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FINAL REPORT

THE WINGED BEAN IN TROPICAL CROPPING SYSTEMS

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INTRODUCTION

Worldwide interested in the winged bean (Psophocarpus tetragonolobus (L) DC) has grown rapidly since 1975 when a National Academy of Sciences panel (NAS, 1975, 1981) released its report extolling the virtue and potentials of this hitherto underutilized and little-known crop. The winged bean's potential contribution to human nutrition in tropical countries is a result of the facts that virtually all of the plant's parts, seeds, leaves, flowers, pods and fleshy roots, (Figure 1) are edible and the protein contents of these are exceptionally high (Hymowitz, 1977). Yield data in the literature suggest that the total amount of protein that can be produced per hectare by winged beans is very large, although the time period required for these yields is rarely specified. As a member of the legume family, winged bean has the additional advantage of not requiring expensive fossil fuel based nitrogen fertilizer.

The winged bean has been observed to be singularily tolerant of adverse conditions found in the humid tropics, including pests, diseases, and soil acidity Recent work (Weil and Khalil, 1986) has shown that the species is more tolerant of soil salinity than many soybean cultivars and may have a role to play in coastal or semi-arid tropical environments, as well.

The current state of our knowledge about production technology for winged beans is somewhat akin to what it was for soybeans in the 1920's (NAS, 1981). The basic technology of crop and soil management for the winged bean remains to be worked out before the crop can achieve its potential. Up until now, the winged bean has been produced as a home or market garden crop by traditional methods in widely scattered areas of tropical Asia and Africa. It is usually grown in small patches or on the margins of cultivated fields. If the economic and nutritional potentials of this crop are to be realized,

Figure 1. Two of the edible parts of the winged bean. A green pod cut in crossection to show its 'wings' (A) and the fleshy roots (B) are of two different field-grown 'SLS-40' winged bean plants.

techniques must be developed for better integrating winged beans into overall cropping systems and growing them more efficiently, at higher yield levels and on a larger scale.

Most of the developing countries lie within the zone of potential adaptation of winged bean. The poor rely on vegetable sources for the bulk of their dietary protein. The winged bean could substantially improve the protein (and vitamin) content of low-income diets (Cerny, K., et al., 1971). The crop could provide additional cash income to small farmers. Winged bean seed could also mean additional foreign exchange and feed stuff for indigenous animal industries if the agronomic techniques of producing it efficiently on a large scale are developed.

Intercropping and the Winged Bean

Many small farmers have traditionally grown crops in mixtures of several species rather than as monocultures (Gomez and Gomez, 1983). The pure stand monoculture favored by large scale Western agriculture has the advantages of simplicity of management and harvest. Conditions can be optimized for the sole crop and mechanical harvesting (whether by scythe or combine) does not have to contend with different kinds of plants at different stages of maturity. On the other hand, mixed cropping has several attributes which make this system attractive to small farmers.

Compared to monoculture, mixed cropping is not as susceptible to devasting disease or pest outbreaks (Steiner, 1984). The more complex plant community slows the spread of destructive organisms since the plant neighboring a given host plant is likely to be a non-host species. The more diverse animal and microbial communities in a mixed crop stand also are likely to harbor natural enemies that help keep pests in check.

Mixed crop stands are also perceived as being more reliable yielders during seasons with periods of adverse weather (Steiner, 1984). The bad weather may come at a time that is critical in the development of one of the crops but not for the others. Thus, total crop failure is less likely as one or more of the crops is likely to give at least some yeild. This advantage would also be realized if the same crops were grown simultaneously by the farmer but on separate plots of land. Stability and security associated with mixed cropping is very important to small farmers who are without access to credit and who may depend upon their crops for their year to year food supply as well as for cash income.

Recent research (Willey, 1979) supports the idea that mixed cropping may not only be more secure and stable than mono-cropping, but it may be a more efficient use of land as well. That is, the total economic yield from a plot of ground planted to several crops in a mixture is often greater than the combined yield of the crops grown in separate portions of that same plot. This may be due to a number of effects such as: 1) better utilization of light, water and nutrients by the combination of plants with different morphologies and growth habits; 2) positive allelopathic effects of one species on another; 3) possible supply of nitrogen from legumes to non-legumes; 4) physical support for indeterminate, viney plants by more erect self-supporting plants; and 5) the ecological benefits discussed above.

Since winged bean has a twining growth habit (Purseglove, 1968), yield improvements by providing supports have been reported by Khan (1978), Anon (1980), and Karikari (1981). Reports from Ghana (Pospisil, et al., 1971), Nigeria and Papua, New Guinea (Rachie, 1974), have shown between 2.3 and 4.6 fold increases in leaf area, and better distribution and display of foliage leading to greater photosynthetic capacity (Wong, 1978; Chandrasegaram and

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jute, soybean, and Sesbania sp. in Pakistan was not successful due to several agronomic problems (Aslam, 1981).

Thirikethesswaran and Senanayake (1981) studied the pod yielding ability of winged bean as a fresh vegetable when mixed with bush and pole beans, (Phaseolus vulgaris). They found that the winged bean yield was reduced by 3% and 20% relative to monocrop yield when mixed with bush beans/ pole beans, respectively. Bushbean and pole bean yields were reduced by 5% and 15%. On the other hand, in terms of total protein productivity, winged beans and pole bean mixture recorded the highest yield. When three crops were mixed, the yields of component crops were severely reduced. It was evident that the relative yield performance of the mixed crops varied in relation to growth duration and growth habit of the component crops.

Legume-Based Crop Rotation

The outstanding feature of leguminous crops is their unique ability to utilize atmospheric nitrogen. This results in highly desirable consequences: 1) Legumes are exceptionally high in protein content. 2) Legumes do not require as much expensive nitrogen fertilizers as required by other crops. 3) In some cases, legumes can enrich the soil with nitrogen to the benefit of other crops grown with or following the legume. The first two of these consequences are known to be true of winged beans. About the third, little is known with respect to winged bean cultivation.

Research in both temperate and tropical zones has documented the practicality of growing legumes to help supply the nitrogen needs of non-leguminous crops in rotation (Okigbo B.N., 1973). Maximum soil enrichment is achieved if the legume is grown as a green manure and the entire plant is incorporated into the soil before its maturity. However, farmers are reluctant to adopt this technique because it requires the investment of time

and resources into the production of a crop without obtaining a harvest from the land that season. More likely to be adopted is the use of the legume in a rotation in which the legume crop is grown to maturity and harvested. Depending on which legume is grown, a benefit may still result, though a lesser one, to the following crop. Some legume crops such as pigeon pea (Cajanus cajan) or lucerne (Meticago sativa) are capable of supplying large amounts of nitrogen to succeeding crops (Hesteran, et al. 1986; Sprague, 1975). Others such as groundnuts supply only moderate amounts. Soybeans supply very little, if any nitrogen, to following crops and most varieties of phaseolus beans deplete the soil of nitrogen rather than enrich it. It is not known to which of these categories winged beans belong.

Only one reference was found in the literature on the use of the winged bean in rotation with other crops or as a fertility building green manure crop. Khan (1982) cites work in Ghana by Sinnadurai which showed that a winged bean crop increased soil N levels and thereby benefited a subsequent tomato crop. In the same review, Khan called for more field studies on this subject. Preliminary studies have been done on cultivation of winged bean as a ground cover (Karikari, 1969; Mendham, 1971; Paul, 1953, Soepadiyo, 1973; and Tong et al., 1961) but no detailed studies have been carried out yet. Senenayake (1976) proposed winged bean as a ground cover for rubber and cocoa. Alvim (1977) proposed it as a cover of oil palm plantations in Brazil. It is presently grown as a ground cover in rubber, tea, oil palm, coconut, citrus, and other perennial tree crops in Ghana (Karikari, 1981). Its potential as a cover crop in Honduras and Ghana has also been reported by Anon (1977) and Karikari and Appiah (1981). If successful crop rotations are developed, winged bean may enhance the soil fertility by providing adequate nutrients, especially nitrogen, to subsequent cereal crops.

Research Objectives

With the above principles in mind, a series of experiments were conducted in the field and in the greenhouse to...

1. evaluate the feasibility and potential advantages and disadvantages of growing winged beans in mixed cropping systems, including competitive and allelopathic effects and the use of companion crops as "living stakes" for the winged beans.
2. determine the effects of a winged bean crop on a following cereal crop, with special emphasis on evaluating the potential of winged beans to contribute to the nitrogen nutrition of the cereal crop.
3. develop agronomic recommendations for growing winged beans in rotations and mixed cropping systems as well as recommendations for future agronomic research on winged beans.

MATERIAL AND METHODS

Studies of Winged Bean Allelopathy On Seed Germination and Seedling Growth

The entire above-ground portion of vigorous, 100 day-old field-grown winged bean plants, was harvested, dried and ground to make extracts for allelopathic testing. Four extracts concentrations were made by adding 0, 4, 20 or 40 g of dried winged bean tissue to 400 mL of solvent. Two types of extracts were made, one with distilled water as the solvent and the other with a solution of 30% ethanol in distilled water as the solvent. The winged bean tissue was allowed to soak in the solvent for 24 hrs with a total of 3 hrs of intermittent shaking. After this time, the extract was filtered through Whatman No. 1 filter paper on a suction filter. The resulting filtrate was then refiltered through a 0.4 millipore filter to remove bacteria. In the case of the ethanol extract, the filtrate was then put through a roto-vac evaporator to remove the ethanol and brought back to the orginial volume with distilled water. The final extract solutions were frozen at -20oC until used.

For each experimental unit, 20 seeds of one crop species were surface-sterilized in chlorine bleach, rinsed in distilled water, and placed on a double layer of sterile filter paper in a 15 cm diameter petri dish. Depending on the seed size of the crop species involved between 8 and 18 mL of extract were added to each petri dish. These amounts were found in preliminary work to be those required to completely moisten the filter paper and allow enough additional liquid for complete swelling of the seeds. The petri dishes were covered and kept in a germinator at 22 $\pm$ 0.5oC. Seeds from the following 8 crops were used: winged bean (*Psophocarpus tetragonolobus*), Kurakkan (*Eleusine coracana*), pole bean (*Phaseolus vulgarus*), rice (*Oryza sativa*), grain amaranth (*Amaranthus hypochondriacus*), maize (*Zea mays*), sorghum (*Sorghum vulgare*), chillie pepper (*Capsicum grosseum*). In addition to

the above 8 species of untreated seed, a ninth type of seed was winged bean with a pretreatment to enhance germination. This pretreatment consisted of soaking the seeds in twice their volume of 12.5% sulfuric acid for 5 minutes at 62oC and then rinsing in distilled water (Csizinsky, 1980).

Germination counts were taken daily for 19 days. Any seed with greater than 2 mm of radicle protruding beyond the seed coat was considered to be germinated. When no additional seeds germinated for two days, an additional 2 days were allowed for elongation of the hypocotyl and radicle. Then 10 germinated seeds were removed and the lengths of the hypocotyl and radicle were measured. In the case of Phaseolus vulgaris only one measurement was taken from the cotyledon to the tip of the radicle and this was reported as radicle length.

The results of the germination counts were recorded as percentage germination. The results of the hypocotyl and radicle length measurements were recorded as a percentage of the respective length for the same species of seed when treated only with distilled water. The experiment had two replications in a RCB design and a factorial set of treatments with two solvents and four extract concentrations. Analysis of variance was performed separately on the data for each type of seed.

Greenhouse Intercropping and Allelopathy Study

The same 8 crops used in the experiment described above were grown in the greenhouse in 4 different cropping systems differing with respect to the association with winged beans. The 4 cropping systems were: 1) sole crop control, 2) companion crop with winged bean, 3) sole crop in rotation after winged bean, and 4) sole crop watered with winged bean extract. There were four replications giving 128 pots in total. The pots used were 15 cm in

diameter and were filled with approximately 1 kg of soil that included 30% by volume of perlite. For the sole crops (1, 3 and 4) six seeds of a crop were planted in each pot and later thinned to four. For the companion cropping system (2), four seeds of each companion crop and four seeds of winged bean were planted in each pot and these were later thinned to two plants of winged bean and two of a companion crop. In the rotation system (3) the companion crops were planted in pots filled with soil that had previously grown winged beans and contained the decaying residues of that earlier winged bean crop.

To prepare the soil for this rotation treatment, 28 pots were planted to winged beans and three or four winged bean plants grown for 90 days in each pot. After 90 days the soil and the chopped winged bean plants were mixed together and distributed into fresh pots two weeks prior to planting the subsequent crops. Approximately 100 g of winged bean tissue (dry weight basis) was included in each of these pots of soil. The soil was kept moist until the following crop was planted.

For the treatment in which the companion crops were watered with winged bean extract, a 10% extract of above ground winged bean parts was made by extracting 100 g of dried ground tissue in one liter of distilled water and filtering as described above. Sixty mL of this filtered winged bean extract was applied with a fine-rose to each pot in this treatment at 25, 40 and 55 days after planting.

The winged bean seeds were pre-germinated to assure good establishment. All pots were watered once a week with a complete nutrient solution for the first 3 weeks and twice a week thereafeter. The soils was maintained at optimum moisture content by bringing each pot up to its original moist weight with distilled water daily. When nutrient solution or winged bean extract were used, these were added prior to bringing the pots up to their proper

weight with distilled water. The temperature in the greenhouse was maintained between 18°C at night and 24-26°C during the day. Growth of all crops was good except for rice which grew slowly and appeared to be slightly iron deficient despite the chelated iron in the nutrient solution. A single 50cm tall, thin bamboo stake was provided for the support of the winged bean plants.

At 65 days after planting, the above ground parts of all plants were harvested and the plant heights, fresh weights and dry weights (after 48 hours drying at 68°C) were recorded. The data were analysed statistically as a randomized complete block design with four replications. The main effects were a factorial combination of eight crops and four cropping systems. Since there was a significant interaction between crop and cropping system an analysis of variance was performed separately for each crop. Means for the 4 cropping systems were separated using the Duncan's New Multiple Range Test.

Mixed Cropping Field Experiments in Sri Lanka

Field experiments were established at two locations in Sri Lanka, one in the Wet Zone on the University of Peradeniya Research Farm at Meewatura and the other in the Intermediate Rainfall Zone on International Winged Bean Institute land at Pallekele. Some characteristics of the environment of these two sites are presented in Table 1. It can be seen that the principle differences between the two sites are the lower rainfall that normally occurs at Pallekele and the more weathered soil type that occurs at Meewatura. During the course of this study, the soil properties were indeed found to be quite different at the two sites and these are summarized in Table 2.

The rainfall patterns, however, were not very different at the two sites during the experimental period. In general, rainfall during the years that

Table 1. Environmental Characteristics at the Field Experiment Sites in Sri Lanka.

Site	Agro-Ecological Zone	Elevation	Average Rainfall	Mean Monthly Temperatures	Latitude
		m	mm/yr	range in °C	
Meewatura	WM3	470	2100	22-25	7°15'N
Pallekele and Dodangolla	IM3	450	1500	23-26	7°17'N

[1] Wet Mid-country (WM3) and Intermediate Mid-country as described in Anon. 1979.

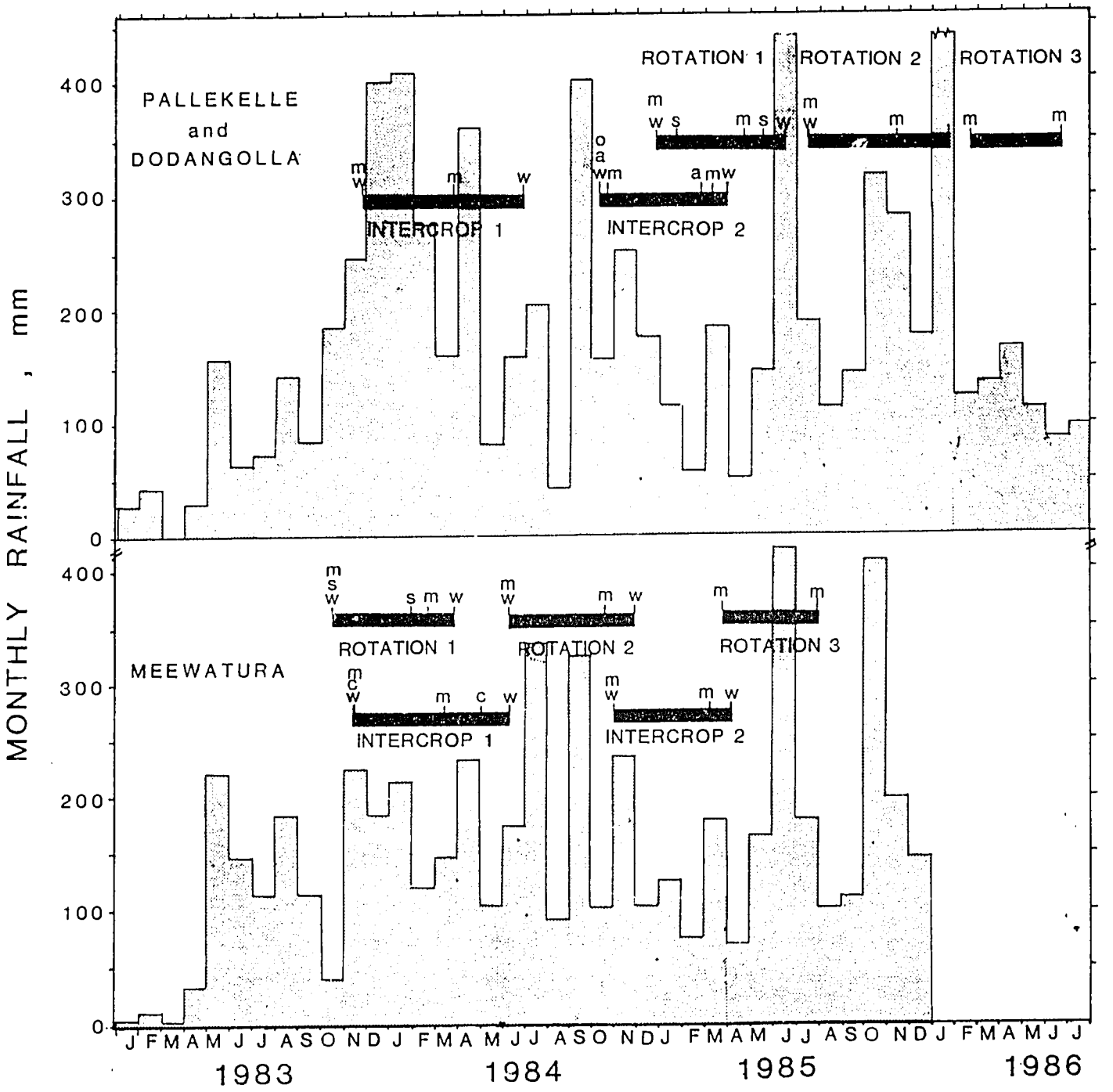
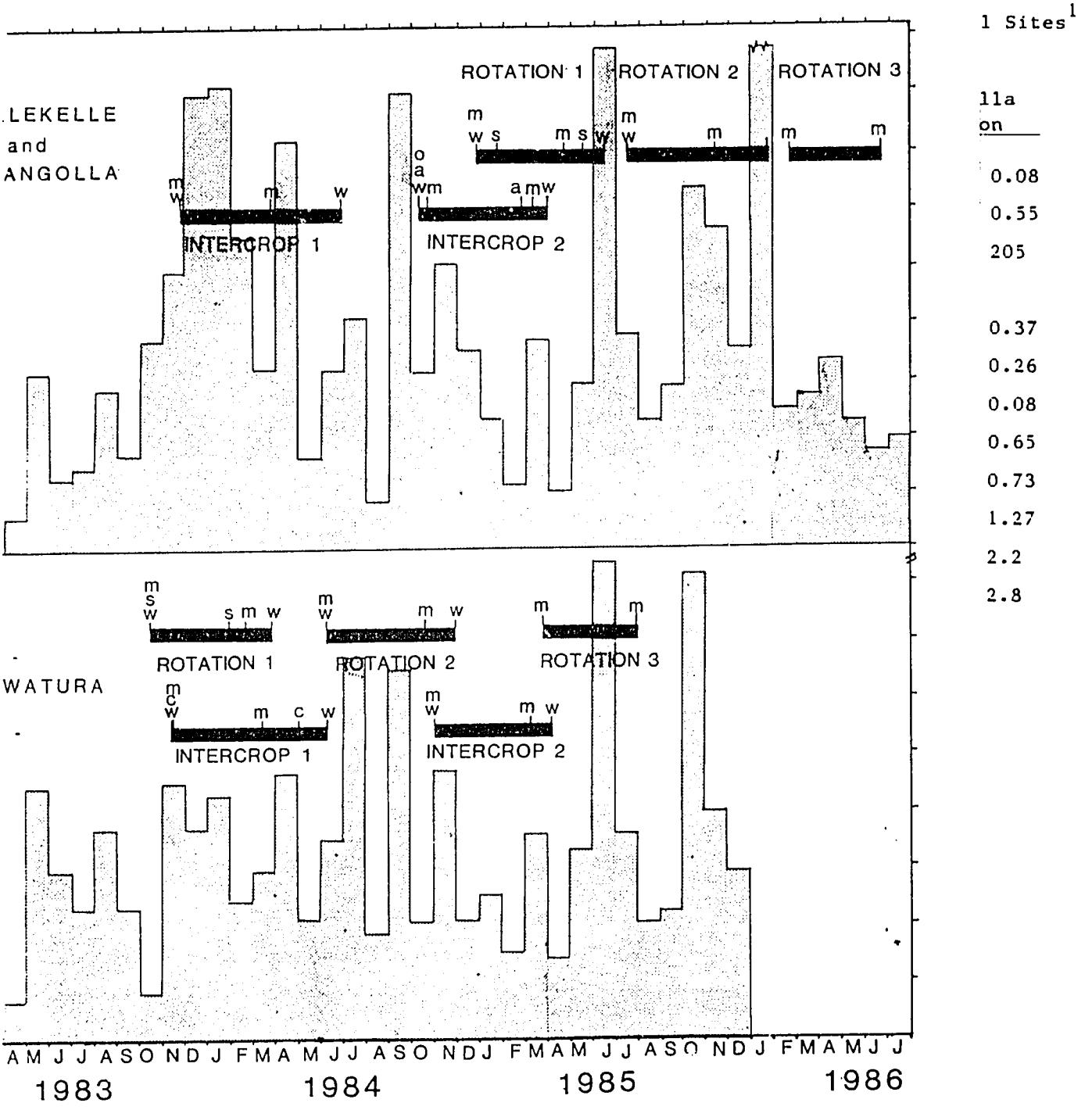


