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YIELD EVALUATION OF MAIZE-BEAN INTERCROPPING IN A SEMI-ARID REGION OF SOUTH AFRICA

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ABSTRACT

Information on the effect of row orientation on land productivity of intercropping systems, especially in a semi-arid environment is limited. Field trials were, therefore, carried out under full irrigation and rainfed conditions in a semi-arid region of South Africa (Bloemfontein, Free State) during 1998-2002. The trials evaluated the intercrop yield advantage in terms of land equivalent ratio (LER), energy value (EV) and monetary value (MV). Treatments included three cropping systems (sole maize, sole bean, and the intercrop) and two cultural practices, namely, row orientation (north-south row vs east-west row) and sowing date (November/December and January). Intercropping showed a higher yield advantage in terms of LER and EV compared to sole cropping. Therefore, intercropping has potential for increasing yields in the semi-arid regions of South Africa. Monetary value is influenced by fluctuations of the price ratio of crops, so it is not always a useful factor for evaluating the yield advantage.

Key Words: Land equivalent ratio, *Phaseolus vulgaris*, row orientation, *Zea mays*

RÉSUMÉ

L'information sur l'effet de l'orientation en rangé sur la productive des terres des systèmes d'intercultures, spécialement dams un environnement semi-aride est limite. Les essais sur le terrain étaient par conséquent menés sous une irrigation complète et conditions de pluie dans une région semi-aride de l'Afrique du sud [Bloemfontein, /état libre] on cours de 1998-2002. Les essais évaluaient l'avantage de la production d'interculture en termes de proportion équivalente de terre [LER], la valeur d'énergie [EV] et la valeur monétaire [VM]. Les traitements avaient inclus trois systèmes de cultures [maïs seul, haricot seul et une combinaison maïs-haricot] et deux pratiques culturales, à savoir, l'orientation en rangé nord-sud contre rangé Est-ouest] et la date des semailles [Novembre/Décembre et Janvier]. L'inter-culture a monté un avantage supérieur en terme de LER et EV, comparer aux cultures seules. Par conséquent, les cultures en combinaison ont une potentialité d'augmenter les rendements en région semi-aride de L'Afrique du sud. La valeur monétaire est influencée par les fluctuations de la proportion des prix de récoltes, donc n'est pas toujours un facteur utile pour l'évaluation de l'avantage du rendement.

Mots Clés: Proportion équivalente de terre, *Phaseolus vulgaris*, orientation en rangé, *Zea mays*

INTRODUCTION

Intercropping is an important practice in subsistence and food production farming systems in many developing countries. It has been practiced by small-scale farmers in the tropics. Intercropping of cereal and legume crops is especially recognised as a common cropping system throughout tropical countries (Ofori and Stern, 1987). Cereal-legume intercropping systems have higher productivity than sole cropping systems in various regions of Africa, including semi-arid regions of eastern Africa (Fisher, 1977a, b; Pilbeam *et al.*, 1994) and southern Africa (Rees, 1986; Austin and Marais, 1987; Lightfoot and Tayler, 1987; Mukhala *et al.*, 1999). In assessments of crop productivity of sole cropping systems, a useful expression is mass yield (weight per unit area). However, in intercropping systems, direct comparison is difficult because products are different for the different plant species growing on one piece of land (Beets, 1982). In this case, crop productivity should be evaluated using a common unit. Several methods of quantitatively evaluating intercrop productivity are often in terms of (i) intensity of land use, (ii) production of constituents (calorie, protein, carbohydrate, fat, etc.), and (iii) capital return (Willey, 1985).

A widely used method is the land equivalent ratio (LER). This is defined as the total land area required under mono-culture cropping to give the yields obtained in the poly-culture cropping system (Mead and Willey, 1980). Osiru and Willey (1972) and Willey and Osiru (1972) first used LER to explain the yield advantage of cereal-legume intercropping in Uganda. Since then, LER has been widely accepted in the evaluation of intercrop yield advantages (Fisher, 1977a; Rees, 1986; Lightfoot and Tayler, 1987; Pilbeam *et al.*, 1994; Mukhala *et al.*, 1999).

