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Abstract

An on-farm rainfed rotational trial with maize (PAN 6479), cowpea (Glenda) and sunflower (Agsun 5551) was conducted at Gelukspan, Potchefstroom and Vryhof from 2004/05 to 2008/09. The study assessed six rotation combinations (sole maize, maize-cowpea-maize-cowpea-maize, maize-sunflower-maize-sunflower–maize; cowpea-maize-cowpea-maize-cowpea, sunflower-maize- sunflower-maize- sunflower, sole sunflower) at three fertiliser levels (0, 50 and 100% of the optimum fertiliser rate). Only N and P fertilisers were applied using limestone ammonium nitrate (LAN) and superphosphate, respectively. Soil analyses results indicated adequate levels of potassium (K) at all trial sites. Treatments were arranged as a split-plot design and replicated three times with rotational sequences in the main plots while fertiliser rates comprised the sub-plots. Results showed significant ($P<0.05$) interaction effects for the different rotation systems and fertiliser rates as influenced by the factors of season and locality. Grain yields obtained were marginally higher at optimum fertiliser rates compared to half the rate. Sunflower grain yield obtained from rotation with maize was statistically comparable with that of mono-cropped sunflower but marginally higher in the rotation. The effect of rotational sequence and fertiliser rate had a profound significant effect on maize, sunflower and cowpea grain yields. The rotational system that included cowpea gave variable effects on maize yield at Gelukspan while grain yield was higher when maize was rotated with sunflower at Potchefstroom and Vryhof. The fact that half the recommended fertiliser rate gave comparable grain yields for the three crops evaluated suggests that crop productivity can be improved through moderate fertiliser application compared to prevailing production practice of none or sub-optimal fertiliser use by small-scale farmers.

Keywords

Crop rotation, fertiliser, legume, productivity, small-scale producer

1. INTRODUCTION

Agriculture is conducted in a complex social-ecological system in which, various factors affecting farmer practices and choices have implications for soil fertility and degradation (Musvoto *et al*., 2008) that also dominate human use of land (FAO, 2002). In South Africa, over 80 % of the area is used for agriculture, with 11% utilised for cropping (DEAT, 2006). In the North West Province of South Africa, over 90 % of maize and oil seeds are planted under semi-arid highveld conditions, which are marginal for crop production (Department of Agriculture, 2005). Farmers in this region operate under risky conditions of low and erratic rainfall (often less than 400 mm per annum), which thus decrease crop and animal productivity (Gibson *et al.,* 2005). Several studies have concluded that farmers produce essentially through crop monoculture practices at high input costs and under high incidence of diseases and pests, coupled with a variable market system (Peel, 1998; Omafra Staff, 2002; Nell, 2004; Maine *et al.*, 2005). The predominantly sandy nature of soils in this region further aggravates crop production constraints due to high incidences of wind erosion and leaching losses of nutrients (Lee *et al*., 1989). Yet, many of the farmers do not apply fertilisers and when they do, it is mostly applied at suboptimal levels. This results in low crop and animal productivity and subsequently widespread food insecurity and poor nutrition in many households.

Crop rotation is planting crops of different genus, species or variety than the previous crop on the same field in a planned sequence for two or three years and longer (Peel, 1998). A well planned cropping sequence is commonly conducted in order to improve or maintain soil fertility, reduce erosion, minimise the risk of weather damage, reduce reliance on agricultural chemicals and increase net profits (Liebman & Davis, 2000; Kumbhar *et al*., 2007). Rotational sequences may be done for two or three years or for longer periods to improve soil physical, chemical and biological quality, improve energy conservation and timeliness of land preparation and better water conservation (Rochester *et al*., 2001; Hulugalle & Daniells, 2005). Earlier studies indicated that legumes form an integral part of rotations and are used to increase the available soil nitrogen (Heywood, 1971). The benefits of legumes in cropping systems are well established and indicated that legumes can fix substantial amounts of atmospheric N_2 and convert it to a useable form for plant growth (Peoples & Craswell, 1992; Giller, 2001). Crop rotation can be used to adjust rainfall limitations and moisture needs (Westerdahl *et al.*, 1998) at the same time. Crops seeded or harvested at different times of the year will not be affected in the same manner by cold, drought or hail, thus improve the potential of an income. It provides income diversification; hence, if something happens to reduce profitability of one crop, income is not likely to be adversely affected as if the total farm was planted to one crop only (Westerdahl *et al.*, 1998).

The greatest benefit from crop rotation comes when crops grown in sequence are genetically different species such as forage, grasses, cereals and broadleaf crop species that build up soil structure and increase profit potential (Kumbhar *et al*., 2007). Among the plant nutrients, nitrogen (N) plays a very important role in crop productivity and its deficiency is one of the major yield limiting factors for cereal production (McDonald, 1989; Shah *et al*., 2003). Through widespread monoculture cropping systems, N supplied from the decomposition of organic matter must be supplemented from other sources (Strong *et al*., 1986, Herridge & Doyle, 1988; McDonald, 1992). In most developed countries, adequate N is supplied as chemical fertiliser but in many developing countries including South Africa, this is not possible for most farmers due to high cost of fertilisers, low income per capita, dry spells and limited credit facilities. As a result, farmers either use available organic sources or crop residues as a source of nutrients that result in a failure to obtain targeted yields (Herridge *et al*., 1995).

There are numerous local and international reports on the inclusion of soybean and/or other legume species except cowpea in cropping sequences. For example, Peel (1998) included row crops such as sunflower, pinto bean, maize and soybean while Andriaanse *et al*. (2005) only included soybeans with maize to quantify the effects of soybeans in supplementing the soil with N. However, cowpeas are significant as they fix considerable quantities of N compared to many other legumes (Peoples & Craswell, 1992; Giller, 2001) and at the same time provide a good diet in many homes in South Africa, notably in Limpopo and Mpumalanga provinces. Its nutritious leaves are usually cooked fresh and eaten with porridge whilst green pods are either cooked fresh or eaten as snack or dried and trashed to make up soup during cold conditions. In Southern Africa, cowpea is primarily planted for fodder, for grain production, green manure and as cover or anti-erosion crop (Aveling, 2003). Crop rotation practices are less adopted in smallholder farming systems as they require additional planning and management skills, thus, increasing the complexity of farming. A well-planned crop rotation system that includes a legume crop will not only contribute to replenishing soil nutrients but also to reduce the demand for chemical fertilisers (Nevens & Reheul, 2001; Aveling, 2003). It will also help break the cycle of disease and pest build-up in the soil. Availability of and access to diverse and nutrient-rich foods to both human and animals will be enhanced and guaranteed while the living condition of people is improved. The goals of this study were

(i) to promote the adoption of crop rotation techniques by small-scale farmers and (ii) to replenish soil nutrients by the inclusion of a legume in their crop production system.

