QUANTIFYING THE RISK ASSOCIATED WITH CROP ROTATION SYSTEMS OF AN EASTERN FREE STATE TRIAL[1]

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The Small Grain and Grain Crops Institutes, both of the Agricultural Research Council, found that the gross margin of maize monoculture was higher than any other crop rotation system tested in a trial. In this paper the effect of different crop rotation systems on net cash flows are quantified. A whole farm simulation model that incorporates risk was used for this purpose. From a net cash flow point of view maize monoculture was found to be the riskiest. However, the choice of a crop rotation system depends on the risk preference of the decision-maker since higher risks are also associated with higher profits.

KWANTIFISERING VAN RISIKO GEASSOSIEER MET DIE WISSELBOUSTELSEL VAN 'N PROEF IN DIE OOS-VRYSTAAT

Die Kleingraaninstituut en die Instituut vir Graangewasse, beide van die Landbounavorsingsraad, het in 'n proef bevind dat monokultuur mielies se bruto marge hoër was as die van enige ander wisselboustelsel. In die artikel word die impak van verskillende wisselboustelsels op netto kontantvloei gekwantifiseer. 'n Geheelplaassimulasiemodel, wat risiko in ag neem, is vir die doel aangewend. Daar is bevind dat mielie monokultuur, uit 'n netto kontantvloei oogpunt, die riskantste is. Die keuse van 'n wisselboustelsel hang egter van die risikovoorkeur van die besluitnemer af omdat hoër risiko ook geassosieer word met hoër winste.

1. INTRODUCTION

Monoculture cropping of wheat or maize may lead to various diseases and problems such as root diseases, weeds and pests (Nel & Purchase, 1998). This normally results in reduced yields and grain quality, which increases the risk of economic failure, especially during seasons with a below average or poorly distributed rainfall. According to Nel & Purchase (1998), crop rotation can solve this problem.

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In 1991 a crop rotation trial was established at the Small Grain Institute (ARC-SGI), conducted in conjunction with the Grain Crops Institute (ARC-GCI), both of the Agricultural Research Council. In this paper the ARC will be used when referring to the two institutes. The main objective with the trail was to determine the potential of different crop rotation systems. Treatments included monocropped maize and wheat and rotations of wheat with lupin, sunflower, fallow land, maize and dry beans (Nel & Purchase, 1998). The preliminary results of the trial show that crop rotation increases grain yield, grain quality and yield stability of wheat significantly. According to Nel & Purchase (1998) the protein content of wheat was increased 12 out of a possible 14 times with crop rotation. Maize yields was also increased with the crop rotation, whilst the protein content was significantly increased in one of the two years of cultivation. The yields of maize and wheat were influenced by a year rotation interaction, with the yield increases due to rotation larger for years with below average rainfall.

Although the above results show significant improvements with crop rotation, these results do not tell the full story. Different crop rotation systems have different impacts on cash flows of farming businesses. For example, when land is left fallow no income is earned from that land for that particular season. When wheat is rotated with maize (i.e. a winter crop with a summer crop) income earnings are lagged.

It is clear from the above that the effects of the different crop rotation systems on the cash flow of farmers should be quantified before it can be recommended to them. It is for this reason that the Agricultural Research Council Group for Development Impact Analysis (ARC-DIA) decided to contract the University of the Orange Free State.

This paper presents the effects of the different crop rotation systems on the farm's cash flow. This is done through two methods. Firstly the impact of yield levels and variability on credit and cash flow and therefore the chance of not being able to cover input costs in a specific month is determined and secondly net cash flow and therefore production risk is evaluated by means of cumulative distribution functions. The following section gives an overview of the production risk associated with farming. Section three is devoted to a description of the different crop rotation systems. The methodology to quantify production risk in financial terms is then discussed, followed by the results of the study. Finally a conclusion is made from the results.

2. PRODUCTION RISK

Most farm management decisions are made in a risky environment. The manager of a farm business seldom, if ever, has complete knowledge of the input-output relationships of the crops being cultivated, as well as of the prices of the crops. Risk can indeed have considerable impact at the individual producer level. For example, risk aversion implies that optimal resource use will favour less risky products relative to more risky ones and that overall resource use will be decreased. If a producer prefers risk, the reverse occurs (Anderson *et al.*, 1977). All risk involves an unavoidable cost in adverse outcomes or in costs incurred to reduce or avert the consequences of risky outcomes (Makeham & Malcolm, 1993). Risk is classified into two types, business risk and financial risk. Business risk is the inherent risk any business faces, independent of the way it is financed. It comes from production and price risk, and variability (Boehlje & Eidman, 1984). Attitudes towards risk vary depending on the individual's objectives and financial resources (Boehlje & Eidman, 1984).

