweet corn
84	78		07.11.	Light interception measurement
97	91		20.11.	Harvesting grain corn
102		3	25.11.	Harvesting hot pepper
112		13	05.12.	Harvesting hot pepper
123		24	16.12.	Harvesting hot pepper
133		34	26.12.	Harvesting hot pepper
138		39	31.12.	Plant sampling snapbean
139		41	02.01.	Light interception measurement
151		52	13.01.	Plant sampling snapbean
153		54	15.01.	Light interception measurement
154		55	16.01.	Harvesting hot pepper
155		56	17.01.	Harvesting snapbean
160		61	22.01.	Harvesting snapbean
165		66	27.01.	Harvesting snapbean
166		67	28.01.	Light interception measurement
169		70	31.01.	Harvesting snapbean
176		77	07.02.	Harvesting snapbean Plant sampling snapbean
182		83	13.02.	Harvesting snapbean
188		89	19.02.	Harvesting snapbean
193		94	24.02.	Light interception measurement
194		95	25.02.	Harvesting snapbean
195		96	26.02.	Plant sampling snapbean
202			04.03.	Harvesting hot pepper Plant sampling hot pepper

Relative growth parameters were calculated using equations in HUNT (1978), MILTHORPE & MOORBY (1978) and KRUG (1991):

Growth analysis of snapbean

Total plant dry weight (W)

Total dry weight of snapbean includes dry weight of stem, root, leaf and interpolated cumulative pod yields, corrected by a dry/fresh weight ratio.

$$W = DW_{SRL} + \left(FW_{P_{exp}} \cdot \frac{DW_P}{FW_P} \right)$$

DW_{SRL}: dry weight (stem+root+leaf)

$FW_{P\exp}$: interpolated cumulative fresh yield

DW_P; FW_P: dry/fresh weight pods

Absolute growth rate (AGR)

AGR measures "speed of growth", and is defined as increase of plant dry weight (W) over time.

$$AGR = \frac{\Delta W}{\Delta T} \approx \left(\frac{W_2 - W_1}{T_2 - T_1} \right)$$

Specific leaf area

Photosynthetic active leaf area related to leaf weight of a plant is SLA.

$$SLA = \frac{L}{W_L}$$

Light use efficiency

Closely related to intercropping is the effective use of available growth factors (resources). Efficiency of light use can be described as a product of (1) efficiency of light interception and (2) efficiency of utilisation of intercepted light (TRENBATH, 1981; TRENBATH, 1986).

$$LUE = \frac{I_i}{I_0} \cdot \frac{Y}{I_i}$$

I_0: light intensity over canopy light interception

Y: yield

Productivity and stability of cropping systems

What are the reasons for a farmer's choice of crops and cropping systems? Is he interested in maximising yields or returns of one crop, a few crops or a variety of crops? Does he want to balance his output according to market conditions or is there a need to ensure stable productivity for his own consumption? Low but invariable yields of many crops might be more important than maximising yields of only a few crops (WILLEY, 1985). Even varieties with a low harvest index may have an advantage for a farmer when he, e.g., uses vegetative plant parts as fodder material for his livestock (mungbean in Indonesia; VAN DEN BOSCH, 1978a). Reasons for growing crops are as diverse as the way they can be grown. For the reason that yields of different crops cannot be compared directly (except monetary values), research has introduced several equivalent ratios to compare the output of intercrops with the output of monocrops (MEAD, 1986).

Correlation of yields

To identify whether yields of one crop affected yields of intercrops, this interspecific competition can be measured by correlation analysis. In case yields are strongly negatively correlated, interspecific competition between these crops is considered high (PEARCE & GILLIVER, 1978; WILES et al., 1989).

Relative variability

As an indicator for yield stability, relative variability (variance of yields / mean of yields) should preferably be calculated over time (different experiments) than over space (replications within one experiment; LYNUM et al., 1986; SCHULTZ et al., 1982). For the reason that exact replications of this experiment have not yet been undertaken, only variability over space could be calculated here.

Land equivalent ratio LER

DE WIT (1960) was the first who related yields of crops in polyculture to those in monocultures *(P/M),* and titled this ratio RCC (relative crowding coefficient). VAN DEN BERG (1968) renamed it RY (relative yield) and defined a RYT (relative yield total). a sum of all RY in a polyculture. WILLEY & OSIRO finally introduced 1972 the most common term for RYT, the LER (land equivalent ratio):

$$LER = \sum_{i=1}^{n} (RY_i) = \sum_{i=1}^{n} \left(\frac{P_i}{M_i} \right)$$

P_i: polycultural yield crop i
M_i: monocultural yield crop i
n: number of crops

LER can describe intensity of land use if land use is regarded as total sum of combined yields or sum of yield advantages/disadvantages of each crop (MEAD, 1980; PATNAM et al., 1985). Values of LER can adopt values ranging from <1.0 to >1.0 and indicate different levels of biological efficiency (TRENBATH, 1974; VANDERMEER, 1989):

- <1.0: antagonism (Two way negative interaction. competition for growth factors)
- =1.0: coexistence (use of same resources, interspecific competition = intraspecific competition)
- >1.0: facilitation (One way or two way positive interaction, use of different niches, complementary crops)

In this experiment, use of LER is only suitable for comparing intercropping treatments among themselves because maize and snapbean were not intercrops for the whole life cycle of hot pepper (202 days). Nevertheless, LERs for intercropping treatments were calculated using monocrop yields of pepper with 2 rows per bed, monocrop yields of the two different corn types, and monocrop yields of snapbean corresponding to preceding corn type.

Area time equivalent ratio ATER

Compared to LER, ATER considers different growth periods of participating crops in polyculture (HIEBSCH, 1980).

$$ATER = \frac{\sum_{i=1}^{n} \left(\frac{P_i}{M_i} \cdot T_i \right)}{T}$$

T_i: duration of crop i in polyculture
T: total duration of polyculture

Relative value total RVT

Following calculations of LER, SCHULTZ et al. (1982) defined a RVT, which relates monetary returns of polycultures to the most valuable monocrop of participating crops.

$$RVT = \frac{\sum_{i=1}^{n}(P_i \cdot p_i)}{M_1 \cdot p_i}$$

p: market price crop *i*
M_1: most valuable monocrop

All variables were subject to statistical analysis using the SAS-PC Version 6.04 package. Statistical model for the three-factorial block experiment is (BÄTZ et al., 1987):

$$x_{ijku} = \mu + \omega_u + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} + \varepsilon_{ijku}.$$

with:

x: mean of treatment
μ: mean of experiment
α: factor maize type
β: factor cropping system
γ: factor maize harvest
$(\alpha\beta)$: one way interaction maize type × cropping system
$(\alpha\gamma)$: one way interaction maize type × maize harvest
$(\beta\gamma)$: one way interaction cropping system × maize harvest
$(\alpha\beta\gamma)$: two way interaction maize type × cropping system × maize harvest
ω: replication error (blocks)
ε: model error

Within this analysis of variance, F-values of all main effects and possible interactions were tested against the null hypothesis (H_0: influence of parameter = 0). If the probability that the parameter is truly equal to zero is smaller than 0.05 (5% level), the influence is called "significant", if it is smaller than 0.01 (1% level), the influence is "highly significant" different from zero. In case that an effect was of influence in the analysis of variance, levels of this effect were tested for significant differences by calculating "least significant differences" (LSD-test):

$$S_D = \sqrt{\frac{2 \cdot MQ_F}{n}}; LSD = \left(t_\alpha \cdot S_D\right)$$

S_D: standard error of the difference

LSD-tests are only suitable for testing levels of main effects and not for testing levels of combinations of main effects in interactions. Although very often used for analysing intercropping experiments, the DUNCAN test (or other multiple range tests) should not be used (MEAD, 1986). Control treatments were tested against levels of main effects in intercropping treatments by calculating "contrasts". Results are F-values, which can be tested for significance as mentioned before.

4. Results

4.1. Plant growth analysis snapbean

Plant height

In early plant growth, maize type and type of maize harvest influenced plant height of snapbean significantly:

Table 5. LSD-test plant height snapbean 39 DAS

Maize type	Plant height cm	Grouping
sweet corn	22.1[2]	a
grain corn	19.4	b
sole snapbean[1]	18.7	b[3]

F-value: 8.90[4]

LSD(α=5%): 2.0[4]

[1] Sole snapbean crop after sole grain corn crop
[2] Means followed by same letters are not significant different
[3] Contrast: sole crop snapbean - snap bean after sweet corn when intercropped with pepper: significant
[4] only for intercropping treatments

Table 6. LSD-test plant height snapbean 39 DAS

Maize harvest	Plant height cm	Grouping
cut down	22.1	a
removed	19.4	b
sole snapbean	18.7	b

F-value: 8.72

LSD(α=5%): 2.0

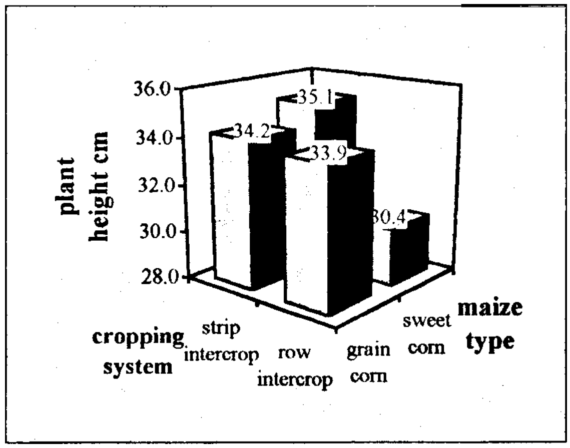
At final harvest, however, plant height of snapbean was only affected by cropping systems (Table 7). Plants were higher when intercropped with pepper on alternate beds. Within this strip-intercropping treatment, plant height was higher when snapbean succeeded sweet corn whereas plants in the row intercropping treatment were higher after preceding grain corn crop. A suitable presentation for such interactions are three dimensional bar charts (SAS INSTITUTE, 1989; Figure 3).

Table 7. LSD-test plant height snapbean

Cropping system	Plant height *cm*	Grouping
strip intercrop	31.0	a
row intercrop	27.7	b
sole snapbean	26.7	b

F-value: 6.42
LSD(α=5%): 2.2

Figure 3. Interaction plant height snapbean 95 DAS (F-value: 4.73)



Plant dry weight

Differences in biomass production of root, stem, and leaf were only due to type of cropping system. Snapbean total plant dry weight was initially higher in the sole crop, but finally greater when intercropped with pepper in strips (Table 8 and 9).

Table 8. LSD-test total plant dry weight snapbean (W) 39 DAS

Cropping system	W *g/plant*	Grouping
sole snapbean	4.71	a
strip intercrop	4.16	a
row intercrop	2.77	b

F-value: 31.76
LSD(α=1%): 0.73

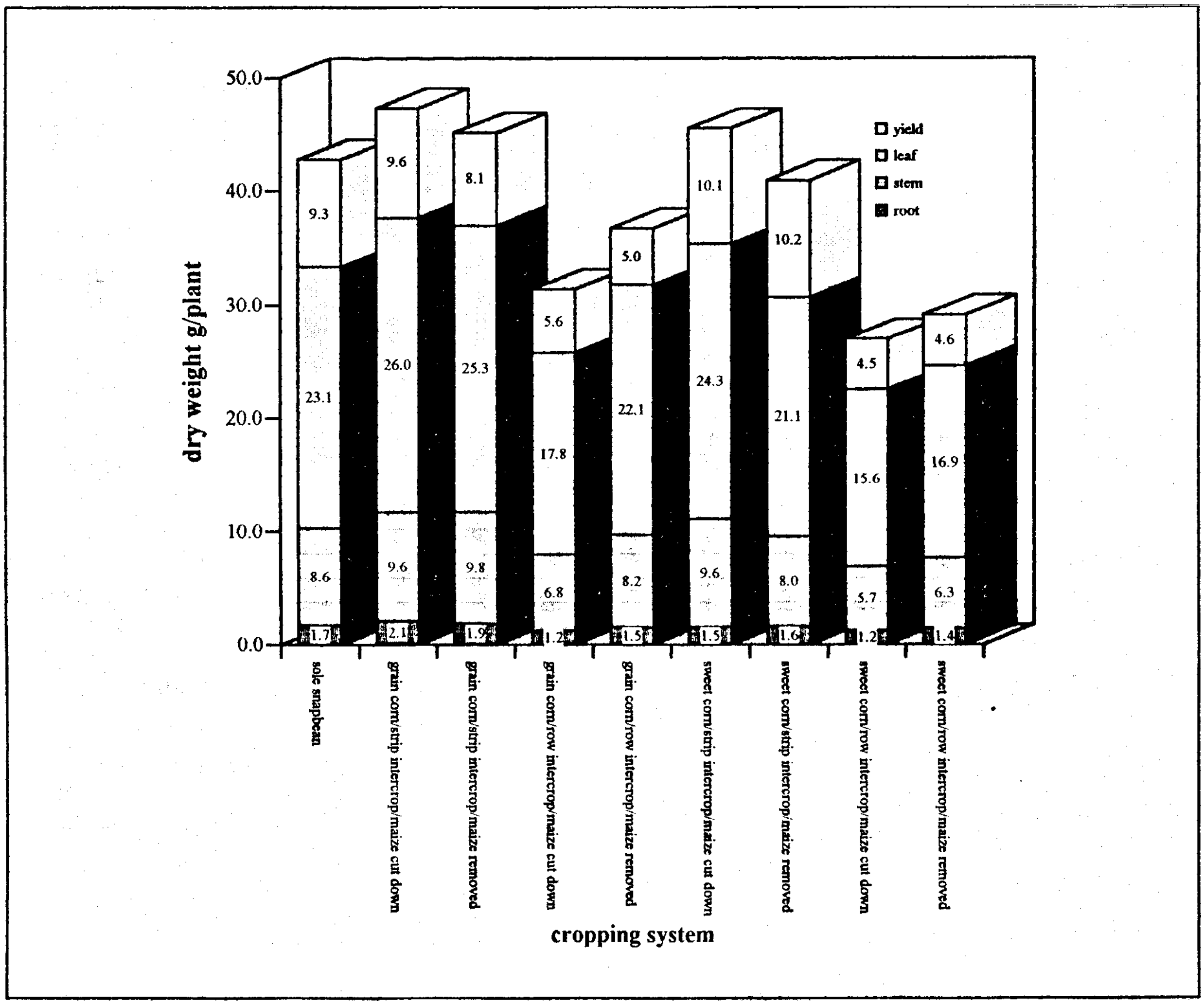
Table 9. LSD-test total plant dry weight snapbean (W) 95 DAS