2. MATERIALS AND METHODS

2.1 Characterisation of trial sites and the details of treatments evaluated

A five-year on-farm rainfed rotation trial was carried out on two communal areas at Gelukspan (Bapong) and Vryhof (Tsunyane) situated approximately 40 and 30 km away from Mafikeng and at ARC-Grain Crops Institute farm at Potchefstroom. The sites represented different soil and climatic characteristics (Table 1). The trial at Potchefstroom was only initiated during the 2005/06 season for the purpose of having another locality with better production management practices as a check site. Crops included in the rotational sequence consisted of maize, sunflower and cowpea. The trials furthermore contained six crop rotation sequences (Table 2) evaluated at three fertiliser rates (0, 50 and 100% of the optimum fertiliser rate).

The crop rotation and fertiliser treatments were laid out as a split-plot arrangement and replicated three times. The various rotational sequences were assigned as main plots while fertiliser rates represented the sub-plots. Treatments were planted in 1.5 m row widths, 10 m long and each constituted of six rows giving the size of the main plot and subplot a total area of 270 m^2 and 90 m^2, respectively. The maize hybrid PAN 6479 was planted at 15 000 plants ha^{-1}, cowpea (Glenda) at 100 000 plants ha^{-1} and sunflower (AG Sun 5551) at 35 000 plants ha^{-1} using a calibrated Gaspardo three row planter. Seeds were planted at soil depths of 2 - 5, 3 - 7 and 5 -7 cm for sunflower, cowpea and maize, respectively. Only nitrogen (N) and phosphorus (P) fertilisers were applied using Limestone Ammonium Nitrate (LAN) and superphosphate, respectively. The pre-planting surface (0-20cm soil depth) soil test resulted in 293, 205 and 163 mg K kg^{-1} at Gelukspan, Potchefstroom and Vryhof indicating sufficient levels of potassium that was, therefore, excluded in the fertilisation program. All the phosphorus and 30% of the nitrogen were applied during planting while the remaining 70% nitrogen was applied as top dressing four weeks after emergence. Vaalburg dolomite lime was applied at the rate of 2 t ha^{-1} at Vryhof in order to raise the soil pH level. Table 3 shows a summary of the fertilisation regimes applied at the sites for the different crops.

Table 1 Climate and soil characteristics at Gelukspan, Potchefstroom and Vryhof during the five-year rotational study.

Characteristics	**Gelukspan**	**Potchefstroom**	**Vryhof**
Climatic			
Latitude	26.23N	26.74N	26.56N
Longitude	26.23E	27.08E	25.09E
Altitude (m)	1489	1349	1367
Ave. rainfall (mm)	427.5	622.4	376.8
Ave. min.Temperature (°C)	10.8	10.1	11.2
Ave. max.Temperature (°C)	25.8	25.9	26.3
Soils			
Clay (%)	13.4	33.1	10.9
Sand (%)	81.7	50.4	83.0
Silt (%)	4.9	16.5	6.1
Textural class	Sandy loam	Sandy clay loam	Loamy sand
Bulk density (g/cm^3)	1.55	1.35	1.58
pH (KCl)	4.98	6.35	4.22
N (mg kg^{-1})	1.97	4.88	2.09
P (mg kg^{-1})	4.0	31.9	3.0
K (mg kg^{-1})	293	205	163
Ca (mg kg^{-1})	385	1591	313
Mg (mg kg^{-1})	95	566	81
Na (mg kg^{-1})	8	23	10
Zinc (mg kg^{-1})	2.8	6.0	3.2

Table 2 Summary of the crop rotation combinations used in the study

Rotational sequence	**2004/05**	**2005/06**	**2006/07**	**2007/08**	**2008/09**
1. M-M-M-M-M	Maize	Maize	Maize	Maize	Maize
2. M-C-M-C-M	Maize	Cowpea	Maize	Cowpea	Maize
3. M-S-M-S-M	Maize	Sunflower	Maize	Sunflower	Maize
4. C-M-C-M-C	Cowpea	Maize	Cowpea	Maize	Cowpea
5. S-M-S-M-S	Sunflower	Maize	Sunflower	Maize	Sunflower
6. S-S-S-S-S	Sunflower	Sunflower	Sunflower	Sunflower	Sunflower

Table 3 Details of the optimum fertilisation rates at the three trial sites

Mean optimum fertiliser application levels (kg ha^{-1})					
Gelukspan		**Potchefstroom**		**Vryhof**	
N	P	N	P	N	P
79.0	73.7	80.0	43.5	86.0	74.1

2.2 Crop husbandry

Thinning for the various crops was conducted at four weeks after plant emergence to obtain the targeted plant population. Regular manual weeding was done using hand hoes to keep the trials weed-free. Kombat granules were applied for stalkborer control.

2.3 Data collection

Harvesting was done manually at all trial sites for all crops. Grain yield was determined in the four middle rows within an area of 48m^2. Maize cobs and sunflower heads were threshed using a Ransomes sims & Jefferies thresher while cowpea pods were threshed by hand. Maize kernel moisture was determined with a 100 g sample in a Steinlite Electronic Moisture Tester and final grain yield adjusted to the standard moisture content of 12.5%.

2.4 Data analyses

Grain yield results of all crops were subjected to analysis of variance using Statistix version 8.1. Differences among treatment means were separated using the Tukey HSD test with significance level set at 5% probability.

3. RESULTS AND DISCUSSION

3.1 Effect of the relationship of rotation sequence and fertiliser amendment on maize productivity

Various interaction combinations revealed statistical significant differences on maize productivity (Table 4).

Table 4 Variance ratio of tested differences between seasons, localities, crop rotation effects and fertiliser rates on maize grain yield

Factors	**Grain yield**
Season (S)	64.1***
Locality (L)	25.4***
Rotation (R)	171^{ns}
Fertiliser rate (F)	532^{ns}
SxL	27.2***
SxR	29.3*
SxF	26.6*
LxR	85.9***
LxF	132*
RxF	42.0*
SxLxR	220^{ns}
SxRxF	225^{ns}
LxRxF	42.1*
SxLxRxF	316^{ns}

ns = not significant; * = significant at P = 0.05; ** = significant at P = 0.01; *** = significant at P = 0.001

3.1.1 Effect of season and locality on maize grain yield

Maize grain yield obtained during the 2008/09 season at Potchefstroom was significantly higher compared to all the other seasons and localities (Figure 1). Grain yield obtained over the seasons at Potchefstroom generally improved and was significantly higher compared to that obtained at Gelukspan and Vryhof. Significantly higher grain yields at Potchefstroom can be associated with better production practices as well as the recurring fertiliser application over years relative to those practices at Gelukspan and Vryhof. Diepen and Van der Wall (1996) showed that there are variable abiotic factors that influence crop yields and these are soil water, soil fertility, soil texture, soil depth and farm management (soil tillage, planting density and sowing date) as well as crop protection against pests and diseases. Grain yields obtained at Gelukspan and Vryhof significantly improved over the years, despite significant yield reduction in the 2005/06 season. This significant depressive effect can be attributed to late rains and dry spells which consequently delayed the sowing date and which in turn might have possibly delayed growth, resulting in reduced crop yield and grain quality. Kumar (1998) indicated that planting dates significantly affect crop yield, thus a crop planted early or late due to the occurrence of drought and the spatial and temporary anomalies in temperature and precipitation may not reach its potential yield.

