Sowing date and water stress effects on sole and intercropped maize/pea cultivars under controlled conditions

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ABSTRACT

Controlled experiments were conducted in Glasshouse 7 at the Experimental Grounds, Plant Sciences Laboratories, Whiteknights, The University of Reading, in 2000 and 2001. Relative sowing date and water stress on maize and pea sole and intercrops were investigated under controlled conditions in 2 years. A two-factor in a completely randomized design was used in both years, comprising two varieties of maize and pea with contrasting morphologies and sowing pea simultaneously with maize or 14 days after maize as well as two levels of water stress. The two maize varieties were 'Nancis' with erectophile leaf habit, and 'Sophy' with a planophile leaf habit; the two pea varieties were 'Maro', a normal-leaved pea, and 'Princess', a semi-leafless pea. In the first-year study in 2000, intercropping maize with pea was generally more advantageous than when either crop was sown sole. Delaying the time of intercropping of pea by 14 days after sowing maize increased the kernel yield of maize compared to when intercropped simultaneously. The best intercropping combination in this study, using the Land Equivalent Ratio (LER) index, was when the normal-leaved pea 'Maro' was intercropped with the erectophile leaf maize 'Nancis' 14 days later. In the second-year study in 2001, intercropping and water stress reduced intercropped maize yield, but the reduction was greater when maize was intercropped with the normal-leaved pea 'Maro' (212%) than the semi-leafless pea 'Princess' (127%). Water stress increased the erectophile-leaved maize 'Nancis' yield when intercropped with the normal-leaved pea 'Maro' (52%), due to an increase in partitioning of dry matter to generative organs compared to the vegetative organs. All intercropping combinations were advantageous, using the averages of the LER and Area-Time Equivalent Ratio (ATER) indices; but the benefits were slightly higher with the planophile-leaved maize 'Sophy' than the erectophile-leaved maize 'Nancis'.

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Introduction

Intercropping is usually defined as the growing together of two or more crops simultaneously on the same area of ground (Andrew & Kassam, 1975; Willey, 1979; Willey, 1990; Fageria, 1992). According to Willey (1979), the crops are usually grown together for a significant part of their growing periods; thus, distinguishing them from relay cropping in which growing periods only overlap. Research on intercropping did not receive much attention in the past because the practice was thought to be suited only to underdeveloped situations, and would be replaced gradually by sole cropping as a natural and inevitable consequence of agricultural development (Willey, 1979). Few studies have focused on intercropping systems in the temperate agro-ecosystems, probably because researchers and many farmers see it as only relevant to low-input agriculture (Willey, 1979).

However, intercropping continues to be important in many countries (Ahmed & Rao, 1982). Research in the late 1970s has confirmed that intercropping makes better use of resources and gives yield advantages that are comparable to sole cropping (Willey, 1979). Yield advantage and economic viability of an intercropping system depends on selecting compatible genotypes and optimal agronomic practices (Rao & Mittra, 1990). Genotypes, which minimize competition and enhance complementarity, are desirable for intercropping (Rao & Mittra, 1990). Francis, Flor & Temple (1986) recommended that for maize the most important characteristics for intercropping are plant height, internode length, leaf width and leaf angle; and for beans, node number, branching and climbing ability. These traits tie up well with the erectophile-leaved maize 'Nancis' and the semi-leafless pea 'Princess' chosen for this study.

Staggering the relative planting time of crops could improve temporal differences in resource use by the component crops of an intercropping system (Baumann, Bastians & Kropff, 2001). Planting date is one variable in tropical intercropping systems that is under direct control of the farmer (Francis, Prager & Tejada, 1982). Francis *et al*. (1982) observed that planting one species earlier might afford it the advantage to establishment before being outcompeted by a taller or more aggressive counterpart. Wahua, Babalola & Aken'ova (1981) concluded that the relative time of planting and relative growth rates of the maize cultivars should be considered along with canopy structure in maize cowpea intercrop.

Ntare (1990) showed that millet yields were significantly lower when cowpea was sown simultaneously than when sowing was delayed until 3 weeks after the millet. No yield advantage was recorded when either maize or cowpea was planted early, in comparison to simultaneous planting (Remison, 1982). Nangju (1979) found that late planting of cowpea in established maize resulted in cowpea grain yield decreases of 58 to 78 per cent. Cowpea grain yield reduction of 715 kg ha^{-1} was observed when planted simultaneously with millet, in comparison to 40 kg ha^{-1} when planted 3 weeks after millet (Blade *et al*., 1997). Millet yield reduction of 16 per cent was recorded when planted simultaneously with cowpea, compared to late-planted cowpea (Terao *et al*., 1997). They concluded that the lower millet yields were due to a reduction in millet seed size, because it was forced to mature at the end of its growth stage in intercropping with simultaneously planted cowpea, due to insufficient water supply at the grain filling stage. Maize yield reduction of 22 per cent was recorded when sown simultaneously with *Medicago sativa* or *Trifolium pratense*. However, yield loss was reduced when the legume sowing was delayed by 30 days (Vrzal, 1992).