Figure 2. Monthly rainfall and dates of the field experiments at two locations in Sri Lanka. The heavy bars show the duration of the experiment. The planting and harvest dates of each crop species are indicated by lower case letters (m=maize, w=winged bean, s=soybean, O=okra, c=cucumber, and a=amaranth). Months and years are shown on the horizontal scale.



Monthly rainfall and dates of the field experiments at two locations in Sri Lanka. The heavy bars show the duration of the experiment. The planting and harvest dates of each crop species are indicated by lower case letters (m=maize, w=winged bean, s=soybean, O=okra, c=cucumber, and a=amaranth). Months and years are shown on the horizontal scale.

the experiments were carried out was not very typical of the sites based on the previous 50 year averages. The actual monthly rainfall that occurred during the study period is shown in Figure 2. The most dramatic abnormality was the severe drought that occurred early in 1983 before the experiments were planted. Also the following two Octobers were much drier than normal and planting could not be started at the anticipated dates. The actual dates of planting and duration of the experiments up until harvest are shown in Figure 2 for both sites and both seasons of the mixed cropping experiments.

The experimental site at Meewatura was on an artificially constructed terrace approximately 200 m from the Mahaweli River. During the terrace construction some 15 years prior to the experiments, much of the top soil from one end of the site was bulldozed towards the other end in order to level the terrace. This resulted in one end of the terrace having a surface soil lower in organic matter and more poorly buffered than that at the other end. Composite soil samples were taken prior to initiation of the experiments to determine the fertility and liming requirements. The results of the pH analysis on the composite sample (pH 5.5) indicated that, on the average, no lime was required. However, for the section of the terrace in which the mixed cropping experiment was established, the pH was much lower than the composite soil sample indicated. Soil properties were determined on samples taken from each replication in 1985 and these are presented in Table 2. At Pallekele, the experiment was established on land cleared from an old cocoa plantation. This soil was an Immature Brown loam soil formed from granite gniess and had higher pH and higher base saturation values than those at Meewatura.

At both sites, raised beds were constructed, one bed per plot. The beds were raised approximatley 15 cm above the 1 m wide paths. The plots were 4.5 x 6 m in overall size. The net plot from which the yield data was taken was

Table 3. Cropping Systems Investigated in the 1983/84 Mixed Cropping Field Experiments.

Trt[1] No.	Crops Planted[2]	Plant Spacing cm x cm	Support System for Winged Beans	Nitrogen[3] applied kg/ha
1	Winged Bean(W1)	90 x 30	no stakes	10
2	Maize 'Badra' (M1)	90 x 20	n.a.	60
3[m,p]	Grain Amaranth (AM)	90 x 30	n.a.	60
4[m]	Cucumber (CU)	90 x 60	n.a.	60
5[m,p]	Kurakkan (KN)	15 x 5	n.a.	60
6[p]	Capsicum (CA)	90 x 45	n.a.	60
7	W1 + M1	90 x 30, 90 x 20	single stakes	60
8[m]	W1 + AM	90 x 30, 90 x 30	single stakes	60
9[m]	W1 + CU	90 x 30, 90 x 60	single stakes	60
10[m,p]	W1 + KN	90 x 30, 15 x 5	single stakes	60
11	W1 + CA	90 x 30, 90 x 45	single stakes	60
12	W1 + M1	90 x 30, 90 x 20	no stakes	60
13[m,p]	w1 + AM	90 x 30, 90 x 30	no stakes	60
14[m]	W1 + CU	45 x 60, 90 x 60	crossed stakes	60
15[m,p]	W1 + KN	45 x 60, 15 x 5	crossed stakes	60
16[p]	W1 + CA	45 x 60, 90 x 45	crossed stakes	60
17	W1	45 x 60	crossed stakes	10
18	W1	90 x 30	single stakes	10
19	W1	45 x 30	single stakes	10
20	W1	90 x 30	single stakes	60

[1] m, p superscript indicates no data for treatment at Meewatura or Pallekele, respectively.

[2] where two crops were planted in a plot these were in alternate rows.

[3] N applied as urea banded 5 cm deep and 5 cm to side of companion crop row, except for treatment 1 for which N was banded 5 cm from winged bean rows.

Table 4. Cropping Systems Investigated in the 1984/85 Mixed Cropping Field Experiments.

Trt[1] No.	Crops Planted[2]	Plant Spacing cm x cm	Support System for Winged Beans	Nitrogen[3] applied
				kg/ha
1	Winged Bean 'SLS 40' (W1)	90 x 30	no stakes	10
2	Winged Bean 'TPT-1' (W2)	90 x 30	no stakes	10
3	Maize 'Badra' (M1)	90 x 20	n.a.	60
4[m,p]	Sorghum (SG)	90 x 20	n.a.	60
5[m]	Grain Amaranth (AM)	90 x 30	n.a.	60
6[p]	Okra (OK)	90 x 30	n.a.	60
7	Maize 'TC' (M2)	90 x 20	n.a.	60
8	W1 + M1	90 x 30, 90 x 20	no stakes	60
9[m,p]	W1 + SG	90 x 30, 90 x 20	no stakes	60
10[m]	W1 + AM	90 x 30, 90 x 30	no stakes	60
11[p]	W1 + OK	90 x 30, 90 x 30	no stakes	60
12	W1 + M2	90 x 30, 90 x 20	no stakes	60
13	W2 + M1	90 x 30, 90 x 20	no stakes	60
14[m,p]	W2 + SG	90 x 30, 90 x 30	no stakes	60
15[m]	W2 + AM	90 x 30, 90 x 30	no stakes	60
16[p]	W2 + OK	90 x 30, 90 x 20	no stakes	60
17	W2 + M2	90 x 30, 90 x 20	no stakes	60
18	W1	90 x 30,	single stakes	10
19	W2	90 x 30	single stakes	10
20	W1	90 x 30	single stakes	60

[1] m,p superscript indicates no data for treatment at Meewatura or Pallekele, respectively.

[2] Where two crops were planted in a plot these were in alternate rows.

[3] N applied as urea banded 5 cm deep and 5 cm to side of companion crop row.

the central 8.1 m^2 (1.8 m x 4.5 m) of the plots. This net plot consisted of 2 rows of each crop that was present (see Figure 3).

The treatments established consisted primarily of different cropping systems by which a number of crops were tested for their potential as companion crops with winged bean in mixed cropping systems. The crop combinations planted in 1983/84 are shown in Table 3 and those used in 1984/85 are shown in Table 3. Due to a number of environmental factors that were not related to the experimental variables at each site, several of the crops failed to produce sufficient growth to allow yield measurements to be made at one or both sites. Failure of the sorghum was due to bird damage at both sites. Amaranth failed to establish at Meewatura because of the soil acidity. Cucumber failed at Meewatura because of insect damage. Okra failed at Pallekele because of damage by monkeys (Figure 4 shows one of the means used in an attempt to overcome the latter problem). In these cases the treatments were ommitted from the analysis.

Seeds from each crop were overplanted and then thinned to the desired spacing indicated in Tables 3 and 4. Each crop, including winged bean, was grown as a sole crop in the control treatments 1-6 in 1983/84 and 1-7 in 1984/85. In other treatments the crops were grown as an intercrop with winged beans, each crop occupying alternate rows. In the intercrop treatments, both crops were present at the same population that was established in there respective sole crops.

Where the cropping system treatment called for support for the winged beans to climb on, single stakes slightly more than 2 m long cut from branches of Gliricidia maculata trees were used. For the treatments listed in Tables 3 and 4 as having single stakes, one stake was pushed into the soil so that it protruded above the soil for 2 m in a vertical position and entered the soil

Figure 3. A view of intercropping plots at Palekelle showing winged bean (w)/ maize (m) and winged bean/cucumber (c) intercrops at an early stage.

Figure 4. Two Sri Lankan women hired by the project to tend the plots at Palekelle and scare off maurading monkeys and birds by shooting at them with slingshots.

approximately 10 cm from each winged bean plant (see Figure 5). For those treatments listed in Table 3 as having crossed stakes, the stakes from adjacent rows were bent together and tied in pairs in the shape of inverted Vs. All leaves were stripped from the Gliricidia branches, which were very straight, approximately 2 to 3 cm in diameter, and made excellent supporting stakes. These were better than dead wood or bamboo for the purpose, since termites did not attack the living Glircidia branches.

Prior to planting the crops, the soil at both sites was given a basil dressing of 25 kg P/ha and 25 kg K/ha. Nitrogen was applied as urea in the amounts indicated in Tables 2 and 3. Where more than 10 kg N/ha was applied, 1/3 of the application was made at planting time and 2/3 was made 25 days later.

Weeds were controlled by hand-pulling and hoeing until the crop canopy closed over. No pesticides or herbicides were used, except an application of 10% monocrotophos solution (dimethyl-(E)-1-methyl-2-methylcarbomoylvinyl phosphate to unsuccessfully combat an infestation of Chrysomellid beetles on the cucumbers at Meewatura. Where maize, grain amaranth and okra were harvested, the stems of these plants were left in the field as long as needed to provide support for the associated winged beans (Figure 6). The capsicum, cucumbers and okra were harvested approximately weekly until no significant numbers of new fruits appeared. Only fresh weights of cucumber and okra fruit were recorded. The winged beans were harvested every ten days once a significant number of pods had matured. In most cases mature winged bean pods were picked on 3 occasions 10 days apart. At the time of the final winged bean mature seed harvest, any immature pods occurring on the plants were also harvested and their fresh and dry weights recorded. For maize and winged bean, the above ground non-reproductive vegetation was also harvested and the

Figure 5. Winged beans ('SLS-40') in a border row of a sole crop plot with single stakes at Meewatura 150 days after planting. Although pods from the net plots rows had been harvested two times by this date, no pods had been picked from this border row.

Figure 6. A winged bean/maize intercrop at Meewatura just before harvest of the maize grain. The winged bean plant is not staked, but has twined around the maize stalk. Both mature and green winged bean pods are present. The cause of the incompletely filled maize ear was probably a heavy rain storm during the end of the pollination period.

fresh and dry weights recorded. The dry weights were calculated on the basis of the moisture content of a subsample for each plot. Seed yields are reported on a 13% moisture basis.

The data were analysed statistically as a randomized complete block consisting of 23 treatments with only replication, treatment and error as sources of variation. Separate subsets of the data were also analysed for each crop and for the effects of stakes and nitrogen on winged beans. The capsicum and amaranth were seeded in containers and transplanted to the field plots when 5 cm high. The other crops were directly seeded on the same day as the transplants were planted. In the 1983/84 experiments all crops were planted or sown on the same day in the field. In the 1984/85 experiments the winged bean seeds were sown 10 days earlier than those of the other crops.

Relative yields were calculated by dividing the yield for an intercrop mixture by its yield in the sole crop system. For cucumbers and okra, the fresh weight of the fruits were used in the calculations. For capsicum, the dry weight of the fruit was used. For maize, amaranth and winged bean the grain yields on a 13% moisture basis was used for the yield and relative yield calculations. The land equivalency ratio (LER) for each of the intercrops was calculated as the sum of the relative yields of the two crops in that mixture (Andrews and Kassam, 1976). Where the intercrop had no supporting stakes provided for the winged beans, the yield of the winged bean in a no-stake sole crop was used in calculating relative yields. For the intercrops in which the winged bean was provided with stakes on which to climb, the yield of a similarly staked sole crop was used in calculating relative yield for the LER calculations.

Rotation Experiments

Field experiments were established at two sites to investigate the effect of the winged bean crop harvested for seed on subsequent maize crops, including the nitrogen contribution of the winged bean to the subsequent crops. One experiment was at the wet zone at Meewatura adjacent to the mixed cropping experiment described above. The second site for the rotation experiment was at Dodangolla in the intermediate rainfall zone approximately 2 km from the Pallekele location described above. At each site the experiment was carried out for 3 growing seasons over a period of approximately 2 years. Meewatura a rotation experiment was begun in October 1983 while at Dodangolla the rotation experiment was begun in early January of 1985. The dates of planting and harvesting at each of the three seasons at each site are given in Figure 2.

The experiment consisted of 14 treatments established in plots 8 m long and 3 m wide (see Figure 11). Each plot consisted of 5 crop rows 60 cm apart. The net plot used for yield estimates consisted of 6 m of the center 2 rows for an area of 7.2 m^2. The experimental design was a randomized complete block with 4 replications at each site.

The cropping sequence and level of nitrogen application for each season and each treatment is given in Table 5. Maize cultivar 'Badra', winged beans accession 'SLS-40', and soybean cultivar 'BT-1' were planted in rows 60 cm apart with spacing within the row being 20 cm, 30 cm and 20 cm, for the 3 respective crops. Nitrogen was applied at the rates indicated in Table 5 as urea with 1/3 of the application banded near the seed at planting time, and the other 2/3 applied as a side-dressing for maize. Where nitrogen was applied to the leguminous crops the entire amount was banded 10 cm from the seed at planting time. A basil application of 25 kg P and 25 kg K per hectare

le 5. Crop Sequence and Nitrogen Applications in the Winged Bean Rotation Experiments.

First Season		Second Season		Third Season	
Crop	kg N/ha	Crop	kg N/ha	Crop	kg N/ha
M[1]	0	M	0	M	100
M	20	W	0	M	100
M	20	M	0	M	0
M	20	M	25	M	25
M	20	M	50	M	50
M	20	M	75	M	75
M	20	M	100	M	100
M	20	M	125	M	125
M	20	M	150	M	150
W[2]	0	M	0	M	0
Wr[3]	20	M	0	M	0
W	20	M	100	M	100
W	20	W	0	M	100
S[4]	20	M	0	M	0

'Badra' maize

'SLS-40' winged bean

above ground crop residues removed

'BT1' soybean

was applied as single superphosphate and potassium chloride respectively in each season. Winged beans were provided with 2 m high wooden stakes (Gliricidia branches as described above) for support on which to twine. Weeding was done by hand pulling and hoeing.

At maturity the maize was harvested and the fresh and dry weights of both grain and vegetative matter recorded. For the soybean plots, seed yield only was recorded. For the winged bean plots, mature pods were picked in three sequential harvests. The fresh and dry weights of the entire above ground vegetation, the immature green pods, the mature pods, and the mature seeds were recorded at the final winged bean harvest. The winged bean seed yield recorded was the cumulative yield from the three harvests.

At the final harvest, all above ground winged bean vegetation was cut and removed from the plots, weighed fresh, and then returned in equal portions to all the winged bean plots except those in treatment 11. All plots were tilled by hand using a heavy hoe to chop and incorporate crop residues present. At Meewatura, 30.5 kg of fresh winged bean tissue (6.7 kg of dry matter) were incorporated per plot. This represented 95 kg N/ha as the tissue contained 34 mg N/g dry weight. At Dogandolla, 15.5 kg of fresh winged bean tissue (4.1 kg dry matter) were added at the end of the first season to each winged bean plot. This represented 58.1 kg N/ha. After the winged bean harvest in the second season, 12.5 kg of fresh tissue (3.4 kg dry matter) were incorporated in each of the plots that had winged bean growing and this represented 48.4 g N/ha.

The nitrogen content and dry matter production of the below ground parts of winged beans was not determined quantitatively, although root samples were taken and analysed for their nitrogen content. The root samples were obtained

by removing several shovels full of soil around the stem of the plant and seperating the larger roots from the soil by hand. In seasons 2 and 3, the ear leaves from 5 maize plants in each plot were sampled, dried, ground and analysed by the micro-Kjeldhal method (Bremner and Mulvaney, 1982) for total nitrogen. Six winged bean plants from each site were harvested and the plant parts analysed for nitrogen at 7, 10 and 13 weeks after germination, and on the final harvest date.

Because soil variability resulted in several plots being markedly less productive than the others, the first season's seed yield data for the 3 crops was used to calculate a relative yield covariate for each plot. This covariate (relgrain) was calculated by the following equation:

$$\text{relgrain} = \text{seed yield}/\text{mean seed yield},$$

where, seed yield is the seed yield from an individual plot and mean seed yield is the mean yield of all plots treated alike during the first season. The variable, relgrain, was then used as a covariate in the statistical analysis of the yields of each season. PROC STEPWISE of the Statistical Analysis System (SAS, 1982) was then used to calculate regression models for the grain and dry matter response of maize to nitrogen application in the second and third seasons (using the data from treatments 3-9). The covariate was also used in a General Linear Models analysis in which the independent variables were replication, treatment, and relgrain. Single degree of freedom contrasts were used to make preplanned comparisons between treatments. The least squares means of maize grain yields were regressed on nitrogen application rate to provide a response curve with which to compare the yield of maize following winged bean or soybean to that of maize following maize at various N application rates. The data were fitted to the Mitscherlich (1909) equation of the form

$$Y = Ymax\ (1-e^{-b(N+a)})$$

where Y is the predicted yield in kg/ha, Ymax is the maximum yield to which the curve is asymtotic, N is the amount of nitrogen applied (kg N/ha), a is the amount of N available in the soil without fertilizer, and b is a parameter related to the efficiency of the fertilizer.