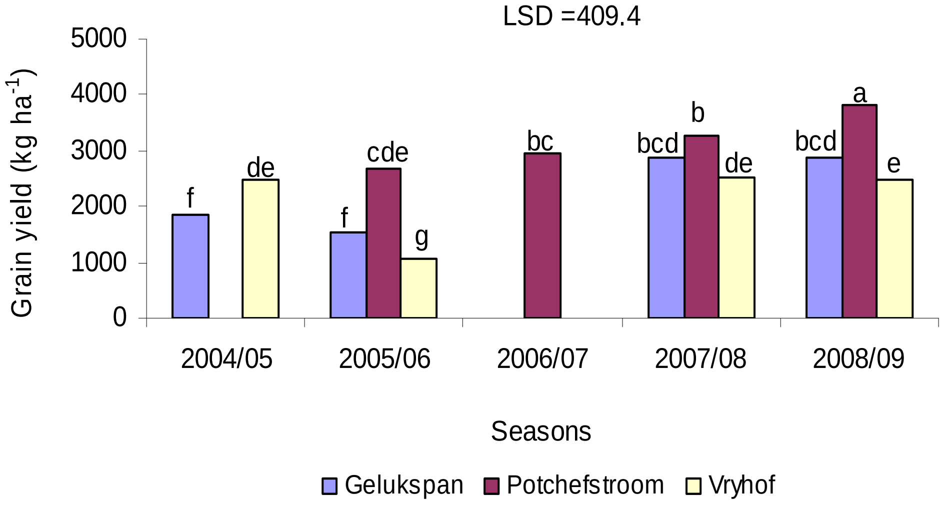

Figure 1 Interaction effects of seasons and locality on maize grain yield during the five-year rotational study (omitted bars indicate crop failure). Different letters indicate significant differences.

3.1.2 Effect of the relationship of season and rotational sequence

The influence of the various seasons showed a profound significant effect on maize grain yield. However, differences were observed only when the various rotational sequences were compared across seasons (Table 4 and Figure 2). Maize grain yield obtained from the variable rotational sequences were comparable during the 2007/08 and 2008/09 seasons, besides it was marginally higher by an average of 3.5 and 8% in both seasons when maize was rotated with sunflower compared to maize in rotation with cowpea and monocrop maize (Figure 2). Sauerborn *et al.* (2000) showed that lowest grain yields of maize and sorghum were obtained when these cereals followed monoculture plantings of the same crop. Marginal grain yield decreases obtained when maize was in rotation with cowpea might be attributed to low cowpea yields obtained across the study sites, possibly because of the prevalent diseases and pests that infested cowpeas since no insecticides were applied. Akande (2009) showed that cowpea is most susceptible to a wide range of insect and pathogen attacks of which the importance vary with ecological zones.

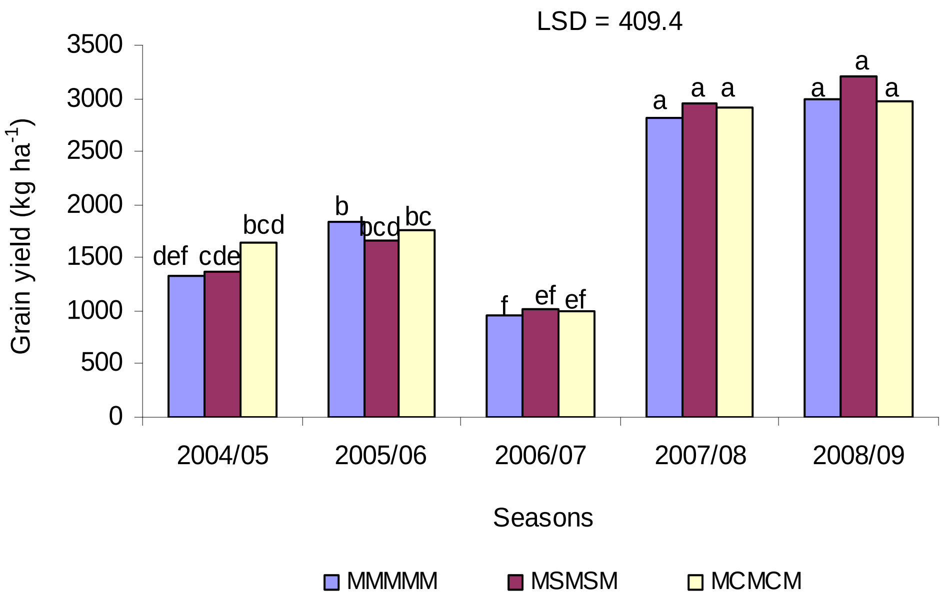

Figure 2 Season x rotational sequence interaction effects on maize grain yield during the five-year rotational study. Different letters indicate significant differences.

3.1.3 Effect on the interaction of season and fertiliser rate

The different seasons had a significant influence on the performance of maize yield at the different fertiliser rates (Table 4 and Figure 3). Grain yield obtained across the variable fertiliser rates were comparable during the 2007/08 and 2008/09 seasons and grain yield marginally decreased by approximately 10% in 2007/08 when fertiliser rates were halved compared to the optimum rate (Figure 3). The efficiency of the different fertiliser rates gradually improved grain yield of maize over the seasons, despite a significant decrease in the 2006/07 season. The condition of drought effect on crop yields is well documented (Boken *et al*., 2005).