This study aimed to: (i) investigate the effect of relative sowing dates of pea on performance of morphologically contrasting maize/pea cultivars, and (ii) determine the response of morphologically contrasting maize and pea sole and intercrops to water stress.

Materials and methods

Two experiments were conducted in 2000 and 2001 in Glasshouse 7 at the Experimental Grounds, Plant Sciences Laboratories, Whiteknights, The University of Reading. Two morphologically contrasting cultivars of maize and pea were used in the experiments (Table 1).

The experiment was established as a factorial in a randomised complete block design with three replicates. The maize and pea were sown in growth tanks with the following dimensions: 41 cm long, 26 cm wide, and 29.5 cm deep. The tanks were placed on a metal bench 1 m above the ground for the relative sowing date, and on the ground for the water stress experiment. They were filled with sieved soil, over a 4 to 5-cm layer of gravel to facilitate drainage. The soil comprised one-third each of loam, sand, and peat; 30 g of

TABLE 1

Characteristics of Maize and Pea Varieties Used in the Study

Crop	*Morphological characteristics*
Nancis (maize)	Erect leaf habit, early-maturing about 90 days, height of 1.9 m
Sophy (maize)	Traditional droopy leaf habit, late-maturing about 120 days, height of 2.0 m
Maro (pea)	Normal-leaved, late-maturing about 90 days, poor standing ability
Princess (pea)	Semi-leafless, slightly late-maturing about 85 days

Osmocote, and 42 g of lime. Two maize rows and four pea rows were planted in each tank. Maize rows were 15 cm apart with a within-row spacing of 12 cm, and the peas were spaced at 15 cm with a between-plant spacing of 6 cm. Thus, peas were sowed at a density of 71 plants m^{-2}, and maize at a density of 6 plants m^{-2} as recommended for pea and maize in Europe.

Experiment 1

Sowing was done on 4th February 2001, using two seeds per hole and thinning to one plant per hole for maize and pea; the pea was sown simultaneously and 14 days after sowing (DAS) maize. The experiment was established as a factorial in a randomised complete block design with three replicates. The intercropping design adopted for the study was the additive design; the intercrop crop populations were the same as their sole crop counterparts. The experimental treatments comprised all combinations of intercrops and sole crops.

Experiment 2

To study the effect of water stress, maize and pea were sown simultaneously on 21st December 2001, using two seeds per hole, and thinned to one plant per hole for maize and pea at 14 DAS. The experiment was established as a factorial in a randomised complete block design with three replicates. Plants were solution fed with Sangral at 32, 63, and 90 DAS. Crops were irrigated each day till 21 DAS. A Theta Probe ML2X (DELTA-T Devices) was used to determine the moisture content; and when the available soil moisture fell below a threshold value, the crops were subsequently irrigated. The treatments comprised of two irrigation regimes; normal irrigation in which plants did not experience any water stress, and stress when plots received irrigation after a standard moisture stress was attained using soil moisture Theta Probe and plants were showing signs of wilting. Soil moisture content was determined using the Theta Probe. Data collected included days to 50 per cent flowering and maturity, leaf number per plant, dry matter partitioning, yield components and yield.

Statistical analysis

Data were analysed using SAS for Windows 1996-1998, Users Guide Version 6.12, SAS Inst. Inc., Cary, NC, USA. Analysis of Variance using Proc GLM (SAS, 1996-1998) was used to identify treatment effects. The treatment means were tested at (P=0.05) level of significance.

Results

Relative sowing date

Maize kernel yield

Table 2 presents Analysis of Variance showing the various interactions between the cultivars of maize and pea, and relative sowing date effects. Kernel yield of maize was significantly (P=0.05) influenced by maize and pea cultivars, maize*pea interaction and sowing date (Table 2). The highest kernel yield was recorded for sole planophile-leaved maize ‘Sophy’, with the intercrop of the erectophile-leaved maize and the normal-leaved pea ‘Nancis’-‘Maro’ simultaneous sowing giving the lowest (Fig. 1a and 1b). The

TABLE 2

Analysis of Variance of Maize Yield and Yield Components as Affected by Maize, Pea Cultivars and Relative Sowing Dates