Cropping system	W *g/plant*	Grouping
strip intercrop	44.7	a
sole snapbean	42.7	a
row intercrop	31.1	b

F-value: 39.50
LSD(α=1%): 6.5

Contribution of bean yield, leaf, stem and root to total plant dry weight is presented in figure 4.

Figure 4. Total plant dry matter production snapbean



Absolute growth rate AGR

Up to 77 DAS, plant growth of snapbean was significantly slower when plants were intercropped with hot pepper on the same ridge (Table 10). At that time, AGR was also influenced by a significant interaction between cropping system and corn type (Figure 5). Plant growth was favoured in the strip intercropping treatment by preceding sweet corn whereas grain corn was advantageous for snapbean growth when intercropped on the same bed.

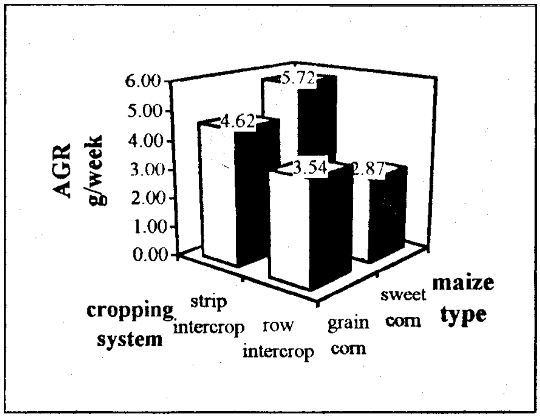
Table 10. LSD-test Absolute Growth Rate snapbean (AGR) 52-77 DAS

Cropping system	AGR *g/week*	Grouping
sole snapbean	6.08	a
strip intercrop	5.17	a
row intercrop	3.21	b

F-value: 38.92

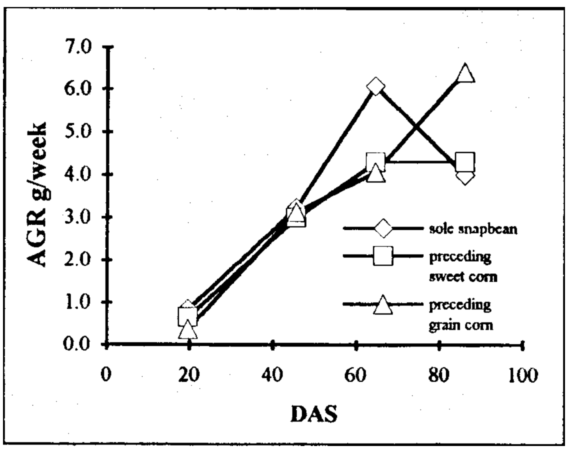
LSD(α=1%): 0.84

Figure 5. Interaction Absolute Growth Rate snapbean 52-77 DAS (F-value:7.99)



Preceding grain corn favoured growth of intercropped snapbean after 77 days, when plants in sole stand had already been matured (Figure 6).

Figure 6. Absolute Growth Rate snapbean (AGR) 0-95 DAS



Leaf area L

Among other influences, development of leaf area depends on general plant growth, and on shading. Up to 77 DAS, less shaded plants in sole crops and strip intercropping treatments had a significant higher total leaf area than snapbean intercropped on the same bed as pepper (Table

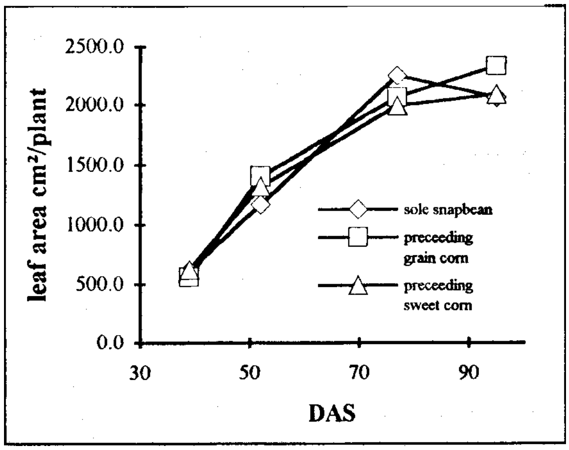
11). From 77 to 95 DAS leaf area growth had already stopped in sole snapbean and strip inter-cropping plots but leaf area of plants intercropped in rows was still increasing (Figure 7).

Table 11. LSD-test leaf area snapbean

Cropping system	L *cm²/plant*	Grouping
sole snapbean	2246	a
strip intercrop	2241	a
row intercrop	1814	b

F-value: 10.55
LSD(α=1%): 391

Figure 7. Leaf area snapbean 0-95 DAS



Specific leaf area SLA

Plants growing under shaded conditions are likely to develop a higher leaf area per leaf weight in order to maximise light interception. Cropping system and type of maize harvest affected light transmission to snapbean canopy, and resulted in expected variations in SLA: more shaded plants in treatments, where they were intercropped with pepper on the same bed and where maize was cut to pepper height had significant higher values (Table 12 and 13).

Table 12. LSD-test Specific Leaf Area snapbean (SLA) 77 DAS

Maize harvest	SLA *cm²/g*	Grouping
maize cut down	171.0	a
maize removed	157.7	b
sole snapbean	144.0	c

F-value: 7.21
LSD(α=1%): 14.9

Table 13. LSD-test Specific Leaf Area snapbean (SLA) 95 DAS

Cropping system	SLA *cm²/g*	Grouping
row intercrop	154.1	a
strip intercrop	128.4	b
sole snapbean	109.6	b

F-value: 7.32
LSD(α=1%): 20.4

Light transmission to canopy

Analysis of light transmission data proofed expected relationship between available light and LA. Plants intercropped with pepper on the same bed, and in treatments where maize was clipped to pepper height received significantly less light (Tables 14 and 15).

Table 14. LSD-test light transmission to snapbean canopy 41 DAS

Maize harvest	Light transmission %	Grouping
sole snapbean	94.8	a
maize removed	76.3	b
maize cut down	66.2	c

F-value: 9.25

LSD(α=1%):10.0

Table 15. LSD-test light transmission to snapbean canopy 94 DAS

Cropping system	Light transmission %	Grouping
sole snapbean	88.9	a
strip intercrop	78.8	b
row intercrop	62.7	c

F-value: 36.97

LSD(α=1%): 7.9

Light interception

Due to lower light intensity over snapbean intercropped with pepper on the same ridge, plants were not able to intercept as much light as in the other treatments (Table 16).

Tale 16. LSD-test light interception by snapbean 94 DAS

Cropping system	Light interception %	Grouping
strip intercrop	55.9	a
sole snapbean	53.5	a
row intercrop	37.3	b

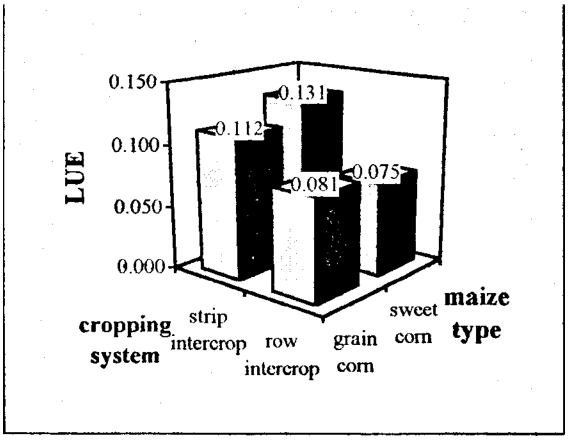
F-value: 30.43

LSD(α=1%): 10.1

Light use efficiency LUE

The expectation that snapbean under shaded conditions could have a higher efficiency of using limited amount of light was disappointed: strip intercropped snapbean used more available light even more efficient than plants intercropped on the same bed. A highly significant interaction (95 DAS) between cropping system and maize type shows that grain corn favoured LUE of snapbean when intercropped in rows but had a less positive effect on LUE of beans when intercropped with pepper on separate beds (Figure 8).

Figure 8. Interaction Light Use Efficiency snapbean (LUE) 95 DAS (F-value:11.97)



Cumulative yield

Due to double plant density in snapbean monocrop, yields exceeded those of the intercrop counterpart (Figure 9). Within intercrops, bean yields were significantly higher when snapbean was intercropped with pepper on alternate beds (Table 17). Sweet corn favoured snapbean yields in the strip intercrop whereas preceding grain corn provided more suitable conditions for snapbean intercropped with pepper on the same bed (Figure 10). Finally, table 18 presents total snapbean yields for all experimental treatments.

Figure 9. Cumulative yield snapbean

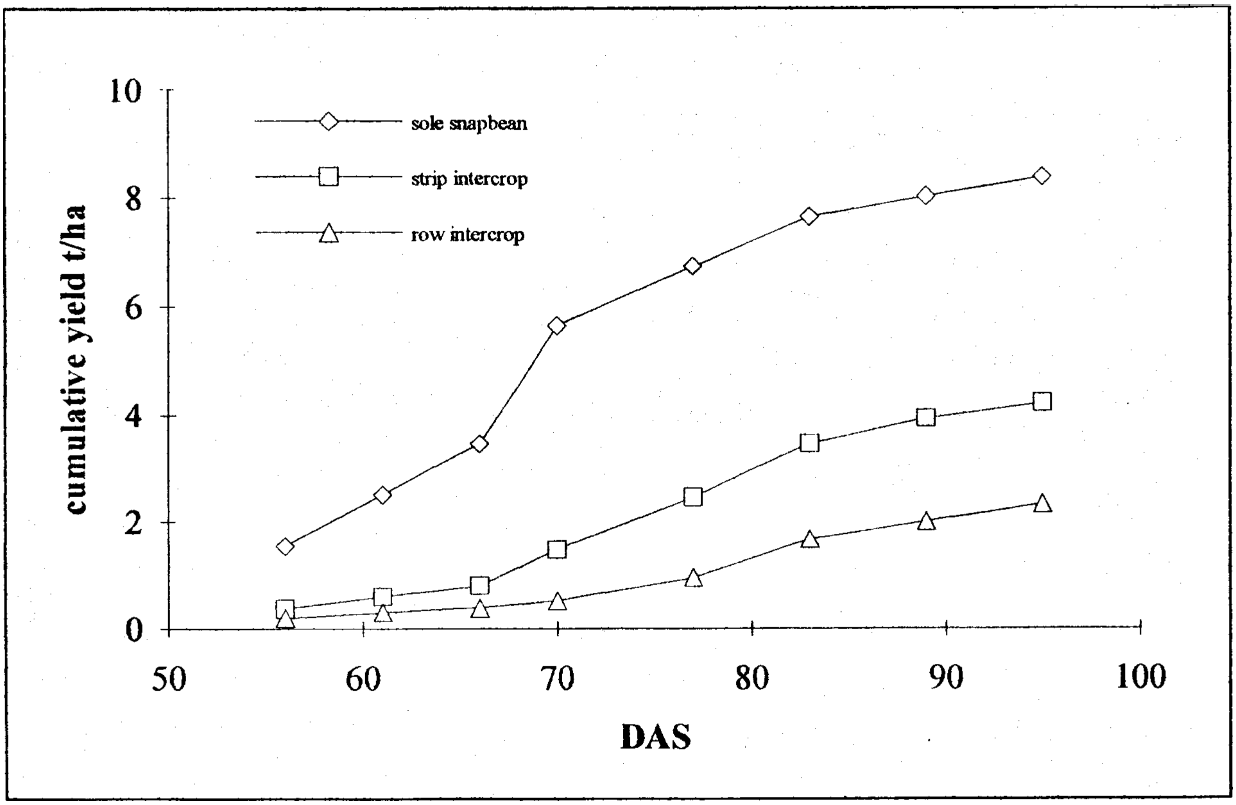


Table 17. LSD-test total yield snapbean 95 DAS

Cropping system	Total yield *t/ha*	Grouping
sole snapbean	8.38	a
strip intercrop	4.22	b
row intercrop	2.32	c