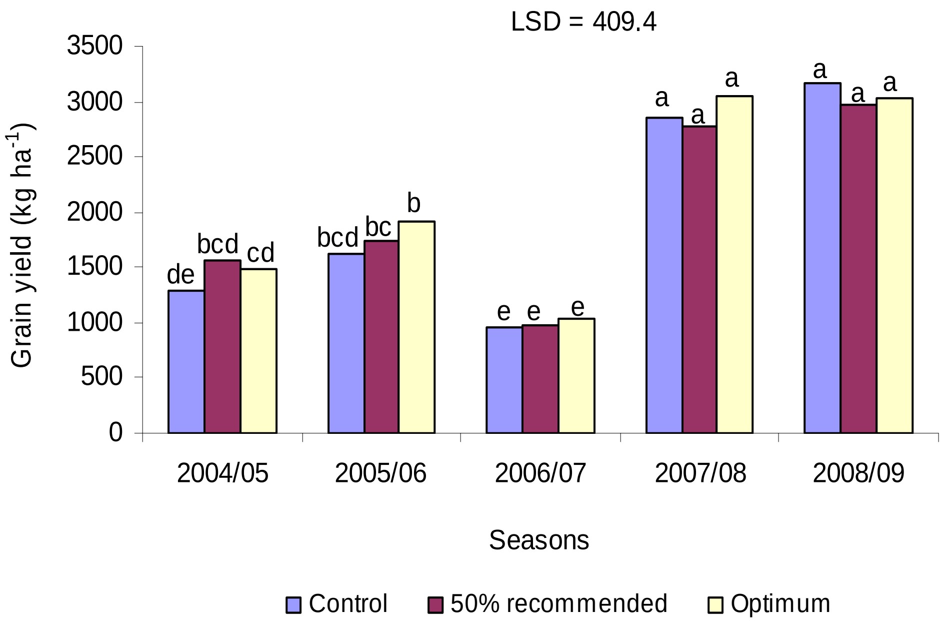

Figure 3 Season x fertiliser interaction effect on maize grain yield during the five-year rotational study. Different letters indicate significant differences.

3.1.4 Effect of the interaction of locality and rotational sequence

As presented in Table 4, the effect of locality had a significant influence on maize grain yields obtained under different rotations. Grain yield obtained at Gelukspan, when maize was in rotation with cowpea, was significantly higher compared to that of maize monocrop but was comparable to yield obtained when maize was rotated with sunflower. Several studies documented higher cereal grain yields in crop sequences which included leguminous crops as a preceding crop (Ghosh *et al*., 2000; Rusu *et al*., 2001; USDA, 2000). Similarly, Anderson (1998) showed that barley yields increased when barley followed soybean or faba bean rather than barley. Grain yields obtained at Potchefstroom were significantly better irrespective of a rotational sequence and they increased by an average of 7.5% when maize was rotated with sunflower compared to either mono-crop maize or maize in rotation with cowpea (Figure 4). At Potchefstroom a depressive effect occurred when maize was in rotation with cowpea and might be attributed to significant quantities of soil nutrient reserves due to recurring fertiliser application over years. Peoples *et al*. (1995) indicated that application rate of fertiliser N to legumes is relatively low compared to cereals, besides, even relatively low levels of nitrate in soil reserves is capable of affecting the biological nitrogen fixation process.

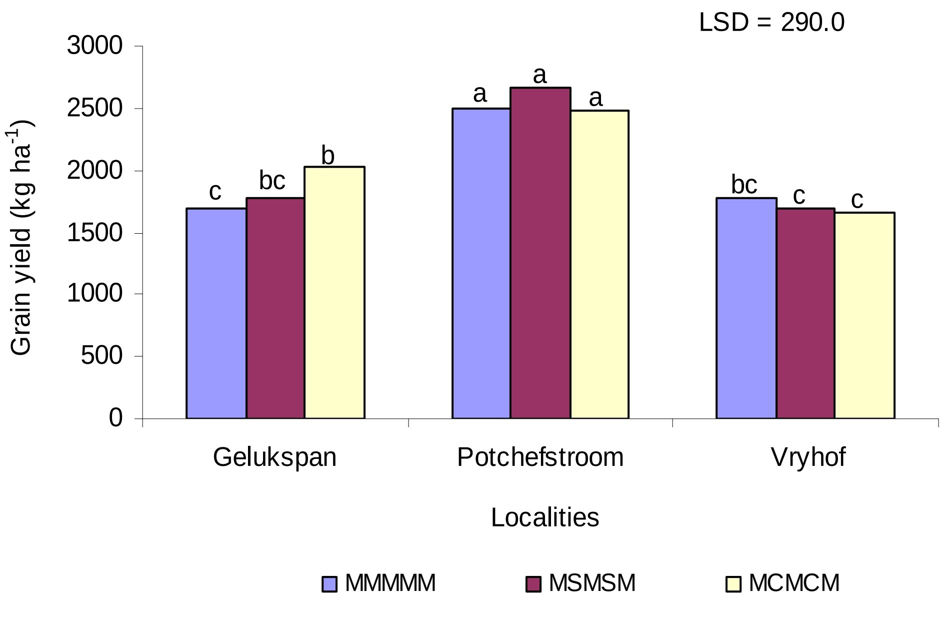

Figure 4 Locality x rotational sequence interaction effect on maize grain yield during the five-year rotational study. Different letters indicate significant differences.

3.1.5 Effect of the interaction of locality and fertiliser rate

As shown in Table 4 and Figure 5, maize grain yield varied significantly across localities through the effect of the different fertiliser levels. Grain yield obtained at Potchefstroom was significantly higher irrespective of the fertiliser rate compared to that at Gelukspan and Vryhof (Figure 5). At Potchefstroom, maize grain yield obtained with optimum fertiliser rate marginally increased by approximately 5.5 and 6.2% compared to unfertilised and when fertiliser rate was halved. Similar responses were obtained at Gelukspan and Vryhof. Comparable grain yields obtained from the control at Potchefstroom can be attributed to the considerable quantities of soil nutrients available as a result of recurring fertiliser amendment over years.

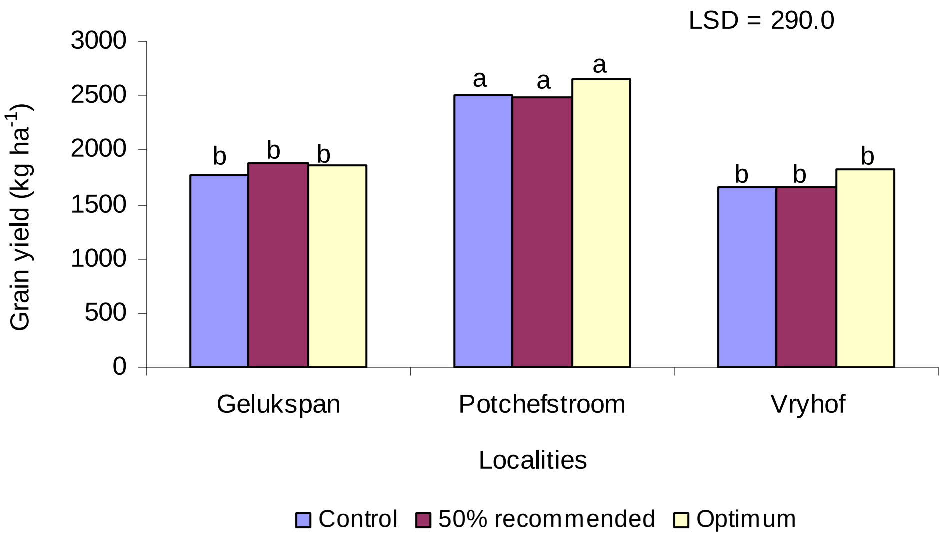

Figure 5 Locality x fertiliser rate interaction effects on maize grain yield during the five-year rotational study. Different letters indicate significant differences.