Diversification is commonly advanced as a method of reducing risk. If enterprises are to offset each other for variations, they must possess certain characteristics. Their yields should have as little positive correlation as possible. The higher the correlation between yields, the less effective is the diversification (Binding *et al.*, 1993). Diversification may in fact make variability greater if similar seasonal and market forces affect the various activities (Makeham & Malcolm, 1993). Diversification to reduce risk, like all other strategies, comes with a cost. The cost is the income sacrificed over a period of years by organising the farm to reduce the variability between years. Diversification to reduce risk means that income will probably not be too low in bad years, but will also not be as high in good years (Binding *et al.*, 1993). Diversification to lessen variability is more effective as a means of combating yield variability (Binding *et al.*, 1993).

Decision-makers frequently prefer to use criteria that consider the total distribution rather than just one or two summary statistics. Two of the simpler criteria that consider the total distribution are first and second degree stochastic dominance. The stochastic dominance criteria can be discussed most conveniently using cumulative distribution functions (Boehlje & Eidman, 1984). Efficiency criteria simply sort those actions that should be considered from those that should not be for specific groups of decision-makers. The efficiency criteria eliminate those actions that are dominated by other actions being considered. Although efficiency criteria may not result in a definite choice, the decision-maker is left with a smaller set of actions to consider in making the decision (Boehlje & Eidman, 1984). First degree stochastic dominance comes down to the cumulative distribution of the dominant function being to the left of the dominated function for all points on the graph. This property is transitive. The transitivity of all the efficiency criteria permits an analysis to be conducted by reviewing only a few risky prospects at a time with the currently efficient prospects, permitting progressive revision and enlargement of the efficient set (Anderson *et al.,* 1977). First degree stochastic dominance assumes the decision-maker prefers more to less (Boehlje & Eidman, 1984). Second degree stochastic dominance assumes in addition that the decision-maker is risk averse. The decision rule for second degree stochastic dominance can be stated in terms of the area under the cumulative distribution curves. Given two uncertain actions, action one is preferred to action two by all decision-makers who are risk averse if the area under the cumulative distribution function of action one never exceeds and somewhere is less than the area under the cumulative distribution function of action two (Boehlje & Eidman, 1984). As a generalisation, most people seem to be averse to risk over the range of payoffs appropriate to their usual managerial decision-making (Anderson *et al.,* 1977). The procedures described can be used to analyse a wide variety of decisions at the enterprise level when uncertainty of outcome is an important consideration. Decision problems, including an evaluation of alternative crop production systems, alternative tillage methods and alternative fallow systems for dryland farming can be analysed with the approach illustrated. The notions of stochastic efficiency provide a useful framework for posing the essentially empirical question of how different selections perform in diverse risky environments (Anderson *et al.*, 1977).

Diversification is an important manner upon which risk can be managed. Because crop rotation is a form of diversification it holds important possibilities for risk management options. Unfortunately many studies regarding crop rotation are done by way of partial budgeting, therefore ignoring price and yield risk (Perry *et al.,* 1985). Because diversification is a technique upon which risk can be managed, risk will have to be reckoned upon in any evaluation of alternatives of diversification. When deciding on a suitable system it must be kept in mind that experimental data has been used with consequent higher yields. All experimental principles are not applicable to real live situations. For example, results obtained in low-yielding environments are usually ignored on the basis that yields are too low and are therefore not very useful for sorting out the differences between selections. This is a serious error, because high-yielding selections under favourable conditions may show relatively greater failure under adverse conditions (Anderson *et al.*, 1977).

3. DESCRIPTION OF THE DIFFERENT CROP ROTATION SYSTEMS

The different crop rotation systems, which are on trial at the ARC, are listed in Table 1. For further reference purposes an explanatory abbreviation has been assigned to every crop rotation system in the tables and figures.