RESULTS AND DISCUSSION

Allelopathic Effects on Seed Germination and Seedling Growth

Extracts of dried winged bean tissue had significant effects on the germination and seedling growth of several of the crops studied. Table 6 gives the results of the analysis of variance for seed germination and seedling growth data. The elongation of the radicle and/or hypocotyl was expressed as a percentage of the maximum elongation of these parts for each crop-solvent combination. The main effects of crop, solvent, and extract concentration were all significant at the 5% level for all three variables. There were also a number of significant interactions indicating that different crops responded differently to the two types of extracts.

Averaged over all crops and all concentrations, the winged bean compounds extracted with ethanol produced lower germination and seedling growth than those compounds extracted with distilled water (Table 7). Since the ethanol used to make the extract was removed before the extract was applied to the seed, and since where no winged bean tissue was included, the effect of water and ethanol was generally the same, the lower germination and growth where the ethanol winged bean extracts were applied must have been a result of allelopathic compounds extracted by the ethanol but not the distilled water.

Because the crop X solvent X concentration interaction was non-significiant, the percentage seed germination data for both the water and the ethanol extracts of winged bean tissue were combined in Table 8. It can readily be seen that some crops were much more sensitive with respect to their seed germination than were others. Maize, sorghum and *Phaseolus* beans appeared to be unaffected by the extracts. The effect of the extracts on winged bean seeds was also statistically not significant, though there appears to have been a trend towards lower germination when more than 50 g of winged

Table 6. Results of Variance for Seed Germination and Radicle and Hypocotyl Elongation Study.

ANOVA	df	Germination Percentage	Radicle Length	Hypocotyl Length
		Probability of >F		
Rep	1	.2148 NS	.0001	.0001
Crop	8	.0001	.0001	.0001
Solvent	1	.0001	.0002	.0265
Concentration	3	.0001	.0001	.0001
Crop x Solvent	8	.0001	.3269 NS	.7867 NS
Crop x Concentration	24	.0544	.0001	.0334
Solvent x Concentration	3	.3108 NS	.0007	.6545 NS
Crop x Solvent x Concentration	24	.4585 NS	.0826 NS	.9996 NS

NS indicates effects considered to be non-significant.

Table 7. Comparison of Effects on Seed Germination and Radicle and Hypocotyl Elongation by Winged Bean Tissue Extracted with Distilled Water and Ethanol.[1]

Solvent	Germination %	Radicle Length	Hypocotyl Length
		--% of Control--	
Water	70	98.1	128
Ethanol	54	76.1	106
T-Test	**	**	**

[1]Mean values for 4 extract concentrations and 9 types of seeds.

**the means differ by T-Test at $P<0.01$.

Table 8. Effect of Extracts of Winged Bean Tissue on Percent Germination of Various Crop Seeds.[1]

Crop		Extract Strengh (g tissue/L) 0	10	50	100
5	Amaranth	66.3 b	95.0 a	60.0 b	21.3 c
8	Chillies	43.8 a	41.3 a	37.5 a	20.0 b
2	Kurakkan	93.8 a	91.3 a	82.5 a	56.3 b
6	Maize	100 a	100 a	97.5 a	97.5 a
3	Phaseolus	100 a	100 a	80 a	87.5 a
4	Rice	92.5 a	91.3 a	82.5 ab	77.5 b
7	Sorghum	93.8 a	93.8 a	92.5 a	91.3 a
1	Winged Bean	22.5 a[3]	22.5 a	7.5 a	11.5 a
9	Winged Bean[2]	23.8 a	31.3 a	18.8 a	13.8 a
Means		67.0 a	70.8 a	58.8 b	50 c

[1]Means of 2 replications, 20 seeds each.

[2]Winged bean seeds treated with warm H_2SO_4 prior to imbibition.

[3]means in a row followed by the same letter do not differ at the 0.05 level of probability.

bean tissue were used per liter of extract. Also, the conditions for germination were apparently not very favorable for winged bean seed. Even in the controls only 23% of the seed germinated within the experimental period, a germination percentage that is low even for winged beans. The treatment of the winged bean seeds with warm sulfuric acid (Csizinsky, 1981) did not appear to improve germination in this case. That the winged bean seed was viable is evidenced by the fact that the same seed lot produced vigorous plants in the greenhouse experiment several months after this seed germination study was completed.

Apparently, the crop most sensitive to the allelopathic effects of winged bean was amaranth. Its germination was positively stimulated by the lowest extract concentration and severely inhibited by the higher concentrations. The germination of capsicum seeds was also markedly inhibited by the winged bean extracts. The germination of rice and kurakkan was inhibited to a lesser extent.

The effect of the winged bean extracts on radicle hypocotyl elongation was also quite variable from crop to crop (Table 9). Averaged across all crops, radicle elongation tended to be more sensitive to the effects of winged bean extract than hypocotyl elongation. Both radicle and hypocotyl elongation were stimulated by the weakest strength extract. However, radicale elongation was markedly inhibited by the stronger extracts whereas the elongation of the hypocotyl was not. The hypocotyls on capsicum and rice seedlings, in particular, elongated almost three times as fast where the weakest strength extract was appled as in the controls. These results generally indicate that a wide range of crops is sensitive to compounds found in winged bean tissues, and that at low concentrations the winged bean extracts tend to have a

Table 9. Effect of Extracts of Winged Bean Tissue on Relative Radicle and Hypocotyl Growth of Various Crops.[1]

Crop	Plant Part	Extract Strength (g tissue/L) 0	10	50	100
		----------% of Control----------			
Winged Bean	Radicle	100 a[3]	114a	55 b	47 b
	Hypocotyl	100 b	116 a	86 c	75 c
Kurakkan	Radicle	100 a	139 a	54 b	25 b
	Hypocotyl	100 a	119 a	139 a	118 a
Phaseolus	Radicle	100 a	134 a	68 b	39 c
Rice	Radicle	100 a	126 a	51 b	18 c
	Hypocotyl	100 b	314 a	154 b	135 b
Amaranth	Radicle	100 b	261 a	79 cb	28 c
	Hypocotyl	100 a	130 a	104 a	61 a
Maize	Radicle	100 a	101 a	43 b	43 b
	Hypocotyl	100 a	104 a	63 ab	41 b
Sorghum	Radicle	100 a	67 b	61 b	55 b
	Hypocotyl	100 a	162 a	111 a	113 a
Chillies	Radicle	100 b	246 a	92 b	26 b
	Hypocotyl	100 b	267 a	134 b	81 b
Winged Bean[2]	Radicle	100 a	99 a	64 a	61 a
	Hypocotyl	100 a	103 a	95 a	78 a

[1]Means of two replications of 10 seeds each.

[2]Winged bean seed treated with warm H_2SO_4 prior to imbibition.

[3]Means within a row followed by the same letter are not different by DMRT $P<0.05$.

stimulatory effect while at higher concentrations they have an inhibitory effect on seed germination and seedling growth.

Greenhouse Intercropping and Allelopathy Study

Although the main objective of the greenhouse experiment was to examine the effect of winged bean on potential companion crops, Table 10 also gives some idea of how the winged beans themselves grew in association with each of the companion crops. The dry weight of the two winged bean plants growing in each pot ranged from an average of 8.65 grams when growing with two rice plants to an average of 1.57 grams when growing with two Phaseolus bean plants. This five-fold difference in the growth of winged beans was probably more the result of competitive factors than of allelopathic factors, although the data in Table 10 does not enable the two effects to be distinguished. Judging from the relative yields of winged bean and the various companion crops, it would appear that the broad leaf crops were more competitive against the winged bean than the grass crops. For example, sorghum and maize plants with dry weights of 17 nd 22 grams, respectively, had a lesser effect on winged bean dry matter accumulation than did the Phaseolus bean plants which produced only 12.5 grams of dry matter. Similarly, winged beans accumulated approximately 4 grams of dry matter per pot when growing with either 8 g of Kurakkan or only slightly more than 4 g of the broad-leaf, amaranth.

The principle results of the greenhouse experiment are given in Table 11. The various types of the associations with the winged bean affected different companion crops differently. Rice and sorghum were not significantly affected by growing either with winged beans, winged bean extract solution, or in rotation after winged beans. The winged beans themselves were also unaffected

Table 10. Dry Matter Yields of Winged Bean and Various Companion Crops When Grown Together in Greenhouse Pots.[1]

Companion Crop	Winged Bean	Companion Crop	Total
	----------g/pot----------		
Amaranth	3.94 c[2]	4.29	8.23
Capsicum	6.43 b	1.60	8.03
Kurakkan	3.99 c	8.20	12.19
Maize	2.18 cd	22.60	24.78
Phaseolus	1.57 d	12.48	14.05
Rice	8.65 a	1.32	9.97
Sorghum	2.96 c	17.32	20.28
Winged Bean	4.56 bc	4.56	9.19

[1]Means of 4 replications (pots), with 4 plants per pot, 2 of each species.

Table 11. Dry Matter Yields of Various Crops as Affected by Cropping System Association with Winged Bean in the Greenhouse[1].

Crops	Cropping Systems			
	Sole Crop	After WB in Rotation	Winged Bean Extract	Grown With Winged Bean[3]
	g/plant			
Amaranth	2.58 b[2]	3.91 a	1.87 c	2.15 bc
Capsicum	1.53 ab	1.48 b	1.96 a	0.80 c
Kurakkan	2.54 b	4.17 a	3.97 a	4.10 a
Maize	6.50 b+	8.55 b+	8.36 b	11.30 a
Phaseolus	4.98 b	7.85 a	4.47 b	6.24 ab
Rice	0.442 a	0.632 a	0.346 a	0.661 a
Sorghum	7.80 a	9.11 a	8.49 a	8.66 a
Winged Bean	2.39 a	1.92 a	2.27 a	2.22 a

[1]Means of 4 replications (pots) with 4 plants per pot.

[2]Means within a row followed by the same letter are not different by DMRT at $P < 0.05$.

+These means differ by DMRT at $P<0.10$.

[3]These pots contained 2 plants of the indicated crop plus 2 plants of winged bean.

by either a previous winged bean crop or the application of winged bean tissue extract.

This apparent lack of auto-allelopathic effects is in contrast to some striking observations made during the preliminary phase of the greenhouse experiment. During the preliminary phase, 28 pots of six winged bean plants each were grown primarily for the purpose of providing the tissue necessary to make the winged bean extract with which to treat the pots in the main experiment. Twelve seeds were planted in each pot but only approximately five or six germinated. These plants were allowed to grow for 90 days, after which time the above ground parts were harvested, dried, and used for making the winged bean extract. At the time of harvest the stems were cut approximatley 2 cm above the soil line. Within two days after the winged bean plants were cut down and removed, in almost every pot several of the remaining winged bean seeds began to germinate and emerge. This observation suggests that there was a strong allelopathic effect whereby growing winged bean plants inhibited the germination of winged bean seeds within their rooting zones. However, the data from the greenhouse experiment was not designed to investigate this particular auto-allelopathic effect and so evidence for it is not conclusive.

The growth of several of the companion crops was stimulated by following winged beans in rotation, i.e. by growing in soil that had previously supported winged bean plants. The possible enrichment of the soil with N biologically fixed by the winged beans cannot be ruled out as a cause of this stimulatory effect. It is unlikely, however, that this was the main cause because a nitrogen fixing crop such as Phaseolus bean was quite markedly stimulated by growing after winged beans whereas several non-nitrogen-fixing crops were not stimualted (e.g. capsicum and sorghum). Also, the nutrient

solution used for all crops had enough N in it to have eliminated any response to nitrogen fixed by the previous winged bean crop.

Only two crops were significantly affected by the application of winged bean extract. They were amaranth and kurakkan, the amaranth being markedly inhibited and the kurakkan being significantly stimulated. The effects of winged bean tissue extract and the previous winged bean crop grown in rotation can be seen in Figure 7. Not only did the winged bean extract inhibit the growth of the amaranth while the previous crop of winged bean stimualted the growth of the amaranth, but the color of the amaranth leaves was also changed by the extract to a more green and less red-pigmented color.

The association of kurakkan with the winged bean was particularly productive relative to the respective sole crops. All three types of association with winged bean increased the kurakkan's dry matter accumulation per plant by approximately 60%. The data in Table 9 indicates that the winged bean also grew quite well in association with kurakkan.

In summary, the greenhouse experiment suggested that a number of crops might be stimulated by growing after winged bean in a rotation, and that only amaranth, among the crops tested, might be inhibited by compounds in winged bean tissue. For the data in the last column of Table 11, the effects of competition and allelopathy cannot be separated since the winged beans are growing simultaneously with the companion crops in the same pot. However, the results indicate a possible positive interaction between winged bean and these crops: maize, Phaseolus beans, and kurakkan. These results are collaborated by observations in the field. Thirikethesswaran and Senanayake (1981) found that a Phaseolus bean/winged bean intercrop was more productive than the sum of the respective sole rops. In field experiments reported here, both kurakkan and winged bean grew very well when in association with each other and each

Figure 7. Grain Amaranth plants from the greenhouse allelopathy experiment. The pot on the left (T4) contains fresh soil (no association with winged bean). The center pot (T20) contains soil that previously supported winged beans. The pot on the right (T28) contains fresh soil, but the amaranth plants were watered three times with an aqueous extract of winged bean tissue. Scale in decimeters.

appeared to be least productive as the respective sole crop, even though the population of each in the intercrop was not reduced. Unfortunately, data on this association are not available because of severe damage to the kurakkan crop caused by fungal diseases and lodging during a period of very heavy rains. Maize was also observed in the field to be uninhibited and sometimes stimulated by association with winged bean. Grown under the same population density in each case, maize actually produced more in some cases when grown in association with the winged bean than as a sole crop. The details of these field experimens are discussed in the next section.

Winged Bean Intercropping Experiments in the Field

Because nitrogen fertilizer was applied to some of the intercrops grown with the winged bean in this experiment, and because the production of maximum yields of some grain legumes is known to require fertilizer to supplement nitrogen fixed biologically (Edje, et al., 1978), two of the treatments included in the intercrop field experiments tested the effect of an additional 50 kg N/ha on the growth yield of winged bean. The results comparing treatment 18 (10 kg N/ha) and treatment 20 (60 kg N/ha) are shown in Table 12. The additional nitrogen had no significant effect on either the vegetative dry matter accumulation, the green pod production, nor the seed yield. Thus, based on four site-years of data, there is no justification for applying nitrogen fertilizer to winged bean in excess of a very small starter application (10 kg N/ha was applied to all of the winged beans in this experiment).

The winged bean has an indeterminte twining growth habit and as such can be expected to yield more if given a source of physical support such as vertical stakes on which to climb. Such supports afford better display of

Table 12. Effect of Added Nitrogen Fertilizer on Yield of Winged Beans at Two Locations.[1]

Trt No.	Nitrogen Applied As Urea	Vegetative[3] Dry Matter	Fresh Wt.[4] Green Pods	Seed Wt[2] Per Plant	Seed[2] Yield
	kg N/ha	------kg/ha------		g/plant	kg/ha
18	10	1613	272	19.5	757
20	60	1896	232	20.6	821
	Difference	+283	-41	+1.1	+64
	T-Test	NS	NS	NS	NS

[1] combined data for two growing seasons, 12 observations per mean.

[2] seed weight expressed on 13% moisture basis.

[3] includes stems, leaves and petioles present at time of final pod harvest

[4] immature pods present at time of final mature pod harvest; approx 80% were marketable as edible green pods.

foliage for light interception and less mutual shading. Gunasena and Gunathilake (1982) compared various types of stakes and support systems for winged bean. They found that a single vertical stake per plant was as good as any system, and that winged beans without any support yielded much less than winged bean with some type of support. Since the intercropping systems tested in this study included some which were meant to provide "living stakes" for physical support of the winged bean, several treatments comparing unsupported and supported winged beans were included in the experiments to determine the effect of stakes, both in an intercropping system and in the winged bean sole crop. Providing even simple, single vertical stakes is a very labor intensive and relatively costly phase of winged bean production. Towards the end of the winged bean growing season some leaves began to sprout on the Gliricidia stakes, and several months after the final winged bean harvest the abandoned stakes began to take on the appearance of a forest planting (see Figure 8). This rooting of the stakes could be used to advantage in an agro-forestry context. It would be advantageous, however, if the need for staking the winged bean could be eliminated, either through breeding a self-supporting bush-type plant or by providing a "living stake" as an intercrop which would not only support the winged bean plants but also produce a yield of its own.

Table 13 provides data for one such intercropping system (maize and winged beans) with and without stakes, as well as several different support systems and population patterns for sole crop winged beans. The effect of providing stakes for support of sole crop winged beans planted at a 90 x 30 cm spacing was to increase both vegetative dry matter and green pod production by at least 64% and seed yield by approximately 300% (treatments 18 vs.1). Where winged beans were planted at a 45 x 60 cm spacing and the single stakes at each planting station were tied together at the top in pairs (crossed stakes,

Figure 8. Gliricidia trees resulting from rooting of stakes used to support a winged bean crop. These trees were adjacent to the current experiment in a field that had been left fallow for the 6 months after the winged bean crop had been harvested.

Table 13. Winged Bean Yield Components as Influenced by Support System at Two Locations in 1983/84[1].

Trt No.	Support System	Winged Bean Spacing	Vegetative Dry Matter	Green Pods[2]	Seed Yield[3]	Seed Weight[3]
		cm	kg/ha	kg/ha	kg/ha	g/plant
1	no support	90 x 30	1785 ab	494 a	236 b	6.34 bc
7	grown w/maize	90 x 30	1331 b	292 a	143 b	4.20 c
12	single stake + maize	90 x 30	1217 b	205 a	114 b	3.94 c
17	crossed stakes	45 x 60	1909 ab	453 a	802 a	18.5 a
18	single stakes	90 x 30	2921 a	815 b	971 a	23.6 a
19	single stakes	45 x 30	2970 a	819 b	930 a	11.4 b
	Results of Analysis of Variance					
	Source of Variance		Significance of F Values			
	Site		NS	NS	NS	NS
	Rep within sites		NS	NS	NS	NS
	Treatments		**	*	***	***
	Site x Treatment		NS	NS	NS	NS

[1] least square means adjusted for missing values; two locations except for Green Pod data which are for Pallekelle only.

[2] immature pods present at time of final mature pod harvest; approx. 80% were marketable as edible green pods.

[3] seed at 13% moisture

treatment 17), yields of vegetative dry matter and seed were not signfiicantly different from that for treatment 18, but green pod yield was significantly less (almost 50% less). Also, for treatment 19, using vertical stakes but at twice the plant population (74,000 plants/ha at 45 x 30 cm spacing) all yield components were nearly identical to those in treatment 18, this indicated that there was no advantage to the higher density planting of winged beans. It should be noted that in doubling plant density, seed yield per plant was cut in half so that the seed yield per ha remained virtually the same.

Although this study did not have treatments designed to test populations lower than those at a spacing of 90 x 30 cm (37,000 plants/ha), on a number of plots where poor stand establishment resulted in lower populations of winged beans, the individual winged bean plants grew large enough to compensate and yield per unit area remained approximately the same. Pospisil et al. (1971) reported that highest seed yields were achieved with a 60 x 60 cm spacing and 2 seeds per hole. Gunasena and Gunathilake (1982) used only 10,000 plants/ha and produced similar seed yields. Thus it is likely that no reduction yield would have been incurred from planting the winged bean at a somewhat lower density. Planting at a lower density would save seed, but mroeimportantly would require fewer stakes per ha.

