Quantifying risk for maize–bean intercrop production in the semi-arid region of southern Africa

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Abstract

In regions like Africa that face food insecurity, small-scale farmers practise traditional cropping techniques such as intercropping. Many studies have reported that intercropping has higher productivity and higher resource use than sole cropping. In this study, risk for maize–bean intercropping was evaluated by quantifying long-term yield of maize and beans in both intercropping and sole cropping in a southern African semi-arid region (Bulawayo, Zimbabwe and Bloemfontein, South Africa). The crop simulation model was run with different cultural practices (sowing date and plant density) for 49 summer cropping seasons (1951–2000). Since soil water content at planting in each of the growing seasons was unknown, the simulation was run with a range of different root zone water contents at planting. Simulated long-term yields for maize–bean intercropping were analysed in terms of intensity of land use, production of constituents and capital return, and clearly demonstrated its advantages.

Media summary

Model runs with long-term weather data demonstrated that intercropping performs better than sole cropping at the same risk level. Resource-poor farmers in the semi-arid areas of southern Africa are therefore able to buffer themselves better by maintaining this traditional cropping system.

Key Words

Intercropping; Risk analysis; Crop simulation; *Phaseolus vulgaris*; *Zea mays*

Introduction

Most African farmers cultivate smallholdings and have limited access to decision support or on-farm extension services (Stigter and Weiss, 1986). They have practised traditional cropping techniques, such as intercropping, in which they unknowingly manipulate the crop microclimates. Several field studies indicate that the risk to the smallholder farmer in multiple cropping is lower than in sole cropping (Stigter and Weiss, 1986). The objective of this study was to assess risk for maize (*Zea mays*) – bean (*Phaseolus vulgaris*) intercropping using the intercrop model developed using experimental data from the semi-arid area of South Africa (Tsubo et al., 2004).

Simulation runs

A problem which arises when making long-term crop simulations is that soil water content at planting in each of the growing seasons is unknown; thus long-term crop simulations have to be run with a range of different initial root zone water content at planting each year. In this study, weather data for 49 years (1951–2000) from Bulawayo, Zimbabwe (20?15'S, 28?55'E) and Bloemfontein Airport, South Africa (29?06′S, 26?18′E, 1351 m asl) was used in simulation runs under the following scenarios: (i) soil profile initial water content at 0%, 50%, 100%; (ii) sowing date as 1st November, 1st December, 1st January; (iii) maize plant density ('000 plants/ha): low (10), medium (20), high (40); (iv) bean plant density ('000 plants/ha): low (40), medium (80), high (160). Since the simulation runs were conducted under rain-fed conditions, a fast maturing cultivar of maize with a similar growth period to beans, (100-120 days) was chosen.

Evaluation method

Although several different methods of quantitatively evaluating intercrop productivity were used in terms of (i) intensity of land use, (ii) production of constituents (calories, protein, carbohydrate, fat, etc.) and (iii) capital return (Willey, 1985), this paper addresses only mass yield and energy value. Land equivalent ratio (LER), i.e. total LER (LER_T), maize partial LER (LER_M) and bean partial LER (LER_B), was calculated as follows:

$$LER_M = Y_{IM}/Y_{SM}\ ;\quad LER_M = Y_{IM}/Y_{SB}\ ;\quad LER_T = LER_M + LER_B$$

where Y_{IM} and Y_{IB} are mass yields per unit area of intercropped maize kernels and bean seeds respectively, and Y_{SM} and Y_{SB} are mass yields per unit area of sole cropped maize kernels and bean seeds respectively. If LER_T is greater than one ($LER_T > 1$), intercropping has a yield advantage, if LER_T <1 there is a yield disadvantage. In addition to LER, energy value (EV) and monetary value (MV) were employed to evaluate intercropping advantages. EV for sole maize (EV_M), sole beans (EV_B) and maize-bean intercrop (EV_I) were calculated as follows:

$$EV_M = m_{EV} Y_{SM}\ ;\quad EV_B = b_{EV} Y_{SB}\ ;\quad EV_I = m_{EV} Y_{IM} + b_{EV} Y_{IB}$$

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 for maize and 16.8 kJ/g for beans (Tsubo, 2000). The cumulative probability curves (CPF) of LER and EV were statistically compared between scenarios using the Kolmogorov-Smirnov (KS) test for two samples.