Table 1: Description of the different crop rotation systems with average yields for the period between 1992/93 and 1996/97 and 1998 product prices

Crop rotation system		Crop	Area (ha)	Average yield (t/ha)	Price (R/t)
1	300W	Wheat	300	1.853	850
2	150W	Wheat	150	2.719	850
3	150L150W	Lupin	150	1.951	1 300
		Wheat	150	2.472	850
4	100Db100M100W	Dry Beans	100	1.384	2 800
		Maize	100	6.215	560
		Wheat	100	2.199	850
5	150M150Sb	Maize	150	5.646	560
		Soya Beans	150	1.748	1 025
6	300M	Maize	300	5.145	560
7	100S100W	Sunflower	100	1.661	1 220
		Wheat	100	3.005	850

System 4 and 7 takes the largest period (i.e. 3 seasons) to complete a full circle. The trial was conducted on 56 small plots of 225 m^2 in size at the ARC. However, to be able to understand the results better and for purposes of the study it was decided to expand the area on which the trial was done to 300 hectares. The figures in the abbreviations refer to the number of hectares planted to a specific crop. In the case where the figures do not add up to 300 (i.e. system 2 and 7) the difference is left fallow in each year of three years.

System 1 consists of monoculture wheat on 300 hectares. An area utilisation of 100 percent is therefore realised annually. System 2 on the contrary consists of wheat and a fallow period of 17 months that results in an annual area utilisation of 50 percent. The advantages of this fallow period are a higher yield as can be seen from the table. However, this is at the expense of a 100 percent annual area utilisation. There is therefore an opportunity cost associated with this system. With the exception of system 2 and 7 all the other systems have a 100 percent utilisation.

Due to conflicting growth periods, every crop can not be planted in every year in the specific crop rotation systems. Therefore the trial's construction was duplicated to accommodate all the crops of each system in each year of the trial. For example, for a crop rotation system with two crops two areas are planted with different crops on each to make provision for both crops within that specific year. In addition the trial's outlay consists of four repetitions for every crop in every system, resulting in four yields per crop per year for statistical analysis purposes. The yields given in Table 1 are an average of the four repetitions in every year, for five years (1992/93 to 1996/97). Unfortunately this procedure could not be followed in three cases. Wheat was not planted on certain plots during the 1993/94 and 1994/95 seasons due to unfavourable planting conditions (drought). Secondly, no soya beans were harvested during the 1993/94 season due to hail damage. Lastly, lupin was only harvested on three of the four plots during the 1995/96 season due to damage by guinea fowl. Prices used are presented in Table 1 and reflect market trends of 1998.

4. METHODOLOGY

Meiring (1994) developed a whole farm simulation model that incorporates risk. This short-term stochastic simulation model utilises cumulative distribution functions of key variables to generate distribution functions of important economic criteria such as cash and credit flow, income parameters, etc. on a monthly basis. The model incorporates all the factors which should be quantified and was therefore used in this study.

The occurrence of production risk is due to factors that causes yield differences between different years, such as weather, and between plots, such as soil properties, etc. within the same year. The assumption was made that these fluctuating yields are a reflection of production risk that can occur in successive production seasons in future. Yield distribution functions were therefore compiled as a basis for Monte Carlo simulation to generate random yields for the crops in the various crop rotation systems in the model. Cultivation practices and production inputs and quantities used by the ARC were simulated for 300 hectares of cropland. Harvesting and transport costs were accounted for by using contractor's fees. A mechanisation system consisting of three tractors and 12 typical implements was included in the analysis to perform the cultivation practices. It was further assumed that no additional implements are necessary for any of the different crop rotation systems. Economic results were generated for each crop rotation system on enterprise level using current input prices with a simulation of 50 iterations.

Because the emphasis is on production risk, product prices have been kept constant for this evaluation.

5. RESULTS

The correlation coefficients between all the crops of all the crop rotation systems are summarised in Table 2. Coefficients were calculated despite the short time series available because correlation coefficients are needed in the model to generate correlated random yield distributions. Some of the correlations in the table, especially some of those applicable to wheat in system 4, are not according to expectations. This is because of unfavourable weather conditions that made it impossible to realise a wheat yield in every year. An already short time series for wheat was therefore shortened even further. Luckily these specific correlation figures are not necessary for the simulations. All correlation coefficients used in the model were in accordance with prior expectations. The difference between the correlation coefficients of wheat in system 1 with itself and wheat in system 1 with system 2, 3 and 7 illustrates the effect of crop rotation on yields of the same crop within the same year. Since external variables have the same influence on all the crop rotation systems annually, it can be assumed that the specific crop rotation system is the only variable determining yield.