Energy value (EV) derived from mass yields has been employed to evaluate intercrop yield advantages because it is a universal gauge of bio-productivity (Beets, 1977; Clark and Francis, 1985; Mukhala *et al.*, 1999). Normally, the reproductive parts of crops are used for the energy conversion. The summed energy yields of component crops in intercropping gives the total intercrop energy yield, which is then compared with the sole crop energy yields. Also, monetary value (MV) can be used when the considered crops are marketable. Yields can be expressed in terms of gross profits (Beets, 1977) or net profits if information on costs of production, such as fertiliser, irrigation and labour, are available (Francis and Sanders, 1978).

There are various agronomic factors influencing intercrop productivity and efficiency (Ofori and Stern, 1987). Many intercropping studies on the effects of plant density, spacing and arrangement have been carried out (Osiru and Willey, 1972; Willey and Osiru, 1972; Beets, 1977; Fisher, 1977b; Rees, 1986; Lightfoot and Tayler, 1987; Pilbeam *et al.*, 1994; Mukhala *et al.*, 1999). With respect to row orientation effects, several studies in mono-culture cropping have been reported (Hunt *et al.*, 1985; Steiner, 1986). Higher yields have been reported for mono-culture crops planted in north-south row direction than in east-west direction by Hunt *et al.* (1985) for soybean, Steiner (1986) for sorghum, Kaul and Kasperbauer (1988) for bush bean, and Karlen and Kasperbauer (1989) for maize. However, not much is known about the effect of row orientation in intercropping.

The objective of this study was, therefore, to examine the effect of row orientation on land productivity in an intercrop in a semi-arid region in Southern Africa. The effect of rainfall distribution on intercrop yield advantage was also investigated.

MATERIALS AND METHODS

This study comprised of two field experiments, the row orientation trial and the sowing date trial. The row orientation trial was conducted under irrigation at the Soil Science site of the Department of Soil, Crop and Climate Sciences, the University of the Free State (29°01'S, 26°09'E, 1354m) during the 1998/1999 and 1999/2000 summer growing seasons. While the sowing date trial was conducted under rainfed conditions at the Agrometeorology site (29°06'S, 26°11'E, 1411m; 15 km from the Soil Science site) during the 2000/2001 and 2001/2002 seasons. The climate of the study region, according to the Köppen climate classification, belongs to Bsk (i.e., arid cold and dry climate, with mean annual temperature below 18°C). The soil (0 - 900 mm) textures of the two sites are sand, loamy sand and/or sandy loam.

Row orientation trial. Treatments included three cropping systems (sole maize, sole beans, maize-bean intercrop), and two row orientations (NS: north-south, EW: east-west). A randomised complete block design was used with four replications for the 1998/1999 growing season and three replications for the 1999/2000 growing season.

Plant densities were 6.67 plants m^{-2} for sole maize, intercropped maize and intercropped beans, and 13.33 plants m^{-2} for sole beans. Row spacing was 1.0 m for sole maize and 0.50 m for sole beans and the intercrop. Intercropping was one row of maize to one row of beans (alternative intercropping). Plot size was 10 m x 15 m and 6 m x 6 m for the 1998/1999 and 1999/2000 growing seasons, respectively. Crops were harvested 140 days after planting. The harvest areas for the 1998/1999 and 1999/2000 growing seasons were 15 and 6 m^{-2}, respectively.

Calorimetric measurement was carried out to determine the conversion factor of mass value (g) into energy value (joule), using an oxygen bomb calorimeter.

The crops used in the experiment (maize cv. SNK 2147 and dry beans cv. PAN 127), were sown by hand on 24 November 1998 for the 1998/1999 growing season and on 23 November 1999 for the 1999/2000 growing season. Full irrigation and fertiliser (172 kg N ha^{-1}, 47 kg P ha^{-1} and 32 kg K ha^{-1}) were applied to all treatments in both seasons. The total rainfall received and irrigation applied during the 1998/2000 and 1999/2000 growing seasons were 636 mm and 723 mm, respectively. Hand-weeding was carried out throughout the growing seasons.