Source	*DF*	*Mean square*	*F-value*	*Pr > F*
Peas	2	1.66950732	46.71	0.0001
Maize	1	1.65403116	46.27	0.0001
Pea*Maize	2	0.12244267	3.43	0.0467
Sow	1	0.50702450	14.18	0.0008
Pea*Sow	1	0.04263200	1.19	0.2841
Maize*Sow	1	0.00016200	0.00	0.9468
Pea*Maize*Sow	1	0.03836450	1.07	0.3091

planophile-leaved maize 'Sophy' had a mean kernel yield which was 38 per cent greater than the erectophile-leaved maize 'Nancis'. Kernel yield of both maize cultivars was significantly (P=0.05) reduced when intercropped with the normal-leaved pea 'Maro', but the reduction was greater for the erectophile-leaved maize 'Nancis' (Fig. 1a and 1b). Intercropping maize with pea resulted in an overall reduction in maize yields of both cultivars compared to sole maize. The normal-leaved pea 'Maro' caused a greater increase in kernel yield of 24 per cent compared to the semi-leafless pea 'Princess' (10%) when sowed 14 DAS maize relative to simultaneous planting with the two pea cultivars (Fig. 1a and 1b). Similarly, the normal-leaved pea 'Maro' caused a greater reduction in maize yield of 22 per cent when simultaneously sowed with maize than the semi-leafless pea 'Princess'. Maize yield for both cultivars increased significantly when intercropping with peas was delayed. Mean increase in kernel yield when pea was sown 14 DAS maize over simultaneous sowing was 24 per cent for the normal-leaved pea 'Maro' and 10 per cent for the semi-leafless pea 'Princess'. The kernel yield for intercropped maize was highest when the planophile-leaved maize 'Sophy' was intercropped with semi-leafless pea 'Princess' 14 DAS (Fig. 1b).

Pea seed yield

Maize cultivar significantly (P=0.05) affected pea seed yield. The pea seed yield was highest when the normal-leaved pea 'Maro' was intercropped with the erectophile-leaved maize 'Nancis' 14 days later, whilst the yield was lowest when the semi-leafless pea 'Princess' was intercropped with the planophile-leaved maize 'Sophy' 14 days later (Fig. 2a and 2b). The semi-leafless pea 'Princess' suffered a greater yield reduction when intercropped compared to the normal-leaved pea 'Maro'. Intercropping peas with the erectophile-leaved maize 'Nancis' resulted in a mean increase in seed yield of 29 per cent over intercropping with the planophile-leaved maize 'Sophy'. Delayed intercropping of both pea cultivars with the erectophile-leaved maize 'Nancis' resulted in increased seed yields compared to their simultaneously intercropped counterparts. Delayed sowing of peas with the planophile-leaved maize 'Sophy' resulted in reduced pea yields compared to their simultaneously intercropped counterparts. Intercropping the normal-leaved pea 'Maro' with the erectophile-leaved maize 'Nancis' 14 days later recorded significantly (P=0.05) higher pea yields, whilst simultaneous intercropping of the normal-leaved pea 'Maro' with the planophile-leaved maize 'Sophy' resulted in significantly (P=0.05)

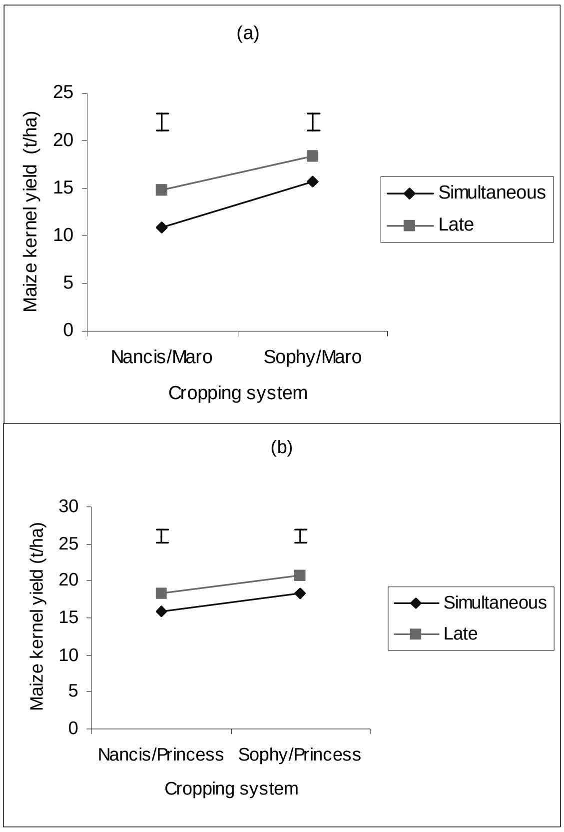

Fig. 1. Maize kernel yield as affected by intercropping an a) erectophile-leaved maize 'Nancis' and b) a planophile-leaved maize 'Sophy' with a normal-leaved pea 'Maro' and a semi-leafless pea 'Princess' and relative sowing date. Bars above graphs are standard error bars.

lower yields.

Generally, intercropping maize with peas resulted in an overall reduction in maize yields of both cultivars compared to sole maize. However, the normal-leaved pea 'Maro' caused a greater increase in kernel yield of 24 per cent compared to the semi-leafless pea 'Princess' (10%) when sowed 14 DAS maize relative to simultaneous planting with the two pea cultivars (Table 3). Intercropping both pea cultivars 14 days after the erectophile-leaved maize 'Nancis' resulted in higher pea yields, whilst intercropping both pea cultivars 14 days after the planophile-leaved maize 'Sophy' reduced both pea yields.