Table 2: Correlation matrix of annual average crop yields for seven crop rotation systems

	Db[1] (4)[2]	L (3)	M (4)	M (5)	M (6)	Sb (5)	S (7)	W (1)	W (2)	W (3)	W (4)	W (7)
Db (4)	1.00	-	-	-	-	-	-	-	-	-	-	-
L (3)	-0.36	1.00	-	-	-	-	-	-	-	-	-	-
M (4)	0.94	-0.20	1.00	-	-	-	-	-	-	-	-	-
M (5)	0.90	0.00	0.98	1.00	-	-	-	-	-	-	-	-
M (6)	0.83	0.08	0.92	0.97	1.00	-	-	-	-	-	-	-
Sb (5)	0.52	0.08	0.31	0.40	0.47	1.00	-	-	-	-	-	-
S (7)	0.88	-0.39	0.74	0.72	0.75	0.75	1.00	-	-	-	-	-
W (1)	0.37	0.30	0.64	0.67	0.60	-0.32	-0.01	1.00	-	-	-	-
W (2)	0.06	0.78	0.31	0.44	0.42	-0.11	-0.23	0.81	1.00	-	-	-
W (3)	-0.55	0.75	0.16	0.27	0.20	-0.20	-0.39	0.73	0.96	1.00	-	-
W (4)	0.30	0.48	0.21	0.37	0.49	0.90	0.53	-0.15	0.20	0.07	1.00	-
W (7)	0.25	0.71	0.45	0.57	0.53	0.07	-0.04	0.79	0.97	0.93	0.31	1.00

1. Alphabetic abbreviations refer to the different crops:
   Db: Dry Beans   L: Lupin   M: Maize
   Sb: Soya Beans   S: Sunflower   W: Wheat
2. The values refer to the specific crop rotation system.

Wheat yields within five different systems are presented on a per hectare basis in Figure 1. Wheat in system 7 is preferred above wheat in all of the other systems because for any given probability the specific yield outcome is higher than the corresponding yield in any of the other systems. This favourable yield probability distribution is a result of the long fallow period (Nel & Purchase, 1998). From a pure scientific point of view system 7 would therefore be recommended as a crop rotation alternative to farmers. According to preliminary calculations by the ARC, maize monoculture delivered the highest gross margin. These findings should however be evaluated economically in terms of its effect on production credit and net cash flows.