A comparison of yields from treatments 7 and 12, in which winged bean and maize were grown together, indicates that the maize provided a suitable support in lieu of vertical stakes. Although the vegetative and seed yield of winged bean was significantly lower where it was grown with maize, as compared to where it was grown with stakes as a sole crop, there was no different in winged bean yield components between the treatment without stakes and the treatment with stakes in the intercropping system (treatment 7 and 12, respectively). Thus, it may be concluded that while staking or some form of

support is necessary for optimal yields of winged bean, where a companion crop has a strong, tall stem that can provide physical support, additional support in the form of stakes is not needed.

Table 14 presents data on winged bean yields and yields of components for all of the inercropping system from which data was successfully collected in the first season of the experiment (1983/84), along with data for the appropriate sole crops and winged bean controls. Intercropping with cucumber or capsicum had little or no effect on winged bean seed yield. Intercropping with maize, on the other hand, significantly reduced winged bean yields (both vegetative and seed yields) as compared to the control sole crops with stakes. However, where no stakes were provided for support, winged beans growing alone did not yield significantly more than winged beans growing with maize (compare treatments 1 and 12). Winged beans growing alone and recieving 60 kg of nitrogen had the highest vegetative and seed yields. However, for the results combined over both years, the sole crop winged beans with stakes but only 10kg N/ha applied nitrogen gave yields that were not significantly different from the comparable plots receiving 60 kg N/ha.

Intercropping with winged beans affected the vegetative and grain yields of maize in the first season of the experiments as shown in Table 15. Although intercropping with winged bean tended to reduce both the grain yield and the vegetative yield of maize, the only statistically significant reduction occurred where maize was grown with winged beans that had stakes provided for their support. This reduction was only in the vegetative dry matter of the maize and not in the grain production either on a per hectare or a per plant basis. Thus winged bean did not compete seriously with maize for environmental factors or such competition was compensated for by stimulatory effects.

Table 14. Winged Bean (WB) Yield Components as Influenced by Intercropping in 1983/84.[1]

Trt No.	N	Cropping System	Vegetative Dry Matter	Seed[3] Yield	Seed[3] Yield	Green[4] Pods
			------kg/ha	------	g/plant	kg/ha
1	6	WB alone, no stakes	1785 bc[2]	236 c	6.34 e	253 a
7	6	WB + Maize, single stakes	1331 c	143 c	4.20 e	219 a
9	3	WB + Cucumber, single stakes	2723 ab	848 ab	21.1 c	992 a
11	3	WB + Capsicum, single stakes	2266 abc	936 ab	22.3 c	--
12	6	WB + Maize, no stakes	1217 c	114 c	3.73 e	154 A
14	3	WB + Cucumber, crossed stakes	2128 abc	669 b	33.6 ab	658 a
16	3	WB + Capsicum, crossed stakes	1371 c	807 ab	37.5 a	--
17	6	WB alone, crossed stakes	1909 bc	802 ab	18.5 cd	212 a
18	6	WB alone, single stakes	2921 ab	971 ab	23.6 c	815 a
19	6	WB double density, single stakes	2970 ab	930 ab	11.4 de	819 a
20	6	WB alone, single stakes + 60 kgN	3211 a	1026 a	25.3 bc	674 a

[1]Means of 3 or 6 replicates, as indicated in column headed "N", at Meewatura and/or Pallekele.

[2]Means followed by the same letter are not different by DMRT, $P<0.05$.

[3]Seed at 13% moisture.

[4]Immature pods present at time of final mature pod harvest; approx. 80% were marketable as edible green pods.

Table 15. Maize Yield as Affected by Intercropping with Winged Beans With or Without Stakes. 1983/84 Season[1].

Trt. No.	Cropping System	Grain Yield[3]		Vegetative Dry Matter
		kg/ha	kg/plant	kg/ha
2	sole maize	4378 a[2]	91.5 a	2947 a
7	w/winged bean, no stake	3443 a	72.8 a	2414 ab
12	w/winged bean + stakes	3725 a	79.6 a	1967 b

[1]Means of 6 replication over two sites.

[2]Means in a column followed by the same letter are not different by DMRT at $P<0.05$.

[3]Grain at 13% moisture

The land equivalency ratio (LER) was calculated for each intercropping system as one means of evaluating the efficiency of the intercrop as compared to the sole crops. The LER is the sum of the yields of the component crops in the intercropping systems relative to their respective sole crop yields. As such, the value of the LER is highly dependent on the value of the sole crop yields. Thus, if sole crop yields are very low, an intercrop of low absolute productivity might have a high LER. The LER should therefore be used cautiously as a cropping system evaluator. If the LER for an intercropping system is greater than 1, more land would be required to produce the same amounts and proportions of the two crops as sole crops than as an intercrop.

Thus the LER value is most useful in evaluating an intercropping system when the system has produced the component crops in the desired ratio. If the farmer desires the component crops in some other particular ratio then other measures of evaluation may be more meaningful (Mead and Wiley, 1980). From an economic standpoint, the most realistic index to use as an evaluation of an intercropping system might be the total value of the component crops take together in the intercropping system, as compared to the combined value of the component crops when grown as sole crops on separate pieces of land. For the purposes of this report the LER will be used to evaluate the various intercropping systems with respect to the monocrops, since the economic value of winged beans is not established nor is it known in what ratio farmers might desire to produce winged beans and the companion crops.

Table 16 gives the seed yields of both maize and winged beans in the first season of the intercropping experiments. In the first season experiments, only one maize variety and one accession of winged bean were grown. The LER for the maize-winged bean intercrop when stakes were provided was slightly less than one, indicating no advantage for intercropping. This lack of

Table 16. Yields and Land Equivalency Ratios of Maize/Winged Bean (WB) Cropping Systems. 1983/84[1]

Trt. No.	Crops	Supports	Maize Grain kg/ha	Maize Grain relative[2]	Winged Bean kg/ha	Winged Bean relative[2]	LER
2	Maize	none	4378 a[3]	--	--	--	--
7	Maize + WB	none	3443 a	0.79	143 b	0.61	1.40
12	Maize + WB	single stakes	3725 a	0.85	114 b	0.12	0.97
1	WB	none	--	--	236 b	--	--
18	WB	single stakes	--	--	971 a	--	--

[1]Means of 6 replicates over two locations.

[2]Ratio of yield to that of appropriate sole crop.

[3]Means in a column followed by the same letter do not differ at the 0.05 level by DNMRT.

advantage to intercropping results from the drastic reduction in the yield of staked winged beans when intercropped with maize, as compared to the staked winged bean sole crop. The LER for the unstaked maize-winged bean intercrop was 1.4 indicating a considerable advantage of intercropping over sole cropping where stakes were not provided. To produce 3443 kg of maize and 143 kg of winged beans, only 1.0 ha of intercropped land but 1.4 ha of sole-cropped land (0.79 ha of maize plus 0.61 ha of winged bean) would be required. The high LER value was primarily a result of the low sole crop yield of the unstaked winged beans. Table 16 presents the combined results for both the Pallekele and the Meewatura sites in Sri Lanka since there were no significant site X treatment interactions.

Maize and winged bean yields at both sites for the second season (1984/1985) are presented in Table 17. In the second season, no stakes were provided in winged bean intercrop plots, but two varieties of maize and two winged bean accessions were grown. For winged bean sole crops without stakes, seed yields were very similar in 1983/84 and 1984/85. Providing stakes tripled winged bean seed yields in the first year. However, stakes had no significant effect on yields in the second year (431 and 408 kg/ha of seed for unstaked and staked sole crop winged beans, respectively). The relative yield of 'SLS-40' winged bean intercropped with 'Badra' maize was lower in 1984/85 than in 1983/84, indicating that no advantage was conferred by the earlier winged bean seeding in the second year. At both locations the 'SLS-40' winged beans out-yielded the 'TPT-1' winged beans by a large margin in the sole crop plots, but this relationship did not hold true when the winged beans were intercropped with maize. The LER's in Table 17 were calculated relative to sole crops with no support stakes. The highest LER, 1.73, was for the intercrop of 'Badra' maize with 'TPT-1' winged beans. Both the maize and the

Table 17. Yields and Land Equivalency Ratios (LER) of Maize/Winged Bean (WB) Cropping Systems. 1984/85[1]

Trt. No.	Crop	Support Stakes	Maize Grain Yield kg/ha	relative	Winged Bean Seed Yield kg/ha	relative	LER
3	Maize 'Badra'	no	4750 a	--	--	--	--
7	Maize 'TC'	no	4271 a	--	--	--	--
8	'Badra' + SLS 40	no	3176 a	0.67	184 bc	0.34	1.01
12	'TC' + SLS 40	no	5087 a	1.07	142 c	0.26	1.33
13	'Badra' + TPT-1'	no	4330 a	0.91	259 b	0.82	1.73
17	'TC' + 'TPT-1'	no	4017a	0.94	114 c	0.36	1.30
1	WB 'SLS-40'	no	--	--	547 a	--	--
2	WB 'TPT-1'	no	--	--	315 ab	--	--
18	WB 'SLS-40'	yes	--	--	544 a	--	--
19	WB 'TPT-1'	yes	--	--	315 ab	--	--

[1]Means of 6 repliations over two locations.

[2]Grain and seed at 13% moisture

winged beans relative yields tended to be lowest when 'Badra' maize was grown with 'SLS-40' winged beans. The high relative yields for intercropped 'TPT-1' winged beans are the result of the low sole crop yield and do not indicate a high absolute level of productivity.

Overall, there was no significant difference between the two varieties of maize in their yields in either intercrop of sole crop. However, there was a site X variety interaction. At the Meewatura site the 'Badra' maize outyielded the 'TC' maize, possibly because the 'TC' maize was more susceptible to aluminum (Al) toxicity at the low pH of the soil at Meewatura. Table 18 shows the relative effect of site conditions on the maize and winged beans in the second season. While the yields of each winged bean accession were the same at both sites, the yield of maize was considerably and significantly lower at Meewatura than at Pallekele. The yield depression at Meewatura was greatest for the 'TC' variety of maize. Since temperature and rainfall patterns were very similar for the two sites during this season, the differences are very likely due to the marked difference in soil properties, especially with regard to pH.

The pH of the soil at Meewatura was low and quite variable, ranging from less than 4.5 to over 5.6 in the upper 15 cm and as low as 3.9 in the subsoil (measured in H_2O, the lower values in Table 2 being for $CaCl_2$ measurements). It was also clear from observations in the field, that while the maize, especially variety 'TC' was very sensitive to the low pH, the winged bean, especially accession 'SLS-40', was not. It also was observed in the field that the maize growing in association with winged bean performed better in the very acid areas of the site than where maize was sole cropped (see Figure 9). The sole crop maize exhibited the stubby roots and darkened nodes characteristic of Al toxicity. In the most acid plots no maize yield data was

Table 18. Effect of Site Conditions on Sole Crop Maize and Winged Bean Yields, 1984/85[1].

Site	Crop Yields			
	Maize Cultivar		Winged Bean Accession	
	'Badra'	'TC'	'SLS-40'	'TPT-1'
	kg/ha			
Pallekelle	6131	6434	538	231
Meewatura	3370	2106	551	310
Difference	2761**[2]	4328**	-13(NS)	-79(NS)

[1]Means of 3 replications at each site.

[2]** and NS indicate highly significant (P<0.01) and non-significant differences, respectively.

Figure 9. Part of replication 2 of the intercropping experiment at Meewatura. Shown are sole crop maize to the left and winged bean/maize intercrop to the right. The soil pH in the immediate vicinity was very low (3.9 to 4.5). It can be seen that the growth of maize was much greater where it was grown in association with winged bean.

collected because most of the plants died, presumably from aluminum toxicity. Height data was collected several times during the season and the relationship between the height of the maize plants 9 weeks after planting and the pH of the upper 15 cm of the soil is shown in Figure 10. Note that the heights of maize grown in sole crop plots are consistently lower than those of maize grown with winged beans. No significant relationship existed between winged bean heights or yields and the soil pH, indicating that the winged bean was much more tolerant than maize to low soil pH.

In addition to maize, four other crops were successfully intercropped with winged bean in the field experiments. These crops were amaranth, okra, capsicum, and cucumber. Their yields with and without intercropping with winged beans are given in Tables 19-22. Like maize, the amaranth and okra crops provided strong vertical stems on which the winged beans could climb and, as such served as "living stakes". In testing the okra and amaranth intercrops, no support stakes were provided in either the sole crops or the intercropped plots. Figure 11 shows the amaranth/winged bean intercrop near the time of amaranth seed harvest. In contrast to the maize/winged bean intercrop, the winged beans yielded equally well when grown as sole crops or in association with amaranth. The yield of the amaranth (Table 19), on the other hand, was reduced by about 40% in the intercrop as compared to its sole crop. The LER values for amaranth/winged bean intercrops with either 'SLS-40' or 'TPT-1' winged beans were 1.48 and 1.61, respectively. Whether these LER figures reflect an economic advantage to intercropping depends on the relative economic value of winged bean seed and amaranth grain. Growing winged beans as an intercrop with amaranth was clearly advantageous over growing them as a sole crop without stakes as the winged beans yielded equally in both systems and the intercrop gave a considerable bonus of amaranth grain. On the other

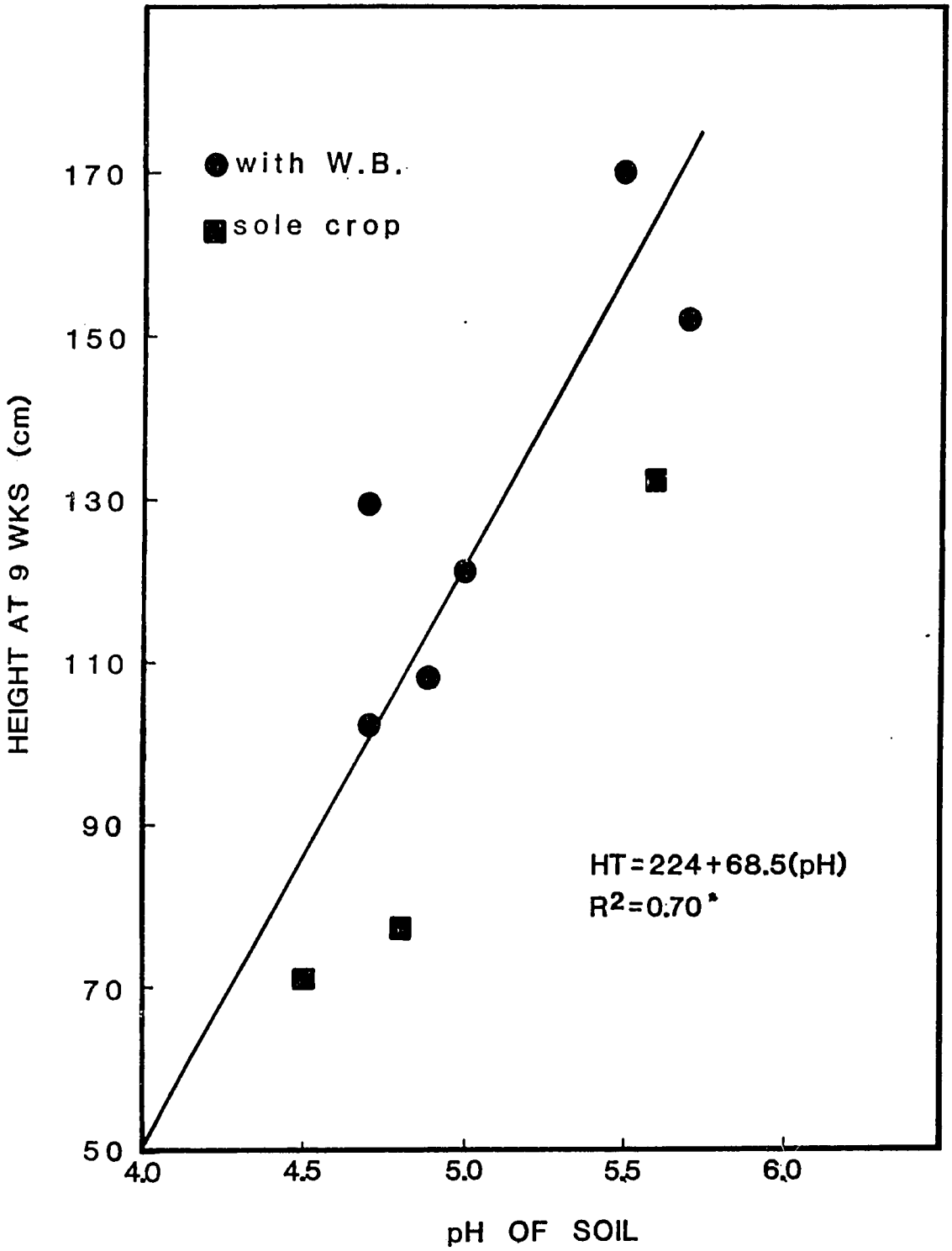


Figure 10. Relationship between height of maize and soil pH (as measured in 1:1 soil-water suspension) at Meewatura.

Figure 11. Grain amaranth/winged bean intercrop at Palekelle. Rod is 1 m with 20 cm markings.

Table 19. Yields and Land Equivalency Ratios for Amaranth/Winged Bean Cropping Systems, 1984/85[1].

Trt. No.	Crops	Amaranth Grain kg/ha	Amaranth Grain relative[3]	Winged Bean kg/ha	Winged Bean relative[3]	LER
5	Amaranth	2346 a[2]	--	--	--	--
10	Amaranth + WB 'SLS-40'	1412 b	0.60	530 a	0.88	1.48
15	Amaranth + WB 'TPT-1'	1457 b	0.62	523 a	0.99	1.61
1	WB 'SLS-40'	--	--	604 a	--	--
2	WB 'TPT-1'	--	--	528 a	--	--

[1]Means of 3 replications at Pallekelle. Yields based on 13% moisture.

[2]Means in a column followed by the same letter do not differ at the 0.05 level by DNMRT.

[3]ratio of yield to yield of appropriate sole crop.

hand, whether or not growing amaranth in association with winged bean was advantageous over growing amaranth as a sole crop would depend on whether the loss of approximately 900 kg/ha of amaranth grain was more than compensated for by the gain of approximately 520 kg/ha of winged bean seed. Although data on relative prices is not known at this time, from the standpoint of total protein production per hectare, the winged bean/amaranth intercrop was clearly superior to either of the the sole crops.

It is not known why the amaranth proved to be such a weak competitor with the winged bean, scarcely affecting the winged bean yields at all. One might speculate that this was because of the rather uneven amaranth canopy resulting from the great variability in height and size of the amaranth plants. The reduction in the amaranth seed yields per hectare was partially due to a lower actual amaranth plant density in the intercrop. While the amaranth grain yields per hectare were reduced by approximately 39% in the intercrop, the amaranth grain yield per plant was reduced by only 28% on the average.

The okra/winged bean intercrop (Table 20) had even higher LER values than did the amaranth/winged bean systems. However the coefficient variation (CV) for the okra yield measurements was nearly 60% and thus the results must be interpreted with caution. There was a tendency for both winged bean accessions to yield more when grown in association with okra than in their respective sole crops. Part of the improved winged bean growth can be attributed to the support provided by the okra stems. However, the winged beans intercropped with okra yielded more than even the staked winged bean sole crop. In the experiment in which okra was grown, the winged bean seed yields when the plants were provided stakes in sole cropped plots (data not shown) were 538 kg/ha for 'SLS-40' and 232 kg/ha for 'TPT-1', actually less than the respective yields when grown in association with okra (although these

Table 20. Yields and Land Equivalency Ratios for Okra/Winged Bean Cropping Systems, 1984/85[1].