3.1.6 Effect of the interaction of rotational sequence and fertiliser rate

The variable fertiliser rate showed a profound positive effect on maize yield across the rotational sequences (Table 4 and Figure 6). Grain yield obtained when maize was rotated with cowpea and fertilised at 100% optimum rate was significantly higher compared to yields obtained from unfertilised plots (Figure 6). Ofori and Stern (1986) reported that intercrop cereal yields increased steadily with N application while legume seed yield either showed depressive effects or responded less.

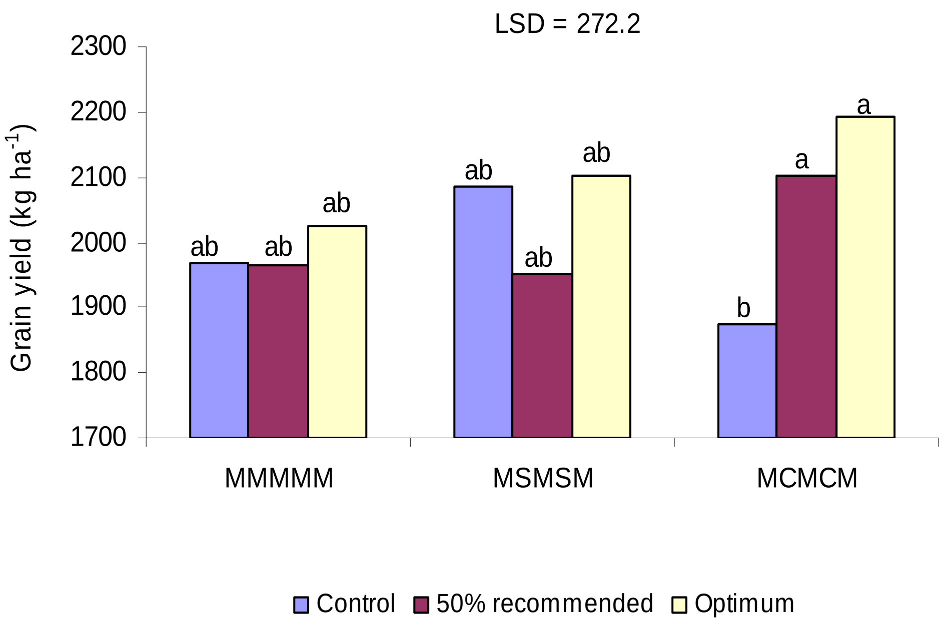

Figure 5 Rotational sequence x fertiliser rate interaction effect on maize grain yield during the five-year rotational study. Different letters indicate significant differences.

3.2 Effect of crop rotation and fertiliser application on sunflower performance

The various interaction combinations had a significant effect on sunflower grain yield (Table 5). Sunflower grain yield generally improved over the seasons, except that staggered yields were observed during the 2006/07 season, possibly due to adverse dry spells during that season. Very low yields during the 2004/05 season were attributed to bird damage and for that reason no results were obtained at Vryhof.

Table 5 Variance ratios for testing differences of seasons, localities, crop rotation and fertiliser rates on sunflower grain yield

Factors	Grain yield
Season (S)	2.25***
Locality (L)	665***
Rotation (R)	910^{ns}
Fertiliser rate (F)	224*
SxL	247***
SxR	140*
SxF	315*
LxR	244*
LxF	142*
RxF	350*
SxLxR	658^{ns}
SxLxF	426^{ns}
SxRxF	733^{ns}
LxRxF	114^{ns}
SxLxRxF	967^{ns}

ns = not significant; * = significant at P = 0.05; ** = significant at P = 0.01; *** = significant at P = 0.001

3.2.1 Effect of the interaction of season and locality

The effect of season showed a profound effect on the performance of sunflower grain yield across localities during the study period (Figure 6). Grain yield observed at Vryhof during the 2007/08 season was significantly reduced compared to that obtained at Gelukspan, but comparable to grain yield obtained at Potchefstroom. At Gelukspan during the 2008/09 season, significantly higher sunflower grain yield was observed amongst all the other localities (Figure 6). Reduced sunflower grain yield obtained at Potchefstroom and Vryhof can be associated with the soil textural classes and soil bulk density (Table 2) which to some extent were compacted. Cass (1999) showed that bulk density plays an important part in plant growth and development and depending on soil texture root penetration is usually restricted by high soil bulk densities.

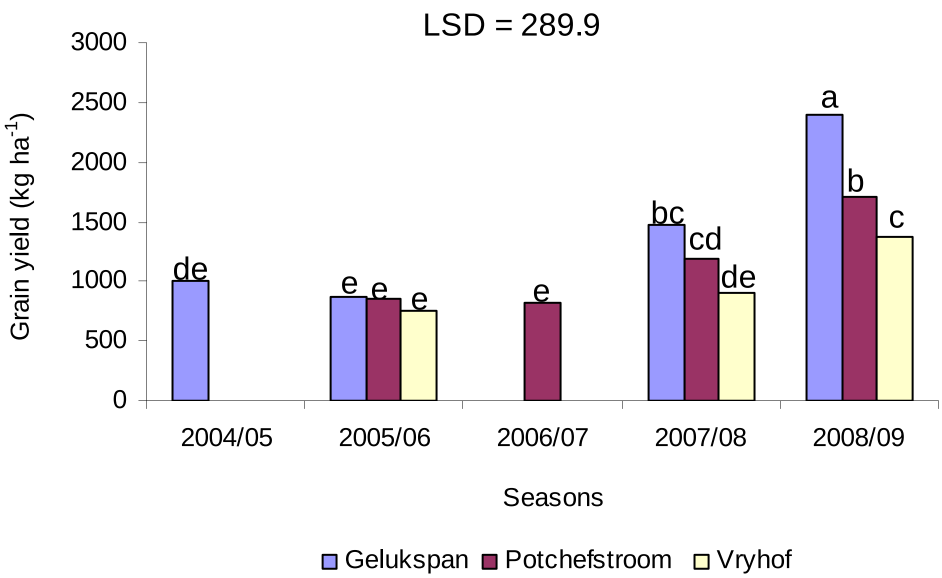

Figure 6 Interaction effects of seasons and locality on sunflower grain yield during the five-year rotational study. Different letters indicate significant differences.