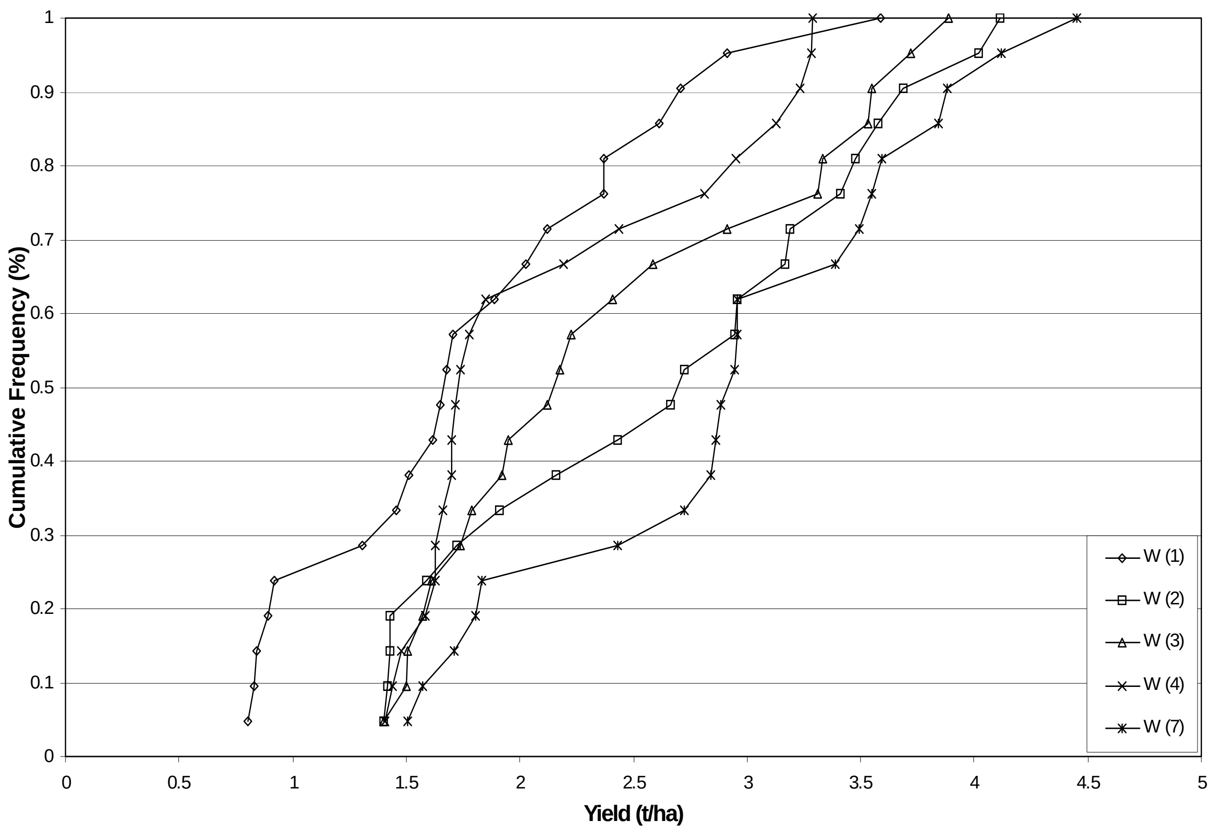

Figure 1: Cumulative distribution function of simulated wheat yield in the Eastern Free State for five different crop rotation systems

The model makes a distinction between cash flow and credit flow. In this case cash flow represents the bank account over a time period whilst credit flow represents the co-operative account. In terms of the model specification credit flow can never be positive because when income from crop yield exceeds input costs, the surplus income is transferred to the cash flow. All production inputs are handled as credit flow in the model. Table 3 summarises the cash and credit flow for each system. As far as minimum cash flow is concerned, system 1 represents the worst systems, closely followed by system 4. System 7 has the largest minimum cash flow and therefore poses the least risk for one to create a loss. As far as maximum cash flow is concerned, system 2 has the smallest amount and system 6 the largest. Credit requirements is the smallest for system 4 and the largest for system 6. Credit requirements are influenced by the distribution of input costs through the season. In the case of system 1, 3, 5 and 6 the total area is planted in the same season. This reflects high input costs and therefore high risk. The advantages in terms of this are clear when input costs are distributed over two seasons, or even over three planting periods, as is the case with system 4. Therefore, although system 4 is amongst those systems with the smallest minimum cash flow, it is also the system with the smallest credit requirement. System 6 has the largest maximum cash flow but it also needs the largest maximum credit facility. One can therefore state that for higher returns the farm manager has to accept higher risk. In four cases there is a probability that the gross income will not cover the input costs in the month when the crop is harvested. In the case of system 1, where a monoculture wheat system is applied, there is a probability of 12 percent that the gross income will not cover the input costs in any year.

Table 3: Cash and credit flow for the different crop rotation systems

Crop rotation system	Minimum cash flow (R)	Maximum cash flow (R)	Maximum credit facility (R)	Harvest month	Probability of negative flow(%)
1 300W	0	690 783	181 521	December	12
2 150W	45 513	387 646	106 288	December	0
3 150L150W	41 970	1 079 878	167 663	December	0
4 100Db100M100W	63	1 379 444	79 308	March June December	0 0 68
5 150M150Sb	58 814	1 153 793	217 296	May June	6 0
6 300M	74 473	1 443 630	344 256	June	0
7 100S100W	84 088	502 369	118 799	April December	0 18

An option in the model was exerted that makes it possible to use cash from the bank account to pay off the co-operative account at the end of the period if there is no income or not sufficient income to cover the outstanding balance. The consequent net cash flow is illustrated in Figure 2. This figure summarises simulated end of the period net cash flow cumulative distribution functions for the seven different crop rotation systems. If variability is taken as an indication of risk, system 2 will probably be preferred over system 4 by a risk averse farm manager. The minimum and maximum net cash flow of system 2 is R45 513 and R342 133 respectively and that of system 4 negative R81 761 and R1 461 205. A farmer who applies crop rotation system 4 has a 60% chance of realising the maximum net cash flow of system 2 or more, whilst he has only a 24% chance of realising less than system 2. If stochastic dominance is taken as an indication of risk patterns, system 3 and 7 will be preferred in all circumstances above system 2. Both systems lie to the right of system 2 for all possible outcomes. System 4 will be preferred above system 3 by a risk seeking farm manager (second order stochastic dominance). Because there is a 68% chance that wheat in this system will not be able to cover input costs, system 4 has a 18% probability of failing. Under poor weather conditions this system is amongst those performing the worst, but it also has a 16% chance to perform the best under better conditions. However, it should be noted from Figure 2 that in some instances system 6 has a higher probability to perform better than any other system. This is in agreement with

