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# Investigation of agronomic factors constraining productivity of grain maize (*Zea mays* L.) at Zanyokwe irrigation scheme, Eastern Cape, South Africa

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**ABSTRACT**
*Objective:* The underperformance of many smallholder irrigation schemes in South Africa is largely attributed to socio-economic constraints, but little attention has been paid to the relationship between farmer agronomic practices and crop productivity. Two on-farm trials were therefore carried out at Zanyokwe irrigation scheme (ZIS) to: (i) evaluate the relationship between cultivar, nitrogen (N) rate, plant population and planting time on maize grain yield (Experiment 1); and (ii) compare grain yields of new hybrids to cultivars commonly grown by farmers (Experiment 2).
*Methodology and results:* The treatments for experiment 1 were maize cultivars (PAN6777 and DKC61-25), N rate (60 and 250 kg N $ha^{-1}$), plant population (40 000 and 90 000 plants $ha^{-1}$) and planting time (early: within the first 28 days of beginning of season on 15 November or late: planting after 15 December). In Experiment 2, eight cultivars were compared; two popularly grown by farmers at ZIS and two each from the three maturity classes (early, medium and late), which were top performers in regional variety trials conducted by the ARC from 2002 to 2004. Regardless of cultivar, higher yields were obtained when maize was planted early and fertilised at 250 kg N $ha^{-1}$. The short-season cultivar DKC61-25 yielded optimally when grown early at 90 000 plants $ha^{-1}$ whilst the long-season cultivar PAN777 performed better at 40 000 plants $ha^{-1}$. Generally, N rate and planting time had the most significant effects on yield. New hybrids yielded 50 to 65% more than the cultivars commonly grown by farmers.
*Conclusion and application of findings:* These preliminary results suggest that lack of viability of smallholder irrigation schemes in South Africa is partly a result of inappropriate agronomic practices for irrigated crop production by farmers. It is recommended that more focused research be designed to address the problems of planting time, fertility, and cultivar selection and population management in ZIS. Training programs on basic management practices such as cultivar selection for irrigated crop production by the Department of Agriculture are expected to benefit farmers as part of the ongoing revitalization of smallholder irrigation schemes in the province.

**Key words:** Maize, grain yield, agronomic constraints, research agenda

## INTRODUCTION
Smallholder irrigation schemes (SIS) in South Africa (SA) were introduced with the primary goal of increasing crop production so as to improve and sustain rural livelihoods in the former homelands

(FAO, 2001). However, a number of studies have noted problems of generally low crop productivity for both grain and vegetable crops in many SIS established in the 1980s (de Lange, 1994; Backeberg *et a*l., 1996; van Averbeke *et al*., 1998; Bembridge, 2000; Crosby *et al*., 2000; Oosthuizen, 2002; Machethe *et al*., 2004; Fanadzo, 2007). This underperformance has been largely attributed to socio-economic constraints, but little attention has been paid to farmer agronomic practices, which might also contribute to the poor performance.

Maize (*Zea mays* L.) is the most important summer grain crop in terms of cultivated area and number of growers in South African SIS. It is one of the most efficient grain crops in terms of water utilization (Department of Agriculture, 2003), and, depending on cultivar, grain yields of up to 12 tonnes ha$^{-1}$ are possible in SA under irrigation (USDA, 2003; du Plessis & Bruwer, 2004). However, grain yields of less than 3 t ha$^{-1}$ are common in SIS in SA (Bembridge, 1996; van Averbeke *et al*., 1998; Bembridge, 2000; Machethe *et al*., 2004; Fanadzo, 2007). For example, in Zanyokwe irrigation scheme (ZIS) in the Eastern Cape, the average grain yield achieved by farmers in 2007 was 1.8 t ha$^{-1}$ (Fanadzo, 2007).

In the study of ZIS by Monde *et al*. (2005), farmers attributed low productivity of maize to three main factors: lack of finance to purchase inputs, shortage of tractors, and dilapidated irrigation infrastructure. In spite of the many problems noted by farmers, the question is whether maize productivity in the scheme could be higher than it is currently. The evidence available from the situation analysis (Monde *et al*., 2005) would seem to suggest that productivity could be higher with changes in the agronomic management of the crop. Causes of low grain maize productivity identified using problem tree analysis were poor weed, fertiliser and water management, late planting and low population densities among other factors. Surprisingly, these differ from farmer perceptions as none of these factors was acknowledged by farmers as contributing to low productivity.