Sowing date trial. The objective of this experiment was to evaluate effect of sowing date on intercrop yield advantage. To do so, yields obtained from an additive intercrop were compared with yields from sole crops. The temporal distribution of rainfall was critical in determining the yield of the cropping systems and, therefore, formed an important basis for comparing yield advantage of the systems. Treatments included three cropping systems (sole maize, sole beans, maize-bean intercrop), and two sowing dates (Nov/Dec: 1st, Jan: 2nd). Hence, the experimental design was a 3 x 2 factorial with three replications. In both sole cropping and intercropping, the plant densities were 4 plants m^{-2} for maize and 10 plants m^{-2} for beans. Row orientation was east-west with row spacings of 1.0 m for maize and 0.4 m for beans. Row arrangement in intercropping was one row maize to two rows beans, using the additive design. Maize (cv. PAN6804) and beans (cv. PAN148) were used in the study.

Planting was done on 23 November 2000 and 11 January 2001 for the 2000/2001 growing season, and on 10 December 2001 and 08 January 2002 for the 2001/2002 growing season. Basal fertiliser (240 kg N ha^{-1}, 96 kg P ha^{-1} and 48 kg K ha^{-1}) was applied. Total rainfall during the growth periods ranged between 250 and 330 mm. Crops were harvested at 120 days after planting, and the harvest areas were 12 – 16 m^{-2} (plot size was 12 m x 15 m.).

Evaluation methods. Three different methods of quantitatively evaluating intercrop productivity were used, namely, (i) intensity of land use, (ii) production of constituents (calorie), and (iii) capital return (Willey, 1985). In addition to LER, energy value (EV) and monetary value (MV) were employed to evaluate intercropping advantages. Energy value for sole maize (EV_M), sole beans (EV_B) and maize-bean intercrop (EV_I) were calculated as follows:

$$EV_M = m_{EV} Y_{SM}$$

$$EV_B = b_{EV} Y_{SB}$$

$$EV_I = m_{EV} Y_{IM} + b_{EV} Y_{IB}$$

Where m_{EV} and b_{EV} are coefficients of the conversion of mass yield into energy yield for maize and beans, respectively (Willey, 1985). The conversion factor for plant materials is 17.8 kJ g^{-1} for maize and 16.8 kJ g^{-1} for beans (Tsubo, 2000).

Gross profits were used to calculate monetary returns because production costs, such as application of water, nutrients and labour, were assumed to be equal among cropping systems. The mean price ratio of beans to maize in South Africa between 1966 and 1999 was five to one with a standard deviation of 1.1 (National

Department of Agriculture, 2000). Based on the maize price of 1999, the conversion factor for maize was 755 Rands (South African currency) per tonne, and that for beans was 755 x 5 = 3775 Rands per tonne.

Statistical analyses. Means and standard errors were calculated using Excel spreadsheet, while analysis of variance (ANOVA) between treatments means were conducted using the statistical package NCSS 2000 (Hintze, 1997). Treatment means were separated using LSD 5% (Steel *et al.*, 1997).

RESULTS

Land equivalent ratio. The total LER (LER_T) for both experiments and cultural practices thereof were greater than one ($LER_T > 1$), (Table 1). In the row orientation trial there were no differences (P>0.05) between row orientations. The mean for LER_T was 1.08 in both the growing seasons. This means that intercropping had an 8% yield advantage over the sole cropping system. In other words, sole cropping needed 8% more land to produce the same yield as produced with intercropping. The partial LER of maize (LER_M) was almost equivalent to one (the mean LER_M = 0.98), while the partial LER of beans (LER_B) was nearly one-tenth (the mean LER_B = 0.10). That is, the association of beans in the intercropping did not reduce maize yield. However, the presence of maize in the intercropping reduced the yield of beans by 90% although the expected reduction was 50% because the plant density of intercropped beans was half of the population of sole beans. Although the LER_T were greater than 1.0 for both row patterns, the increase in yield were less than 10%, indicating a small intercropping advantage.