F-value: 59.08
LSD(α=1%): 0.74

Figure 10. Interaction total yield snapbean 95 snapbean 95 DAS (F-value:8.28)

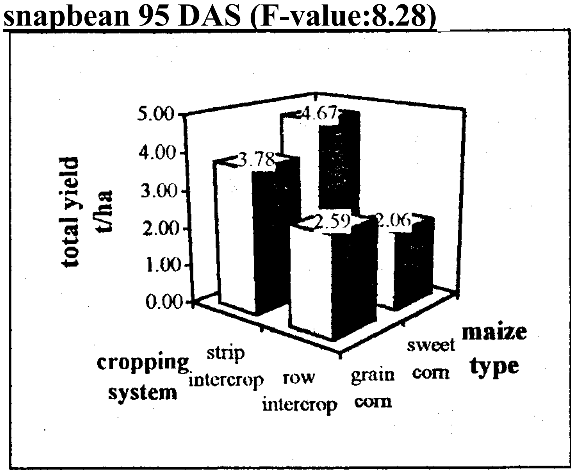


Table 18. LSD-test total yield snapbean (95 DAS)

Maize	Treatment Cropping system	Maize harvest	Total yield *t/ha*	Grouping
Sweet corn	sole snapbean		13.99	a[1]
Grain corn	sole snapbean		8.38	b
Sweet corn	strip intercrop	removed	5.01	c
Sweet corn	strip intercrop	cut down	4.33	cd
Grain corn	strip intercrop	cut down	4.02	cd
Grain corn	strip intercrop	removed	3.53	cd
Grain corn	row intercrop	cut down	2.83	cd
Grain corn	row intercrop	removed	2.34	d
Sweet corn	row intercrop	cut down	2.20	d
Sweet corn	row intercrop	removed	1.91	d

LSD(α=1%): 25.4

[1] Test of treatments

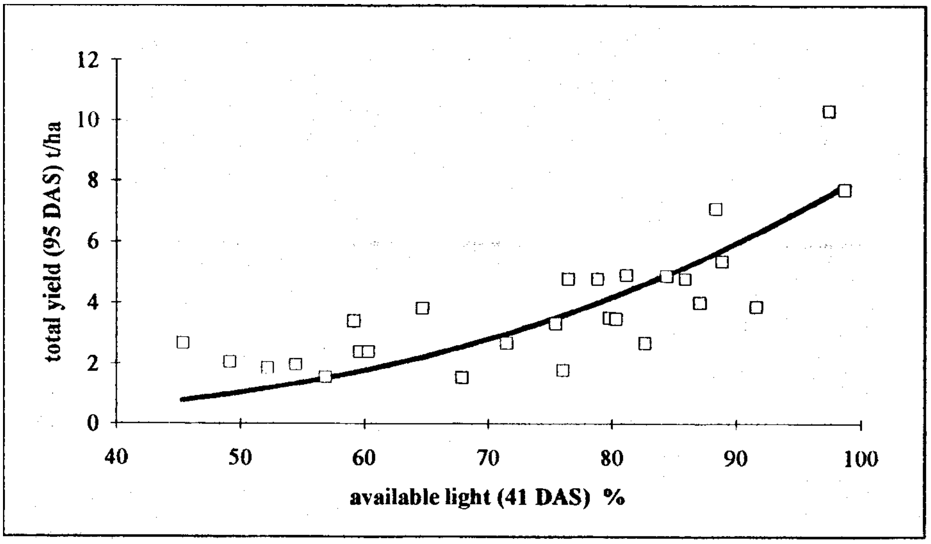
Correlation yield - parameter of growth analysis

To evaluate whether there was any relationship between total yield of snapbean and growth parameters, a correlation matrix was calculated. Table 19 and figure 11 show high correlation of total yield with light availability, especially during early plant growth. Less available light induced higher SLA (bigger, but thinner leafs), and lower yields. SLA seems to be a good indicator of a plant's reaction to competition for light in intercropping.

Table 19. Correlation total yield snapbean - growth parameters

Parameter	Correlation with total yield
Plant height 95 DAS	0.62
Leaf dry weight 95 DAS	0.63
Leaf area 95 DAS	0.12
Specific leaf area SLA 95 DAS	-0.57
Light transmission to canopy 94 DAS	0.71
Light interception 94 DAS	0.62

Figure 11. Dependency snapbean yield and light availability in early plant growth



Yield = 0.82×10-5×light intensity^3; r^2 = 91.9 %

4.2. Productivity of maize and pepper

Maize

Not only for reason of a two weeks longer growth period, grain corn yields exceeded those of sweet corn (Table 20).

Table 20. Yields of maize

Treatment: Maize type	Treatment: Cropping system	Yield *t/ha*	Grouping	Yield *kg/ha·day*	Grouping
Grain corn	sole crop	3.85	a[1]	42.3	a[1]
Grain corn	row intercrop	3.77	a	41.4	a
Grain corn	strip intercrop	3.25	a	35.7	ab
Sweet corn	row intercrop	2.65	b	35.3	ab
Sweet corn	strip intercrop	2.18	b	29.1	b
Sweet corn	sole crop	1.30	c	17.4	c

[1]Testing treatments against each other (α=5%)

Hot pepper

Final biomass of pepper plants (202 days after transplanting) intercropped with maize and succeeding snapbean showed significant variations due to both maize type and cropping system (Tables 21 and 22). Total dry weight of pepper plants intercropped with sweet corn on the same bed was not lower than dry weight of peppers in monocrops (Table 23).

Table 21. LSD-test total dry weight hot pepper 202 DAT

Maize type	Dry weight *g/plant*	Grouping
Sweet corn	303.2	a
Grain corn	250.7	b

F-value: 9.14
LSD(α=1%): 51.7

Table 22. LSD-test total dry weight hot pepper 202 DAT

Cropping system	Dry weight *g/plant*	Grouping
row intercrop	300.0	a
strip intercrop	253.9	b

F-value: 7.05
LSD(α=5%): 37.2

Table 23. LSD-test total dry weight hot pepper (202 DAT)

Treatment: Maize	Cropping system	Maize harvest	Dry weight *g/plant*	Grouping
Sole pepper (single row per bed)			396.8	a
Sweet corn	row intercrop	cut down	348.2	ab
Sole pepper (double row per bed)			317.6	abc
Sweet corn	row intercrop	removed	317.0	abc
Sweet corn	strip intercrop	removed	291.6	bcd
Grain corn	row intercrop	cut down	272.8	cd
Grain corn	row intercrop	removed	261.8	cd
Sweet corn	strip intercrop	cut down	255.8	cd
Grain corn	strip intercrop	cut down	251.5	cd
Grain corn	strip intercrop	removed	216.7	d

LSD(α=5%): 86.4

Total cumulative pepper yields were highest in monocrops and particularly when planted with 2 rows per bed (Table 24). Within intercrops, grain corn reduced pepper yields more than sweet corn in general (Table 25). Detrimental effects of grain corn were more significant for pepper intercropped on the same bed, whereas sweet corn reduced pepper yields more when intercropped in separate strips (Figure 12).

Table 24. LSD-test total yield hot pepper (202 DAT)

Maize	Treatment Cropping system	Maize harvest	Total yield *t/ha*	Grouping
Sole pepper (double row per bed)			21.77	
Sole pepper (single row per bed)			17.76	
Sweet corn	row intercrop	removed	12.31 a	
		cut down	11.56 ab	
	strip intercrop	cut down	10.66 ab	
		removed	10·23 abc	
Grain corn	row intercrop	removed	9.02 be	
	strip intercrop	removed	8.88 be	
	strip intercrop	cut down	8.84 bc	
	row intercrop	cut down	7.53 c	

LSD(α=1%): 28.3

Table 25. LSD-test total yield hot pepper 202 DAT

Maize type	Total yield *t/ha*	Grouping
Sweet corn	11.19	a
Grain corn	8.57	b

F-value: 32.27

LSD(α=1%): 1.38

Figure 12. Interaction total yield hot pepper 202 DAT (F-value:5.05)

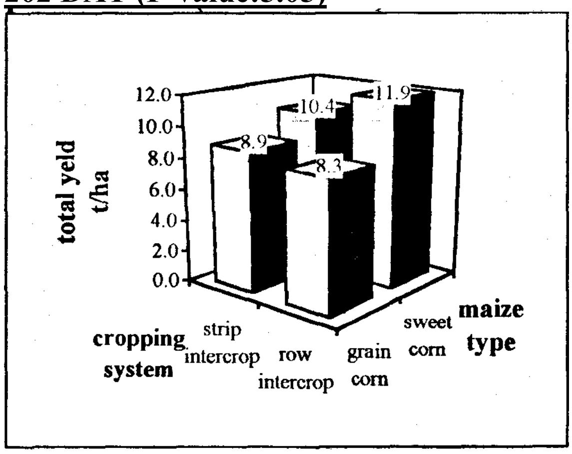
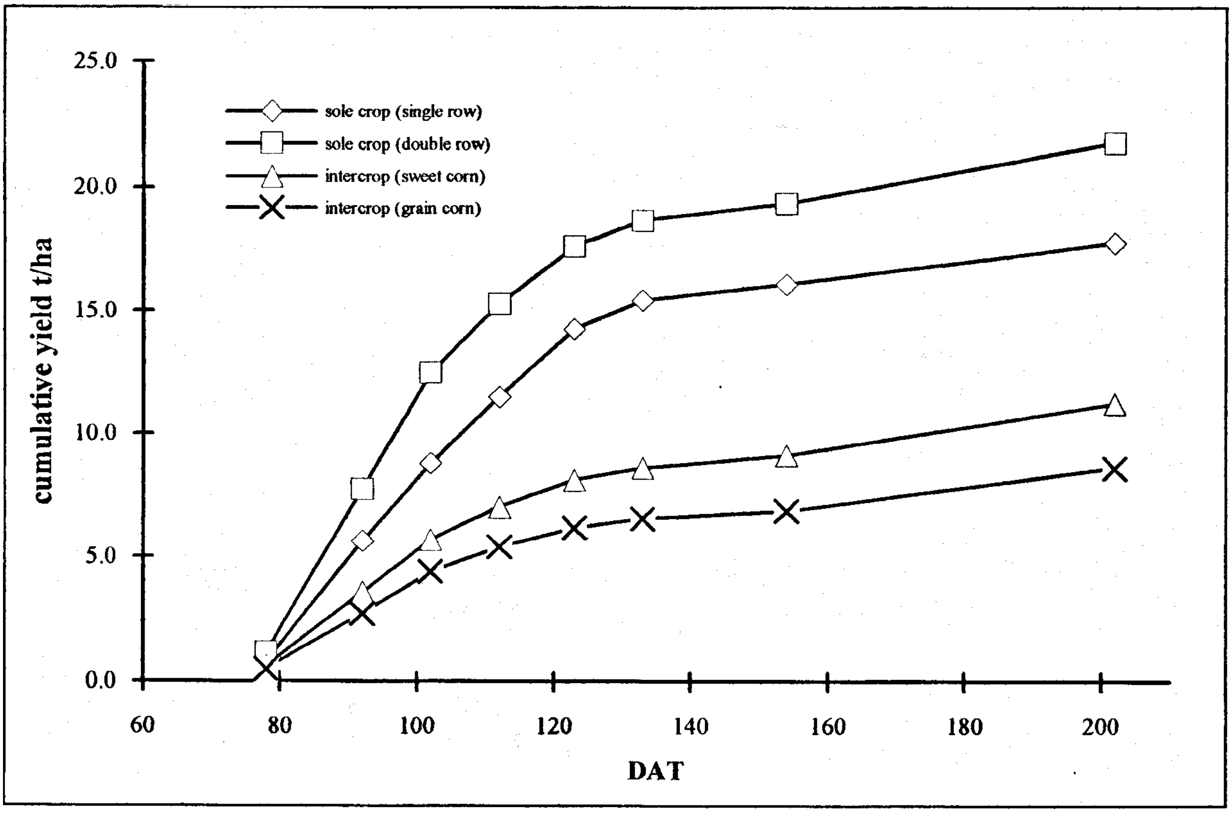


Figure 13 presents the development of pepper yields in monocrop treatments and when inter-cropped with different maize types.