Trt. No.	Crops	Okra Yield kg/ha	Okra Yield relative	Winged Bean Yield kg/ha	Winged Bean Yield relative	LER
6	Okra	2264 a	--	--	--	--
11	Okra + WB 'SLS-40'	906 a	0.40	897 a	1.83	2.23
16	Okra + WB 'TPT1'	1194 a	0.53	389 bc	2.25	2.78
1	WB 'SLS-40'	--	--	489 abc	--	--
2	WB 'TPT-1'	--	--	173 bc	--	--

[1]Means of 3 replications at Meewatura. No stakes used.

[2]Fresh weights of marketable pods.

differences were not statistically significant at the 5% level). On the other hand, the okra produced only about half as much in the intercrop as it did in its sole crop, though these differences were also not statistically significant. Nonetheless it would appear that the positive effect of the okra stem as a stake on which the winged bean can climb, more than offsets any negative effects of shading and other competition from the okra plants. Although no light intensity or leaf area index measurements were made, it was observed that the okra canopy was not very dense and did not severely shade the winged beans. The okra stems were strong and remained upright throughout the growing season of the winged bean. Thus it can be concluded that at the very least, okra has a good potential as a "living stake" for the production of winged beans, saving much of the money and effort that would otherwise be expended on providing stakes on which the winged beans can climb.

Winged beans grown in association with either capsicum or cucumber (1983/84) were given either single or crossed stakes on which to climb, as were the winged beans grown in the sole crop plots used as controls for comparison to the capsicum or the cucumber intercrops (Tables 21 and 22). Although in either system, the yield of winged beans was not significantly effected by association with the other crop, the LER values for the cucumber/winged intercrop were superior to those for the capsicum/winged bean system, largely because the cucumber yields were not reduced by intercropping with winged beans while the capsicum yields were. Since capsicum is a rather labor-intensive crop, requiring the production and transplanting of seedlings, and since it has a rather high market value, the intercropping of capsicum with winged beans is probably not adviseable as the capsicum yields were reduced by almost 65% in that system. On the otherhand, the cucumber/winged bean systems appears to be quite advantageous since neither the winged bean

Table 21. Yields and Land Equivalency Ratios of Capsicum/Winged Bean (WB) Cropping Systems. 1983/84[1]

Trt. No.	Crop	Stakes	Capsicum kg/ha	Capsicum relative[2]	Winged Bean kg/ha	Winged Bean relative[2]	LER
6	Capsicum	none	469 a	--	--	--	--
11	Capsicum + WB	single[3]	139 b	0.30	936 ab	0.870	1.17
16	Capsicum + WB	crossed[4]	127 b	0.27	807 b	0.996	1.27
17	WB	crossed	--	--	810 b	--	--
18	WB	single	--	--	1072 a	--	--

[1] means of 3 replications at Meewatura.

[2] ratio of yield to yield of appropriate sole crop.

[3] single vertical stakes 2 m long, 90 x 30 cm WB planting

Table 22. Yields and Land Equivalency Ratios of Cucumber/Winged Bean (WB) Cropping Systems. 1983/84[1]

Trt. No.	Crop	Stakes	Cucumber Yield Mg/ha[2]	Cucumber Yield relative[3]	Winged Bean Yield kg/ha	Winged Bean Yield relative[3]	LER
4	Cucumber	none	62.6 a	--	--	--	--
9	Cucumber + WB	single[4]	65.1 a	1.04	848 a	0.98	2.02
14	Cucumber + WB	crossed[5]	51.3 a	0.82	669 a	0.85	1.67
17	WB	crossed[5]	--	--	789 a	--	--
18	WB	single	--	--	869 a	--	--

[1]Means of 3 replications at Pallekele, 1983/84.

[2]Fresh fruit weights

[3]Ratio of intercropped yield to appropriate sole crop yield

[4]Single vertical takes, 2 m long, 90 x 30 cm WB spacing

[5]Crossed pairs of stakes, 2 m long, 45 x 60 cm WB spacing.

nor the cucumber yields were much reduced and therefore a single hectare of the intercrop would produce almost as much as two hectares divided equally into the respective sole crops. Thus, if it were considered desirable to produce a crop of winged beans using stakes, it would be possible to produce a sizeable crop of cucumbers simultaneously on the same land.

Winged Bean Nitrogen Accumulation

Little is known about dry matter and nitrogen accumulation and partitioning in winged beans. Data relevant to these topics are given in Tables 23 and 24 for winged beans grown at Pallekele and Meewatura, respectively. The data at both sites were quite similar so only that from Pallekele will be discussed here. It should be noted that while data are presented for roots and nodules, these underground parts were not harvested quantitatively and the contribution of these parts to the total dry matter and nitrogen accumulation in the plant is undoubtedly greater than represented by these data.

In terms of dry matter accumulation and partitioning several trends can be seen. First, dry matter accumulated rather slowly and began to accelerate between weeks 7 and 13, reaching a very rapid rate between weeks 13 and 31. Initially, the dry matter was primarily present in the leaf tissue, but as the plant grew larger and matured, the proportion in the leaves decreased and that in the stems and petioles increased. Thus at week 7 the leaves contained approximately 3 times as much dry matter as the stems ,while by week 31 the dry matter in the stem was virtually equal to that in the leaf tissue. The winged bean, being an indeterminate plant, never reached a state of complete maturity but continued to produce vegetative growth even up to 31 weeks (210 days). However, at this time the production of new pods was considered insignificant and the plant was harvested.

Table 23. Winged Bean Dry Matter and Nitrogen Accumulation at Pallekelle. 1983/84

Plant Part	Dry Matter g/plant	Nitrogen Concentration mg N/g	Total Nitrogen mg/plant
		Week 7	
Leaf	2.7 ± 0.58	45.7 ± 2.8	133. ± 36.
Stem	0.96 ± 0.36	26.9 ± 0.36	26.2 ± 10.
Petiole	0.66 ± 0.16	25.1 ± 0.66	17.2 ± 4.4
Root	0.51 ± 0.12	21.9 ± 0.94	11.0 ± 2.4
Nodule	0.13 ± 0.033	48.4 ± 0.83	6.14 ± 1.6
		Week 10	
Leaf	8.5 ± 0.79 *	49.6 ± 0.052 *	420. ± 39. *
Stem	4.6 ± 0.75 *	23.3 ± 1.6 *	101. ± 10. *
Petiole	2.2 ± 0.36 *	25.1 ± 0.17 *	54.4 ± 9.4 *
Root	1.3 ± 0.15 *	22.9 ± 0.99 *	27.9 ± 2.1 *
Nodule	0.33 ± 0.033*	43.8 ± 1.2 *	14.6 ± 1.9 *
Flower	0.45 ± 0.11 *	54.6 ± 0.18 *	24.5 ± 5.8 *
		Week 13	
Leaf	18.4 ± 2.9	45.4 ± 1.1 *	946. ± 130. *
Stem	11.2 ± 1.9	16.2 ± 1.3	176. ± 27.
Petiole	2.97 ± 0.22	14.1 ± 1.1 *	47.2 ± 6.2 *
Root	2.97 ± 0.39	18.2 ± 0.26 *	65.5 ± 1.7 *
Nodule	0.60 ± 0.053	45.6 ± 0.26 *	31.4 ± 0.47*
Flower	0.59 ± 0.15	47.8 ± 0.29	27.8 ± 7.2
Immature Pod	3.25 ± 1.17	42.2 ± 0.93	141.4 ± 53.
		Week 31 (final harvest date)	
Leaf	59.3 ± 6.2	48.9 ± 1.1	2900. ± 300.
Stem	62.3 ± 8.7	17.5 ± 0.57	1090. ± 130.
Petiole	14.6 ± 2.5	22.1 ± 0.74	322. ± 50.
Root	23.2 ± 5.3	28.9 ± 2.0	671 ± 180. *
Nodule	1.03 ± **	45.2 ± **	46.6 ± **
Immature Pod	6.88 ± 0.97	33.0 ± 1.4	227 ± 28.
Mature Pod	43.41 ± 5.6	10.7 ± 0.56	466. ± 66.
Seed	46.2 + 7.3	56.1 + 0.74	2590 + 400

[1] means and SE for 3 replications, 6 plants in each sample, except 3 plants in each sample for week 31.

* two replications, only

**one replication, only

Table 24. Winged Bean Dry Matter and Nitrogen Accumulation at Meewatura. 1983/84.

Plant Part	Dry Matter g/plant	Nitrogen Concentration mg N/g	Total Nitrogen mg/plant
		Week 10	
Leaf	5.20 ± 0.58	45.6 ± 1.9 *	283. ± 14. *
Stem	2.98 ± 0.42	19.3 ± 1.08	58.7 ± 9.5
Petiole	1.21 ± 0.17	18.4 ± 0.42	22.6 ± 3.4
Root	1.15 ± 0.41	17.8 ± 0.33	20.7 ± 2.7
Node	0.31 ± 0.092	43.1 ± 2.82	12.3 ± 3.1
Flower	0.15 ± 0.028	51.1 ± 1.28	2.98 ± 1.5
		Week 13	
Leaf	13.7 ± 1.1	48.9 ± 1.4	665. ± 49.
Stem	9.71 ± 0.64	23.0 ± 1.2	214. ± 25.
Petiole	4.02 ± 0.43	24.3 ± 0.80*	85.o ± 9.5*
Root	2.44 ± 0.034	23.2 ± 0.40	56.6 ± 0.4
Node	0.56 ± 0.16	53.8 ± 3.3	27.0 ± 6.0
Flower	1.15 ± 0.16	50.2 ± 0.45	57.3 ± 7.7
Immature Pod	2.67 ± 0.62	43.6 ± 2.6	109. ± 25.
		Week 31	
Leaf	69.[illegible] ± 8.2	38.3 ± 0.69	2660. ± 320.
Stem	97.8 ± 7.5	14.4 ± 0.67	1420. ± 150
Petiole	18.3 ± 1.8	15.5 ± 0.49	288. ± 37.
Root	24.7 ± 4.1	23.0 ± 1.0	550. ± 74.
Immature Pod	15.3 ± 6.2*	36.7 ± 1.4*	520. ± 210. *
Mature Pod	53.0 ± 8.4	13.0 ± 0.4	665. ± 94.
Seed	54.3 + 9.5	54.0 + 1.6	2870. + 480.

[1] means and SE for 3 replications, 6 plants each samples, except 3 plants per sample for week 31.

*2 replications only.

Even after this long growing season, the proportion of the total plant that consisted of seed (harvest index) was not more than 20% and usually somewhat less (for plant harvest once, only). Considering all the various fertility and intercropping treatments under which the winged beans were grown in these experiments, there was a considerable range in harvest index values. The harvest index ranged from less than 8% for winged beans grown with maize to slightly over 30% in the highest yielding sole crop plots given stakes to climb on and in which the mature pods were picked in 3 or 4 sequential harvests. A low harvest index is typical of plants that have not been intensively bred and indeed most progress in improving yields in breeding programs is achieved through improving the harvest index (Gifford et al, 1984). The data in Tables 23 and 24 are for replications of 6-plant samples which were harvested on the dates indicated and thus the mature pods were only harvested one time. This accounts for the lower harvest index for these plants. The sequential picking of pods as they become mature (harvests spaced approximately 10-14 days apart) had the effect of increasing seed production and harvest index.

The concentration of nitrogen in the winged bean tissue from various plant parts was generally quite high relative to the N concentration in other species. The leaf tissue was in excess of 45 mg N/g throughout the growing season, including at the time of final harvest. Several individual samples contained more than 50 mg N/g of tissue. In the young plants (ie. prior to 13 weeks after planting) the stem, petiole, and root tissue had similar nitrogen contents of approximately 20 to 25 mg N/g. The highest nitrogen contents were found in the flowers which contained more than 50 mg N/g and the mature seeds which generally contained in excess of 55 mg N/g. The nitrogen content of the seed indicates a crude protein content of approximately 35% and this agrees

with values given in the literature (Khan, 1982). The data for total nitrogen is a function of the dry matter and the nitrogen concentration in that dry matter. It shows that nitrogen accumulated rather slowly at first (4 mgN plant^{-1} day^{-1}), much faster during the next 21 days (21 mgN plant^{-1} day^{-1}), still faster during the following 21 days (38 mgN plant^{-1} day^{-1}), and very rapidly indeed for the last 126 days (55 mgN plant^{-1} day^{-1}). This latter value is equivalent to 2.0 kg N ha^{-1} day^{-1} during the last 126 days. It is clear that in order to enable winged beans to contribute significant amounts of nitrogen to a cropping system the long growing season must be allowed for the maturation of winged beans and an accumulation of nitrogen in the crop. After 210 days, when the final harvest of mature seed was made, the winged beans had accumulated a very large quantity of nitrogen. If we use the data in Table 23 for dry matter accumulation and nitrogen concentration we can calculate that a total of 8.312 g of nitrogen was accumulated per plant by the final harvest date. Considering that these plants grew at a spacing of 90 x 30 cm, and providing for approximately 10% fewer plants than the theoretical number, this gives a total nitrogen accumulation of 275 kg/ha in the entire plant and 180 kg/ha even after the removal of all the mature seed. This compares quite favorably with the nitrogen content of seven tropical forage legumes grown as green manures by Reddy et. al. (1986). Assuming that the pods and seeds are removed at harvest, the nitrogen concentration of the remaining above ground winged bean tissue would be in the range of 23 to 32 mg N/g (the values found at Meewatura and Pallekele, respectively). The green manure crops used by Reddy et. al. (1986) contained from 24 to 267 kg N/ha and their tissue N concentration ranged from 13 to 20 mg N/kg. These green manure crops did not provide a harvest of seed.

As large as these values are, they probably significantly underestimate the nitrogen accumulation by the winged bean since only a small portion of the below ground plant parts were recovered in this study. Even when considering only the above-ground parts of the plant, no more than 34% of the nitrogen was found in the mature seeds. At the final harvest date, the leaf tissue was still a major source of nitrogen. Thus, unlike for soybean and some other grain legumes, much nitrogen remains in the crop residue after the seed is removed.

Winged Bean-Maize Rotation Experiments

An experiment was established at each of two sites (Meewatura and Dodangolla) to determine the effect of a crop of winged beans grown for seed on the following two crops of maize (see Figure 12). In the first season the crop planted for 9 of the 14 treatments was maize and all maize treatments except No. 1 were fertilized with only 20 kg N/ha. Treatments 10 to 13 were planted to winged bean, which except in treatment 10 also received the 20 kg N/ha. Treatment 14 was planted to soybean and received 20 kg N/ha. The yield data from the first season (Table 25) at each site was used as an indicator of the variability of the soil at each site and of the relative yield potentials of the three crops. Single degree of freedom contrasts within the analysis of variance indicated that at both sites there was no significant effects of the 20 kg /ha N applied either to maize or to winged bean (Table 25). The data also indicated that the winged bean accession ('SLS-40') and the soybean variety used (BT-1) had approximately equal seed yield potentials. Seed yields of both grain legumes were approximately 1000 kg/ha at Meewatura (grown from mid-October 1983 to late March 1984) and were approximately 200 kg/ha at Dodangolla (January to June 1985). Maize yields were approximately 6000 kg/ha at Meewatura the first season and approximately 3000 kg/ha at Dodangolla. The

Figure 12. First season of the rotation experiment at Meewatura. Soybeans are in foreground, winged beans (with stakes) in center background, and maize to the left.

Table 25. First season seed yields of maize, winged bean and soybean at two sites.

Trt. No.	N applied kg/ha	Crop Grown	Seed Yield Meewatura kg/ha	Seed Yield Dodangolla kg/ha
1	0	Maize	6129	3207
2	20	Maize	6126	3860
3	20	Maize	5998	3140
4	20	Maize	6244	4050
5	20	Maize	5588	3953
6	20	Maize	5843	3073
7	20	Maize	5743	4425
8	20	Maize	6099	3047
9	20	Maize	5807	3909
10	0	WB	1378	264
11	20	WB	1924	147
12	20	WB	1188	291
13	20	WB	736	161
14	20	Soybean	1211	147
Single D.F. Contrasts			-------P > F---------	
Trt 1 vs. 2-9			0.548 NS	0.269 NS
TrT 10 vs. 11-13			0.784 NS	0.729 NS
Trt 14 vs. 11-13			0.838 NS	0.922 NS

[1] Least squares means of seed at 13% moisture.

Table 26. Second Season Seed Yields of Maize and Winged Bean as Affected by Nitrogen Application and Preceding Crop.[1]

Trt No.	N Added kg/ha	Crop	Preceding Crop	Seed Yield Meewatura	Seed Yield Dodangolla
				kg/ha	
1	0	M	M	5829	4203
2	0	WB	M	1594	480
3	0	M	M	6030	2924
4	25	M	M	6557	4979
5	50	M	M	7139	5994
6	75	M	M	8997	6771
7	100	M	M	7760	8387
8	125	M	M	6781	7821
9	150	M	M	8997	8314
10	0	M	WB	8408	6613
11	0	M	WB	8991	6821
12	100	M	WB	9314	8379
13	0	WB	WB	1415	596
14	0	M	SB	6597	4504
Single DF Contrasts				--------P > F---------	
trt 2 vs 13				0.837 NS	0.849 NS
trt 1 vs 3				0.819 NS	0.040 *
trt 14 vs 11				0.010**	0.001***
trt 14 vs 10				0.044*	0.001***
trt 12 vs 7				0.086+	0.991 NS

[1] least squares means of seed at 13% moisture.

considerably lower yields at Dodangolla in the first season of the experiment were probably a result of the droughty conditions during that time (see Figure 2).

In the subsequent two seasons maize in treatments 3-9 was given several levels of nitrogen fertilizer, ranging from 0 to 150 kg N/ha, in order to quantify the expected response by maize to nitrogen. For each season the response of maize grain yield to nitrogen was fitted to a Mitscherlich equation of the form

$$Y = Y_{max}(1-e^{-b(N+a)}).$$

The resulting response curves are shown in Figure 13. Also shown on the figure are the yields of maize, with and without nitrogen fertiizer, for crops following winged beans or soybeans. The data for the second season at Dodangolla indicates that the previous crop of winged bean supplied approximately 70 kg N/ha to the succeeding maize crop. This value for nitrogen contributed by the winged beans was about the same whether calculated for the maize receiving no nitrogen or the maize receiving 100 kg N/ha as fertilizer. The crop of soybeans contributed only approximately 25 kg N/ha to the following maize crop at Dodangolla. Maize yields and response to N were generally much lower in the third than in the second season at Dodangolla, probably as a result of the 40% less rainfall during the former than the latter. Still, there were positive responses to winged bean in the previous one or two seasons. Winged beans in the first season followed by maize in the second season had not effect on maize in the third season.