Maize grain yields are known to be influenced by a number of factors, including soil fertility, growing season conditions, moisture status, planting time and cultivar grown (Sangoi, 2000; NSW Grains Report, 2004). However, the impact of each of these factors on productivity is not clearly established to allow priority setting in establishing a research agenda in SIS in SA. Available literature is also not specific in detailing practices and relating these to productivity levels in SIS in SA. It is also difficult to unravel the complexity of low productivity through farmer interviews.

Maize is the agronomic species that is most sensitive to variations in plant density such that for each production system there is a population that maximises grain yield (Sangoi, 2000). The situation analysis at ZIS indicated that farmers planted their maize at a target plant population of about 40 000 plants ha$^{-1}$ regardless of cultivar, planting time and other management factors. The optimum maize planting season in the study area is mid-November to mid-December. However, farmers were observed to plant their maize until as late as mid-March. The tendency to grow all maize at a constant and low plant population of 40 000 plants ha$^{-1}$ might have compromised yields since the recommendation for irrigated maize in SA is to plant at 45 000 to 65 000 plants ha$^{-1}$ for medium to long-season cultivars and 80 000 to 90 000 plants ha$^{-1}$ for ultra-short cultivars to achieve optimum yields (Department of Agriculture, 2003).

For irrigation to be profitable, yields must be high and higher yields mean greater nutrient uptake by crops, since nutrient uptake is roughly proportional to crop yield (Crosby *et al*., 2000). The recommended fertiliser rates for irrigated maize vary depending on yield potential, but can be as high as 220 kg N ha$^{-1}$ for a yield target of 10 t ha$^{-1}$ in SA (FSSA, 2007). However, the situation analysis at ZIS indicated that the average N rate used by farmers was 60 kg N ha$^{-1}$ which is about 27% of the recommendation.

In SA, USDA (2003) reported an increase in grain yields from 6 t ha$^{-1}$ in 1997 to 9-11 t ha$^{-1}$ in 2003 due to the introduction of higher-yielding cultivars and more efficient irrigation practices. However, in ZIS, it was noted that the majority of farmers grew cultivar SR52 (a 1960s Southern Rhodesia release two-way hybrid) and Sahara or Okavango, all open-pollinated varieties (OPVs). Irrigated maize trials by the Agricultural Research Council (ARC) of SA indicated good hybrids are available that are capable of yielding more than 9 t $ha^{-1}$ (du Plessis & Bruwer, 2004). Promising hybrids ranged in terms of maturity class from short to long season cultivars, thus offering farmers the opportunity to obtain high yields even with late planting by appropriate selection of cultivar.

Most studies conducted in ZIS to date have relied on farmer interviews and have not generated quantitative data needed to explain and prioritise effect of factors cited by farmers on the low level of crop performance in the scheme. The studies have also been incomplete for purposes of designing a research programme to address the low productivity noted in ZIS. The situation analysis revealed that fertility and plant population management, cultivar choice, and planting time were the major factors limiting grain yield. Literature also cites these as the main determinants of grain yield as already highlighted (NSW Grains Report, 2004). However, there was insufficient data available to prioritise these factors for purposes of design of a research agenda and intervention to increase maize grain yield.

The study reported here was aimed at investigating agronomic factors responsible for low maize productivity in ZIS so as to enable design of a focussed research agenda to address the constraints. The specific objectives were to: (i) test the relationship between planting time, N rate, cultivar and plant population on maize grain yield, and (ii) compare yield of new hybrids from the ARC regional trials with cultivars grown by farmers at ZIS.

## MATERIALS AND METHODS

**Experimental site:** The studies were conducted at ZIS (32°45´S, 27°03´E) in the central Eastern Cape province of South Africa during the 2005/06 summer season. Mean annual rainfall in the area is 580 mm of which about 445 mm is received in summer, thus necessitating supplementary irrigation (van Averbeke *et al.*, 1998). The experiments were carried out at three farmers' fields; Nofemele, Kalawe and Sisando. Nofemele has deep dark coloured soils of the Oakleaf form, while Kalawe and Sisando have dark coloured heavy-textured soils of the Valsrivier form according to the South African system of soil classification (Soil Classification Working Group, 1991). According to FAO (1988), these soils are classified as fluvisols and luvisols, respectively.