Figure 13. Cumulative yield hot pepper



4.3. Total productivity

Although difficult to determine, several methods of calculating a "total value" for the different cropping systems in this experiment will be presented.

Total of combined yields, correlation between yields, relative variability of cropping systems

Figure 14 and table 26 compare total yields and proportions of pepper yields to those of maize and snapbean and how single or combined yields affected each other. Finally, table 27 presents data for relative variability of all 12 cropping systems suggesting that with exception of high density sole planting of hot pepper, all intercropping treatments were superior to monocrops.

Figure 14. Total combined yields of treatments

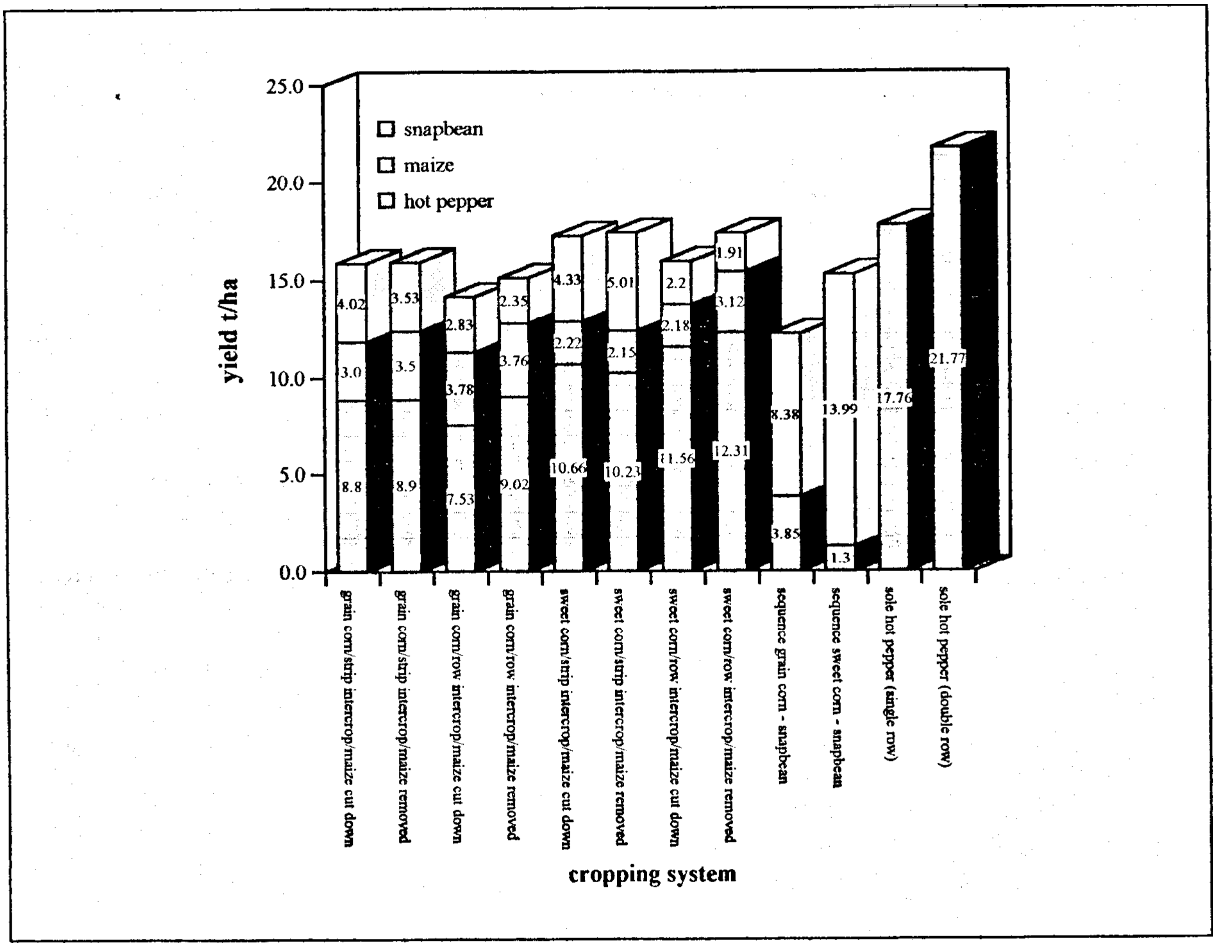


Table 26. Correlation of individual yields and yield combinations

Comparison	Correlation coefficient
Maize - hot pepper	-0.45
Maize - snapbean	-0.32
Hot pepper - snapbean	-0.31
Maize + hot pepper - snapbean	-0.50
Maize + snapbean - hot pepper	-0.61
Maize - hot pepper + bean	-0.65

Table 27. **Relative variability cropping systems**

Treatment			Relative variability			
Maize	Cropping system	Maize harvest	Maize	Hot pepper	Snap-bean	Total
Sole crop hot pepper (double row)			-	0.006	-	0.006
Sole hot pepper (single row)			-	0.152	-	0.152
Crop sequence grain corn - snapbean			0.062	-	0.207	0.156
Crop sequence sweet corn - snapbean			0.192	-	0·214	0.211
Grain corn	strip intercrop	cut down	0.106	0.137	0·201	0.008
		removed	0.151	0.193	0.207	0.082
	row intercrop	cut down	0.037	0.183	0.183	0.071
		removed	0.029	0.299	0.439	0.115
Sweet corn	strip intercrop	cut down	0.032	0.039	0.171	0.046
		removed	0.463	0.135	0.062	0.109
	row intercrop	cut down	0·291	0.067	0.200	0.040
		removed	0·328	0.109	0.229	0.106

Land equivalent ratio LER

Although LER is not the best indicator of land use efficiency in this experiment, it is suitable to compare intercropping treatments among themselves. Figure 15 shows the development of LER for the most significant influence within intercrops, type of maize. Probably due to low yields in sweet corn sole crop, LERs were much higher in sweet corn intercrops, as table 27 and figure 16 indicate.

Figure 15. Development of LER over time

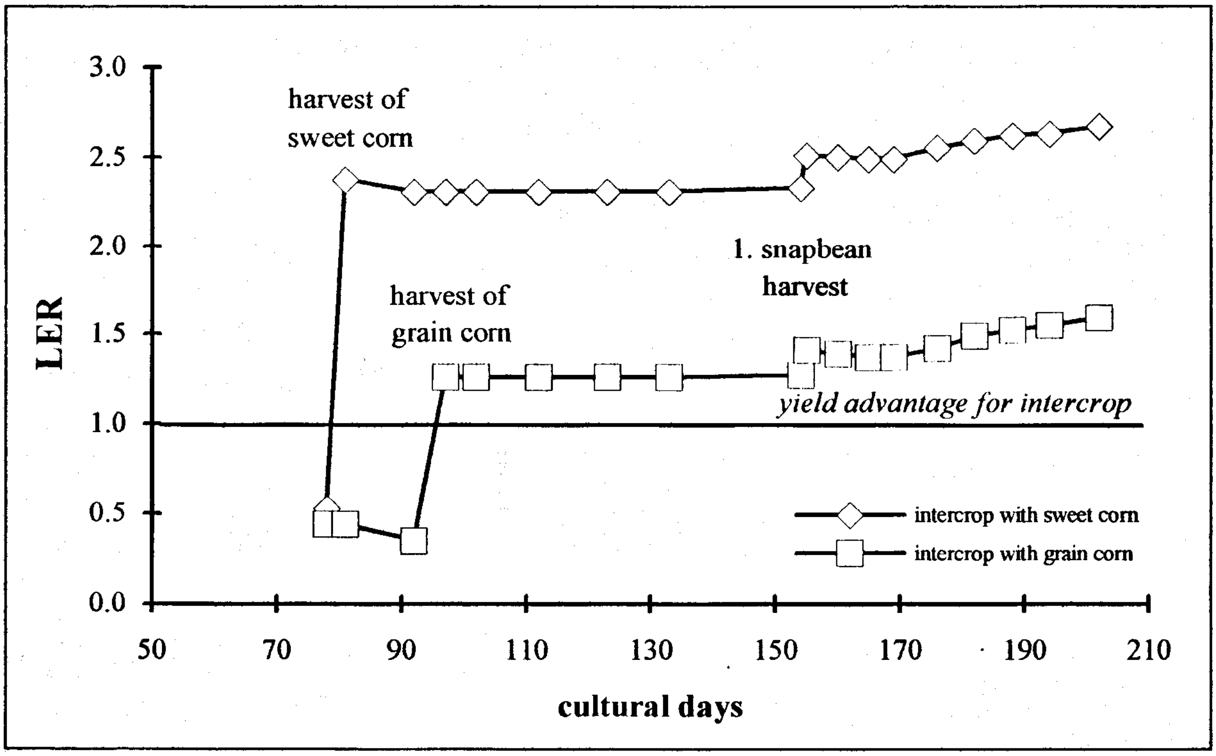


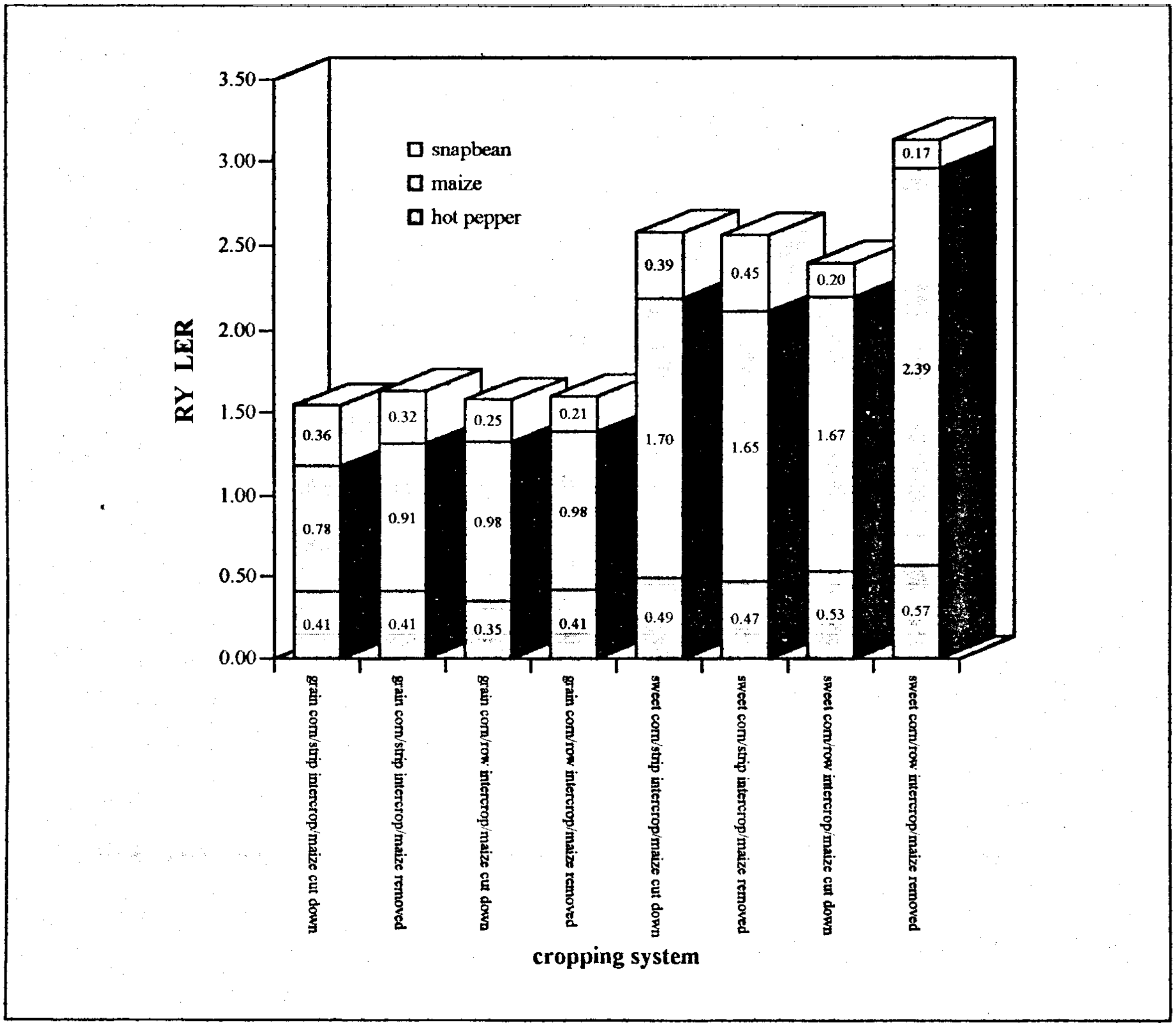
Table 27. LSD-test LER

Maize type	LER	Grouping
Sweet corn	2.67	a
Grain corn	1.59	b

F-value: 33.76

LSD(α=1%): 0.55

Figure 16. RY and LER of intercrops



Area time equivalent ratio ATER

In contrast to LER, ATER takes into consideration growth periods of individual crops in inter-cropping systems. Therefore, ATER is more suitable to compare sole crops and intercrops in this experiment. In conclusion, values for ATER were significantly lower than LERs and only treatments with sweet corn were able to exceed productivity of monocrops (Figure 17, table 28 and 29).