For the sowing date trial LER_T during both seasons and sowing dates were greater than 1.0 (Table 1). Mean LER_T was 1.29 for all sowing dates with 22% fluctuation between seasons. During the 2000/2001 season, 1st sowing date, the reduction in yields of both maize and beans due to the association was 46 and 48%, respectively. The highest LER_T of 1.57 occurred in the 2nd sowing date, 2000/2001 season. In this treatment, the LER_M was only 0.49, implying a 51% reduction in maize yield, while the LER_B was greater than 1, showing that bean yield within the intercrop surpassed that of the sole bean crop. The 2001/2002 season exhibited a similar LER_T trend, with maize performing better than beans within the intercrop. Maize experienced 19 and 14% yield reduction due to the association with beans while the beans had a 63 and 50% reduction in yields due to the association. During the 2001/2002 season, maize grew much taller than in the 2000/2001 season, with differences in heights for 1st and 2nd sowing dates of 98 and 48cm, respectively. This resulted in lower intercrop yield during the 2001/2002 season compared to the 2000/2001 season. Overall, the intercropping system was more effective and efficient than the sole crop in the use of environmental resources as demonstrated by higher LER_T in all sowing dates.

TABLE 1. Land equivalent ratio (LER) of the maize-bean intercropping

LER*	Row orientation trial			Sowing date trial		
	Row orientation	Growing season		Sowing date	Growing season	
		1998/1999	1999/2000		2000/2001	2001/2002
LER_M	North-South	0.97±0.07	0.97±0.08	Nov/Dec	0.54±0.03	0.81±0.03
LER_B	(NS)	0.10±0.02	0.11±0.04	(1st)	0.52±0.05	0.37±0.05
LER_T		1.07±0.06	1.08±0.05		1.06±0.08	1.18±0.08
LER_M	East-West	1.00±0.04	0.97±0.06	Jan	0.49±0.08	0.86±0.08
LER_B	(EW)	0.09±0.01	0.10±0.02	(2nd)	1.09±0.02	0.50±0.02
LER_T		1.09±0.05	1.07±0.08		1.57±0.06	1.36±0.06

Mean ± standard error; * LER_M = maize partial LER; LER_B = bean partial LER; LER_T = total LER

Energy value. In the row orientation trial, EV in sole maize was greater in the NS row orientation treatment than in the EW treatment, while for sole beans, the value was higher in the EW than in the NS row direction (Table 2). In the intercrop system, the NS row treatment gave a slightly higher EV than the EW treatment. However, the differences in EV between row orientation in all cropping systems were not significant (P<0.05). The EV_I was not significantly different from the EV_M in both growing seasons. Therefore, energy supplied by the intercrop was equivalent to sole maize. The EV_I, value was on average 4% energy from beans and 96% energy from maize, and the EV_M significantly exceeded the EV_B (p-values < 0.05). The intercrop produced 157% more energy than sole beans. Similarly, sole maize had 154% more energy than sole beans.

In the sowing date experiment, there was no significant (P>0.05) difference between sole maize and the intercrop EV, although the sowing date of the 2000/2001 had a slightly higher EV for sole maize compared to the intercrop (14.7%). For the rest of the treatments, the intercrop exhibited a slightly higher EV value over sole maize of no more than 1%. The sole and intercrops had mean EV of 49% greater than sole beans with the highest EV of 69% in the sowing date of 2001/2002. A similar trend as in the row orientation experiment was exhibited by the sowing date experiment on the basis of EV.

Monetary value. Table 3 shows monetary values for sole maize (MV_M), sole beans (MV_B) and the intercrop (MV_I). In the row orientation trial there were no significant (P>0.05) difference in MV

TABLE 2. Energy values for sole- and inter-cropping of maize and beans (GJ ha^{-1})†

