The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

No endorsement of AgEcon Search or its fundraising activities by the author(s) of the following work or their employer(s) is intended or implied.

THE IMPACT OF CROP ROTATION ON PROFITABILITY AND PRODUCTION RISK IN THE EASTERN AND NORTH WESTERN FREE STATE

AA Nel & HL Loubser[1]

Abstract

Diversification is a generally accepted measure against production risk. Crop rotation as a unit of diversification can reduce risk even further. Net returns and risk, defined as the cumulative sum of shortfalls below a disaster target level of net return, were estimated for two long term crop rotation trials. One was conducted in the eastern Free State where maize and wheat in monoculture were compared with rotations involving fallow, drybean, soybean and sunflower crops. In the second trial located in the north western Free State monocropped maize was compared with rotations involving groundnut, soyabean and sunflower crops. Crop rotation and the associated diversification produced results varying from increased to reduced net returns and increased risk to dramatically reduced risk depending on crops involved and the net return level accepted as a disaster threshold. Compared to monoculture, groundnut improved net returns without affecting risk. Drybean and soybean improved net returns and reduced risk while sunflower was the most effective in reducing risk with little effect on the net return. Risk reduction in the eastern Free State was mainly due to rotational benefits such as improved yields. In the north western Free State, however, risk reduction was mainly due to the inclusion of crops with relatively low risk.

1. INTRODUCTION

An inherent characteristic of dryland crop production in South Africa is the high production risk due to adverse weather conditions, drought probably being the most important. Diversification is an on-farm strategy that is generally propagated as a measure against risk. The theory is that profit with specialisation in a single crop will be greater, but two or more products may be produced to reduce the risk of very low incomes in some years (Binding, Van Schalkwyk, Van Zyl & Sartorius von Bach, 1993).

In terms of crop production, diversification means growing more crops than were previously grown. In propagating diversification, however, the importance of

[1] *ARC-Grain Crops Institute, Private Bag X1251, Potchefstroom 2520. Tel: (018) 299-6396; Fax: (018) 297-6572; E-mail: a_nel@ops1.agric.za.*

sound crop rotation systems is usually neglected. According to Helmers, Yamoah & Varvel (2001) the risk benefits of crop diversification are generally well understood, but the additional effect of rotational cropping on risk is less understood. In this regard they demonstrated that in the diversification from maize to a maize-soyabean rotation system, 71% of the reduction in risk was due to the rotational effect and 29% due to diversification.

The benefit of crop rotation in reducing production risk involves three distinct influences that were described by Helmers *et al* (2001). Firstly, rotations, as opposed to monoculture cropping, may result in overall higher crop yields as well as reduced production costs. Secondly, rotation cropping is generally thought to reduce yield variability compared with monoculture practices. Thirdly, crop rotation involves diversification, with the theoretical advantage that low returns in a specific year for one crop is combined with a relatively high return for a different crop. Drought however, is usually detrimental to all crops, often preventing this advantage from occurring. An obvious benefit of diversification is the reduction of risk through the inclusion of alternative crops with relatively low risk.

2. PRODUCTION RISK

Different concepts of risk and its quantification exist and are well described by Harwood *et al* (1999). Simple methods of risk quantification include the calculation of the yield variance from historic yield data, or estimation of the probability of falling below some critical level. A popular approach is stochastic dominance. It is implemented by comparing cumulative distribution function curves of alternatives. This approach rests on the axiomatic foundation that more is preferred to less for first-degree dominance while second and third-degree stochastic dominance rests on other behavioural assumptions (Helmers *et al*, 2001).

Yet another approach to risk is termed *safety first* where the focus is placed on minimising the probability of falling below a disaster target level (Harwood *et al*, 1999; Helmers *et al*, 2001). The benefit of this approach is that it is relatively simple, has a strong intuitive appeal and empirical support (Helmers *et al*, 2001). Risk is calculated as the cumulative sum of shortfalls when annual net returns fall below a specified net target for a specified number of years.

The aim of this study was to determine the effect of crop rotation on the net return and risk according to the safety first approach of wheat and maize in monoculture and in rotation with alternative crops using results from two long-term crop rotation trials.

3. METHODOLOGY

Two crop rotation trials, one at the ARC-Small Grains Institute close to Bethlehem in the eastern Free State and the second close to the town of Viljoenskroon in the north western Free State were conducted for nine and seven years respectively. The Bethlehem trial and its agronomic results were described by Nel, Purchase & Barnard (2003) and the northwestern Free State trial by Loubser & Nel (2004). The effect of crop rotation on grain yields and grain quality was quantified in these trials.