Water stress

Maize kernel yield (t ha^{-1})

Table 2 presents Analysis of Variance showing the various interactions of the cultivars of maize and pea, as well as water stress effects. Pea cultivars and irrigation effects on maize kernel yield were significant (P=0.05). 'Nancis' under irrigation had the highest kernel yield (Fig. 3a), and the lowest by 'Sophy'-'Maro' (Fig. 4a) intercrop under water stress. Water stress resulted in kernel yield reduction except for 'Nancis'-'Maro' in which the stress treatment had greater yield than the irrigated treatment (Fig. 3a). The reduction in maize yield was greatest with 'Sophy'-'Maro' stress compared to 'Sophy' irrigated (89%) (Fig. 4a and 4b). Sole maize under both cropping systems and irrigation regimes produced greater maize yield than their intercrop counterparts. The reduction in maize yield for the intercrops was greatest when maize was intercropped with 'Princess' under stress. Water stress caused greater reduction in sole yield of 'Sophy' (21%) than 'Nancis'. The best intercropping partner for the erectophile-leaved maize 'Nancis' under water stress was the normal-leaved pea 'Maro' (Fig. 3a); and for the planophile-leaved maize 'Sophy', it was the semi-leafless pea 'Princess' (Fig. 4b).

Pea seed yield (t ha^{-1})

Maize cultivar and water stress effects on pea seed yield were significant (P=0.05). The intercrop seed yield was highest when the normal-leaved pea 'Maro' was intercropped with the erectophile-leaved maize 'Nancis' under irrigated conditions (2.7 t ha^{-1}) (Fig. 5a); and lowest when the normal-leaved pea 'Maro' was intercropped with the planophile-leaved maize 'Sophy' (Fig. 5b), and the semi-leafless pea 'Princess' was intercropped with the planophile-leaved maize 'Sophy' under stress (2.0 t ha^{-1}) (Fig. 5b). Seed yield of sole peas

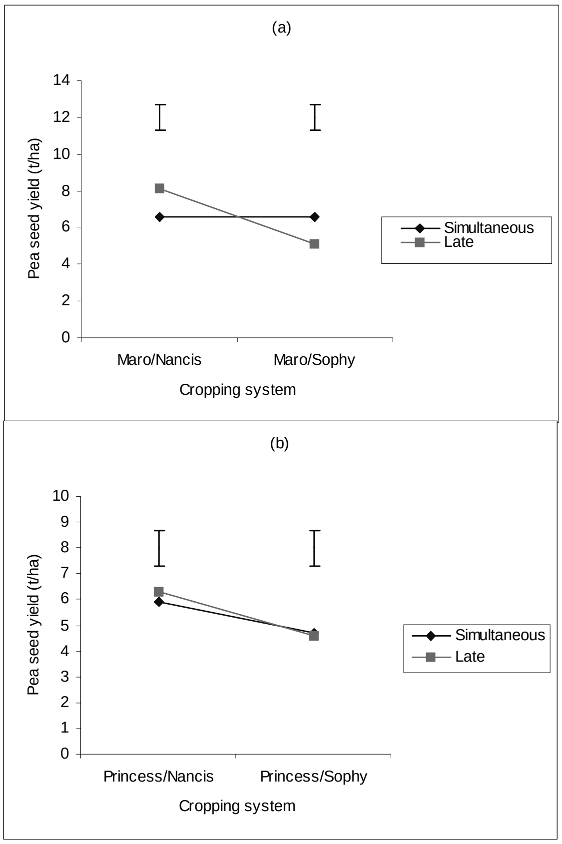

Fig. 2. a) Normal-leaved pea 'Maro' and b) a semi-leafless pea Princess seed yield as affected by intercropping an erectophile-leaved maize (Nancis) and planophile-leaved maize (Sophy) and relative sowing date. Bars above graphs are standard error bars.

was reduced most because of water stress (53%) relative to the irrigated treatments. Generally, intercropping pea with the erectophile-leaved maize 'Nancis' under stress had greater yield (2.0 t ha^{-1}) than when intercropped with the planophile-leaved maize 'Sophy' under stress (1.7 t ha^{-1}).

Generally, water stress reduced maize kernel yield for the planophile-leaved maize 'Sophy' when intercropped with both the normal-leaved pea 'Maro' and semi-leafless pea 'Princess'. However, intercropping the erectophile-leaved maize 'Nancis' with the normal-leaved pea 'Maro' resulted in an increase in maize kernel yield. For both pea varieties, water stress caused a reduction in both intercrops and sole crops. All the intercropping combinations in both years showed an advantage as expressed by the averages of the LER and the ATER indices across the seasons, but the benefits were slightly higher with the erectophile-leaved maize 'Nancis' than the planophile-leaved maize 'Sophy' (Table 4).