3.2.2 Effect of the interaction of season and rotation sequence

The effect of the different rotational sequences on sunflower grain yield, as influenced by the different seasons, was significant despite that the effect of the rotational sequences was comparable during each season (Figure 7). In the 2008/09 season, yields obtained when sunflower was in rotation with maize were marginally (4.2%) higher compared to mono-crop sunflower (Figure 7). However, sunflower grain yields obtained in 2008/09, irrespective of rotation, were significantly better compared to other seasons (Figure 7).

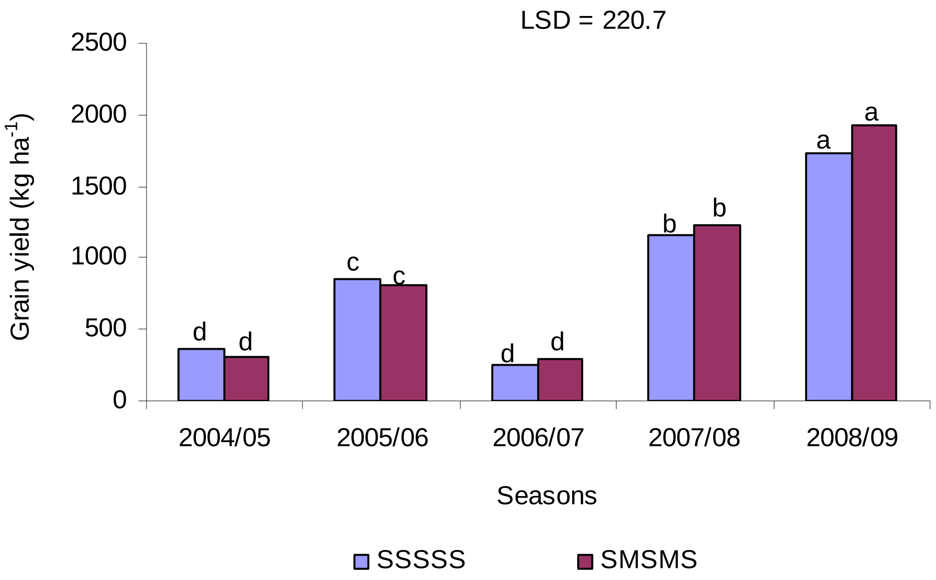

Figure 7 Influence of season and rotation on sunflower grain yield during the five-year rotational study. Different letters indicate significant differences.

3.2.3 Effect of the interaction of season and fertiliser rate

Grain yield generally improved over seasons, despite a significant reduction reported in the 2006/07 season. The trend of fertiliser rate on sunflower grain yield was significantly affected by the various seasons (Table 5). In the 2007/08 season, grain yields obtained from unfertilised plots and where fertilisers were halved were significantly lower relatively to those at optimum rate (Figure 8). Schatz *et al*. (1999) showed that in a wheat - sunflower - barley rotation, sunflower yield increased slightly with increases in fertilisation (low, medium and optimum), but differences were not statistically significant. Yields obtained in the 2008/09 season at 50% and optimum recommended rates showed comparable results, however, marginally higher at 50% rate but were significantly higher than unfertilised plots (Figure 8).

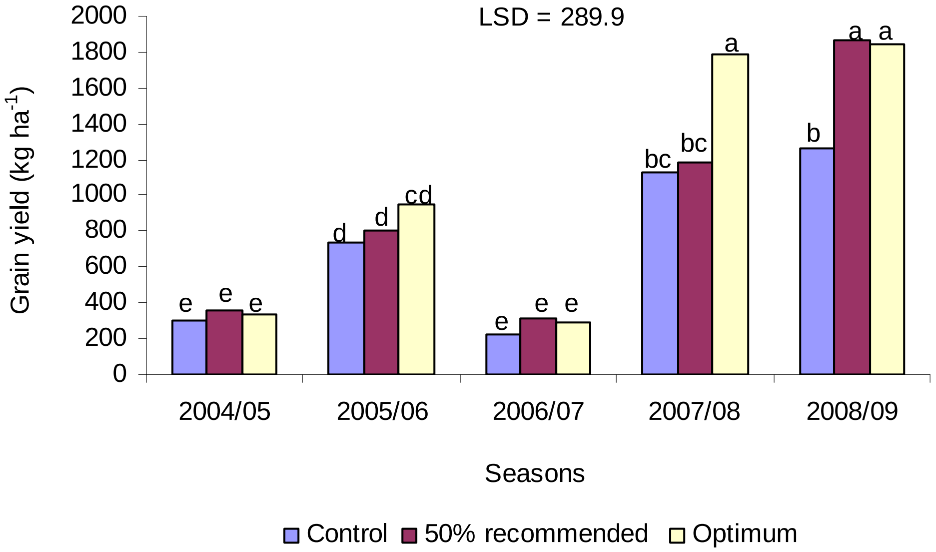

Figure 8 Influence of season and fertiliser rate on sunflower grain yield during the 5-year rotational study. Different letters indicate significant differences.

3.2.4 Influence of the interaction of locality and rotational sequence

There was a significant locality x rotation sequence interaction effect on sunflower grain yield (Table 5). At Gelukspan and Potchefstroom grain yields obtained within the individual localities were comparable for both rotations, despite being marginally higher when sunflower was in rotation with maize compared to sole sunflower (Figure 9). Yields obtained at Gelukspan were significantly higher than those at Potchefstroom and Vryhof, irrespective of rotational sequence (Figure 9).

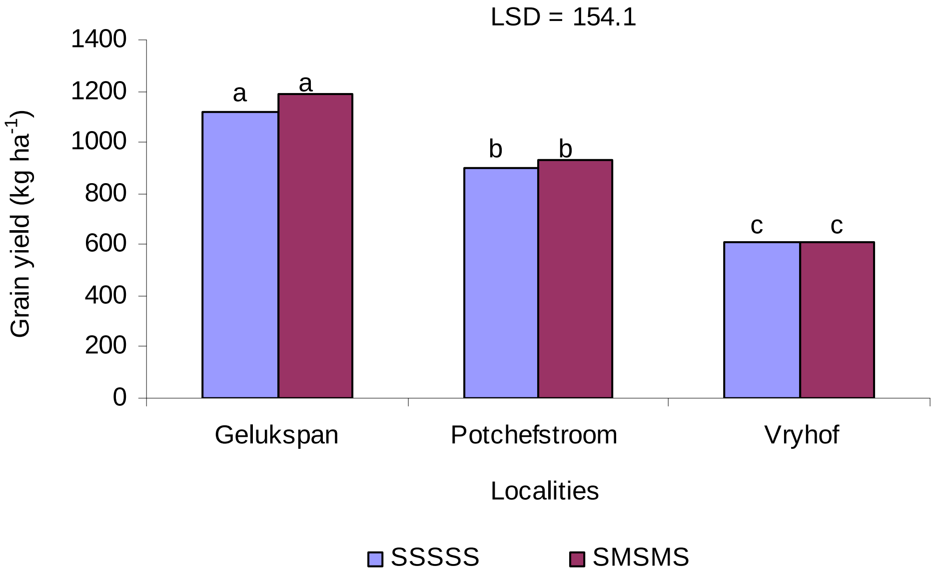

Figure 9 Effect of locality and rotation on sunflower grain yield during the five-year rotational study. Different letters indicate significant differences.