At Meewatura the response of maize to nitrogen was not as pronounced as that at Dodangolla. This may have been a result of a greater inherent N supplying capability of the soil at Meewatura (64 vs 26 kg N/ha) as well as limitations due to the much lower pH and phosphorus levels in the soil at

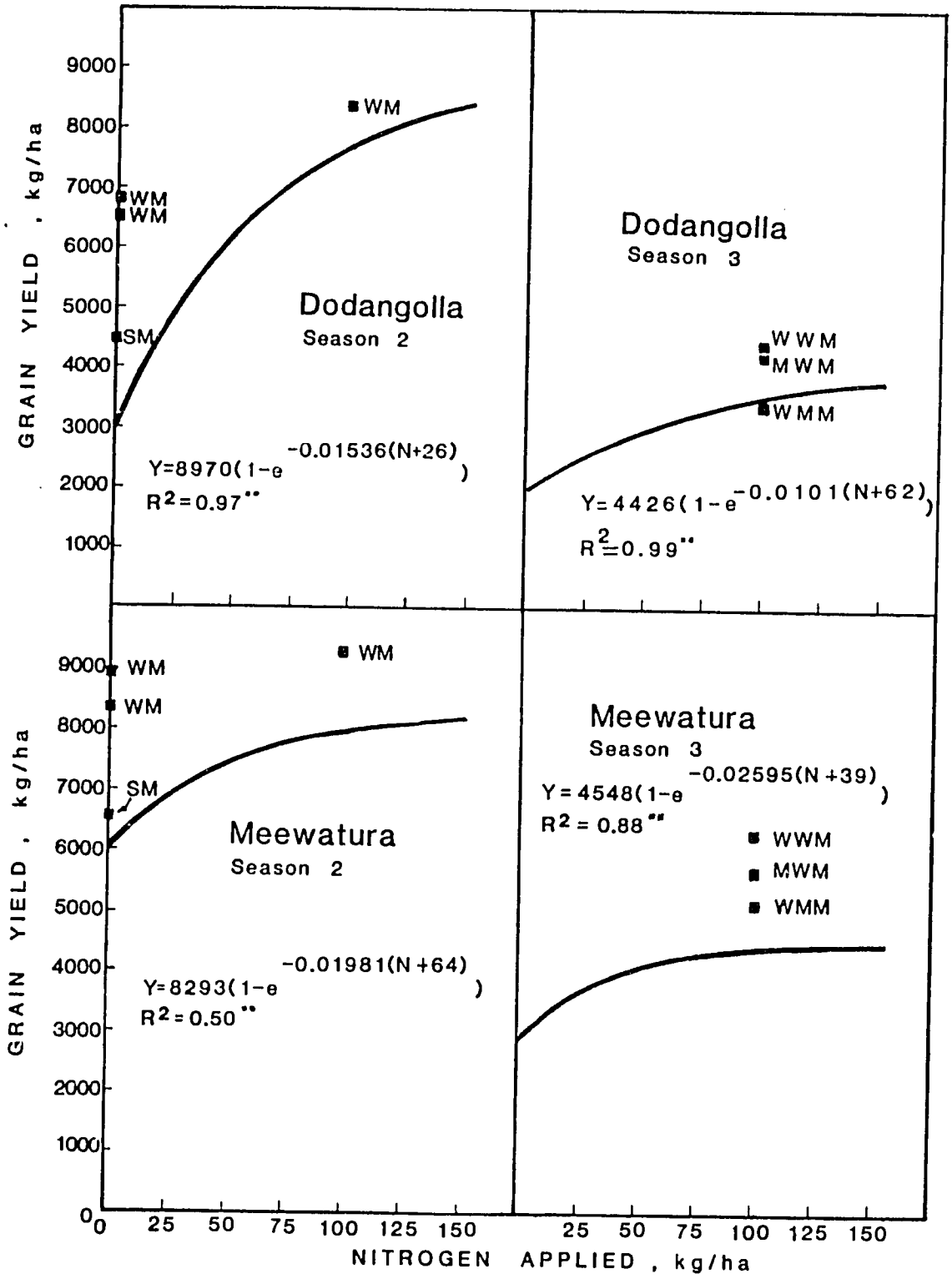


Figure 13. Yield responses of maize to applied nitrogen and effects of the previous crops. Curves are least squares f_: to the Mitscherlich equation. Data points are the least squares means of 4 replications. Capital letters indicate the cropping sequences for the treatment represented by the adjacent data point (W=winged bean, M=maize, S=soybean).

Meewatura (Table 2). As at Dodangolla, the yield of maize following winged bean was markedly greater than that of maize following maize at Meewatura (Table 26, Figure 13). This was true both where no nitrogen was applied to the maize and where 100 kg/ha of nitrogen was applied. The previous crop of soybeans had a much smaller effect than did winged beans. The yields of maize following winged beans were, in fact, greater than the maximum yield indicated by the nitrogen response equation (Figure 13), suggesting that the winged bean had improved the yield of the following maize crop by some mechanism in addition to the contribution of biologically fixed nitrogen.

In the third season at Meewatura (Table 27, Figure 13) the maize response to nitrogen was similar to that in the second season except that the yield levels were considerably lower as a result of very heavy rains during maize pollination. Again, there appeared to be some mechanism, in addition to the contribution of nitrogen, by which the previous crop of winged bean improved maize yields. The Ymax maize yield was again exceeded where the maize was grown in plots that had produced winged beans in either of the two preceding seasons. Thus the effect of a winged bean crop lasted for approximately two years. There was no effect detectable of the first season soybean crop on the third season maize.

Based on observations in both the rotation and mixed cropping experiments at Meewatura where the soils were very acid, it is hypothesized that the winged beans ameliorated the aluminum toxicity that is normally associated with such low soil pH values. It was observed that the maize grew better when associated with winged beans either growing simultaneously with them or in rotation after them, on the more acid areas where the pH was less than 5.0 (in H_2O). It is possible that the winged bean roots produced, either as direct excretion or as products of their decomposition, organic acids that

Table 27. Third Season Seed and Vegetative Dry Matter Yields of Maize as Affected by Nitrogen Application and Preceding Two Crops at Meewatura and Dodangolla.[1]

Trt. No.	Previous Crops	N Added	Meewatura Seed Yield	Meewatura Dry Matter	Dodangolla Seed Yield	Dodangolla Dry Matter
		kg/ha				
1	M then M	100	4414	6348	3779	9603
2	M then WB	100	5735	8621	4322	11136
3	M then M	0	3822	4149	2141	7631
4	M then M	25	3469	4815	2282	7198
5	M then M	50	4213	5882	2552	7968
6	M then M	75	4710	6065	3179	9343
7	M then M	100	3362	5495	3952	10734
8	M then M	125	4191	5661	4137	10067
9	M then M	150	4425	5819	3929	10432
10	WB then M	0	3903	5473	2482	8526
11	WB then M	0	4166	6066	2895	8[illegible]
12	WB then M	100	5176	6087	3451	9604
13	WB then WB	100	6302	8839	4406	11666
14	SB then M	0	2723	3785	1421	5787
Single DF Contrasts				P > F		
trt 1 vs 2			0.038 *	0.008 **	0.301 NS	0.173 NS
trt 3 vs 10			0.091 +	0.114 NS	0.512 NS	0.[illegible]17 NS
trt 3 vs 11			0.041 *	0.027 *	0.166 NS	0.550 NS
trt 10 vs 11			0.675 NS	0.478 NS	0.441 NS	0.853 NS
trt 3 vs 14			0.857 NS	0.658 NS	0.171 NS	0.101 +
trt 2 vs 13			0.364 NS	0.791 NS	0.872 NS	0.630 NS
trt 12 vs 13			0.077 +	0.002 **	0.072 +	0.068 +

[1] least squares means for seed at 13% moisture

acted as chellates to render the aluminum non-toxic. Hue et al (1986) found that certain organic acids, especially citric, oxalic, and tartaric, were effective in alleviating alluminum toxicity by chellating the monomeric aluminum. Although an investigation of this phenomenom was beyond the scope of the present research project, the observations in the field were so striking as to justify further research to examine the possibility that winged beans produce organic complexes that can alleviate aluminum toxicity in susceptible crops. The production of such compounds could also explain why the winged beans themselves are quite tolerant to low soil pH, as reported in the present study and by others (Shamsuddin and Zkaria, 1978).

Most of the positive effects on the following maize crop must have resulted from either the nitrogen or other compounds in the roots of the winged bean rather than from the winged bean tops, because the yield of maize following winged beans was approximately the same whether the above ground vegetative parts of the winged beans had been removed from the plots (as in treatment 11) or incorporated into the soil (as in treatment 10). This hypothesis is also supported by the fact that the response of maize to a preceding winged bean crop was just as great or greater at Dodangolla as it was at Meewatura despite the fact that the initial winged bean crop at Dodangolla produced only about half as much above ground vegetation as the crop at Meewatura.

SUMMARY AND CONCLUSIONS

Winged beans appear to produce allelopathically active compounds, but the effects were species-specific. The main deleterious effect was on amaranth while the main stimulatory effects were on kurakkan and Phaseolus beans. Except possibly with amaranth, allelopathy did not appear to be a problem in the field. Winged beans were a suitable crop for intercropping with

cucumbers, one hectare of this intercrop yielding almost as much as 2 hectares divided equally amongst the two crops as sole crops. As "living stakes" providing physical support for the winged bean, both okra and amaranth were suitable. Maize, however, was more competitive and was less practical as a "living stake" companion crop since it significantly reduced the seed yield of the winged beans.

The winged beans proved to assimilate very large quantities of nitrogen per unit land area. Their initial growth was very slow but during the third through fifth month, growth and nitrogen fixation was rapid. In all cases, the harvest index was very low, generally below 30%. Nonetheless the seed yields produced were comparable to those of soybeans, being in the range of 1000-2000 kg seed/ha under the best conditions prevailing in this study. In the rotation experiments it was shown that a crop of winged beans greatly enhanced the yield of the following crop of maize, probably even beyond the effect of simple nitrogen contribution. Winged beans had this positive effect on the following crops even if the seed and pods were removed from the field. In fact, even where all of the above ground plant material was removed (as might be desirable if cattle fodder was needed as well as seed and pods) the winged beans still had a marked stimulatory effect on the following maize crop. Where nitrogen was limiting and the nitrogen contribution of the winged beans could be properly estimated the winged beans supplied approximately 70 kg/ha of nitrogen to the following maize crop.

Several basic problems proved to be associated with winged bean production. A major problem is its indeterminate habit which results in a requirement for a very long growing season to produce a crop of mature seeds (150 to >200 days). This may be a problem in that a winged bean crop would occupy the land for a period of time during which two other crops could have

been grown. The indeterminancy of the winged bean also results in a need for staking, an expensive and labor intensive operation, but one that may be replaced by "living stakes" such as okra or amaranth. As with any crop at an early stage of domestication and improvement, the harvest index of winged bean is very low. For seed production it would be very desirable to breed winged bean cultivars that partioned more of the photosynthate into the seed and less into vegetative growth.

RECOMMENDATIONS

1. For seed production, winged beans should be planted at a population between 20,000-35,000 plants/ha.
2. Single vertical stakes 2 m high should be provided to support winged beans grown for seed.
3. No Rhizobia inoculum or N fertilizer should be required for winged beans in most circumstances.
4. The winged beans accessions tested are not suitable as a short season green manure crop and should be grown only when > 150 days are available in the growing season.
5. For maximizing seed yield, winged bean pods should be picked as they mature in 3 or 4 harvests about 10 days apart.
6. Maize, okra or grain amaranth can be intercropped to provide support for winged beans instead of stakes or trellises.
7. Intercropping of winged beans with either grain amaranth or okra are likely to make more efficient use of land than would sole cropping.
8. Staked winged beans can be intercropped with cucumber without significantly reducing the yield of either crop.
9. Where a market for winged bean seed can be arranged and a long growing season is available, winged beans can substantially improve maize yield grown in rotation, replacing much, if not all of the N fertilizer otherwise required by the maize.
10. Based on the experience gained in this project, future agronomic research on winged beans seed production should focus on these areas:
    a. improvement of maize density and spacing to allow better winged bean relative yields.

b. genetic or environmental factors affecting winged bean maturity and harvest index.

c. mechanisms involved in winged bean tolerance of low soil pH and apparent protective effects on companion crops.

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To maintain our readers up to date on the latest research development in any aspects associated with amaranth, we kindly request scientific contributions for inclusion in the Newsletter. These should not exceed 1,000 words and include at least a table of results. Color, or black and white glossy prints should measure 3 1/2"x 5".

We would also appreciate remittance of abstracts of publications on the topic, to include title of same, authors names, institutions where they work and location, bibliography, and address of persons responsible for sending the information.

For further details, kindly contact the Editor-in-Chief or the Editorial Office of *Archivos Latinoamericanos de Nutrición*, P. O. Box 1188, Guatemala City, Guatemala, C. A.

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* **Grain amaranth plants from the greenhouse allelopathy experiment. The pot on the left (T4) contains fresh soil (no association with winged bean). The center pot (T20) contains soil that previously supported winged beans. The pot on the right (T28) contains fresh soil, but the amaranth plants were watered three times with an aqueous extract of winged bean tissue. (Scale in decimeters). Fig. 1 of article by Weil and Belmont in this issue.**

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EDITORIAL

THE BEGINNING OF A NEW ERA

The present issue is the starting point of a new era for our **Amaranth Newsletter,** *one which, we hope, is as effective as we would like to think has been that which our readers have been receiving as of March, 1983.*

It is true that, if in the first stage of the Newsletter we depended on you, our dependence on your publications and recent news in this second stage will be even greater. In other words, more than ever, today we need your scientific contributions which will impart the desired stimulus to the commercial cultivation of the plant, both for consumption as a vegetable and for its utilization as a grain. Amaranth will thus be able to form part of the industrial food production systems, and of the habitual feeding patterns of our populations.

The proposed goal must be achieved not because amaranth is associated with the development of great civilization of the past, nor with the heroes of those days. The goal must be reached solely on the basis of the agronomic and nutritional merits of amaranth, whether it is utilized as a vegetable or as a grain. Those desirable characteristics can be attained through the research work and studies in which all of us are endeavoured in different aspects of the food chain, and in different regions of the world. Knowledge acquired and results obtained should, of course, be made available for analysis by other researchers, making them known to all those interested in amaranth.

Dissemination of information —to which their generators are obliged— can evidently be made through a number of journals. For multiple reasons, however, this course of action may in some way prevent knowledge of this information from reaching persons interested in the plant, who now receive the **Amaranth Newsletter.**

On the other hand, the quality and wealth of information their articles may contain will undoubtedly contribute to give stability, category and, more than anything, character of permanency to our publication. In summary, the truth is that we are anxious to see amaranth plants embellesing the farmers fields, providing them an attractive income, being used in the commercial production of palatable and nutritious foodstuffs, improving and, thus, contributing to the good nutrition of man in all regions of the world.

We shall therefore receive with interest your valuable contributions: four issues per year with three articles each represent a total of 12 which, as minimum, is our goal. If your articles have already been published in other journals, we will publish their respective summaries, and if they are originals, these will form the main body of our publication. Needless to say, we look forward to any suggestions you may have both for upgrading this informative source, and concerning the introduction process of the crop itself. This is the real purpose of the **Amaranth Newsletter,** *a feeling which, we trust, is shared by our readers.*

One more word. We wish to express our appreciation for your stimulating and encouraging words in our past efforts, and to thank you in advance for your favorable response to our request for a greater number of scientific contributions as well as for your comments concerning the present publication.

Ricardo Bressani
Editor-in-Chief

INTERACTIONS BETWEEN WINGED BEAN AND GRAIN AMARANTH

Introduction

Small-scale farmers in many countries have traditionally grown food crops in mixed rather than monocrop stands. In recent years agronomists have begun to investigate the potential benefits of mixed cropping which include greater resistance to pest infestation and more reliable yields in seasons with adverse weather conditions (1-3). In many cases, agronomic studies have shown that mixed cropping also uses land and labor more efficiently than sole-cropping, with greater yield per hectare and per hour of labor. Where yield advantages occur, they may result from a sharing of soil and light resources by the associated crops, in such a way as to more efficiently exploit the total environment. Among the most common and most successful crop combinations are those that mix a grain legume with a cereal crop. A climbing legume such as winged bean (*Psophocarpus tetragonolobus*) might especially benefit from a tall, strong-stemmed intercrop, maize (*Zea mays*) or amaranth (*Amaranthus hypochondriacus*) for example, on which it could climb. Not all interplanting combinations are compatible however. In addition to competitive effects, associated species may interact allelopathically by toxins released into the soil by root excretion, residue composition or foliage leaching. We report here on the results of laboratory, greenhouse and field studies that evaluate the effects of winged bean on amaranth and compare the field performance of the amaranth/winged bean intercrop to that of the respective sole crops in sub-humid tropical environment.

Material and Methods

Seedling Study

Four extract concentrations were prepared by adding 0, 4, 20 or 40 g of dried, ground winged bean leaf and stem tissue to 100 ml of either distilled water or 30% ethanol. The winged bean tissue was soaked in either solvent for 24 hr, with intermittent shaking. The extract was then filtered through Whatman No. 1 filter paper, and, in the case of the ethanol extract, the filtrate was then put through a roto-vac evaporator to remove the ethanol,and brought back to the original volume with distilled water.

For each experimental unit, 20 seeds of one crop species were surfacesterilized with chrorine bleach, rinsed in distilled water, and placed in a 15 cm diameter petri dish, on a double layer of sterile filter paper moistened with 8 ml of extract. The petri dishes were covered and kept in a germinator at 22 ± 0.5°C. Grain amaranth (*Amaranthus hypochondriacus*), and sorghum (*Sorghum vulgare*) seed were used, as well as those of other species not reported here.

Germination counts were taken daily. When no additional seeds germinated for two days, two more days were allowed for elongation of the hypocotyl and radicle. Then 10 germinated seeds were removed, and the lengths of the hypocotyl and radicle, measured.

Germination counts, hypocotyl length and radicle length measurements were recorded as percentages of the respective values for the same species when treated only with distilled water. The experiment had two replications in a RCB design and a factorial set of treatments with two solvents and four extract concentrations. Analysis of variance was performed separately on the data for each type of seed.

Greenhouse Study

Grain amaranth was grown in a greenhouse in four cropping systems: 1) sole crop control, 2) companion crop with winged bean, 3) sole crop in rotation after winged bean, and 4) sole crop watered with winged bean tissue extract. There were four replications. The pots used were 15 cm in diameter and were filled with approximately 1 kg of soil that included 30% by volume of perlite. For the sole crops [1), 3) and 4)] seeds were planted in each pot and later thinned to four. For the companion cropping system 2), four seeds of amaranth and four seeds of winged bean were planted in each pot, and these were later thinned to two plants of each. In the rotation system 3), the amaranth (or other companion crop) was planted in pots filled with soil that had previously grown winged beans and contained the decaying residues of that earlier winged bean crop.

For the treatment wherein the companion crops were watered with winged bean extract, a 10% extract of above-ground winged bean parts was made by extracting 100 g of dried ground tissue in one liter of distilled water, and filtering as described previously. In this treatment, 60 ml of the filtered winged bean extract were applied with a fine-rose watering can to each pot at 25, 40 and 55 days after planting.

The winged bean seeds were pre-germinated to assure good establishment. All pots were watered once a week with a complete nutrient solution for the first three weeks, and twice a week thereafter. The soil was maintained at optimum moisture content by bringing each pot up to its original moist weight with distilled water daily. When nutrient solution or winged bean extract were used, these were added prior to bringing the pots up to their proper weight with distilled water. The temperature in the greenhouse was maintained between 18°C at night and 24-26°C during the day. A single 50 cm tall, thin bamboo stake was provided for the support of the winged bean plants. At 65 days after planting, the above ground parts of all plants were harvested and the plant heights, fresh weights and dry weights (after 48 hours drying at 68°C) were recorded. Analysis of variance was performed and means for the four cropping systems were separated using the Duncan's New Multiple Range Test.