Figure 17. Development of ATER over time

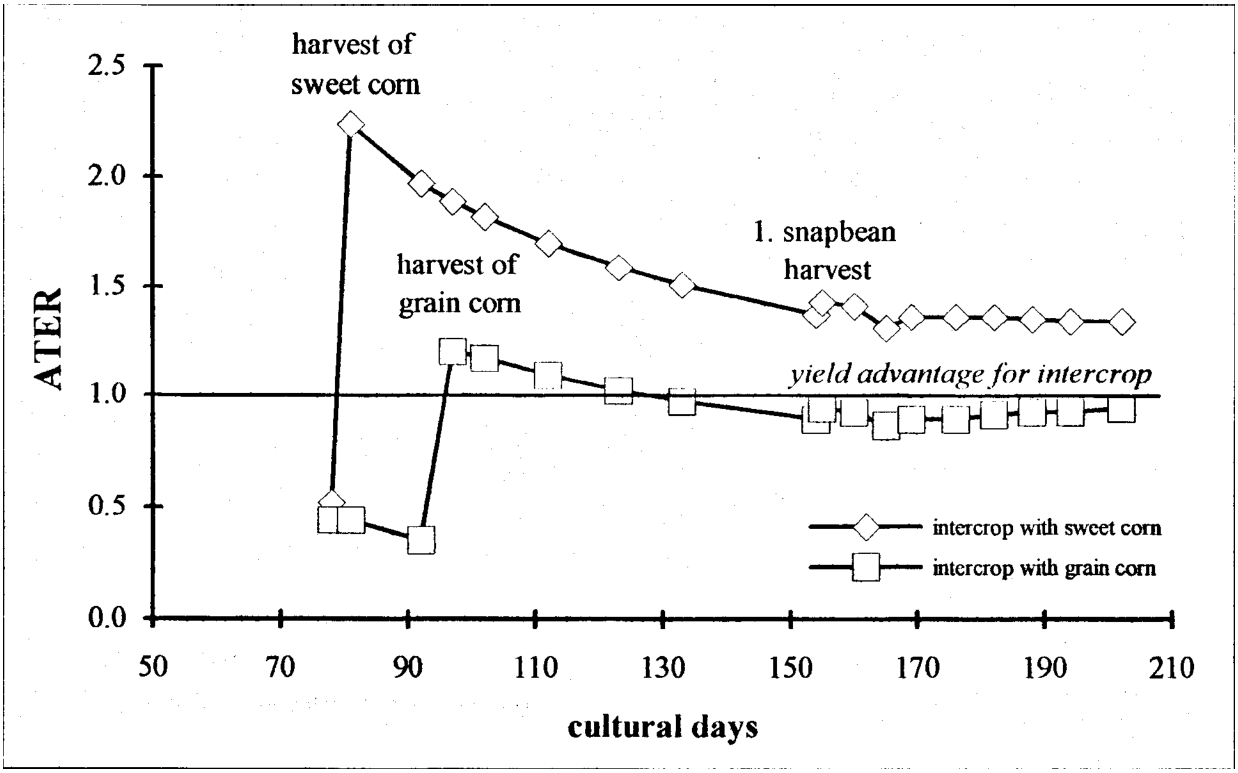


Table 28. LSD-test ATER

Maize type	ATER	Grouping
Sweet corn	1.34	a
Grain corn	0.94	b

F-value: 32.90

LSD(α=1%): 0·21

Table 29. ATER for intercrops

Maize type	Treatment Cropping system	Maize harvest	ATER
Grain corn	strip intercrop	cut down	0.93
		removed	0.97
	row intercrop	cut down	0.91
		removed	0.95
Sweet corn	strip intercrop	cut down	1.31
		removed	1.29
	row intercrop	cut down	1.24
		removed	1.54

Relative value total RVT

RVT compares returns of intercrops with the most valuable monocrop, which was in this experiment high density planting of hot pepper (double row per bed). Yields on a per ha basis have been multiplied by average monthly prices in Taiwan (TAPTC, 1991-92) in order to simulate realistic market conditions. No intercrop was able to reach the monetary value of sole hot pepper and compared to LER and ATER, influence of maize was less significant (table 30, figure 18 and 19).

Table 30. LSD-test RVT

Maize type	RVT	Grouping
Sweet corn	0.76	a
Grain corn	0.65	b

F-value: 20.76

LSD(α=1 %): 0.07

Figure 18. Development of RVT over time

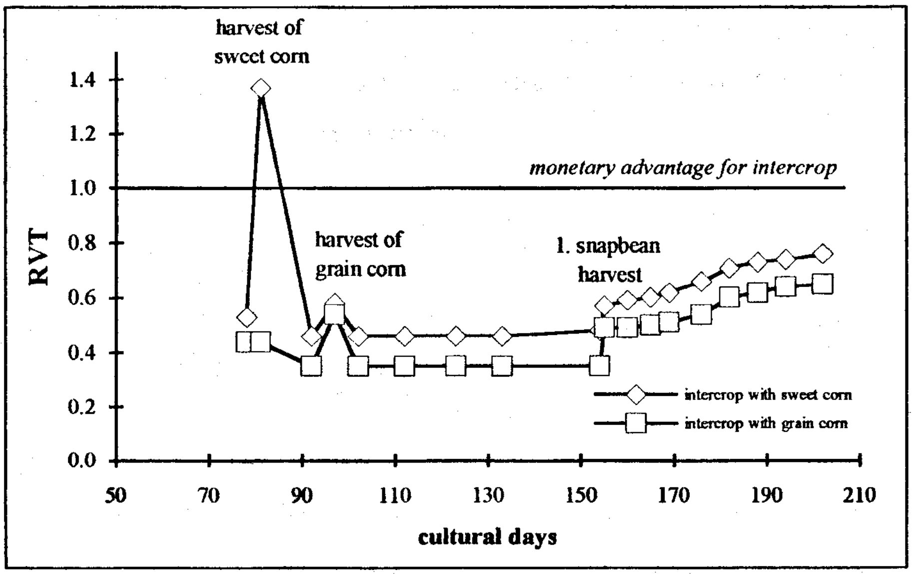
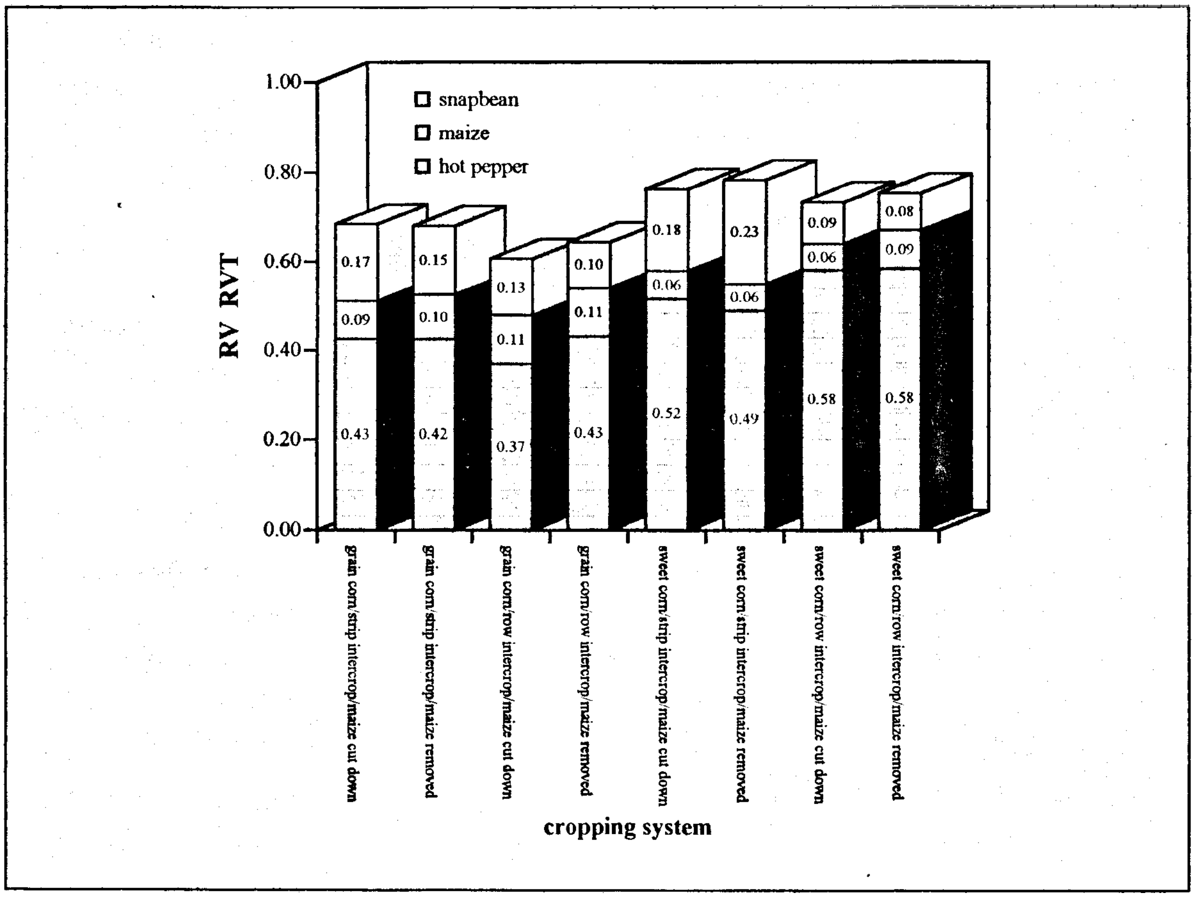


Figure 19. RV and RVT of intercrops



5. Discussion

A number of intercropping experiments with hot pepper and maize on the AVRDC farm in Taiwan aimed at reduction of cucumber mosaic virus (CMV) in peppers. Probably due to a physical barrier effect, taller grain corn was more suitable to control CMV incidence but also reduced pepper yields significantly. This was particularly true when peppers and maize were interplanted on the same bed. In a preceding experiment, vegetable soybean was intersown after maize. Monocrop yields of all vegetables were significantly higher, and within intercrops grain corn; especially when intersown on the same bed; reduced pepper yields more than sweet corn and, therefore, provided better conditions for succeeding soybean. To estimate total productivity of cropping systems, ATERs were calculated which were ranging from 0.7 to 1.2. In this experiment with snapbean, more emphasis was put on the legume crop.

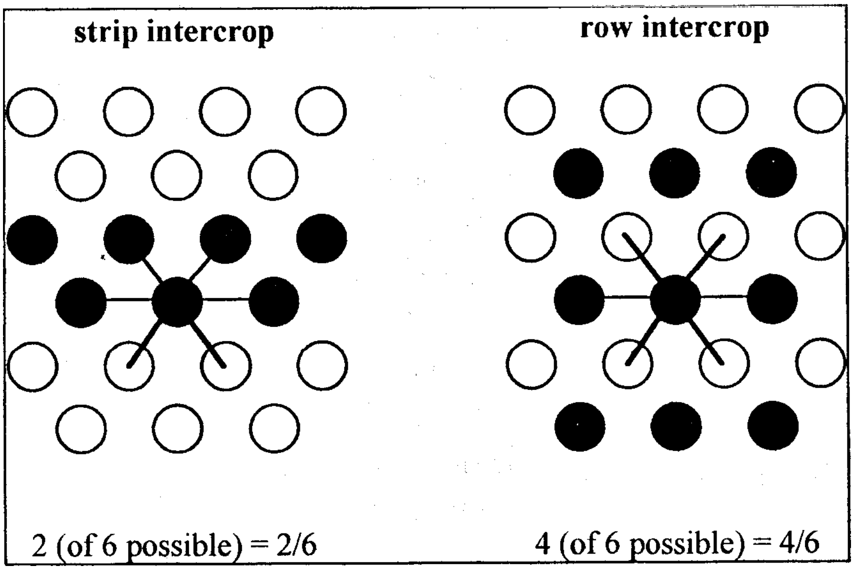
Growth analysis snapbean

Due to compensatory effects, it can be expected that a shaded plant grows taller than a non-shaded plant (elongation of internodes). Throughout the experiment, this was true for the comparison sole snapbean - intercropped snapbean in terns of plant height. Non-shaded sole snapbean grew shorter than plants intercropped with pepper. Only at 39 DAS, shading by maize residues had a significant effect on plant height of snapbean. Growth factors other than light were probably reason for the influences that type of maize and cropping systems had on snapbean plant height: at 39 DAS plants were significantly higher in plots with preceding sweet corn. At 95 DAS, however, they were taller in grain corn treatments. This was possibly due to earlier release of residual fertility in sweet corn plots (sweet corn was harvested 16 days before grain corn). Improved micro-climate (higher humidity, wind-protection) could have favoured snapbean growth when inter-cropped on alternate beds with pepper.