Simulation output

Quantifying risk for intercropping

Figure 1 shows the CPF for simulated mass yield for maize-bean intercropping and sole cropping systems over the 81 simulation scenarios (3 profiles of initial soil water ? 3 sowing dates ? 3 maize plant densities ? 3 bean plant densities) averaged each year. The CPFs explain probabilities of non-exceedance of (or less than) specific yields. There was a 50% probability of producing less than 3055 kg/ha, respectively, for sole maize and 2898 kg/ha, for intercropped maize, with 1459 kg/ha for sole beans and 546 kg/ha for intercropped beans for the Bloemfontein site. Similar probabilities for Bulawayo were 4185 kg/ha for sole maize, 3465 kg/ha for sole bean, 1622 kg/ha for intercrop beans and 3840 kg/ha for intercrop maize for the Bulawayo site. The Bulawayo site performed better in terms of yield than the Bloemfontein site because of its higher rainfall. Thus, intercropped maize was equivalent in mass yield to sole maize (the Kolmogorov-Smirnov test: $p > 0.05$), but intercropped beans had lower mass yield than sole beans ($p \leq 0.05$). Figure 1 shows the CPFs for the two sites.

In terms of energy value, sole maize EV was 54.4 GJ/ha at a 50% cumulative probability level, sole beans 24.5 GJ/ha, and the maize-bean intercrop 59.5 GJ/ha (Figure 2). There was no statistical significant difference in EV between the intercrop and sole maize, but the EV was greater than sole beans at the Bloemfontein site. At the Bulawayo site and at the 50% probability level, the sole bean had an EV of 58 GJ/ha, sole maize had 74, GJ/ha, while intercrop had 93 GJ/ha. These values were higher than those at Bloemfontein. These values are converted from the yield values which were higher for Bulawayo than for Bloemfontein (see Figure 1).

Effects of ENSO on intercropping

One of the indicators normally used to identify El Ni?o-Southern Oscillation (ENSO) episodes is the Southern Oscillation Index (SOI). The SOI is strongly negative (SOI<–5) during El Ni?o episodes and strongly positive (SOI >+5) during La Ni?a episodes. In the present simulation study, the effects of ENSO on maize–bean intercrop productivity are presented for the December sowing date scenario in this paper. The SOI was averaged over September, October and November before the December sowing.

Averaging the simulated outputs for each SOI class, Table 1 shows the cumulative probabilities of simulated long-term (1951–2000) mass yields of intercropped maize and beans for SOI <−5, SOI neutral and SOI >+5. With December planting, the El Ni?o years had remarkably lower yield potential than the La Ni?a years in both intercropped maize and beans, with statistically significant differences in both maize and bean yields for the Bloemfontein site but not for the Bulawayo site (Table 1).

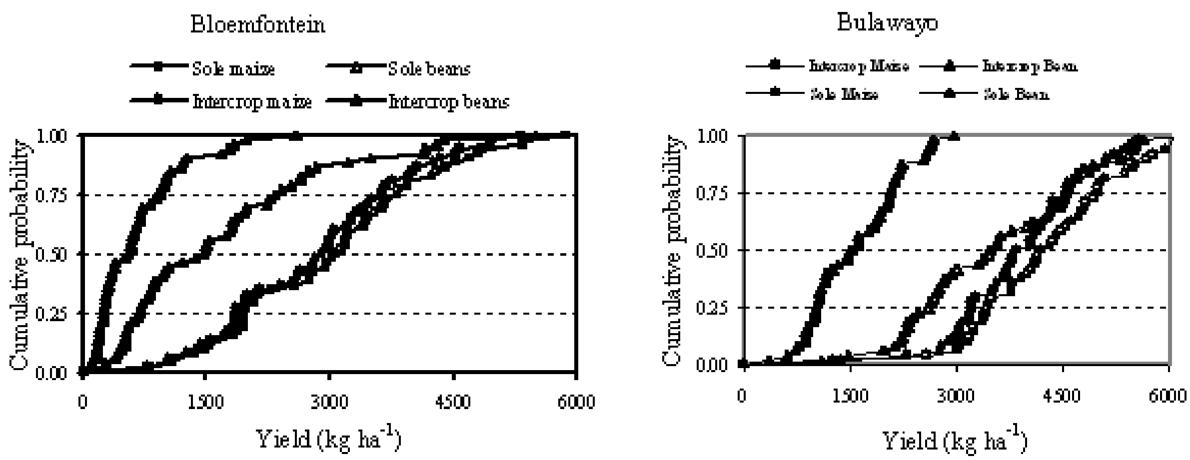

Figure 1. Cumulative probabilities of simulated long-term (1951-2000) mass yield of intercropped and sole cropped beans (averaged for 81 scenarios).