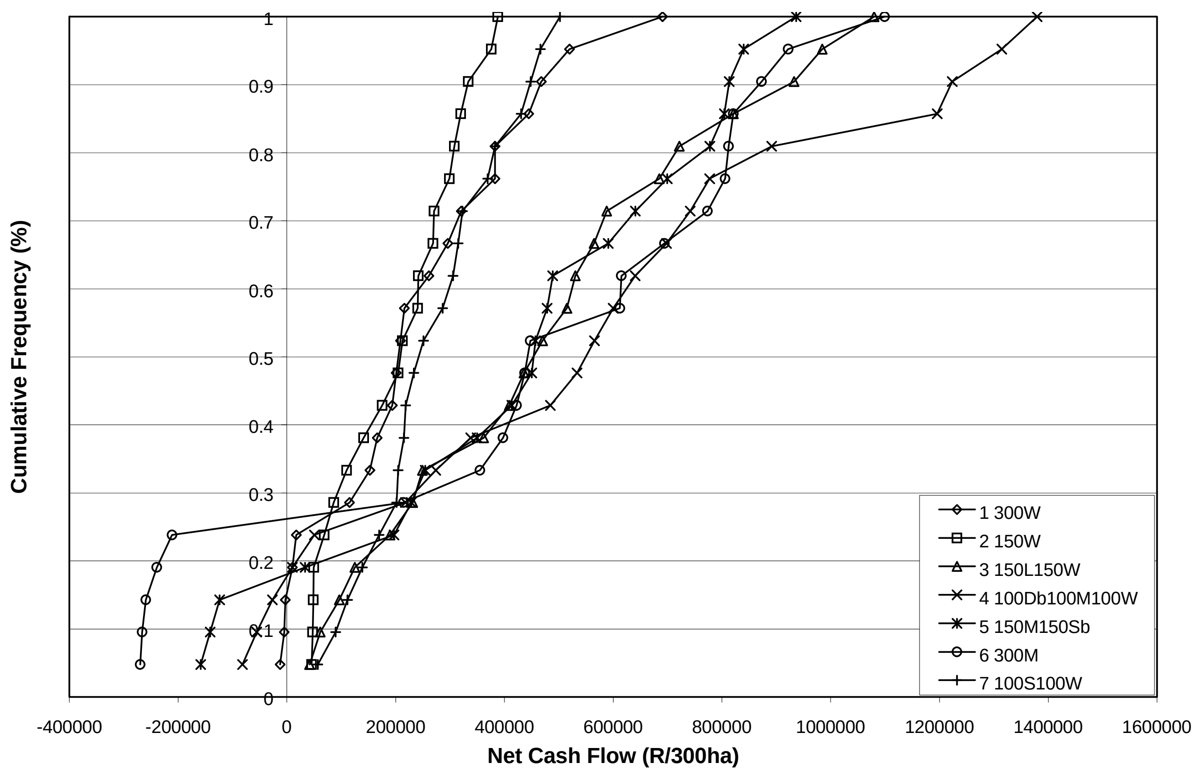

Figure 2: Cumulative distribution functions of simulated net cash flows of different crop rotation systems

Nel and Purchase (1998) who stated that crop rotation systems do not always perform as well as monoculture under favourable conditions. However it should also be noted that the same authors stated that crop rotation systems are much more stable under poor conditions. This is also illustrated in Figure 2 with system 6 performing the worst under poor conditions and system 1 also showing a 15% probability of negative net cash flows. It is interesting to note that, except for the two monoculture systems, all the crop rotation systems which have maize as a crop have a probability to turn negative. From a production risk point of view (*ceteris paribus)* one can therefore state that maize is the riskiest crop of all the crops tested in the trial.

6. CONCLUSION

From preliminary gross margin figures, the ARC found that maize monoculture performed better than any other crop rotation system tested in a trial at Bethlehem. The results of this study prove that when the effect of cash and credit flows are accounted for, this recommendation can not be followed. Although maize monoculture is one of the systems performing better than many others, it is also the crop represented in three out of the four crop rotation systems showing negative net cash flow probabilities. This crop can therefore be regarded as riskier than many of the others from a net cash flow point of view. However it should be noted that in practice this crop has an additional value because the crop residue is used for cattle feed in winter. However, no single crop rotation system can be recommended as the best system. The choice of a system depends on the risk attitude of the decision-maker. It is clear from the results that the more profitable crops are also associated with higher risk probabilities. For the purpose of this paper only production risk were quantified. However, in a free market situation price risk should also be accounted for before any system is chosen.

7. ACKNOWLEDGEMENT

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