Cropping system	Row orientation trial			Sowing date trial		
	Row orientation	Growing season		Sowing date	Growing season	
		1998/1999	1999/2000		2000/2001	2001/2002
Sole maize	North-South(NS)	184.2±22.7a	198.1±21.8a	Nov/Dec (1st)	44.3±2.5a	88.3±4.6a
Sole beans		70.5±9.7b	70.6±13.5b		28.4±7.9b	48.4±3.5b
Intercrop		183.7±11.8a	197.9±16.9a		38.6±5.3a	89.2±4.6a
Sole maize	East-West(EW)	169.8±13.3a	186.7±23.0a	Jan(2nd)	60.7±8.3a	79.9±9.4a
Sole beans		71.8±9.5b	78.3±11.6b		29.2±8.2b	25.0±4.0b
Intercrop		176.4±7.3a	188.9±25.3a		61.3±9.4a	81.1±2.9a

Mean ± standard error; † Evs derived using conversion factors of 17.8 kJ g^{-1} for maize and 16.8 kJ g^{-1} for beans; means within columns followed by the same letter are not significantly different at P < 0.05

TABLE 3. Monetary value for sole- and inter-cropping of maize and beans (Rands ha^{-1})

Cropping system	Row orientation trial			Sowing date trial		
	Row orientation	Growing season		Sowing date	Growing season	
		1998/1999	1999/2000		2000/2001	2001/2002
Sole maize	North-South (NS)	7812± 961a	8402± 924a	Nov/Dec(1st)	1880± 106b	3745±196b
Sole beans		15834±2190b	15868±3031b		6380± 177a	10870±793a
Intercrop		9063±742a	9760± 593a		4334± 944a	7029±393a
Sole maize	East-West (EW)	7203± 562a	7919± 975a	Jan (2nd)	2575± 355b	3390±400a
Sole beans		16126±2129b	17592±2611b		6569±1850a	5625±906a
Intercrop		8711± 363a	9368±1297a		8388±1223a	5708±242a

Mean ± standard error; means within columns followed by the same letter are not significantly different at P < 0.05

between row orientation treatments. In both seasons, monetary returns from sole beans were 77 and 109% higher than that from the intercrop and the sole maize, respectively ($P < 0.05$). Although the intercrop had an 18% higher monetary return than the sole maize, the difference was not significant. Seventeen percent of the monetary return of the intercrop came from the associated beans.

In the sowing date trial sole bean had the highest gross monetary return, followed by the intercrop and lastly sole maize. Sole beans had an MV of 59% higher than that of sole maize, while the intercrop had an MV of 53% higher than the sole maize. Sole beans performed better on MV basis in the 1st sowing during both seasons at 32 and 35%, respectively. The converse was true during the season 2000/2001, 1st sowing and 2001/2002, 2nd sowing date at 22 and 1%, respectively.

DISCUSSION

Land equivalent ratio. The yield advantages observed in the row orientation trial are less than those of Pilbeam *et al.* (1994) and Mukhala *et al.* (1999). A 20% advantage ($LER_T = 1.21$, $LER_M = 0.74$, $LER_B = 0.47$) was obtained by Pilbeam *et al.* (1994), yet Mukhala *et al.* (1999) measured $LER_T = 1.15$ ($LER_M = 0.87$ and $LER_B = 0.28$). The higher LER_B probably explains the higher LER_T. In the cited cases as well as in this study there was a greater effect of crop association on bean than on maize yields. Maize yields were not reduced as much by competition from beans, as with the reduction in bean yields.

The results of the sowing date experiment showed greater fluctuation in LER_M and LER_M compared to the row orientation experiment. The explanation lies in resource availability, especially supplementary irrigation during the row orientation experiment. The sowing date experiment depended wholly on rainfall which was low and poorly distributed, leading to wide variations in the growth of maize. This influenced the radiation environment of the intercropped beans and, therefore, its productivity. For example, season 2000/2001 experienced very poor rains and higher temperatures compared to season 2001/2002. The intercropped maize was, therefore, severely stressed and much stunted, allowing more radiation penetration within the intercrop canopy. The effect of the crop association resulted in almost similar reduction in yields for the intercropped maize and beans. The sowing date of the 2000/2001 season had poor rainfall, but lower soil fertility and cooler temperatures which encouraged intercropped bean growth and yields. The 2001/2002 season, had a similar pattern to that for the row orientation experiment.