3.2.5 Effect of the interaction of locality and fertiliser rate

The effect of fertiliser rate on sunflower grain yield varied significantly across the study sites. Sunflower grain yields obtained at Vryhof showed depressive effects and were significantly lower compared to those produced at Gelukspan and Potchefstroom, irrespective of the fertiliser rate. Yields obtained at Gelukspan and Potchefstroom were comparable but marginally higher at Gelukspan across the fertiliser rates (Figure 10).

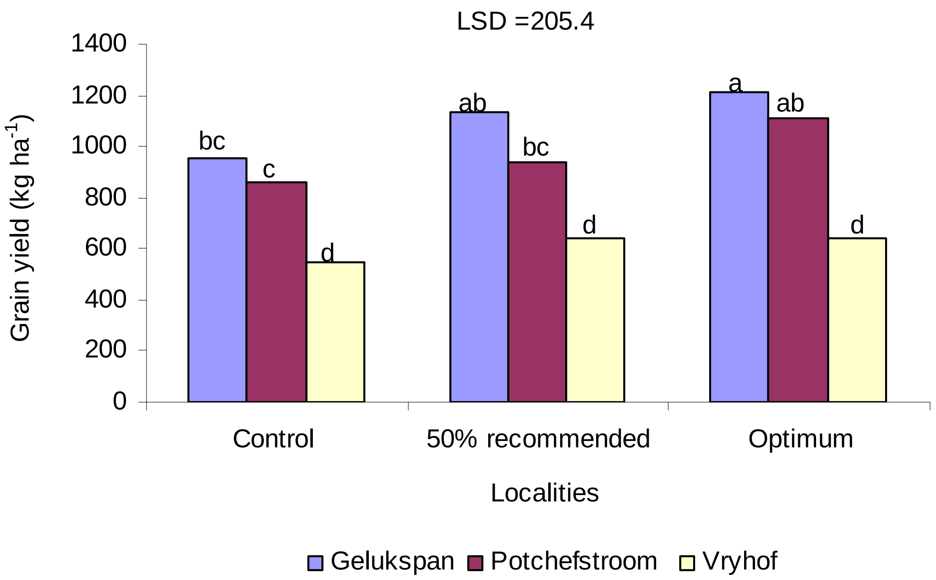

Figure 10 Effect of locality and fertiliser rate on sunflower grain yield during the five-year rotational study. Different letters indicate significant differences.

3.3 Effect of fertiliser application and rotational sequence on cowpea performance

There were significant interaction combinations over season, locality and fertiliser rate as well as the main effects of season and locality on cowpea grain yield (Table 6).

Table 6 Variance ratio of testing differences of season, locality and fertiliser rates on cowpea grain yield.

Factors	**Cowpea grain yield**
Season (S)	52.9***
Locality (L)	1207***
Fertiliser rate (F)	690^{ns}
SxL	105***
SxF	93.3*
LxF	106*
SxLxF	232^{ns}

ns = not significant; * = significant at P = 0.05; ** = significant at P = 0.01; *** = significant at P = 0.001

3.3.1 Effect of the interaction of season x locality

Response of cowpea grain yield in various localities varied significantly over the study seasons. In the 2005/06 season, cowpea yields obtained at Gelukspan were significantly higher compared to those obtained at Potchefstroom and Vryhof (Figure 11). Similar results were observed in the 2007/08 season. Cowpea yields at all study sites generally improved over the seasons, possibly due to the soil nutrient reserves building up through variable cropping sequence and fertiliser rates (Peoples *et al*., 1995). The generally low cowpea grain yields obtained across localities could be associated with the cowpea variety used in the study and/or insect damage due to lack of pest control measures. Akande (2009) reported that cowpea is most susceptible to a wide range of insect and pathogen attacks.

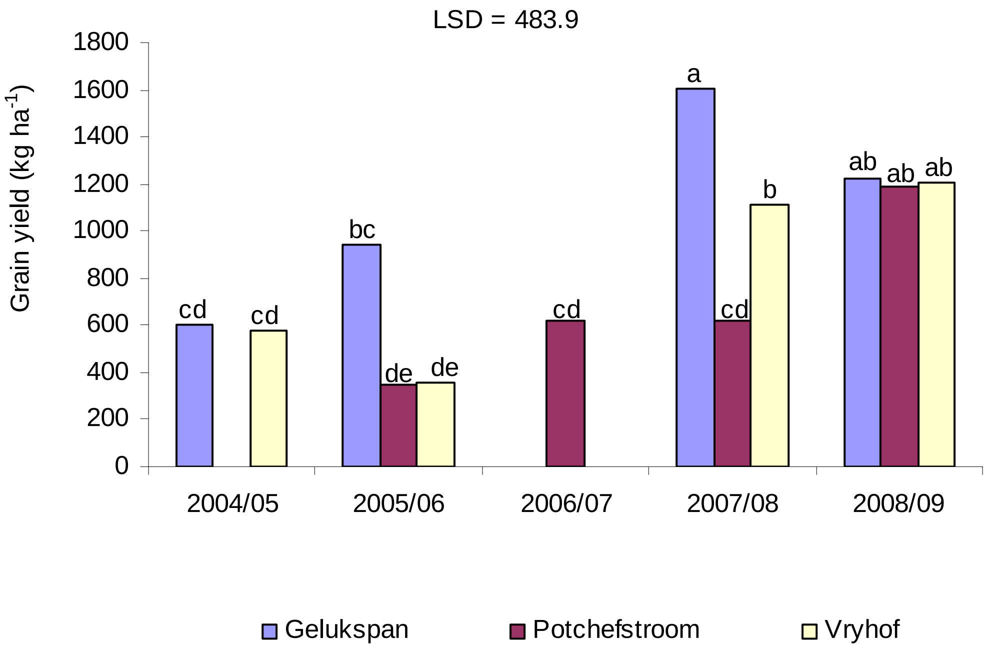

Figure 11 Interaction effects of season x locality on cowpea grain yield during the five-year rotational study. Different letters indicate significant differences.