Crop rotations included in the trial at Bethlehem were a two-year maize-soyabean, a three-year maize-drybean-wheat, a three-year wheat-sunflower and a two-year wheat-fallow system. Mean yields of rotated maize exceeded monocropped yields up to 56% and rotated wheat yields exceeded monocropped wheat up to 54%. With only one exception, crop rotation also reduced season-to-season variability of wheat and maize yields slightly. The grain quality of wheat in rotation was also superior to monocropped wheat in several seasons. Botha, Meiring & Van Schalkwyk (1999) calculated the risk in these rotation systems using the results of the first five years of this trial and a whole farm simulation model. This model utilizes cumulative distribution functions of key variables to generate distribution functions of financial criteria such as cash and credit flow from which the stochastic dominance of crop systems is compared.

In the trial at Viljoenskroon, maize grown in monoculture was compared to two years of maize in rotation with one year of groundnut, soybean or sunflower. Due to late rains in 1994/1995, the groundnut crop was planted in January, three weeks later than the last recommended planting date. Accordingly the yield of this groundnut crop was left out of the economic and risk analyses reported on in this article. The mean yield of first year maize after the alternative crops improved from zero to 16% compared to monocropped maize. Second year maize yields were not significantly different from those of monocropped maize. Seasonal yield variability was slightly higher for first year maize than for second year or monocropped maize. Monocropped drybean, groundnut, soybean and sunflower were not included in the trials.

Net returns were calculated annually for each crop using the nine year yield data from the trial at Bethlehem and the seven year yield data from the trial at Viljoenskroon and total costs and prices shown in Table 1. The costs and prices used for the Bethlehem trial represent three year means (1999/2000 - 2001/2002) of figures calculated for farmers in the eastern Free State (supplied by Computus Bestuursburo (CC), PO Box 1615, Bethlehem 9700), while those used for the

Viljoenskroon trial are three year means (1999/2000 - 2001/2002) of budgets compiled and supplied by Senwes (Ltd) (Senwes Landboudienste, PO Box 31, Klerksdorp 2570). The value of hay was not taken into account for any of the crops.

Table 1: Mean total cost of production and mean prices of grain (1999/2000 to 2001/2002)

Crop	Total cost of production (R ha^{-1} $year^{-1}$)	Price (R $tonne^{-1}$)
Bethlehem*		
Drybean	2509	3495
Maize	1985	825
Soyabean	1749	1619
Sunflower	1334	1490
Wheat	1101	1647
Viljoenskroon**		
Groundnut	2042	2600
Maize	1847	825
Soyabean	1532	1619
Sunflower	1281	1490

* Supplied by Computus Bestuursburo (CC).
** Supplied by SENWES (Ltd).

The wheat price shown in Table 1 represents the price for grades BP1 and BSS. Based on historic data, this price was raised by 1% for grade BPS and reduced by 1.6% for grade BS1, 4.7% for grades BS2 and BL1, 7.8% for grade BL2 and 57.4% for grades UT1 and UT2. The wheat-fallow, maize-drybean-wheat and wheat-sunflower rotation systems each include a fallow period during summer when occasional weeding was done. An annual cost of R350 ha^{-1} was assumed for these activities. Wheat yields were damaged by hail during two seasons. As insurance against hail was accounted for in the costs, it was assumed that payouts were made for the losses encountered.

Mean net returns and the risk for each individual crop and for the rotation systems were calculated for the duration of each trial from the annual net returns. Within the rotation systems, it was assumed that a one to one area ratio existed amongst crops. The choice of a disaster target level is arbitrary and risk was thus calculated by totalling the Rand deficits for all years where net returns fell below R600 and R300 ha^{-1} respectively.

4. RESULTS

4.1 Bethlehem trial

The estimated net returns for individual crops and crop rotation systems investigated in the Bethlehem trial are shown in Table 2. Compared to maize in monoculture, the net returns for drybean and soyabean crops were respectively 20 and 5% higher and the risk at the R600 ha^{-1} level, respectively 11 and 29% less than that for the monoculture maize. Judging from these results, drybean and soyabean are suitable alternative crops to maize for improving net returns and reducing risk. The mean net return for sunflower was 24% less than for the monocropped maize. The risk of sunflower is remarkable, as it was 68% less than the risk of maize in monoculture. The net return for maize grown after soyabean showed an increase of 27% above the monocropped maize. Risk at the R600 ha^{-1} level also declined by 27%.