Cropping Field Experiments in Sri Lanka

A field experiment was established in Sri Lanka near Pallekele in the intermediate rainfall zone (7°17' N latitude,

650 m elevation, 1500 mm/yr rainfall). Plots were raised beds 4.5 x 6 m in size. Amaranth or winged bean, or both, were over-planted and thinned to 30 cm apart in rows 60 cm wide. Both crops were planted simultaneously on 5-7 October 1984. In intercropped plots, winged bean plants were grown in the same rows as amaranth. The experiment was to have been repeated at another site, but amaranth failed to establish there because of the extreme acidity of the soil (pH in H_2O = 4.5) at that site. N, P and K were applied prior to planting at rates 60, 25 and 25 kg/ha, respectively. The amaranth grain was harvested by hand 120 days after sowing with only the seed-head removed. The remainder of the plant was left standing until the harvest of winged beans was complete some 45 days later (matured winged bean pods were picked by hand every 10 days between 120 and 165 days after planting). The moisture content of all harvested materials was determined, and the yield results were expressed on the basis of 13% moisture in the grain. The land equivalency ratio (LER) was calculated according to Mead and Willey (4) as one measure of the relative efficiency of intercropping as compared to sole cropping.

Results and Discussion

Allelopathic Effects on Seed Germination and Seedling Growth

Extracts of the dried winged bean tissue had significant effects on the germination and seedling growth of several of the crops studied, including amaranth. The main effects of crop, solvent, and extract concentration were all significant at the 5% level for all three variables. There were also a number of significant interactions indicating that different crops responded differently to the two types of extracts. Averaged over all crops and all concentrations, the winged bean compounds extracted with ethanol produced lower germination and seedling growth than those compounds extracted with distilled water (Table 1). Since the ethanol used to make the extract was removed before the extract was applied to the seed and —since where no winged bean tissue was included the effect of water and ethanol was generally the same— the lower germination and growth where the ethanol winged bean extracts were applied, probably resulted from allelopathic compounds extracted by the ethanol but not by the distilled water.

Because the crop x solvent x concentration interaction was non-significant, the data for both the water and the ethanol extracts were combined. The results for amaranth and sorghum are presented in Table 1. It can readily be seen that amaranth was more sensitive with respect to seed germination and radicle growth, than was sorghum. In the case of amaranth, both parameters were stimulated by the lowest level of winged bean extract, but markedly inhibited by higher levels. Amaranth radicle elongation also was more sensitive to the effects of winged bean extract than was amaranth hypocotyl elongation. Overall, amaranth was the most sensitive of the eight crops tested (data not shown).

Table 1. Effects of winged bean tissue extracts on germination and seedling growth of amaranth and sorghum

Crop	Parameter	Extract strength (g tissue/lt)			
		0	10	50	100
Amaranth	Germination[1]	100[b,3]	143[a]	90[b]	32[c]
Amaranth	Radicle length[2]	100[b]	261[a]	79[cb]	28[c]
Amaranth	Hypocotyl length[2]	100[a]	130[a]	104[a]	61[a]
Sorghum	Germination[1]	100[a]	100[a]	99[a]	97[a]
Sorghum	Radicle length[2]	100[a]	67[b]	61[b]	55[b]
Sorghum	Hypocotyl length[2]	100[a]	162[a]	111[a]	113[a]

1 Means of 2 replications with 20 seeds each.
2 Means of 2 replications with 10 seeds each, 2 days after germination.
3 Means in a row not followed by the same letter are significantly different by DNMR test; p = 0.05.

The growth of amaranth was stimulated by following winged beans in rotation, i.e. amaranth grown in soil previously used for winged bean produced 3.91 g/plant, significantly more than 2.58 g/plant produced by amaranth in fresh soil. The possible enrichment of the soil with N biologically fixed by the winged beans, cannot be ruled out as a cause of this stimulatory effect. It is unlikely, however, that it was the main cause, because a nitrogen-fixing crop *(Phaseolus vulgaris)* was quite markedly stimulated by growing after winged beans whereas several non-nitrogen-fixing crops were not stimulated (e.g. capsicum and sorghum). Furthermore, the nutrient solution used for all crops has enough N in it to have eliminated any response to nitrogen fixed by the previous winged bean crop. Thus, the rotation effect of winged bean may have been due to allelopathic compounds.

Only amaranth, of the eight test crops, was significantly affected by the applications of winged bean tissue extract. The extract treatment reduced amaranth dry matter production 27%, from 2.58 to 1.87 g/plant. The winged extract treatment also reduced plant height (Figure 1 on front cover of this Newsletter) and changed the color of the upper amaranth leaves from red to green. In contrast, the presence of winged bean plants growing together with the amaranth had no effect on the dry matter or appearance of the amaranth plants.

In the field experiment (Figure 2) no foliar symptoms of allelopathic inhibition were noted. Nevertheless, seed yields were significantly reduced by intercropping with winged bean, probably by competitive effects, but possibly with some contribution by allelopathy as well. The yields of other tall-growing cereals such as maize, were not reduced significantly by intercropping with winged beans (data not shown). Table 2 shows the seed yields of amaranth and winged bean when grown separately or together at a constant population density of each crop. Association with amaranth had no effect on the winged bean yields, but association with winged bean reduced amaranth yields by approximately 40%.

FIGURE 2

Grain amaranth/winged bean intercrop plot at Palekelle. Rod is 1 m with 20 cm markings.

Table 2. Yields and land equivalency ratios (LER) for amaranth/winged bean cropping systems[1]

Crops	Amaranth grain		Winged bean seed		LER[4]
	kg/ha[2]	Relative yield[3]	kg/ha[2]	Relative yield[3]	
Amaranth	2,346[a]	—	—	—	—
Amaranth + WB 'SLS-40'	1,412[b]	0.60[a]	530[a]	0.88[a]	1.48[a]
Amaranth + WB 'TPT-1'	1,457[b]	0.62[a]	523[a]	0.99[a]	1.61[a]
Winged bean 'SLS-40'	—	—	604[a]	—	—
Winged bean 'TPT-1'	—	—	528[a]	—	—

1 Means of 3 replications. Yield based on 13% moisture.
2 Means in a column not followed by the same letter are significantly different by DNRM test; p = 0.05.
3 Relative = Ratio of yield to yield of appropriate sole crop.
4 LER = Land equivalency ratio, the sum of component relative yields.

The efficiency of the intercrop relative to that of the sole crops can be evaluated from several points of view. Total grain production per unit land area was greatest for the amaranth sole crop, while intercrops yielded 15 to 16% less, a non-significant difference. If the market price of winged bean seed were higher than that for amaranth, intercropping would be most profitable. Since there is no reliable data on the market prices of these two crops, the profitability of the three cropping systems could not be properly evaluated. Using the LER (Table 2) to evaluate the intercropping system, the values of 1.48 and 1.61 for the two winged bean/amaranth intercrops indicate that approximately 50% more land would be required to produce the same yields of the two crops in sole cropped fields as in intercropped fields. The yields produced were approximately in the ratio of three amaranth for one winged bean. One could also compare the productivity of a rotation of the two crops with that of the intercrop system. If a farmer desired to grow both crops and divided his land into two equal fields, one for each crop, the combined yield would be 1,475 to 1,437 kg/ha, depending on the winged bean assession used. This compares with 1,942 to 1,980 kg/ha for the intercrops.

In conclusion, it appears that amaranth is quite sensitive to the allelopathic influence of winged bean under some conditions, but that winged bean grows very well in association with amaranth. Since the robust stems of the tall *Amaranthus hypochondriacus* used served well as "living stakes" for the climbing winged beans, intercropping should be investigated further where there is interest in producing both of these crops.

Acknowledgements

This work was partially funded by USAID Program in Science and Technology Cooperation Grant DPE-5542-G-SS-3013-00. The authors express their appreciation to A. Samaranayake and H.P.M. Gunasena for their valuable assistance with the field work in Sri Lanka.

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EFFECT OF TEMPERATURE ON THE FUNCTIONAL PROPERTIES OF AMARANTH SEED FLOUR

Enrichment of traditional foods and replacement of proteins of conventional use by others not widely utilized, depend from the fact that the latter have adequate functional properties which facilitate their incorporation in the food industry. In this sense, a summary on the studies related to the properties of amaranth seed flours which we have been conducting here in Venezuela, where the plant is a native one, is herein presented.

Analyses of amaranth K112 seed flours, subjected to various temperatures (60°C for 4 hours; 80°C for 1 hour, 90°C for 30 minutes, and 120°C for 10 minutes) were performed. For this purpose, previous publications recommending that heat be applied before consumption so as to improve digestibility, were considered. Besides, we must keep in mind that foods where these flours could be incorporated, are processed by thermal treatments.

The proximal composition analyses of the flours proved to be similar to those notified in the literature, thermal treatment not affecting their composition.

In effect, as stated in Table 1, results of the study on the functional properties indicated that as far as water and oil absorption is concerned, temperature does not affect these properties. Values were maintained practically constant as temperature increased until it reached 120°C, when water absorption diminished 10% with regard to that detected at the temperature of 60°C. This finding confirms the fact that proteins are not the only factors responsible for the formation of hydrogen bridges through water absorption; the carbohydrate content —which in amaranth flours represents approximately 70%— also influences it in great measure. Oil absorption of the flours was reduced in 15% when sterilization temperature was applied, in contrast, to those subjected to 60°C.

Comparison of the data obtained with values determined in soy flour (Table 1), reveals that water and oil absorption is higher in amaranth flours. Therefore, they can be used in preparing bakery products, as in fact has been done.

Table 1. Water and oil absorption of amaranth seed flour

Amaranth flour samples subjected to	Water absorption %	Oil absorption %
60°C for 4 hours	420	150
80°C for 1 hour	420	150
90°C for 1/2 hour	415	150
120°C for 10 minutes	380	130
Soy flour	250	140

Now, in regard to the study on emulsification properties of amaranth seed flours, this rendered very interesting data because, as Table 2 shows, values indicate the feasibility of incorporating them in pork-meat products (charcuterie) and their use as meat extenders, since the emulsion formed is stable at 24 hours, and similar in appearance to mayonnaise. It should be pointed out that in spite of the fact that amaranth flours contain 15% protein while soy flour contains three times as much (48%), the emulsifying activity values varied only in 8%. Formation of the emulsion (oil in water) was seriously affected by heat, because at the 120°C temperature, the value determined at 60°C had been reduced to almost a half, reduction which occurs due to denaturalization of the proteins caused by heat.

3. A-07

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78th Annual Meeting

AMERICAN SOCIETY OF AGRONOMY

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purchased by Swazi farmers show a trend of increased fertilizer use. On-station fertilizer research has shown large responses to applied fertilizers which have not been duplicated on-farm. The results of on-farm fertilizer trials are presented and discussed. Directions for future research and extension programs in fertilizer use are also presented.

Phosphorus Fertilization Alternatives for Intensive Cropping on Oxisols in the Brazilian Amazon. T. J. SMYTH* and M. A. CRAVO, North Carolina State Univ. and EMBRAPA/UEPAE-Manaus.

During four consecutive years, a field trial was conducted on a clayey Typic Acrorthox in Manaus, Brazil to determine optimum fertilizer P rates and placement for production of an annual corn-cowpea rotation. Phosphorus treatments were arranged in a split plot design. Broadcast P rates (0, 22, 44, 88 and 176 kg P ha^{-1}), applied only to the first crop, were main plot treatments. Subplots contained banded P rates (0, 11, 22, and 44 kg P ha^{-1}) applied to each crop. Without applied P initial seed yields for corn and cowpea were 600 and 15 kg ha^{-1}, respectively, and declined progressively in subsequent crops. In all crops P fertilization significantly increased yields over the control. Cummulative yields of each treatment, for either all crops or individual species, were more closely related to total quantities of applied P than to placement method. Among the P treatments studied, banded applications of 22 kg P ha^{-1} $crop^{-1}$ maintained near optimum yields and avoided large capital investments in P fertilizer for an individual crop.

Response of Forage Sorghum to Tropical Photoperiod During Two Years in Puerto Rico

A. SOTOMAYOR-RIOS* and S. TORRES-CARDONA. Tropical Agriculture Research Station, Mayaguez, Puerto Rico.

Cytoplasmic male-sterile sorghum ATx623 (Sorghum bicolor (L.) Moench) was crossed with male parents "Millo Blanco" (MB), photoperiod sensitive, and Greenleaf sudangrass (GL), photoperiod isensitive. The F_1 hybrids and male parents were planted monthly during 1984 and 1985 at Isabela, Puerto Rico and evaluated each 60 days for dry matter content (DMC), dry forage yield (DFY), crude protein content (CPC), crude protein yield (CPY), leaf area (LA), plant height (PH), rust (R) and in vitro dry matter digestibility (IVDMD). Years (Y) and Y x planting date (PD) F values were significant for all traits except R and IVDMD for Y and R for Y x PD. Significant differences were observed among PD and genotypes (G) for all traits except DMC, CPC and IVDMD in the latter. The significant Y x G abd PD x G interactions indicates that G responded differently at the different PD and Y for most traits. During the two Y ATx623 x GL and GL had nearly constant DFY (3-4 t ha^{-1}) while ATx623 x MB ranged from 5 (December-January) to 7.4 t ha^{-1} (June) during 1984 and from 3 (December) to 5.8 t ha^{-1} (June-July) during 1985. During both years long days stimulated greater PH, LA and less R incidence in photoperiod sensitive G.

Inoculum Production of VA Mycorrhizal Fungi

D. M. SYLVIA, Univ. of Florida.

The agronomic application of VA mycorrhizae has been hindered by inadequate methods for large-scale inoculum production. The VA mycorrhizal fungi have not been grown successfully in pure culture and are usually maintained and increased in pot cultures. Pot cultures contain the host plant, VA mycorrhizal fungus, and potting medium. Factors that affect inoculum production include the host plant, growth medium, inoculum type and density, container size, fertility regime, light intensity and duration, temperature, soil moisture, and associated microorganisms. The quality and quantity of propagules produced in pot cultures can vary widely due to the many interactions among these factors. For this reason, several alternatives to the pot-culture system have been proposed. The VA mycorrhizae have been formed on root-organ cultures; however, colonization and sporulation have been limited in these monoxenic systems. The VA mycorrhizae have also been established on plant roots in hydroponic and aeroponic systems. Root colonization and sporulation, comparable to or exceeding that achieved in pot cultures, have been report for these solution-based systems.

Erosion Control for Cultivated Steeplands in The Dominican Republic. R. VELOZ* and T.J. LOGAN, Secretary of Agriculture, Dominican Republic and The Ohio State University.

Ten erosion plots (3m x 15m) were established (1984) on an ultisol with 30% slope in the Dominican Republic. Treatments on the plots include: maize/peanuts/beans (Phaseolus)/pigeon peas (Cajanus cajan) mixed seeding cultivated with and without fertilizer; the same crops with minimum cultivation and with zero tillage; bare soil; perennial grass; cultivated mixed cropping as on the other plots but with cross-slope treatments of: perennial grass, rock wall, and hillside ditch. Since installation, 32 runoff events have been sampled and analyzed. Cumulative runoff (cm) was highest from the bare plot (21.4cm), 4.3cm for the cultivated plots, and 0.3cm for the no-till and minimum till plots; the cross-slope treatments had little effect on runoff volume while the grass plot had 1.1cm runoff. Cumulative erosion was 962 Mg/ha from the bare plot, 61 Mg/ha from the cultivated plots, 14-17 Mg/ha for the rock wall and grass cross-slope treatments; 41 Mg/ha for the hillside ditches; and 2.2, 1.1, and <0.1 Mg/ha for the grass, minimum till, and no-till plots, respectively.

Effects of Winged Bean on Maize Crops Following in Rotation.

R.R. WEIL*, H.P.M. GUNASENA, A. SAMARANAYAKE and G. BELMONT. U. of Maryland and U. of Peradeniya (Sri Lanka).

Field experiments were conducted at two sites in Sri Lanka to assess the effects of staked winged bean (Psophocarpus tetragonolobus(L.) D.C.) grown for seed on crops of maize (Zea mays L.) following in rotation. The N contribution of the winged bean was assessed by comparing maize yield after winged bean to a maize N response curve (0 to 150 kgN/ha). Other treatments looked at the effects of winged bean on the second maize crop, of removing above-ground winged bean vegetation, and of 20 kgN/ha applied to winged bean. After a growing season of 180 days, 49 to 95 kgN/ha were incorporated into the soil as above ground tissue (34 mgN/g) exclusive of the harvested seeds and pods. Winged beans did not respond to 20 kgN/ha as fertilizer. Maize responses to N were fitted to Mitscherlich equations (eg. Yield=8970 (1-e**- 0.01536 (N+26)), R^2=0.97). Winged beans significantly increased maize yields by an amount equivalent to 70 kgN/ha at the drier site. At a very acid site, maize following winged bean yielded more than the maximum predicted by the N response equation for maize after maize. Preliminary observation suggests that winged bean reduced Al toxicity in associated maize.

Aluminum Toxicity and other Causes of Variability in Millet Growth in Niger, West Africa. J. W. WENDT*, R. G. CHASE, and L. R. HOSSNER, Texas A&M University.

Extreme variability in pearl millet [Pennisetum americanum (L.) Leeke] stands over very short (2-10 meter) distances poses a major constraint to grain production in Niger and other Sahelian countries. Causes of and solutions to variability were examined in a series of pot studies. An experiment using soils taken along a transect from productive to unproductive field regions showed that millet growth correlated best with plant Al concentration. Poorly growing plants had necrotic, poorly branched root systems, the primary symptom of Al toxicity. Millet tops had Al levels exceeding 1400 mg/kg. The critical Al concentration was approximately 700 mg/kg. Some plant tops had toxic concentrations of Mn, exceeding 1600 mg/kg in some case. Deficiencies in P and N were also detected. Other pot studies showed that nutrient additions that decreased plant Al and Mn concentrations improved millet growth. Field regions of productive growth were associated with recent depositions of fertile blowing sand, which is actively enriching Sahelian soils. Productive soils also responded well to the addition of a combination of nutrients, indicating the need for an extensive fertility program. Liming and mangement of natural fertility inputs are the recommended strategies for reducing variability.

The Benor T&V System of Agricultural Extension in Shinyanga, Tanzania C. S. WORTMANN* and J. R. BAYONA, Univ. of Nebraska and Shinyanga Reg. Agri. Development Office.

The implementation of the Benor Training and Visit System of agricultural extension was evaluated after 18 months of use in four pilot divisions of Shinyanga Region. The project involved 32 extension workers (EW), and their supervisors. The regular in-services training was found to be especially beneficial to the extension program. Improvement of skills in situation analysis and problem solving was emphasized in quarterly training, and specific training on practices to be promoted was emphasized in the fortnightly training. Following fortnightly timetables of training, visiting, and supervision was difficult but generally EWs found these to be effective. The concept of contact farmers was well received by farmers and EWs, and it was recommended that the more effective EWs begin working with follower farmers also. The system was not very successful in reaching women whose many duties interfered with their regular attendance at meetings, and greater emphasis on result and method demonstrations which could convey specific messages more efficiently was recommended.

20-03-85

Preliminary Results

3A-07

The Winged Bean in Tropical
Cropping Systems
(USAID - Sand T Grant)
R.R. Weil, H.P.M. Gunasena and H.M.W. Herath

Alleleopathic interactions:

A greenhouse pot experiment and a preliminary seed germination experiment have been completed at the University of Maryland. In the greenhouse experiment the effects of Winged bean on maize, sorghum, kurakkan, amaranth, rice, phaseolus beans and Winged beans were investigated. Each crop was grown in the following four systems:

1. Sole crop on fresh soil,
2. Sole crop on soil previously cropped to Winged bean,
3. Sole crop watered 3x with dilute aqueous extract of Winged bean leaves, and
4. Companion crop grown with an equal number of Winged bean plants.

In all cases there were four plants per pot and all pots were given a complete nutrient solution so that any small amount of nutrients provided by the extract would be insignificant.