Discussion

Intercropping maize with pea resulted in a reduction in intercropped maize yields compared to their sole cropped counterparts, probably because of competition from the legume. This assertion is confirmed by the greater yield reduction in intercropped maize yields when maize and pea were sowed simultaneously compared to when the peas were delayed. The normal-leaved pea was more competitive than the semi-leafless pea when both were simultaneously intercropped with maize. However, the semi-leafless pea caused a greater reduction in maize yields when sowed 14 days after sowing maize. These differences in performance of the pea cultivars might be ascribed to their differences in physiological and morphological traits. These results are also at variance with those reported by Isenmilla , Babalola & Obigbesam (1981) who did not find any maize yield reduction due to contrasting cowpea genotype effects. The reductions in maize yield reported in this study do not support those reported by Hazel (1974) who worked on maize-cowpea, Andrew (1972) who worked with sorghum-cowpea, and Jeanyama *et al.* (2000) who worked on maize-sunhemp and maize-cowpea. These differences might be ascribed to variety, and the environment; and also because of management systems compared to those used in this study. Maize kernel yields were reduced more when sown simultaneously with peas, compared to later sowing of peas, because of increased

TABLE 3

Maize Yield (t/ha) as Affected by Intercropping, Sole Cropping and Relative Sowing Date of Pea

	Maro	*Maro*	*Princess*	*Princess*	*Intercrop mean*	*Sole maize*
	Simultaneous	Late	Simultaneous	Late	Both dates	
Nancis	10.9	14.8	16.1	17.1	14.7	19.9
Sophy	15.8	18.4	18.2	20.7	18.3	27.5
Mean	13.4	16.6	17.2	18.9	16.5	23.7

s.e. = 0.94
d.f. = 28
CV (%)

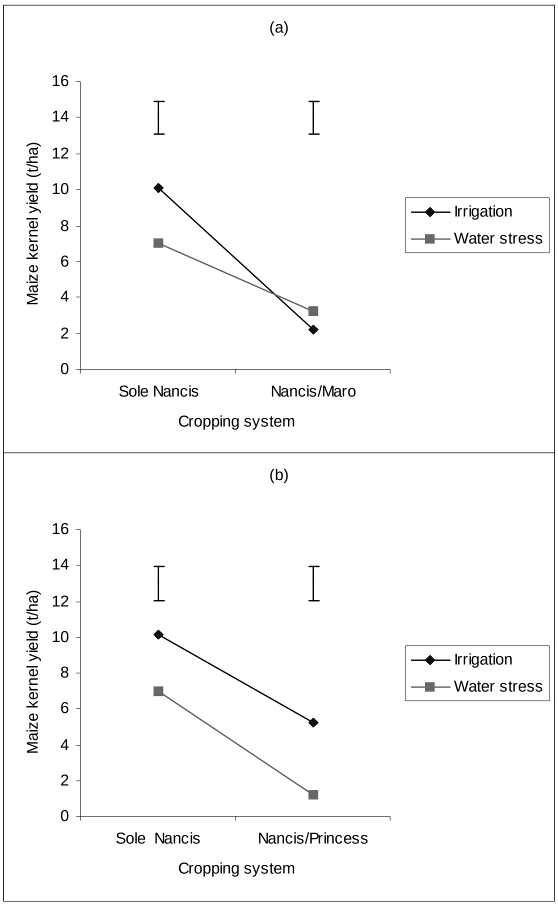

Fig. 3. Kernel yield (t/ha) of a) an erectophile-leaved maize 'Nancis' as affected by sole and intercropping with a normal-leaved pea and b) a semi-leafless pea and water stress. Bars above graphs are standard error bars.

competition from the legume crop, which was sown simultaneously with the maize. Maize kernel yields were most reduced when intercropped with 'Maro' compared to 'Princess'. Significantly lower millet yields were produced when sowed simultaneously with cowpea than when its sowing was delayed until 3 weeks after millet (Ntare, 1989). Reddy (1988) showed that simultaneous planting of pearl millet with cowpeas significantly reduced pearl millet yields. Maize and sorghum yields were reduced by an associated cowpea under moisture stress (Stoop, 1986). Pearl millet yields were reduced by mungbean in a pearl millet and mungbean intercropping system (Anjaneyulu, Singh & Pal, 1982).