Table 2: Estimated mean net returns and risk-accumulated net returns for crops individually and for rotation cropping systems at Bethlehem for the period 1992/1993 to 2000/2001

Crops/Cropping Systems	Mean net return	Risk-accumulated returns below	
		R600	R300
	(R ha^{-1} year^{-1})	(R ha^{-1})	(R ha^{-1})
Individual crops			
Maize in monoculture	1782	2435	1835
Maize after soyabean	2271	1783	1325
Drybean after maize	2139	2162	1862
Soyabean after maize	1871	1722	972
Sunflower after wheat	1347	772	172
Wheat in monoculture	1539	1447	418
Wheat after drybean*	2220	1024	271
Wheat after fallow	2850	287	0
Wheat after sunflower	3346	108	0
Crop rotation systems			
2 yr-maize – soyabean	2071	1409	1109
3-yr-maize - drybean -wheat	2179	1445	1145
2-yr-wheat – fallow	1250	1181	493
3-yr-wheat – sunflower	1448	248	0
4-yr-maize - sunflower – wheat**	1546	333	33
6-yr-maize - sunflower – wheat***	1842	529	229

* Results of only six years.
** Theoretical system with a crop area ratio of 1:1:1.
*** Theoretical system with an area ratio for maize : sunflower : wheat of 2:1:2.

The effect of crop rotation on net return and risk was more pronounced for wheat than maize. Although only a rough estimate due to the differences in the period of measurement, the mean net return of wheat after drybean increased by 44%

and the risk (R600 ha^{-1} level) decreased by 29%. Net returns for wheat after fallow and sunflower were respectively 85 and 117% higher and the risk (R600 ha^{-1} level) respectively 80 and 93% less than that for wheat in monoculture.

The advantages of crop rotation and accompanying diversification are evident when the net returns and risk (R600 ha^{-1} level) of the rotation systems are compared to the risk of monoculture maize and wheat crops. The net return for the maize-soyabean system improved by 16% and the risk decreased by 42%. Although wheat was not grown in three of the nine years in the maize-drybean-wheat system, its net return increased by 31% and the risk declined by 26% compared to the mean net return and mean risk of the monocropped maize and wheat. The performance of this system was unexpected considering the absence of a wheat crop in some years, the loss of income during those years and the added cost of weed control during the fallow period. The exceptionally long fallow period of 18 months created by the absence of wheat, however, improved maize yields by 56% (Nel *et al,* 2003), which compensated for the lack of return from wheat.

A disadvantage of the wheat-fallow system is that 50% of the cropping area lies fallow within a year. During this period regular weeding is needed which also increase the susceptibility of the area to soil erosion. From a business point of view, the large fallow area can also be seen as a lost opportunity to generate income, particularly during favourable years with high crop yields. Due to the added costs and low occupation of the area by a crop, the net return for this system is only 81% of that of the wheat monoculture system. The risk however, is 18% less than that of monocultured wheat.

One third of the area of the three-year wheat-sunflower system is fallow during the year, which has the same disadvantages as mentioned for the wheat-fallow system. The net return for this system was 6% less than that of the monocropped wheat, while the risk was a remarkable 83% less than the risk of the monocropped wheat crop.

Due to the remarkable decline in risk in the wheat-sunflower system, two theoretical systems were included in the analysis, namely a four-year maize-sunflower-wheat system and a six-year maize-maize-sunflower-wheat-wheat system. The advantage of these systems is that the area allocated to fallow is reduced from 33% for the three-year system to 25 and 17% for the four and six-year systems respectively while retaining the benefits of the three-year system. Assumptions made were that the second year maize and wheat yields are equal to the respective monocropped yields and that yields of sunflower crops are equal when grown after maize or after wheat. The net return for the four-year system is 7% less than the mean net return for the monocropped maize and wheat while the risk was reduced by 83%. The net return for the six-year system is 11% higher than the mean net return for the monocropped maize and wheat while the risk is reduced by 73%. The evidence suggests that reducing the fallow area (of the three-year wheat-sunflower system) with crops better suited for short-term monocropping (maize and wheat) will increase the net return, while the risk will increase slightly.