When intercropped on the same bed, preceding grain corn was advantageous for snapbean growth when intercropped in separate strips. However, plants were slightly higher when following sweet corn. Taller growing and higher yielding grain corn obviously competed more for growth factors than sweet corn. As a result, weakened pepper plants could not affect snap-bean growth as much they did in sweet corn plots. For strip intercrops, the reverse was true.

Dry matter production of snapbean was seriously affected by competition with pepper plants when intercropped on the same bed. Although plant populations of pepper and snapbean were the same in all intercrops, productivity of snapbean was much higher when intercropped in strips than in rows. TRENBATH (1976) argued that different species have a greater "contact frequency" when intercropped on the same ridge (Figure 20).

Figure 20. "Contact frequency" of intercrops in different row arrangements (TRENBATH, 1976)



On a per-plant basis, final biomass and total yield of snapbean in strip intercrops exceeded those in the monocrop. KIMBENGA (1987) observed the same effects in several intercrop experiments with maize and snapbean and accounted these advantages for a more favourable micro-climate.

In support of results in snapbean plant height, development of Absolute Growth Rate (AGR) confirmed the detrimental effect of sweet corn on snapbean growth when intercropped with pepper on the same ridge. The analysis also underpins positive effects of preceding grain corn on late snapbean growth (77-95 DAS).

Total leaf area (L) of snapbean plants was influenced in a similar way to total plant growth. Sole snapbean was able to build up higher total leaf area and within intercrops; preceding grain corn provided higher fertility for late snapbean growth. OKIGBO (1979) and ALLEN & OBURA (1976) gave examples (cowpea, soybean) that total leaf area more likely depends on the influence of a sum of growth factors than on availability of light alone.

Shading was apparently reason for compensatory effects in snapbean to maximise interception of limited light by building up a high Specific Leaf Area (SLA). In treatments, where plants were shaded by maize residues and adjacent pepper plants, SLA was significantly higher. TRENBATH (1976) described high rates of SLA of species in intercrops as an expression of adaptation to low light intensity.

Conclusions for differences in SLA were confirmed by analysis of available light. Snapbeans with high SLAs in treatments where maize was cut to pepper height and where the legume was intersown on the same bed as pepper received significantly less light.

Although SLA was higher in treatments where less light was available, the plants were not able to intercept it completely or use it more efficiently. Compared to strip intercropped snapbean, light loss (transmission-interception) was higher and Light Use Efficiency (LUE) lower in row-intercropping treatments. AKBOOLA & FAYEMI (1971) proofed in several experiments with maize that legumes were not able to compensate for shading.

Monocrop snapbean started fruiting earlier and total yields exceeded those of intercrops due to a 100 % higher plant density. Delayed flowering and fruiting of legume intercrops has repeatedly been observed (CABAHUG & PAVA, 1984).

Preceding sweet corn provided much better conditions for snapbean sole crop than grain corn. Longer growth period and higher biomass production of grain corn probably reduced soil fertility much more than sweet corn. Within intercrops, however, influence of the different maize types is more diverse: to achieve higher snapbean yields in the strip intercropping system, sweet corn should be chosen as preceding crop because it probably leaves greater soil fertility for succeeding snapbean. When snapbean is intercropped with peppers on the same bed, however, it is more advantageous to choose grain corn as preceding crop in order to reduce competitive ability of pepper and thereby provide a better environment for snapbean. To sum up, highest snapbean intercrop yields were achieved when plants were intercropped with pepper in separate strips.

Although only data for snapbean sole crop following grain corn was recorded, the correlation matrix yield - parameter of growth analysis indicates that availability of light was the decisive growth factor for intercropped snapbean. Adverse effects of shading were particularly true for young snapbean plants at a stage where competition for soil factors was likely to be less important.

Yields of maize and pepper

Type of maize was only secondarily important for snapbean yields but not so for maize and pepper. Grain corn yields exceeded sweet corn yields in general and within intercrops, sweet corn yielded better when intercropped with pepper on the same bed. This can lead to the conclusion that peppers were less competitive than maize.

Biomass production and yields of pepper were influenced by maize type. Grain corn was more competitive than sweet corn, and this effect was more significant for the row intercrop treatment where plants were closer in contact. CABAHUG & PAVA (1984) and AHMED & GUNASENA (1979) showed that intercropped maize is a strong competitor for soil resources and EZUMAH (1983) emphasised the strong competitive ability of taller growing corn types. Monocrop pepper yields were greater than intercrop yields. When there was no more competition following corn harvest, peppers did not show any sign of recovery or compensation.

Overall, intercrop yields for both maize types were greater when intersown on the same bed with pepper. For peppers, however, only the choice of intersown maize had a significant effect on yields. For this, sweet corn should be preferred.

Total productivity

Monocrop yields of hot pepper were superior to all other treatments. Although total number of plants was only 50 % compared to the high-density treatment, yields of low-density planting pepper reached 82 %.

Within crop sequences of maize-snapbean, the legume was able to over-compensate low yields in sweet corn monocrop, so that total combined yield was 20 % higher than in the sequence grain corn-snapbean.

Due to additional pepper yields, total productivity of almost all intercrop treatments exceeded overall productivity in crop sequences of maize and snapbean. Grain corn had apparently a detrimental effect on total yields: with exception of the row intercrop treatment, grain corn negatively affected both hot pepper and snapbean yields. Therefore, it is advantageous to choose sweet corn as intercrop.

The correlation matrix of individual or combined yields confirmed that maize yields reduced combined yields of pepper and snapbean (coefficient: -0.65). At the same time, snapbean and hot pepper yields were relatively independent (coefficient: -0.31). In this respect, SMITH & FRANCIS (1986) state that snapbean does not affect yields of intercrops due to its short life cycle.

Relative variability was lowest in high-density sole hot pepper but all intercrops showed higher stability over space than the other sole crops. This is particularly true for treatments where maize was cut down to pepper height after harvest. The results also indicate that individual yields might be less stable than their monocrop counterpart might, but variability of the whole system in itself is less.

Land Equivalent Ratios (LER) was not a suitable basis for comparing intercrops with monocrops in this experiment because pepper, maize and snapbean were not full intercrops throughout the experiment. Nevertheless, data for intercropping treatments shows a significant effect of corn type: land-use efficiency was much higher in sweet corn plots than it was in intercrops with grain corn. High levels of LER are probably due to low plant densities of maize and exceptionable low yields in sweet corn monocrop. Yields of intercropped sweet corn were up to 240 % higher than in monocrop and high RY of maize and were, therefore, the most important component of LER as a whole. According to division of land, only one intercrop treatment was able to produce more than expected 50 % of monocrop pepper yields and no RY of snapbean reached this 50 % level. In terms of LER, intercropping treatment "sweet corn/row intercrop/maize removed after harvest" was the best.

Area Time Equivalent Ratios (ATER) as a valid basis for comparing productivity of sole and intercrops indicate no advantage for grain corn intercrops but up to 54 % higher area-time productivity of sweet corn intercrops. In contrast to development of LER, ATERs were declining during the hot pepper harvest period, indicating that pepper yields in monocrops exceeded those in intercrops throughout the experiment and that peppers were not able to compensate for early competition with maize. Snapbean seemed to influence this development not at all. Compared to LER, overall productivity indicated by ATER was lower for all intercrops but differences between individual treatments were the same.

Monetary returns of maize were generally low so that in contrast to LER and ATER, this crop did not influence Relative Value Total (RVT) much. Final RVTs of all intercrops were clearly below high-density planting of sole hot pepper (= 1.0) but it is obvious that snapbean yields contributed more to the final LER than the legume. In contrast to LER and ATER, strip intercropping of hot pepper with sweet corn seemed to be more advantageous.

6. Summary

An intercropping experiment with hot pepper, maize and snapbean as succeeding crop for maize was conducted at the AVRDC farm in Taiwan from July 1991 to March 1992.

Individual crops were either intercropped on the same bed as row intercrops, or on alternate beds as strip intercrops. Participating maize types were taller, higher yielding grain corn, and sweet corn. Maize was either cut down to pepper height, or removed after harvest. Control treatments were monocrops of hot pepper with low (one row per bed) or high planting density (two rows per bed) and crop sequences of sole grain corn or sole sweet corn preceding snapbean. Fertilization and plant protection measures followed common recommendations for individual crops.

Objectives studied included: (1) determining factors influencing growth of snapbean. (2) explaining significant interactions between all three crops and (3) finding out a suitable index for comparing productivity of monocrops and intercrops.

The primary effect influencing snapbean growth was cropping system. More available light favoured snapbean intercropped with pepper in separate strips for building up higher biomass and producing greater yields than snapbean intercropped on the same bed with pepper. Growth of strip-intercropped snapbean was even better than in the monocrop most likely due to improved micro-climate. Early maturing sweet corn provided a better environment for snapbean at early plant growth whereas later harvested grain corn favoured late snapbean growth, and this might have been due to delayed release of residual fertility. Influence of maize type was more significant in an interaction with cropping systems: grain corn competed more intensively with pepper in the row intercrop treatment and, therefore, provided a better environment for succeeding snapbean. Within strip intercrops, however, sweet corn was more advantageous for snapbean growth because it presumably left higher soil fertility.

Specific Leaf Area (SLA) proofed to be a good indicator for shading in intercrops. Maize residues only had a significant shading effect on snapbean during early plant growth and SLAs were particularly high in this treatment. Total yields were not affected by shading so that it could be assumed that snapbean was able to compensate for this minor shading through maximisation of its leaf area per leaf weight. Nevertheless, this compensation seemed only to be very limited because snapbean was not able to overcome shading when intercropped with pepper on the same bed. Light Use Efficiency (LUE) was unexpectedly low and a high correlation coefficient light availability - total yield proofed that availability of light played a determining role for snapbean growth within intercrops.

High yielding grain corn was more competitive than pepper and reduced pepper yields especially when interplanted on the same bed. Even after corn harvest, peppers were not able to recover from early competition. Although grain corn provided slightly better conditions for snapbean growth within row intercrops, it had a detrimental effect on total yields and all measures for total productivity of intercrops.

Land Equivalent Ratio (LER) was not suitable to compare productivity of sole crops and intercrops but it valued intercrops in the same way Area Time Equivalent Ratio (ATER) did. ATER of grain corn intercrops was close to unity and due to low yields in sweet corn monocrops, it showed advantages for sweet corn intercrops. This was particularly true for row intercrops where maize was removed after harvest (1.54).

Relative maize yields were probably overestimated in LER or ATER, but played a less important role for final Relative Value Total (RVT). None of the intercrops were able to reach monetary returns of the high density sole hot pepper treatment.

Suitable intercrop systems of hot pepper, maize and snapbean have to be chosen according to a farmer's specific interest. Due to complex interactions, one measure cannot be taken without considering others. However, choosing grain corn as an intercrop is likely to reduce productivity of the whole system due to its strong competitive ability.

7. Literature

ADETILOYE, P.O., ADEKUNLE, A.A., 1989: Concept of monetary equivalent ratio and its usefulness in the evaluation of intercropping advantages. *Trop. Agric. (Trinidad)* 66: 337-41.

AHMED, S., GUNASENA, H.P.M. 1979: N utilization and economics of some intercropped systems in tropical countries. *Trop. Agric. (Trinidad)* 115-23.

AKBOOLA. A.A., FAYEMI. A.A. 1971: Preliminary trials on the intercropping of maize with different tropical legumes in western Nigeria. *J. agric. Sci., Camb.* 77: 219-25.

ALLEN, J.R., OBURA. R.K. 1976: Yield of corn, cowpea, and soybean under different intercropping systems. Annual report. lnternational Rice Research lnstitute (IRRI). Los Banos, Philippines: 1005-9.