The pea seed yield was highest when peas were intercropped with the erectophile-leaved maize 'Nancis'. Similarly, intercropping both pea cultivars with 'Nancis' outyielded those intercropped with 'Sophy' and sole crop peas. These results indicate that 'Nancis' provided a better environment for the growth and development of both pea cultivars as reflected in their superior yields. The highest pea yield recorded for 'Nancis'-'Maro' sown late was due to the significantly (P=0.05) higher number of pods per plant and bigger seeds as reflected in its superior 100-seed weight. The time of sowing of intercropped pea, simultaneously or 14 days later, did not have any significant

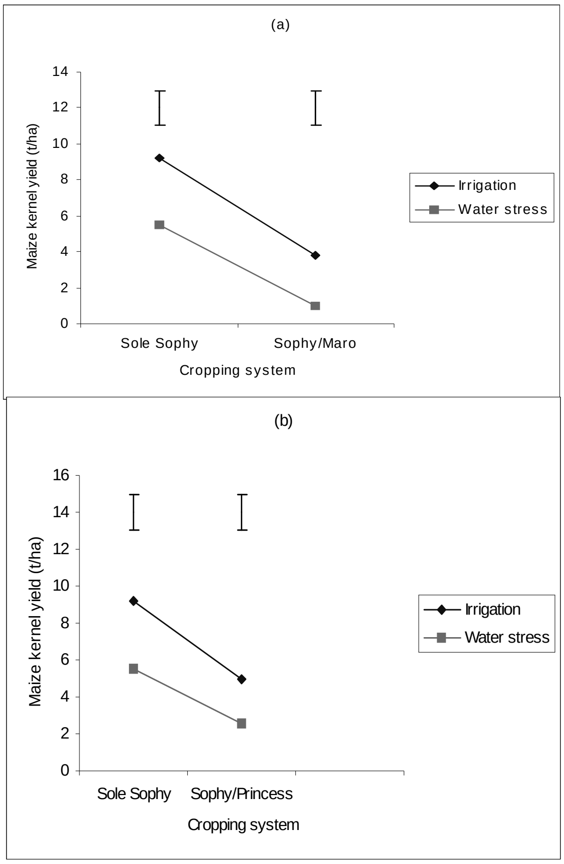

Fig. 4. Kernel yield (t/ha) of a) a planophile-leaved maize 'Sophy'as affected by sole and intercropping with a normal-leaved pea 'Maro' and b) a semi-leafless pea 'Princess' and water stress. Bars above graphs are standard error bars.

effect on pea yields. Francis *et al*. (1982) suggested that near simultaneous planting was optimal for producing highest total yield from intercropped maize and several plant types of beans. Cowpea yields were reduced when sowed 1 to 3 weeks after millet, ascribing the yield reductions to decreased vegetative and reproductive durations and crop growth rate (Ntare, Williams & Bationo, 1989). Ntare (1989), however, did not observe any significant changes in yield and yield components of cowpea genotypes when intercropped with pearl millet.

Intercropping 'Nancis' with 'Maro' under water stress resulted in an increase in maize kernel yield due to increase in partitioning of dry matter to seed, probably because of the intercropping effect. The relatively stable maize yield observed when maize was intercropped with 'Maro' could be ascribed to less competition for water under water stress, because this was the only resource that was most limiting. This finding could have useful implications for the dry regions where rainfall is not only unreliable in distribution, but also limited in amount in the last decades due to climate change. The practical application of this study is that selection of crop varieties with contrasting morphological and physiological differences for arid and semi-arid regions is crucial for successful production.

The lower maize yields associated with the intercropped maize might be ascribed to drastic reduction in the photosynthetic surface of the water stress treatments, which were experienced in the water stress treatments. However, for the intercropped pea, the tall companion maize might have provided an improved microclimate conducive for leaf initiation, expansion and retention as evident in their superior or comparable growth variables and yield. Higher harvest indices were recorded for intercropped sorghum, millet and groundnut under stress than their sole crop counterparts (Natarajan & Willey, 1986). The assertion is further amplified by the findings of this study. Sorghum yields were higher when intercropped with groundnut, which was ascribed to reduction in competition due to lower plant density (Natarajan & Willey, 1986). The much less reduction in maize kernel yield due to water stress when maize was intercropped with 'Maro' is similar to that reported by Natarajan & Willey (1986). However, intercropping with 'Princess' resulted in much greater reduction than sole maize, which sharply contrasts the findings of Natarajan &