The competitive ability of a specific crop relative to an associated crop in intercropping has been evaluated by aggressiveness (Pilbeam *et al.*, 1994). The aggressiveness of the specific crop to the associated crop is determined by subtracting the partial LER of the associated crop from the partial LER of that specific crop (e.g., LER_M - LER_B). When the value is positive, the specific crop is dominant in intercropping. All the aggressiveness values of the maize in the row orientation experiment were positive, indicating that maize had more competitive ability than the beans. The sowing date experiment exhibited marginal aggressivity by the maize in the 1st sowing date of 2000/2001 season ($LER_M - LER_B = 0.54 - 0.52 = 0.02$). However, the sowing date of the 2000/2001 season exhibited a large but negative value for the (LER_M – LER_B) relationship. The intercropped beans had a higher partial LER compared to the intercropped maize due to the stress imposed by the low soil water availability, while at the same time the cooler temperatures promoted bean growth. Studies conducted under irrigation conditions by Mukhala *et al.* (1999) ($LER_M - LER_B = 0.87 - 0.28 = 0.59$), in the same location gave similar results. Apart from season 2000/2001 sowing date, the rest of the results are in agreement with those of Pilbeam *et al.* (1994) and Mukhala *et al.* (1999). Crop growth rate is generally higher in C_4 plant species than C_3 plant species. As maize is a C_4 plant species, whereas beans are C_3 plants, the former grows faster than beans, and this was clearly shown from the final yield results. Moreover, maize forms relatively larger upper canopy structures compared to beans, and the roots of maize grow to a greater depth than those of beans. Thus, in maize-bean intercropping, maize is more competitive than beans, and this has been confirmed by the above observations.

Energy value. From the findings of the row orientation trial, it is clear that in a given area of land an increase in the area of sole bean planting (or decrease in the area of sole maize planting) results in a lower total sole crop EV. This suggests that intercropping is more productive than sole maize cropping planted alongside sole beans although under these particular circumstances there was no significant advantage of intercropping when the intercrop was compared with 100% of sole maize. Clark and Francis (1985) found that a maize-bean intercrop had a similar energy yield to sole maize but yielded more energy than sole beans. Thus, intercropping gave more yields than sole cropping. Mukhala *et al.* (1999), however, reported that a maize-bean intercrop yielded 11 and 32% more energy than sole maize and beans, respectively. This was probably because of a higher yield in the intercropped beans (LER_B = 0.47), compared with the result obtained in the row orientation trial (LER_B=0.10). Also, Mukhala *et al.* (1999) used a double alternate row arrangement of the legume component crop, while the single alternate row arrangement was used in this study. Several authors have reported a yield increase in legume component crops when the crops were planted in double alternate rows rather than single alternate rows (Ofori and Stern, 1987).

In the sowing date trial, intercrop and sole maize consistently exhibited no significant differences in EVs, while the sole bean crop had significantly lower EVs compared to the sole maize and the intercrop.

Monetary value. This study shows that the maize-bean intercrop planted in a given area of land is equivalent in monetary return to the sole maize. When the partial planting area for beans in sole cropping increases, the difference in monetary return from the intercrop and the total sole crop increases, showing that there is no monetary advantage of intercropping with this combination of the two crops. The price ratio of beans to maize used in this study was fixed (5:1). However, from 1966 to 1999 the bean price fluctuated over the maize price between 3.33 and 8.22. Moreover, if the price ratio was less than 2:1, there would be a monetary advantage of intercropping in the row orientation trial. This re-emphasises the fact that fluctuation in seasonal crop prices is the main difficulty in using this evaluation method. Beets (1977) reported that growing maize was more profitable than soybeans, or its intercrop, when the prevailing crop prices in Zimbabwe were used. However, when the price of soybeans was doubled, the intercrop gave higher gross income than the sole crops. Francis and Sanders (1978) reported similar effects from fluctuations of the price ratio of beans to maize on monetary returns (net incomes) in Colombia (the range 3:1 to 5:1 from 1950 to 1975), emphasising the importance of the price ratio of component crops.

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