ALLEN, L.H., SINCLAIR, T.R., LEMON, E.R. 1976: Radiation and microclimate relationships in multiple cropping systems. In Papendick, R.I., Sanchez. A., Triplett. G.B. (eds.): Multiple cropping. ASA (American Society of Agronomy) Spec. Pub. 27: 171-200.

ALTIERI. M.A., SCHOONHOVEN VAN. A., DOLL. J. 1977: The ecological role of weeds in insect pest management systems: A review illustrated by bean *(Phaseolus vulgaris)* cropping systems. *PANS* 23(2): 195-205.

ALTIERI, M.A., LIEBMAN, M. 1986: lnsect, weed, and plant disease management in multiple cropping systems. In Francis. C.A. (ed.): Multiple cropping systems. Macmillan. New York: 183-218.

ANDREWS. D.J., KASSAM, A.H. 1976: The importance of multiple cropping in increasing world food supplies. In Papendick, R.I., Sanchez, A., Triplett, G.B. (eds.): Multiple cropping. ASA (American Society of Agronomy) Spec. Pub. 27: 1-10.

ANDREWS, R.E., NEWMAN. E.I. 1970: Root density and competition for nutrients. *Ecol. Plant. Gauthier-Villars 5: 319-34.*

ASHOKAN, P.K., VIKRAMAN NAIR, R., SUDHAKARA, K. 1985: Studies on cassava-legume intercropping systems for the Oxisols of Kerala State, lndia. *Trop. Agric.* (Trinidad) 62(4): 313-18.

AVRDC 1992: 1991 Progress report. Asian Vegetable Research and Development Center. Shanhua, Tainan.

AYENI, A.O., DUKE. W.B., AKOBUNDU, I.O. 1984: Weed interference in maize, cowpea, and maize/cowpea intercrop in a subhumid tropical environment. I. Influence of cropping season. *Weed Research 24:* 269-79.

BARKER, T.C., FRANCIS, C.A. 1986: Agronomy of multiple cropping systems. In Francis, C.A. (ed.): Multiple cropping systems. Macmillan. New York: 161-82.

BÄTZ, G., DORFEL, H., FUCHS, A., THOMAS. E. 1987: Einführung in die Methodik des Feldversuchs. VEB Deutscher Landwirtschaftsverlag, Berlin.

BENDER. F.E., DOUGLAS, L.W., KRAMER, A. 1982: Statistical methods for food and agriculture. AVI Publishing Company, Westport, Connecticut.

BERG VAN DEN. J.P. 1968: An analysis of yields of grasses in mixed and pure stands. *Versl. Landbouwkd Onderz* 714: 1-71.

BHATNAGAR, V.S., DAVIES, J.C. 1981: Pest management in intercrop subsistence farming. In Willey. R.W. (ed.): Proceedings of the lnternational Workshop in lntercropping. ICRISAT, Hyderabad, India: 249-57.

BISHNOI, K.C., SINGH, B., SINGH. A. 1987: Studies on compatibility of greengram and blackgram cultivars in pigeonpea based intercropping systems. *Indian J. Agron.* 32(2): 127-9.

BORUAH, A.R., HAZARIKA, B.D., PAUL, A.M. 1984: Multiple cropping under rainfed conditions. *Indian J. Agron.* 29(1): 46-50.

BOSCH VAN DEN, F.G.J.M. 1987b: Indonesian mungbean landraces. Il. Comparison of performance. components of variance and selection for grain yield under wide row-spacing in monoculture and when intercropped with maize. *Euphytica* 36*:* 791-801.

BOSCH VAN DEN, F.G.J.M. 1987a: Indonesian mungbean landraces. I. Pure-line selection for yield when intercropped with maize. *Euphytica* 36: 783-90.

BRADFIELD. S. 1986: Sociocultural factors in multiple cropping. In Francis. C.A. (ed.): Multiple cropping systems. Macmillan. New York: 267-84.

CABAHUG, G.B., PAVA. H.M. 1984: Influence of inoculant and inoculant-fertilizer combination on five mungbean cultivars *(Vigna radiata L.)* under monoculture and intercropped with corn *(Zea mays L.). CMU Journal of Agriculture, Food and Nutrition* 6(3): 162-200.

CERVANCIA, C.R., REJESUS, R.S. 1984: Soybean insect pest abundance and succession in different cropping combinations. *Philipp. Ent.* 6(1): 47-64.

CHANDEL, A.S., PANDEY. K.N., SAXENA, S.C. 1989: Symbiotic nitrogen fixation and nitrogen benefits by nodulated soybean (*Glycine max* (L.) Merrill) to interplanted crops in northern lndia. *Trop. Agric. (Trinidad)* 66(1): 73-7.

CHANDEL, A.S., SINGH. V.K., SAXENA. S.C. 1987: Suitability of soybean varieties for maize+soybean intercropping. *Indian Journal of Agricultural Sciences* 75(5): 330-5.

CHAVEZ, V.P., MENDOZA. T.C. 1986: Seed quality of three field legumes as affected by sugarcane intercropping. *Philipp. J. Crop Sci.* 11(1): 61-66.

COMMITTEE FOR THE WORLD ATLAS OF AGRICULTURE 1973: World Atlas of Agriculture. Instituto Geografico de Agostini, Novara.

CROOKSTON, R.K. 1976: Intercropping: A new version of an old idea. *Crops and Soils* 28: 7-9.

DAHIYA, D.R., RAO, P. 1985: Returns from weed management in pigeonpea. *International Pigeonpea Newsletter* 4: 24-5.

DAVIS, J.H.C., WOOLLEY, J.N., MORENO, R.A. 1986: Multiple cropping with legumes and starchy pots. In Francis. C.A. (ed.): Multiple cropping systems. Macmillan, New York: 133-60.

DISSEMOND, A. 1987: Der Einfluß von Mischkulturen aus Sorghum, Mais und Vigna auf den Be-ill durch Schädlinge. Krankheiten und Unkräuter in Kenia. (Diss.) Hohe Landwirtschaftliche Fakultät. Rheinische Friedrich-Wilhelms-Universität zu Bonn, Bonn.

EZUMAH. H.C. 1983: Maize/cowpea intercropping. In Annual report. lnt. Inst. Trop. Agr. (IITA), Ibadan, Nigeria: 167-8.

FISHER. N.M. 1977b: Studies in mixed cropping. II. Population pressures in maize-bean mixtures. *Expl. Agric.* 13: 185-91.

FISHER. N.M. 1977a: Studies in mixed cropping. I. Seasonal differences in relative productivity of crop mixtures and pure stands in the Kenya highlands. *Expl. Agric.* 13: 177-84.

FRANCIS, C.A., FLOR. C.A., TEMPLE, S.R. 1976: Adapting varieties for intercropping systems in the tropics. In Papendick, R.I., Sanchez. A., Triplett, G.B. (eds.): Multiple cropping. ASA (American Society of Agronomy) Spec. Pub. 27: 235-53.

FRITZ, D., STOLZ. W. 1989: Gemüsebau. Eugen Ulmer Verlag, Stuttgart.

GEISSLER. E., LIBBERT, E., NITSCHMANN, J., THOMAS-PETERSEIN, G. (eds.) 1981: Kleine Enzyklopädie Leben. VEB Bibliographisches Institut, Leipzig.

GHOSH, R.K., DASGUPTA, B., BARAL, K. 1986: Intercropping of direct seeded upland rice with legumes. *Indian J. Agron.* 31(3): 293.

GIRI, G., DE. R. 1978: Intercropping of pigeonpea with other grain legumes under semiarid rain-fed conditions. *Indian J. agric. Sci.* 48(11): 659-65.

GLIESSMAN. S.R. 1986: Plant interactions in multiple cropping systems. In Francis. C.A. (ed.): Multiple cropping systems. Macmillan, New York: 82-95.

GOMEZ, A.A., GOMEZ. K.A. 1983: Multiple cropping in the humid tropics of Asia. Int. Dev. Res. Centre, Ottawa. Canada.

GÖTTSCHE, T. 1990: Einführung in das SAS-System für den PC. Gustav Fischer Verlag. Stuttgart.

GOVINDEN. N., ARNASON, J.T., PHILOGENE, B.J.R., LAMBERT, J.D.H. 1984: Intercropping in the tropics: Advantages and relevance to the small farmer. *Canadian J. Dev. Studies* 5: 213-32.

HALL, R.L. 1974: Analysis of the nature of interference between plants of different species. I. Concepts and extension of the de Wit analysis to examine effects. *Aust. J. Agric. Res.* 25: 739-47.

HART, R.D. 1986: Ecological framework for multiple cropping research. In Francis, C.A. (ed.): Multiple cropping systems. Macmillan, New York: 40-56.

HART. R.D. 1975: A bean, corn and manioc polyculture cropping system. *Turrialba* 25(3): 294-301.

HARWOOD. R.R., PRICE. E.C. 1976: Multiple cropping in tropical Asia. In Papendick, R.I., Sanchez, A., Triplett, G.B. (eds.): Multiple cropping. ASA (American Society of Agronomy) Spec. Pub. 27: 11-40.

HAYSTEAD. A. 1983: The efficiency of utilization of biologically fixed nitrogen in crop production systems. In Jones. D.G., Davies, D.R. (eds.): Temperate legumes: Physiology, genetics, and nodulation. Pitman Adv. Publ. Program, Boston: 395-415.

HIEBSCH, C.K. 1980: Principles of intercropping: Effects of nitrogen fertilization. plant population and crop duration on equivalency ratios in intercrop versus monoculture comparisons. (Diss.), Raleigh. U.S.A.

HILDEBRAND. P.E. 1976: Multiple cropping systems are dollars and 'sense' agronomy. In Papen-dick, R.I., Sanchez, A., Triplett. G.B. (eds.): Multiple cropping. ASA (American Society of Agronomy) Spec. Pub. 27: 347-71.

HUNG. A.T., CHENG, J.H., MA, C.H., KOBAYASHI, H. 1991: Effect of fertilizer management and rhizobia inoculation on yield and quality of vegetable soybean. In Shanmugsundaram, S. (ed.): Vegetable soybean: Research needs for production and quality improvement. Asian Vegetable Research and Development Center (AVRDC), Shanhua. Tainan: 73-84.

HUNT. R. 1978: Plant growth analysis. Studies in Biologie No. 96, Edward Arnold. London.

HUXLEY, P.A., MAINGU. Z. 1978: Use of a systematic spacing design as an aid to the study of inter-cropping: Some general considerations. *Expl Agric.* 14: 49-56.

KASS, D.C. 1978: Polyculture cropping systems: Review and analysis. Cornell Int. Agr. Bull. No. 32.

KIMBENGA. A. 1987: Artenwahl und Anbauverfahren im Mischfruchtanbau unter geographisch differenzierten Anbaubedingungen (Berlin-West/Deutschland, Bornova-Izmir und Sasun/Türkei und Brazzaville/Kongo). (Diss.) Fachbereich lnternationale Agrarentwicklung, Technische Universität Berlin.

KRUG. H. 1991: Gemüseproduktion. Verlag Paul Parey. Berlin.

KUO, C.G., HUANG, R.S. 1982: Effect of vesicular-arbuscular mycorrhizae on the growth and yield of rice-stubble cultured soybeans. *Plant and Soil* 64: 325-30.

LITSINGER, J.A., MOODY, *K. 1976:* lntegrated pest management in multiple cropping systems. In Papendick, R.I., Sanchez. A., Triplett, G.B. (eds.): Multiple cropping. ASA (American Society of Agronomy) Spec. Pub. 27: 293-316.

LYNAM, J.K., SANDERS, J.H., MASON, S.C. 1986: Economics and risk in multiple cropping. In Francis, C.A. (ed.): Multiple cropping systems. Macmillan, New York: 250-66.

MAHMUD, Z., RUMAWAS, F., SUSENO, H., KOSWARA, J., ANWAR NUR, M., SOLAHUDDIN, S. 1985: Release of nitrogen from root nodules of soybean, Glycine max (L.) Merril. *Forum Pascasarjana* 8: 39-57.

MANDAL. B.K., DHARA, M.C., MANDAL, B.B., DAS. S.K., NANDY, *R. 1990:* Rice, mungbean, soybean, peanut. ricebean, and blackgram yields under different intercropping systems. *Agron. J.* 82: 1063-6.

MARTIN. R.C., THOR ARNASON, J., LAMBERT. J.D.H., ISABELLE. P., VOLDENG, H.D., SMITH, D.L. *1989:* Reduction of European corn borer (Lepidoptera: Pyralidae) damage by intercropping corn with soybean. *J. Econ. Entomol. 82(5): 1455-9.*

MEAD. R. 1986: Statistical methods for multiple cropping. In Francis, C.A. (ed.): Multiple cropping systems. Macmillan. New York: 317-50.