3.3.2 Effect of the interaction of season x fertiliser rate

The effect of fertiliser rate on cowpea grain yield was significantly influenced by the seasons (Table 6). However, the effects of the various fertiliser rates obtained for the individual seasons were comparable, but differed significantly when compared across seasons (Figure 12). Grain yield response was, however, higher where plots received 50 and 100% recommended rates compared to unfertilised plots, although yields were marginally higher where fertilisers were halved compared to that obtained from the optimum rate. Cowpea yields during the various seasons improved irrespective of fertiliser rate except for a significant decline in yields during the 2006/07 season which can be attributed to severe dry spells (Boken *et al*., 2005).

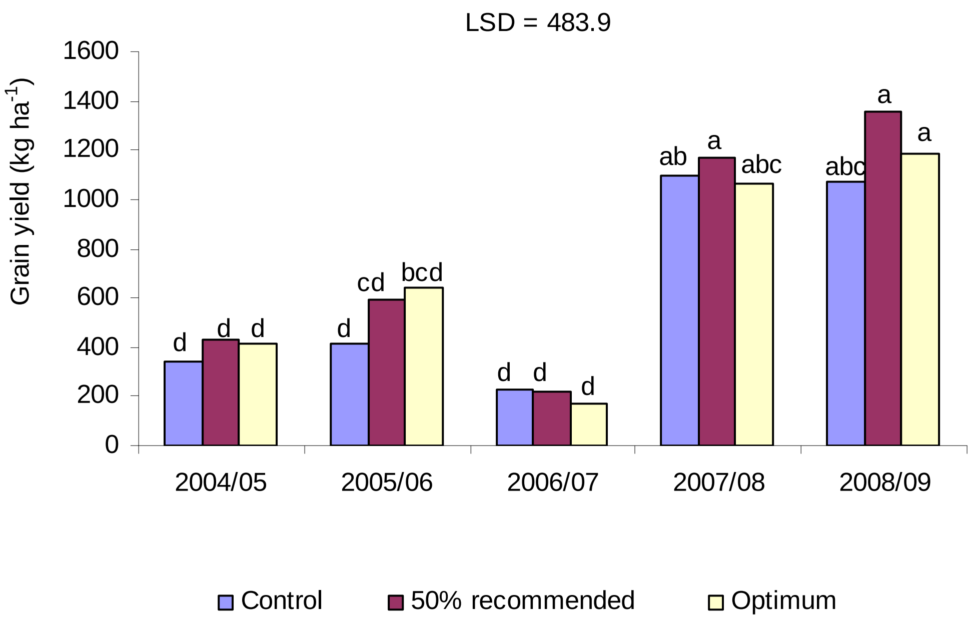

Figure 12 Interaction effects of season x fertiliser rate on cowpea grain yield during the five-year rotational study. Different letters indicate significant differences.

3.3.3 Effect of the interaction of locality x fertiliser rate

Locality showed a significant effect on the effect of fertiliser on cowpea grain yield. However, differences were observed only when the various fertiliser rates were compared across localities (Table 6). Cowpea grain yields where fertiliser rates were halved and optimum rate used at Gelukspan were higher by approximately 14 and 20% while they increased by 3 and 7% at Vryhof compared to unfertilised plots. Half and optimum fertiliser rates at Potchefstroom showed depressive effects on cowpea grain yield and yields decreased by 25 and 32%, respectively, compared to unfertilised plots (Figure 13). This trend might be attributed to the residual soil nutrient reserves that might have negatively influenced the biological nitrogen fixation process (BNF). Several studies indicated that small amounts of fertiliser stimulate growth and BNF in some cases and that the use of starter N can negatively affect BNF in other areas (Becker *et al*., 1991; Peoples *et al*., 1995).

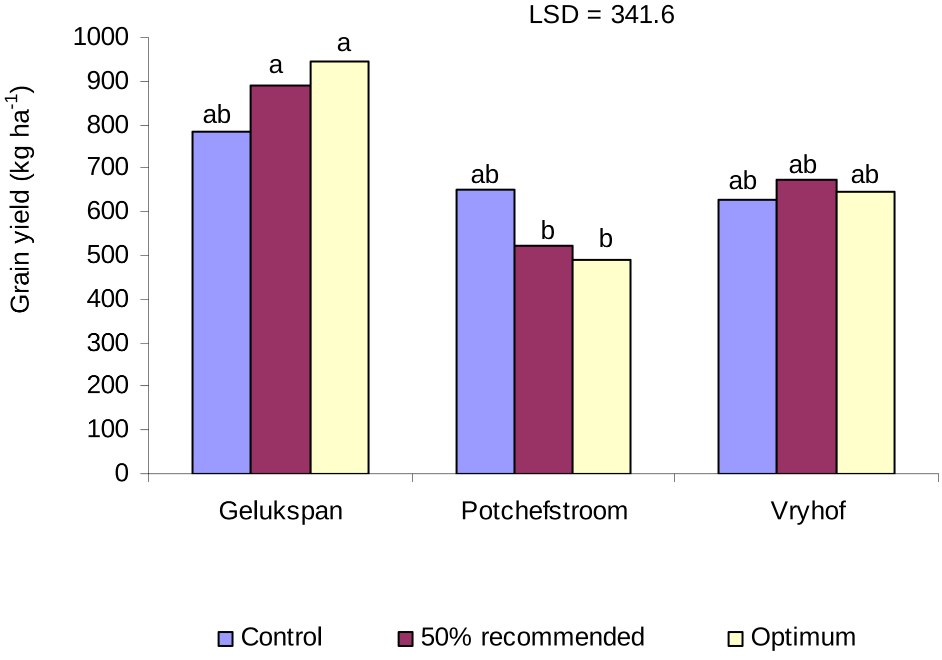

Figure 13 Locality x fertiliser rate interaction effects on cowpea grain yield during the five-year rotational study. Different letters indicate significant differences.

4. CONCLUSIONS

Rotational sequence and fertiliser rates had significant effects on maize, sunflower and cowpea grain yields. This study demonstrated that crop rotational sequences improved maize grain yield compared to mono-crop maize. However, the trend will depend on the type of crop included in the rotation. The results suggest that rotational systems that included cowpea will mostly be appropriate to increase maize yield on soils that are sandy loam. A rotational program that includes sunflower will improve grain yield on soils that are of clay loam characteristics. Depressive effects on cowpea growth and phenological development will ultimately reduce its N fixing potential and subsequently the performance of the preceding cereal crop. Grain yields were comparable when fertiliser rates were halved compared to optimum rates for the three crops evaluated. These results suggest that small-scale farmer's crop productivity can be improved through moderate fertiliser application and rotating crops than applying higher fertiliser rates or no application. Planting of small hectares of sunflower would also require protection against bird damage.

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