Helmers *et al* (2001), found a more dramatic reduction in risk for rotations when the disaster target level is reduced. At the lower R300 ha^{-1} level, risk was reduced to zero for the three-year wheat-sunflower system and by 97 and 80% respectively for the four and six-year theoretical maize-sunflower-wheat systems compared to much lower values at the R600 ha^{-1} level. Risk was however increased in the wheat fallow system by 18% above the monocropped wheat at the R300 ha^{-1} level while it decreased by 18% using the R600 ha^{-1} level. Risk in the maize-drybean-wheat system was 2% higher than the mean risk of monocropped maize and wheat at the R300 ha^{-1} level while it decreased by 26% at the R600 ha^{-1} level.

4.2 Viljoenskroon trial

The estimated mean net returns and risk at two disaster target levels for the different crops and rotations investigated at Viljoenskroon are shown in Table 3. The mean net return for first year maize increased by 36% after groundnut, by 11% after soyabean and by 9% after sunflower above maize grown in monoculture. Risk at the R600 ha^{-1} level however, increased marginally from 2 to 7% depending on the rotation crop.

Compared to the net return of monocropped maize, the net return for second year maize was increased by 22% after groundnut, 23% after soyabean and by 13% after sunflower. Risk for the second year maize after groundnut remained constant, after soyabean was reduced by 8% and after sunflower reduced by 32%.

The mean net return for groundnut was 64% higher, 19% less for soyabean and 31% less for sunflower compared to monocropped maize. Risk (R600 ha^{-1} level) for these crops were 11% for groundnut, 37% for soyabean and 81% for sunflower less than the risk of monocropped maize.

The net return for the groundnut-maize-maize system was 33% higher, for the soybean-maize-maize 11% higher and for the sunflower-maize-maize system 3% less than the net return for the monocropped maize. Compared to monoculture maize, risk at the R600 ha^{-1} level was 2% less for the groundnut-maize-maize system, 13% less for the soyabean-maize-maize system and 45% less for the sunflower-maize-maize system.

Table 3 Estimated mean net returns and risk for individual crops and for rotation cropping systems at Viljoenskroon for the period 1990/1991 to 1996/1997

Crops/Rotation Systems	Mean net return	Risk-accumulated returns below	
		R600	R300
	(R ha^{-1} $year^{-1}$)	(R ha^{-1})	(R ha^{-1})
Individual crops			
Maize in monoculture	1974	2268	1968
First year maize after			
Groundnut	2675	2426	2126
Soyabean	2519	2387	2087
Sunflower	2143	2318	2018
Second year maize after			
Groundnut	2412	2251	1951
Soybean	2424	2091	1792
Sunflower	2233	1545	1108
Rotational crops			
Groundnut after maize	3246	2026	1726
Soyabean after maize	1602	1436	1136
Sunflower after maize	1353	360	55
Crop rotation systems			
3 yr-groundnut - maize – maize*	2623	2235	1935
3 yr-soyabean - maize - maize	2182	1972	1672
3 yr-sunflower - maize - maize	1910	1244	944

* Results of only six years.

At the R300 ha^{-1} level, risk for the first and second season maize after groundnut and soybean crops as well as the rotation system involving these crops are approximately equal or slightly less than the risk at the R600 ha^{-1} level. Sunflower is an outlier in this respect. The risk of the sunflower crop at the R300 ha^{-1} level was 97% less and that of the sunflower-maize-maize system 52% less than the risk for monocultured maize while the respective values at the R600 ha^{-1} level were 81 and 45%.

4.3 Rotation versus diversification

In order to differentiate between the risk benefits from crop diversification and those from crop rotation, monocultured yields of the oil and protein rich crops (drybean, soyabean and sunflower at Bethlehem and groundnut, soyabean and sunflower at Viljoenskroon) are needed. For example, the mean risk for maize and an oilseed crop each grown in monoculture with a one to one area ratio, will account for the risk benefit due to diversification only. On the other hand, risk for a two-year-maize-oilseed rotation system will account for the risk benefit of both diversification and rotation. As monocultured systems of the oil and protein rich crops were not included in the two trials, accurate calculation of the risk benefit from crop diversification is not possible. If, however, it is assumed that the yields of the oil and protein rich crops in rotation are similar to those in monoculture, it is possible to estimate the risk benefit due to diversification. It is well known that yields of oil and protein rich crops usually decline in monoculture due to increasing damage caused by diseases and pests. Equal yields therefore represent the best possible senario for diversification.

Compared to monocultured maize, risk was 42% lower for the two-year-maize-soyabean rotation system (Bethlehem, R600 ha^{-1} target level), accounting for rotational and diversification benefits. The estimated mean risk for a diversified maize-soyabean system (both in monoculture) is only 28% lower than that for the monocultured maize. At least two thirds of the risk benefit for the two-year-maize- soyabean rotation system was, therefore, due to the yield enhancement associated with crop rotation and one third due to diversification.