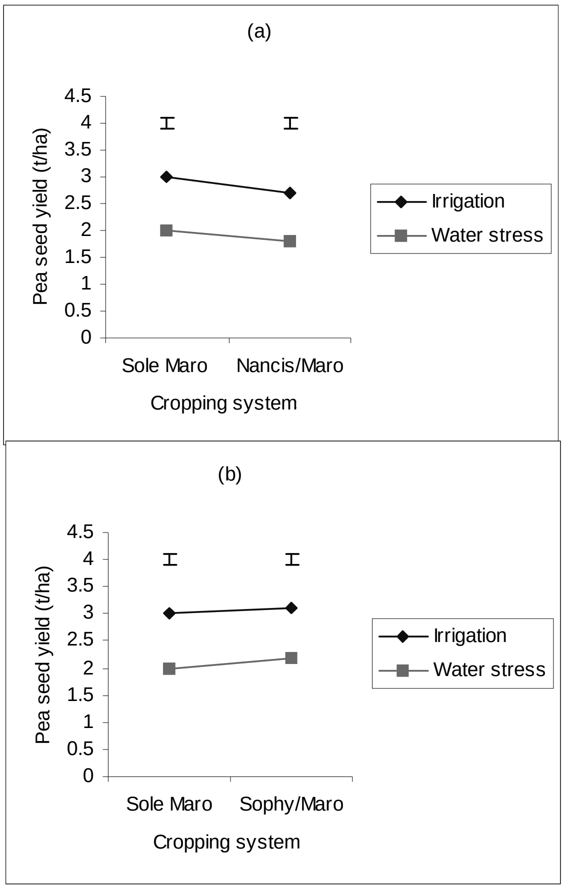

Fig. 5. Seed yield (t/ha) of a) a normal-leaved pea 'Maro' as affected by sole and intercropping with an erectophile-leaved maize 'Nancis' and b) a planophile-leaved maize 'Sophy' and water stress. Bars above graphs are standard error bars.

Willey (1986). Similar reductions were recorded in total dry matter of sorghum and groundnut intercrop and sole crops with increase in stress (Natarajan & Willey, 1986). The greater or comparable seed yields of the intercropped pea relative to sole cropped pea could be attributed to improved microclimate created by the tall maize canopy, thereby reducing any possible light saturation effect as might be encountered for the sole pea. Greater pods for a dry season intercrop groundnut were attributed to shading by sorghum relative to sole groundnut (Ngam, Dwivedi & Gibbons, 1980).

In this study, the increase (30 to 54%) in pea seed yield for wet treatments compared to water stress treatments might be attributed to competition for limited water resources experienced by the stress-imposed treatments. Yield reductions in groundnuts due to stress by intercrops was less compared to sole groundnuts (Natarajan & Willey, 1986), which is consistent with the results of this study.

TABLE 4

Average Land Equivalent Ratio (LER) and Area Time Equivalent Ratio (ATER) of Maize-pea Intercrops, 2000-2001

2000	*Maro*	*Princess*	*Means*
Nancis	1.57	1.26	1.42
Sophy	1.63	1.45	1.54
Mean	1.60	1.35	
LSD (0.05)	0.38		
CV (%)	13.02		
2001	*Maro*	*Princess*	*Means*
Nancis	1.29	1.25	1.27
Sophy	1.38	1.23	1.31
Mean	1.34	1.24	
LSD (0.05)	0.04		
CV (%)	11.43		

Conclusion

The results of the 2-year glasshouse study should be treated with caution, because they were not conducted at ambient conditions and, therefore, likely to oversimplify real field conditions. Intercropping maize with pea and varying pea sowing date reduced maize yields, but the reduction was greater when the normal-leaved pea was intercropped with the maize, causing a double reduction in maize yields compared to the semi-leafless pea in the first-year study. Similarly, in the second-year study, imposition of water resulted in a reduction in intercropped and sole crop maize yields, but resulted in an increase in the yield of the erectophile-leaved maize 'Nancis' when intercropped with normal-leaved pea 'Maro'. These findings have important practical implications for cereal with grain legumes, particularly in the arid and semi-arid regions where water is the most important singular factor prohibiting increased food crop production, and also where intercropping is the dominant practice. However, the need is to validate these results under field conditions.

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REFERENCES

Ahmed, R. & Rao, M. R. (1982) Performance of maize-soybean intercrop combination in the tropics: Results of a multi-location study. *Fld Crops Res*. **5**, 147-161.

Andrew, D. J. (1972) Intercropping sorghum in Nigeria. *Expl Agric*. **8,** 139-150.

Andrew, D. J. & Kassam, A. H. (1975) Importance of multiple cropping in increasing world food supplies. In *Multiple cropping (*ed. R. I. Papendick, P. A. Sanchez and G. B. Tripplet), pp. 1-10. American Society of Agronomy Special Publication 27, Madison, USA.

Anjaneyulu, V. R., Singh, S. P. & Pal, M. (1982) Effect of competition-free period and technique and pattern of pear millet planting on growth and yield of mungbean and total productivity in sole pearl millet and pearl millet/mungbean intercropping systems. *Indian Jnl Agron*. **27**, 219-226.

Baumann, D. T., Bastians, L. & Kropff, M. J. (2001) Competition and crop performance in a Leek-Celery intercropping system. *Crop Sci*. **41**, 764-774.

Blade, S. F., Shettey, S. V. R., Terao, T. & Singh, B. B. (1997) Recent developments in cowpea cropping systems. In *Advances in cowpea research* (ed. B. B. Singh, D. R. Mohanraj, K. E. Dashiell, and L. E. N. Jackai), pp.114-128. Co-publication of International Institute of Tropical Agriculture (IITA) and Japan International Recent Centre for Agricultural Sciences (JIRCAS). IITA, Ibadan, Nigeria.