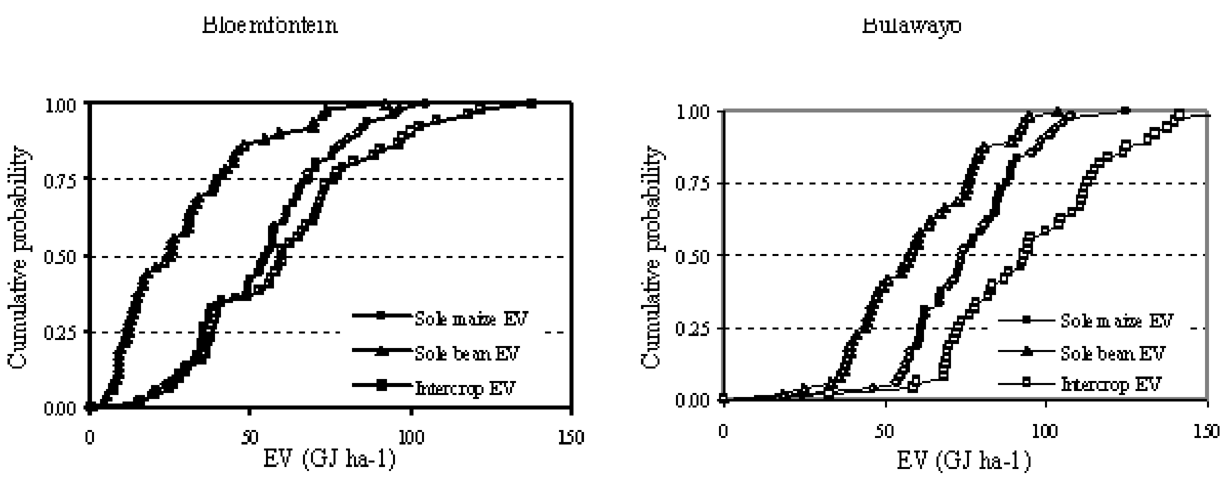

Figure 2. Cumulative probabilities of simulated long-term (1951-2000) energy value (EV) for sole maize, sole bean and intercrop (averaged for 81 scenarios).

Table 1. Probability of non-exceedance of simulated long-term (1951-2000) mass yield for maize–bean intercropping planted in December under different classes of the SOI.[†]

Cumulativeprobability	Bloemfontein			Bulawayo		
	SOI<–5	SOI neutral	SOI>+5	SOI<–5	SOI neutral	SOI>+5
			Intercrop maize kernel yield (kg/ha)			
25%	1205	2165	2875	3195	3675	2925
50%	2010	3410	3490	3215	4050	4205
75%	3110	4525	4510	4130	4575	4555
KS-test	a	b	b	b	b	b
			Intercrop bean seed yield (kg/ha)			
25%	180	165	370	1005	1055	1000
50%	305	315	880	1150	1620	1855
75%	535	975	1285	1760	2135	2035
KS-test	a	ab	b	b	b	b

[†] The same letter within rows indicates no significant difference at P≤0.05.

Conclusion

In this study, long-term maize–bean intercrop yields with different cultural practices under semi-arid conditions were assessed using a cereal-legume intercrop model (Tsubo et al., 2004). The mean of eighty-one scenarios, based on 3 levels each of initial soil water, sowing date, maize population and bean population were assessed. The value of the total LER was greater than one, showing intercropping to be advantageous over sole cropping. The intercrop (equivalent to sole maize) had greater EV than sole beans, and the intercrop (equivalent to sole beans) had greater MV than sole maize**.** We conclude that maize–bean intercropping is advantageous for the semi-arid region; while also giving higher production in La Ni?a years than in El Ni?o years. Seasonal forecasting may allow the most appropriate cultural practices to be used to maximize maize–bean intercrop yields for a specific season.

Acknowledgments

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