All the crops were affected by the various types of association with Winged bean. Most of the crops were inhibited but Kurakkan was definately stimulated by the winged beans. Each crop reacted differently. Table 1 presents the results for amaranth, which was stimulated by being grown in rotation after Winged bean but markedly inhibited by the extract of winged bean leaves, and Kurakkan, which yielded from 56% to 64% ~~present~~ more when associated with Winged bean than when unassociated

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In other work, seeds incubated on filter paper moistened with winged bean extracts (organic and aqueous) generally germinated more slowly and produced shorter hypocotlys and radicals than those incubated on paper moistened with distilled water. The same species as in the greenhouse experiment, plus turnip, were used. Again, the response was species specific. Further work is being done to better characterize which species are sensitive to alleleopathic compounds produced by Winged bean and which are not.

Mixed Cropping Experiments

The plan for the mixed cropping experiment originally called for trying maize, amaranth, chillies, sorghum and sweet potato as companion crops with winged bean. However sorghum was later replaced by kurakkan and sweet potato by Cucumber. Unfortunatly the 1983/84 season was very unfavourable; very droughty in mid-season and extremely wet later. This unusal rainfall pattern accounted for a crop failure for the kurakkan which put on excellent growth early on but was so badly lodged and diseased from the late rains that no seed could be harvested. The amaranth (a local leafy vegetable variety) was also a failure, but in this case because of poor germination and seedling growth. The results from the 1983/84 season for maize, cucumber and capsicum (chillies) are presented in table 2,3, and 4, respectively.

In the case of maize, the companion crop was also tested as a support for the winged beans in lieu of stakes. A comparison of treatment 1 to treatment 18 demonstrates the importance of providing support for the winged bean vines, the staked winged beans yielded 4 times as much as the unstaked. Competition with maize also drastically reduced winged beanyields, while the winged beans had a smaller affect on the maize. As a result of these interactions the total combined yield of the maize and winged bean intercrop was lower than that from an equal area of sole crop maize.

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The land equivalancy ratio(LER) was just under 1.0 for the system with staked winged bean, but a very favourable 1.41 for the system without stakes. An evaluation of the advantage or disadvantage of intercropping over sole cropping depends greatly on what measure is used to compare the componant crops (eg. dry matter, calories, protein, or monetary value) and the ratio of the two crops desired by the farmer. Nonetheless, these first season results do not suggest any dramatic advantage for intercropping, unless stakes for the winged bean are unavailable or too expensive to use. During the second season, the winged beans were sown 2 weeks earlier than the maize and this practise appears to have lead to a more productive interpropping system than that of the first season. The final yields, however, have not yet been measured and the data analysed.

Intercropping winged beans with capsicum (Table 3) and especially with cucumber (Table 4) was more successful than the winged bean-maize intercrop, however in both the former intercrops stakes were required to support the winged beans. Also, whereas the production of winged bean seed is potentially possible on a large scale, the production of a perishable vegetable like cucumber is not. Being too short to complete for light, the capsicum and cucumber reduced winged bean yields much less than did maize, the peductions compared to sole crop winged beans ranging from 4% to 32%, depending on the companion crop and staking system.

Rotation Experiment

A rotation experiment was initiated a two sites in order to estimate the nitrogen contribution of a winged bean crop to a following cereal (maize) crop. The results for the first maize crop following winged beans are available for the Meewatura site (the experiment was begun later at Dodangolla).

Table 5 presents some of the maize grain yields where the source of added nitrogen was Urea(at rates of up to 150 Kg/ha N) and or the residves (roots, stems and leaves) of a previous winged bean crop. Maize yields were generally very good. There was a significant reponse to N fertilizer and a quite dramatic effect of the previous winged bean crop. The highest yield was from maize fertilized with 100 Kg/ha N and following winged bean (9163 Kg/ha grain). The same rate of fertilizer on maize following maize produced 2345 Kg/ha ;ess grain (6818 Kg/ha grain). Also maize receiving no N fertilizer produced 2034 Kg/ha less grain when following maize than when following winged bean. The response to N fertilizer was described by the linear equation:
$Y = 10.56x + 6245$ ($r = 0.57$), where Y is grain yield (Kg/ha) and X is added N (Kg/ha). According to regression analysis the residues of a single winged bean crop (with all pods harvested) was the equivalent of 165 to 176 Kg/ha of N from urea. The residues from a soya bean crop, by comparison, had little no significant effect on the following maize crop.

The seed yields of the winged beans in this experiment have ranged from 1000 to 2,400 Kg/ha of seed (adjusted to 12% moisture), considerably better than the soya bean seed yields in the same experiment.

These are exciting data and suggest that winged beans may be of great value as a green manure, even when harvested as a grain legume.

Future Plans

The second season mixed cropping experiments will be completed by late April at both sites and the results should be available with a month or two after that. The rotation experiment should be completed by February 1986 at both sites.

A new experiment will be initiated a one site to test the effect of relative sowing dates and winged bean variety on the productivity of a winged - maize intercrop. This later experiment will also be the basis for an M. Phil.

Table I. Allelopathic Effects of Winged Bean on Grain Amaranth and Millet (Kurakkan). 1/

Cropping System with Winged Bean	Dry Matter Per Plant (g) Amaranth	Kurakkan
Sole Crop not associate with WB	2.58 b 2/	2.54 b
Companion Crop grown with WB	2.15 b	4.10 a
Rotation crop grown after WB	3.91 a	4.17 a
Watered 3x with extract of WB leaves	1.88 c	3.97 a

1/ means of 5 replicate pots grown in greenhouse soil mix with complete nutrient solution.

2/ Values within a column followed by different letters are significantly different (P = 0.05) by DMRT.

Table 2:

Seed yield of sole cropped and intercropped maize and Winged bean and land equivalency ratios (LER) for the first season of the mixed cropping experiment 1/

Trt	Cropping System	Dry Seed Yield (Kg/ha) Maize	Winged Bean	Total	LER	Maize:Winged Bean Ratio 2/
1	Sole WB, no stakes	-	213	213	-	22:1
2	Sole Maize	4760	[illegible]	4760	-	5.6:1
18	Sole WB, with stakes	-	845	845	-	
7	Maize+WB, with stakes	3736	149	3885	0.96	25:1
12	Maize+WB, no stakes	4068	118	4186	1.41	34:1

1/ Means of 5 replications, 2 at Meewatura and 3 at Pallekale.

2/ Assumes equal area of land sown to each crop in monoculture.

Table 3. First season Wet Zone mixed cropping experiment dry fruit and seed yield of Capsicum and Winged Beans grown alone or intercropped. 1/

Trt. No.	Cropping System	Dry Weight Yield Capsicum	Winged Bean	Total	LER
		Kg/ha			
6.	Sole Capsicum	469	-	469	-
18.	Sole WB ,Single stakes	-	932	932	-
17.	Sole WB cross Stakes	-	742	742	-
11.	Capsicum/ WB Single stakes	139	659	798	1.00
16.	Capsicum/ WB cross stakes	127	701	828	1.22

1/ Means of 3 replications at Meewatura.

Table 4. First Season mixed cropping experiment Cucumber fruit and Winged bean seed yield of sole crops and intercrops at Pallekale 1/.

Trt. No.	Cropping System	Fresh Weight Cucumbers t/ha	Dry Weight WB Seeds Kg/ha	LER
4.	Sole Cucumber	20.6	-	-
18.	Sole WB, Single stakes	-	766	-
17.	Sole WB Crossed stakes	-	852	-
9.	Cucumber/ WB single stakes	19.5	737	1.91
14.	Cucumber/ WB crossed stakes	15.4	578	1.43

1/ Means of 3 replications at Pallekale except one missing plot was estimated for Cucumber in trt. 4 and for WB is trt. 17.

Table 5.

Effect of Nitrogen Fertilizer and Rotation with Winged Bean on Grain Yield of Maize 1/

Trt. No.	Nitrogen Added Kg/ha	Previous Crops	Grain Yield (15.5% moisture) Kg/ha
3	0	Maize	5959
5	50	Maize	5721
7	100	Maize	6818
9	150	Maize	8214
10	0	Winged Bean	7993
12	100	Winged Bean	9163
14	0	Soya Bean	6359

1/ Means of 4 replications at Meewatura.

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Progress Report
July 1 - December 31, 1983

Winged Beans in Tropical Cropping Systems

Principle Investigator: Dr. Ray R. Weil, University of Maryland

Cooperating Investigator: Dr. Walter Herath, University of Peradeniya and International Dambala (Winged Bean) Institute

Dr. H. P. M. Gunasena, University of Peradeniya

Actions and Accomplishments

The project funding received final AID approval on 14 June, 1983. Dr. Weil arrived in Sri Lanka on July 9 for a 4-week visit. During this time the project got off the ground despite periods of civil unrest in Sri Lanka. Detailed research plans and work schedules were drawn up by Dr. Weil (University of Maryland), Dr. Gunasena (University of Peradeniya) and Dr. Herath (International Dambala (Winged Bean Institute). Field locations were chosen, one on International Dambala Institute land at Pallakele and the other on University of Peradeniya Land at Meewatura. Pallekelle is in the intermediate Rainfall Zone with slightly acid to nearly neutral soils formed from igneous rock and a rolling topography. The Meewatura site is terraced alluvial land along the Mahaweli Conga in the Wet Zone and has strongly acid soils.

The research laboratories at the International Dambala Institute and the University of Peradeniya Crop Science Department were evaluated and a list of equipment and supplies essential for the project, particilarly for nitrogen analysis, was compiled. Much of this material was purchased through the University of Maryland in November and December. It is planned to send an airfreight shipment to Sri Lanka once all the needed items are on hand.

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Interviews were held with the top five applicants at the University of Peradeniya and Mr. R. G. A. R. Samaranayake was awarded an assistantship for M. Phil. studies under the project. The University of Maryland research assistant, Mr. Gregory S. Belmont arrived in Sri Lanka in July and has been responsible for the daily operation of the project experiments. A field supervisor and 5 day laborers were hired at the University of Peradeniya. These people are receiving training in field experimental techniques and data collection as they work on the project under Mr. Belmont's guidance. Additional labor (from 5 to 25 people per day) was hired as needed at Pallekelle from among the International Dambala (Winged Bean) Institute's labor force.

At both locations, two experimental sites were laid out, cleared, plowed and worked raised bed plots and alleyways. At Meewatura, low fencing was installed around each site to ward off rabbits. This was an unexpected expense that may also need to be incurred at the Pallakelle sites.

Planting of the field experiments was planned for September and October, but had to be delayed until November and early December because the monsoon rains of the Maha season came very late and sporadically. As a result of these delays there was not enough time to plant the rotation experiment (exp.I) at both sites and it was decided to wait until the second season (May 1984) to plant exp. I at Pallakelle.

Germination of the winged beans and other crops was very good, except for grain amaranth which failed to establish. Okra (a tall, heavy-stemmed local variety) was planted in December on the failed amaranth plots. Weeding was carried out by hand hoeing approximately every three weeks. One month after planting single stakes made from gliricidia branches were inserted close to each winged bean plant as called for in the proposal.

Data on germination, plant heights, and growth analysis were taken during December.

Preliminary Observations

As of the end of December, the crops were growing well at both locations. The earliest planted winged beans had flowered and begun to set pods. The winged beans appear equally vigorous and healthy in the mixed-cropping experiments (Exp.II) whether growing up stakes or the stems of corn plants. Although the corn plants showed rapid initial growth, the shading did not inhibit the early growth of the winged bean. This is in marked contrast to the behavior of other legumes (soybean phaseolus bean, cowpea, peanuts) when intercropped with corn.

The winged beans showed no signs of disease or insect damage, although some of the intercrops, cucumber in particular, were attacked by both diseases and insects.

Quantitative data should be available in time for inclusion in the January thru June 1984 progress report.

Expenditures

Project funds spent and/or commited through December 31, 1983 are indicated on the attached University of Maryland Accounting System Report. As indicated under sub-code 3732, the first installment of $4,668 was made to the University of Peradeniya for the subcontract with that institution. A copy of the expenditures under that sub-contract is included as received from the University of Peradeniya under the heading Maryland Project - Budget Summary. The allocation on this sheet is for the whole year (July 1 - June 30) while the expenditures are those made through December 31 only. The currency is Sri Lankan Rupees (25.9 Rupees ≈ U.S. $1.00).

UNIVERSITY OF MARYLAND ACCOUNTING SYSTEM REPORT

ACCOUNT STATEMENT IN WHOLE DOLLARS FOR 12/31/83

ACCT: 01-5-29353
DEPT: 1001

AIDE DPE-5542G-3013-

TO: WEIL R R
1109 H J PATTERSON

TF	TR	C/G	SA	PUR	PI-NO	SPON	SP-NO	FED/ST-ID-NO	OH-RT1	OH-RT2	START	END	TECH-RPT	FISC-RPT	INVT-RPT	RNWL-RPT
61	10	12	11	00	0000	1000			3 0240	0 0000	06/14/83	06/13/85	00/00/00	00/00/00	00/00/00	00/00/00

SUB CODE	DESCRIPTION	BUDGETS ORIGINAL	BUDGETS REVISED	ACTUAL CURRENT MONTH	ACTUAL FISCAL YEAR	ACTUAL PROJ TO DATE	OPEN COMMITMENTS	BALANCE AVAILABLE	PER USE
2071	FACULTY			522	7,522	7,522	3,523	11,045-	0
3000	EXPENSE POOL	63,395	63,395					63,395	0
3220	COMM - TELEPHONE			16	33	33		33-	0
3360	FOREIGN TRAVEL				2,449	5,375	874	6,249-	0
3732	SUBCONTR LT $25,000					4,668		4,668-	0
3914	LABORATORY			382	625	625	1,097	1,722-	0
3936	EQUIP UP $100-$500				1,755	1,755	418	2,173-	0
	SUPPLIES & MATERIALS			382	2,380	2,380	1,516	3,895-	0
4770	UNEMPLOYMENT INSUR				11	11		11-	0
4780	HEALTH INS.			167	941	941		941-	0
4810	SOCIAL SECURITY FICA				283	283		283-	0
	GRANTS,SUBSDY,CONTRB			167	1,235	1,235		1,235-	0
	TOTAL OPER & EQUIP	63,395	63,395	565	6,097	13,691	2,390	47,314	2
	TOTAL DIRECT EXP	63,395	63,395	1,087	13,619	21,213	5,913	36,270	4
9998	INDIRECT COST EXP	10,080	10,080	261	3,268	5,091		4,989	5
	TOTAL INDIRECT EXP	10,080	10,080	261	3,268	5,091		4,989	5
	ACCOUNT TOTAL	73,475	73,475	1,348	16,887	26,304	5,913	41,259	4

THIS IS A MONTH-END STATUS REPORT FOR YOUR ACCOUNT SUMMARIZING CURRENT MONTH AND YEAR-TO-DATE ACCOUNTING INFORMATION.

OPEN COMMITMENTS STATUS

ACCOUNT	R/E	REF.	DATE	DESCRIPTION	ORIGINAL AMOUNT	LIQUIDATING EXPENDITURES	ADJUST-MENTS	CURRENT AMOUNT
01-5-29353-3914	E	103900	12/14	SAM & RAJ ENTERPRISE	194.00			194.00

Maryland Project - Budget Summary

		Allocation	Expenditure	Balance
1.	Travel	18000.00	5660.50	12339.50
2.	Salaries of staff	12000.00	12000.00	Nil
3.	Graduate Student	19200.00	6200.00	13000.00
4.	*Pallekelle, Labour	37032.00	10000.00	27032.00
5.	Labour, Peradeniya	37056.00	14039.10	
6.	Book allowances	2400.00	461.90	1938.10
7.	Field Supplies	33600.00	11831.55	21768.45
8.	Postages (air freight)	2400.00	4.80	2395.20
9.	Communication	4800.00	Nil	4800.00
10.	Equipment	19200.00	Nil	19200.00
11.	Transport	18000.00	8719.60	9280.40
12.	Transport (M.Sc.student)	9600.00	1467.28	8132.72
13.	Tuition fees	2400.00	750.00	1650.00
14.	Clerical	6000.00	500.00	5500.00
15.	Administrative charges	20352.00	Nil	20352.00
	Total:	242040.00	71634.73	170405.27

* Some vouchers not received from Pallekelle

Progress Report No.1 - June 1984 3. A-07

The Winged bean in Tropical Cropping Systems - A Collaborative Research Project with the University of Maryland USA, fundded by USAID

1. Project objectives

The objective of the series of investigations was
(a) to determine the effect of a winged bean crop on a following cereal crop, with special emphasis on evaluating the potential of wingedbeans to contribute to the nitrogen nutrition of the cereal crop.
(b) to evaluate the feasibility and potential advantages of growing winged beans in mixed cropping systems including competitive and allelopathic effects and the use of companion crop as living status for the winged beans, and
(c) to develop agronomic recommendations for growing winged beans in rotations and mixed cropping systems as well as recommendations for future agronomic research on winged bean.

2. Field experimentation

Two experiments have been carried out at Meewatura, and Pallekelle in the wet and intermediate zones of Sri Lanka, respectively. Both experiments were replicated trials designed by Dr.Raymond R.Weil, University of Maryland,USA and local advisors together with the two postgraduate students namely, Mr.Gregory Belmont from the University of Maryland,USA and Mr.R.G.A.R.Samaranayake from Sri Lanka. A considerable volume of data has been collected from the first two trials and they are presently being analysed. The field preparation is now in progress to assess the beneficial effect of the rotation of crops of which one is the multipurpose legume, the winged bean. This report does not intend to present much technical information as it is yet too premature, but they will be detailed in future reports.

3. Participation of postgraduate students

The participation of two graduate students, one from the USA, and the other from Sri Lanka is a special feature of this collaborative research project. There is much scientific interaction, between the participants and

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the advisors of the collaborating universities. Both the University of Maryland and the Faculty of Agriculture of the Peradeniya University will benefit from this linkage and pave way for futhre collaborative research projects.

4. Visit of Prof.Raymond R.Weil

Prof.Weil visited Sri Lanka twice during the course of 1983/84, to design the trials and supervise the work progress. His visits have been very useful and productive discussions have been held with reference to the future direction of the research project.

5. Receipt of scientific equipment

The equipment received under the project have been set up at the Crop Science Laboratory of the Faculty of Agriculture and are being used for Nitrogen analysis. The consignment of consumables, mainly rubber and glass ware has been cleared from customs.

6. General

The research project in general has made excellent progress. There were no serious problems, except that clearing of equipment has become a problem due to the recent introduction of a tax on all imports of scientific equipment. We have made representations to the government to exempt these from tax payments, which is presently being considered.

7. Financial Statement

A financial statement is annexed herewith.

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Maryland Project - Budget Summary

	Allocation	Expenditure	Balance
1. Salaries of Staff	12,000.00	12,000.00	-
2. Graduate Students	19,200.00	12,400.00	6800.00
3. Labour - Pallekelle	37,032.00	10,000.00	27032.00
4. Labour - Peradeniya	37,056.00	34,253.10	2802.90
5. Book Allowance	2,400.00	1,467.75	932.25
6. Field Supplies	33,600.00	15,995.25	17604.75
7. Postage (Air Freight)	2,400.00	1,004.80	1395.20
8. Communication	4,800.00	-	4800.00
9. Equipment	19,200.00	14,148.00	5052.00
10. Transport	18,000.00	11,251.89	6748.11
11. Transport (M.Sc Student)	9,600.00	2,761.53	6838.47
12. Tution Fees	2,400.00	1,450.00	950.00
13. Clerical	6,000.00	900.00	5100.00
14. Administration charge by University - 10%	22,404.00	22,404.00	-
TOTAL	226092.00	140036.32	86055.68