Fageria, N. K. (1992) *Maximising crop yields*. Marcel Dekker, Inc., New York, USA.

Francis, C. A., Prager, M. & Tejada, G. (1982) Effects of relative planting dates in beans (*Phaseolus vulgaris* L.) and maize (*Zea mays* L.) intercropping patterns. *Fld Crops Res*. **5**, 45-54.

Francis, C. A., Flor, C. A. & Temple, S. R. (1986) Adapting varieties for intercropped systems in the tropics. In *Multiple cropping* (ed. R. I. Papendick, P. A. Sanchez and R. Triplett), pp. 235-253. American Society of Agronomy Special Publication 27, Madison, Wisconsin.

Hazel, K. A. (1974) Maize-cowpea intercropping study in Kumasi. *Ghana Jnl agric. Sci*. **7**, 169-178.

Harris, D. & Natarajan, M. (1987) Physiological basis for yield advantage in a sorghum/groundnut intercrop exposed to drought. II. Plant temperature, water status and components of yield. *Fld Crops Res*. **17,** 273-288.

Isenmilla, E. A., Babalola, O. & **Obigbesam, G. O.** (1981) Varietal influence of intercropped cowpea on growth, yield and water relations of maize. *Plt Soil* **62,** 153-156.

Jeanyama, P., Hesterman, O. B., Waddington, S. R. & **Harwood, R. R.** (2000) Relay-intercropping of sunhemp and cowpea into smallholder maize system in Zimbabwe. *Agron. J*. **92,** 239-243.

Nangju, D. J. (1979) Effect of density, plant type and season on growth and yield of cowpea. *Am. Jnl Soc. Hort. Sci*. **104**, 466-470.

Natarajan, M. & **Willey, R. W.** (1986) The effect of water stress on yield advantages of intercropping systems. *Fld Crops Res*. **13**,117-131.

Ngam, S. N., Dwivedi, S. L. & **Gibbons, R. W.** (1980) Groundnut breeding at ICRISAT. In *Proceedings of the International Workshop on Groundnuts*, pp. 62-68. Patencheru, India.

Ntare, B. R. (1989) Evaluation of cowpea cultivars for intercropping with pearl millet in the Sahelian Zone of West Africa. *Fld Crops Res*. **20**, 31-40.

Ntare, B. R. (1990) Evaluation of cowpea cultivars for intercropping with pearl millet in the Sahelian Zone of West Africa. *Fld Crops Res*. **20**, 31-40.

Ntare, B. R., Williams, J. H. & Bationo, A. (1993) Physiological determinants of cowpea seed yield as affected by phosphorus fertiliser and sowing dates in intercrop with millet. *Fld Crops Res.* **35,** 151-158.

Rao, L. J. & **Mittra, B. N.** (1990) Evaluation of groundnut (*Arachis hypogeae*) genotypes for intercropping with two types of pigeon pea (*Cajanus cajan*). *Jnl Agric*. *Sci*. **115**, 337-342.

Reddy, K. C. (1988) *Alternative pearl millet and cowpea rainfed production strategies*. *HandBook* 1 (French). Niamey, Niger, National Agricultural Research Institute/Purdue University, USA.

Remison, S. U. (1982) Interaction between maize and cowpea sown simultaneously and at intervals in a forest zone of Nigeria. *Indian Jnl Agric*. *Sci*. **52**, 500-505.

Stoop, W. A. (1986) Agronomic management of cereal/legume cropping system for major toposequence land types in the West Africa savanna. *Fld Crops Res*. **14**, 301-319.

Terao, T., Watanabe, I., Mastunaga, R., Hakoyama, S. & **Singh, B. B.** (1997) Agro-physiological constraints in intercropped cowpea: An analysis. In *Advances in cowpea research* (ed. B. B. Singh, D. R. Mohan Raj, K. E. Dashiell and L. E. N. Jackai), pp. 129-140. Co-publication of International Institute of Tropical Agriculture (IITA) and Japan International Research Centre for Agricultural Sciences (JIRCAS). IITA, Ibadan, Nigeria.

Vrzal, J. (1992) Use of silage maize as a companion crop for fodder legumes (Czech.). Sbornik Vysoke Skoly Zemedelske v Praze, Faculta Agronomika Roda A. *Rostlina Vyroba* **54**, 269-276.

Wahua, T. A., Babalola, O. & **Aken'ova, M. E.** (1981) Intercropping morphologically different maize and cowpeas: LER and growth attributes of associated cowpeas. *Expl Agric.* **17**, 407-413.

Willey, R. W. (1979) Intercropping-its importance and research needs. Part 1. Competition and yield advantages. *Fld Crops Abstracts* **32**, 1-10.

Willey, R. W. (1990) Resource use in intercropping. *Agric. Water Mgt* **17**, 215-231.