The considerable contribution of crop rotation to the risk benefit in systems involving wheat is also evident. For example, the estimated risk for a wheat-sunflower diversified system is only 23% lower than that for monocultured wheat, whereas the risk for the three-year-wheat-sunflower rotation system was 93% lower. For the latter system, at the most one quarter of the risk benefit was due to diversification whereas three quarters was due to the yield and quality enhancements of rotated crops.

The risk benefit of the three-year-groundnut-maize-maize system above that of the monocultured maize at Viljoenskroon was only 2%. For this reason, an acceptable estimate of the relative contributions of diversification and rotation is not possible.

The estimated risk benefit of diversification from monocultured maize to a soyabean and maize in a one to two area ratio, is approximately 12% (Viljoenskroon, R600 ha^{-1} target level). Risk for the three-year-soyabean-maize-maize rotation system was 13% less than that for the monocultured maize. Approximately nine tenths of the risk benefit of this cropping system was thus due to diversification and only one tenth due to rotation.

Diversification from monoculture maize to sunflower and maize in a two to one area ratio would reduce risk with an estimated 28% at Viljoenskroon (R600 ha^{-1} target level). Risk for the three-year-sunflower-maize-maize rotation system was

45% less than that for monocultured maize. At least six tenths of the risk benefit was, therefore, due diversification, whereas the remainder was due to rotational effects of this system.

5 DISCUSSION AND CONCLUSIONS

The calculated net returns and risk can only be considered estimates due to the assumptions for maize and wheat that costs of production for monoculture crops or in rotation, are similar. Higher yields associated with rotated crops will increase the per hectare cost of activities such as harvesting. On the other hand, weed and often pest control costs are less on rotated than monocultured crops, which will increase the net return. It is also known that nitrogen fertilization of grain crops can be reduced when grown in rotation with oil and protein rich crops without affecting the yield. The savings on inputs most probably outweigh the extra costs of harvesting higher yields, which suggests that the net returns and risk for the rotation systems are conservative estimates.

Of the rotational crops, drybean and soyabean can be described as dual-purpose crops as net returns were improved and risk was reduced. Groundnut appears to be a crop mainly suitable for increasing the net return of monocropped maize with minimal effect on risk. At both localities, it is evident that sunflower is a crop with an inherent low risk. It also affected the follow-up crops to such an extent that the risk of cropping systems was substantially reduced despite the disaster target level. If the primary aim of crop diversification and rotation is to reduce risk, sunflower appears to be the best-suited crop for this purpose.

In the eastern Free State, yield increases and yield stabilization (and grain quality improvements in the case of wheat), due to crop rotation, were the main contributors towards the lowered risk of crop rotation systems. In the north western Free State, however, one of the advantages of diversification namely, the inclusion of crops with relatively low risk such as soyabean and sunflower, was the main contributor towards the lowering of risk.

ACKNOWLEDGEMENTS

Dr P Theunissen of Computus Bestuursburo (CC) and Mr T Grobbelaar of Senwes (Ltd) are thanked for their willingness to make data on production costs and prices of crops available.

REFERENCES

BINDING HR, VAN SCHALKWYK HD, VAN ZYL J & SARTORIUS VON BACH HJ (1993). Diversification as a risk strategy in times of change: A study in the eastern Orange Free State. *Agrekon* 32(4):182-186.

BOTHA PW, MEIRING JA & VAN SCHALKWYK HD (1999). Quantifying the risk associated with crop rotation systems of an eastern free state trial. *Agrekon* 38(2):229-240.

HARWOOD JL, HEIFNER R, COBLE K, PERRY J & SOMWARU A (1999). *Managing risk in farming: Concepts, research and analysis*. Agricultural Economic Report No 774, Division, Economic Research Service, US Department of Agriculture, Washington, DC.

HELMERS GA, YAMOAH C & VARVEL GE (2001). Separating the impacts of crop diversification and rotations on risk. *Agronomy Journal* 93:1337-1340.

LOUBSER HL & NEL AA (2004). Productivity and stability of grain yield in maize and sorghum as affected by rotational cropping systems in the north western Free State. *South African Journal of Plant and Soil,* 21(2).

NEL AA, PURCHASE JL & BARNARD A (2003). Productivity and stability of grain yield in wheat and maize as affected by rotational cropping systems in the eastern Free State. *South African Journal of Plant and Soil* 20(2):81