MEAD, R. 1980: The concept of a 'Land Equivalent ratio' and advantages in yields from intercropping. *Expl Agric.* 16: 217-28.

MILTHORPE. F.L., MOORBY, J. 1978: An introduction to crop physiology. Cambridge University Press. Cambridge.

NAIR, K.P.P., PATEL, U.K., SINGH. R.P., KAUSHIK, M.K. 1979: Evaluation of legume intercropping in conservation of fertilizer nitrogen in maize culture. *J. agric. Sci., Camb.* 93: 189-94.

NEEF, E. 1981: Das Gesicht der Erde. Haari Deutsch Verlag, Thun.

NOE, J.P. 1988: Theory and practice of the cropping systems approach to reducing nematode problems in the tropics. *Journal of Nematology* 20(2): 204-13.

NORMAN, D.W. 1974: Rationalizing mixed cropping under indigenous conditions: The example of northern Nigeria. *J. Devel. Stud* 1: 3-21.

NORMAN. D.W. 1977: The rationalization of intercropping. *African Env.* 2/3: 97-109.

OELSLIGLE. D.D., MCCOLLUM, R.E., KANG, B.T. 1976: Soil fertility management in tropical multiple cropping. In Papendick, R.I., Sanchez. A., Triplett, G.B. (eds.): Multiple cropping. ASA (American Society of Agronomy) Spec. Pub. 27: 275-92.

OKIGBO, B.N., GREENLAND, D.J. 1976: lntercropping systems in tropical Africa. In Papendick. R.I., Sanchez. A., Triplett. G.B. (eds.): Multiple cropping. ASA (American Society of Agronomy) Spec. Pub. 27: 63-102.

OKIGBO. B.N. 1979: Evaluation of plant interactions and productivity in complex mixtures as a basis for improved cropping systems design. In Proceedings of the lnternational Workshop on Intercropping. International Crops Research Institute for the Semi-arid Tropics (ICRISAT), Hyderabad, India: 155-81.

OLASANTAN. F.O. 1985: Effects of intercropping. mulching, and staking on growth and yield of tomatoes. *Expl Agric.* 21: 135-44.

PANDEY. R.K., PENDLETON. J.W. 1986: Soyabeans as green manures in a maize intercropping system. *Expl Agric.* 22: 179-85.

PARKHURST, A.M., FRANCIS, C.A. 1986: Research methods for multiple cropping. In Francis, C.A. (ed.): Multiple cropping systems. Macmillan, New York: 285-316.

PCARRD 1984: Rainfed agriculture in perspective. Philippine Council for Agriculture and Re-sources Research and Development, Los Banos, Philippines.

PEARCE. S.C., GILLIVER. B. 1978: The statistical analysis of data from intercropping experiments. *J. agric. Sci., Camb.* 91: 625-32.

PEARCE. S.C., EDMONDSON, R.N. 1982: Historical data as a guide to selecting systems for inter-cropping two species. *Expl Agric.* 18: 353-62.

PERFECTO. I., HORWITH, B., VANDERMEER. J., SCHULTZ. B., MCGUINNESS, H., DOS SANTOS, A. 1986: Effects of plant diversity and density on the emigration rate of two ground beetles, Harpalus pennsylvanicus and Evarthrum sodalis (*Coleoptera*: *Carabidae*), in a system of tomatoes and beans. *Environmental Entomology* 15(5): 1028-31.

PINCHINAT. A.M., SOMA. J., BAZAN, R. 1976: Multiple cropping in tropical America. In Papen-dick, R.I., Sanchez, A., Triplett, G.B. (eds.): Multiple cropping. ASA (American Society of Agronomy) Spec. Pub. 27: 51-61.

PLUCKNETT, D.L., SMITH. N.J.H. 1986: Historical perspectives on multiple cropping. In Francis. C.A. (ed.): Multiple cropping systems. Macmillan. New York: 20-39.

PRASAD, A., PARASHAR. K.S. 1989: Harvest full bag of mung from spring-planted sugarcane. *Indian Farming* 39(7): 43-5.

PRASAD. K., GAUTAM, R.C., MOHTA, N.K. 1985a: Studies on weed control in arhar and soybean as influenced by planting patterns, intercropping and weed control methods. *Indian J. Agron.* 30(4): 434-9.

PRASAD. K., GAUTAM. R.C., MOHTA. N.K. 1985b: Effect of planting patterns and weed control methods on growth characters, yield and yield attributes of arhar intercropped with soybean. *Indian J. Agron.* 30(4): 429-33.

PUTNAM. D.H., HERBERT. S.J., VARGAS. A. 1985: Intercropped corn-soybean density studies. I. Yield complementarity. *Expl. Agric.* 21: 41-51.

RADKE, J.K., HAGSTROM, R.T. 1976: Strip intercropping for wind protection. In Papendick, R.I., Sanchez. A., Triplett. G.B. (eds.): Multiple cropping. ASA (American Society of Agronomy) Spec. Pub. 27: 201-22.

RADOSEVICH. S.R., WAGNER, R.G. 1986: Predicting effects of modified cropping systems: Forestry examples. *HortScience* 21(3): 413-18.

RAJU. M.S., DEVI. B.R., REDDY. S.N., RAMAIAH. N.V., REDDY. G.V. 1986: Study on intercropping pigeonpea with low canopy legumes under rainfed conditions. *J. Res. APAU* 14: 72-4.

RAO. M.R. 1986: Cereals in multiple cropping. In Francis, C.A. (ed.): Multiple cropping systems. Macmillan, New York: 96-132.

REHM. S., ESPIG, G. 1984: Die Kulturpflanzen der Tropen und Subtropen. Ulmer Verlag, Stuttgart.

ROSSET, P.M., AMBROSE. R.J., POWER, A.G., HRUSKA, A.J. 1984: Overyielding in polycultures of tomato and bean in Costa Rica. *Trop. Agric. (Trinidad)* 61(3): 208-12.

RUSSELL. J.T., CALDWELL. R.M. 1989: Effects of component densities and nitrogen fertilization on efficiency and yield of a maize/soyabean intercrop. *Expl. Agric.* 25: 529-40.

SAS INSTITUTE 1989: SAS/STAT User's Guide Version 6. SAS lnstitute lnc., Cary NC.

SCHULTZ, B., PHILIPPS, C., ROSSET, P., VANDERMEER, J. 1982: An experiment in intercropping cucumbers and tomatoes in southern Michigan, U.S.A. *Scientia Horticulturae* 18: 1-8.

SENGUPTA. K., BHATTACHARYYA. K.K., CHATTERJEE. B.N. 1985: lntercropping of upland rice with blackgram (Vigna mungo L.). *Journal of Agricultural Science* 104(1): 217-21.

SHARMA, B.M., SHARMA. V.K., KUMAR. V. 1984: An economic analysis of farm income, labour employment and credit needs under multiple-cropping system in Delhi region. *Indian J. agric. Sci.* 54(7): 590-8.

SHARMA, S.K., MEHTA, H. 1988: Effect of cropping system on genetic variability and component analysis in soybean. *Field Crops Research* 19: 103-11.

SIDDOWAY, F.H., BARNETT, A.P. 1976: Water and wind erosion control aspects of multiple cropping. In Papendick, R.I., Sanchez. A., Triplett. G.B. (eds.): Multiple cropping. ASA (American Society of Agronomy) Spec. Pub. 27: 317-35.

SINGH. N.B., SINGH, P.P. 1984: Effect of intercropping with legumes on grain yield of maize and its residual effect on succeeding wheat. *Indian J. Agron.* 29(3): 295-8.

SINGH, N.B., SINGH, P.P., NAIR, K.P.P. 1986: Effect of legume intercropping on enrichment of soil nitrogen, bacterial activity and productivity of associated maize crops. *Expl Agric.* 22: 339-44.

SINGH. R.C., FARODA, A.S., SINGH. H. 1986: Response of pigeonpea to phosphate fertilization under different cropping *systems*. *Indian J. Agron.* 31(3): 244-7.

SMITH, M.E., FRANCIS, C.A. 1986: Breeding for multiple cropping systems. In Francis, C.A. (ed.): -Multiple cropping systems. Macmillan, New York: 219-49.

SINGH. K., VERMA, R.P., YADAV, R.L. 1985: Have more income from autumn-planted sugarcane. *Indian Farming* 35(2): 3-5.

SUWANARIT. A., VERASAN. V., SUWANNARAT. C., CHAOCHONG, S. 1984: Comparative water uses of maize-mungbean intercrop. sole maize, and sole mungbean. *Kasetsart J. (Nat. Sci.)* 18: 117-21.

SUWANARIT, A., SUWANNARAT, C., CHOTCHUNGMANEERAT, S. 1985: ^{15}N-aided studies on N-placement and amount of nitrogen fixed by mungbean in maize-mungbean intercrop. *Thai J. Agric. Sci.* 18: 1-16.

SUWANNARAT. C., WAJANANAWAT. W. 1987: Effects of sources of phosphorus fertilizer on crop yields in rice-soybean double cropping. *Kasetsart Journal* 21: 93-101.

TAPTC 1991-92: Monthly report on vegetable and fruit transportation. (chin.) Taipei Agric. Prod and Transp. Company 199-207.

TEASDALE. J.R., DEAHL, K.L. 1987: Performance of four tomato cultivars intercropped with snapbeans. *HortScience* 22(4): 668-9.

THAKUR, R.C., BORA, U.C. 1987: Effect of planting geometry in maize+blackgram intercropping system. Indian J. Agron. 32(1): 91-2.

TRENBATH. B.R. 1976: Plant interactions in mixed plant communities. In Papendick, RI., Sanchez. A., Triplett, G.B. (eds.): Multiple cropping. ASA (American Society of Agronomy) Spec. Pub. 27: 129-69.

TRENBATH. B.R. 1981: Light-use efficiency of crops and the potential for improvement through intercropping. In Willey. R.W. (ed.): Proceedings of the lnternational Workshop in lntercropping. ICRISAT, Hyderabad, India: 249-57.

TRENBATH, B.R. 1986: Resource use by intercrops. In Francis, C.A. (ed.): Multiple cropping systems. Macmillan, New York: 57-81.

TRENBATH, B.R. 1974: Biomass productivity of mixtures. *Adv. Agron.* 26: 177-210.

UNGER. P.W., STEWART, B.A. 1976: Land preparation and seedling establishment practices in multiple cropping systems. In Papendick, R.I., Sanchez, A., Triplett, G.B. (eds.): Multiple cropping. ASA (American Society of Agronomy) Spec. Pub. 27: 255-73.

VANDERMEER, J. 1989: The ecology of intercropping. Cambridge University Press. Cambridge.

VANDERMEER, J. 1981: The interference production principle: An ecological theory for agriculture. Bioscience 31: 361-4.

VANDERMEER, J. 1986: A computer-based technique for rapidly screening intercropping designs. *Expl Agric.* 22: 215-32.

VANDERMEER. J., AMBROSE. R., HANSEN. M., MCGUINESS. H., PERFECTO. I., PHILLIPS. C., ROSSET. P., SCHULTZ. B. 1984: An ecologically-based approach to the design of intercrop agroecosystems: An intercropping system of soybeans and tomatoes in southern Michigan. *Ecological Modelling 25:* 121-50.

VANDERMEER. J. 1984: The interpretation and design of intercrop systems involving environmental modification by one of the components: A theoretical framework. *Biological Agriculture and Horticulture* 2(2): 135-56.

VEEVERS. A., ZAFAR-YAB. M. 1980: Balanced designs for two-component competition experiments on a square lattice. *Euphytica* 29: 459-464.

WESTERMANN VERLAG 1973: Lexikon der Geographie. Georg Westermann Verlag, Braunschweig.

WILES. L.J., WILLIAM. R.D., CRABTREE. G.D., RADOSEVICH, S.R. 1989: Analyzing competition between a living mulch and a vegetable crop in a interplanting system. *J. Amer. Soc. Hort. Sci.* 114(6): 1029-34.

WILLEY. R.W., OSIRU. D.S.O. 1972: Studies on mixtures of maize and beans (Phaseolus vulgaris) with particular reference to plant population. *J. Agr. Sci., Cambridge* 79: 519-29.

WILLEY, R.W. 1985: Evaluation and presentation of intercropping advantages. *Expl Agric.* 21: 119-33.

WIT DE. C.T. 1960: On competition. *Vers. Landbouwkd Onderz* 66(8): 1-82.

YADAV, R.L., PRASAD. S.R., SINGH, K. 1987: Fertilizer requirement and row arrangement of pulses in sugarcane based intercropping *systems. Indian J. Agron.* 32(1): 80-4.

YADURAJU. N.T., GAUTAM, K.C., MANI, V.S. 1986: Studies on weed control in maize based intercropping *system. Indian J. Agron.* 31(3): 240-3.