**Experiment 1: Participatory evaluation of the relationship between maize grain yield and cultivar, N rate, plant population and planting time**

The experiment was designed as a $2^4$ factorial laid in a randomised complete block design (RCBD) with three replications per site. The four factors were plant population, rate of nitrogen fertilisation (N rate), cultivar and planting time. The populations used were 40 000 and 90 000 plants $ha^{-1}$. To achieve the former, plants were spaced at 0.75 m between rows and 0.33 m within rows and for the latter plant population a spacing of 0.75 m × 0.15 m was used. N rates were 60 and 250 kg $ha^{-1}$ both applied as three splits; a third each at planting, 5 weeks after emergence (WAE) and 7 WAE. Compound fertilizer 2:3:4 (30) was used as basal dressing at planting while lime ammonium nitrate (LAN) (with 28% N) was used as topdressing. The two cultivars tested were DKC61-25 and PAN6777 produced by Monsanto and PANNAR (Pty.) Ltd, respectively. The former is a short season cultivar taking 55 - 70 days to attain 50% flowering while the latter is a long season cultivar taking 65-85 days to 50% flowering in cool and warm areas. The cultivars were among the top performers from ARC regional trials in the two maturity classes (du Plessis & Bruwer, 2004). Two planting times, early and late were used but the actual dates varied with site. Differences in planting times were caused by bird damage on emerging seedlings at Sisando and Kalawe, which reduced crop stand to less than 10% of the target, necessitating replanting of the two sites at later dates. At Nofemele farm, early planting was on 28th November and late planting on 19th December 2005. At Kalawe, early planting was on 10th December 2005 and late planting on 1st January 2006. At Sisando, dates were similar to Kalawe with a difference of one day later for each date of planting.

**Experiment 2: Participatory evaluation of new maize hybrids and standard cultivars.** This experiment was carried out at the same three sites where experiment 1 was set and was planted on 28th November 2005 for Nofemele farm and on 12th and 13th December 2005 for Kalawe and Sisando farms, respectively. Eight cultivars; two popularly grown by farmers at ZIS (Okavango and SC701) and two each from three maturity classes (early, medium and long season) that were top performers in regional cultivar trials conducted by the ARC from 2002 to 2004 (Table 1), were planted at each site in a RCBD with three replications per site.

Maize was planted at intervals of 0.27 m in rows spaced 0.75 m apart for a target plant population of 50 000 plants $ha^{-1}$ as standard procedure in ARC trials (du Plessis & Bruwer, 2004). N fertilizer was applied at a rate of 250 kg $ha^{-1}$, a third of which was applied at planting as compound fertilizer 2:3:4 (30) and two thirds as LAN (with 28 % N) topdressing in two equal splits at 5 and 7 WAE.

**Table 1:** Characteristics of maize cultivars included in participatory evaluation trials at Zanyokwe Irrigation Scheme, Eastern Cape, South Africa.

| Cultivar | [1]Maturity class | Yield potential (t $ha^{-1}$) | Grain colour |
|---|---|---|---|
| Okavango | Late | 4-5 | Yellow |
| SC701 | Late | 7-13 | White |
| DKC61-25 | Short | 9-10 | Yellow |
| PHB33A14 | Short | 9-10 | Yellow |
| CRN3505 | Medium | 9-11 | White |
| PAN6479 | Medium | 8-10 | White |
| PAN6777 | Long | 10+ | White |
| PAN6568 | Long | 8-10 | Yellow |

[1]Maturity class in terms of days to 50% flowering in cool and warm areas, respectively; Short: 70-75, 60-65; Medium: 75-80, 65-70; Long: 80-85, 70-75 (du Plessis & Bruwer, 2004)

**Non-experimental variables for both experiments:** Land was ploughed and disked once using a tractor drawn plough and disc harrow, respectively, before the plots were marked. Planting furrows, 0.75 m apart, were opened using hoes and three maize seeds were dropped per hole. The maize was thinned to one plant per hole at 2 WAE. Gross plots consisted of eight rows 6 m long, and the net plots consisted of the six middle rows measuring 4 m long. Weed control was done by hand hoeing as is common practice in the scheme. Maize stalk borer (*Buseola fusca*) was controlled by applying a pinch of Bulldock® (*active ingredient:* pyrethroid) granules in the maize funnel at 4 WAE.

**Data collection:** For both experiments, farmer and extension officer information days were conducted during late vegetative stage and at harvest to evaluate performance of technologies tested in the trials. During the late vegetative stage, qualitative information was collected on uniformity of crop stand, and plant and cob size, using focused group discussions. At harvest, farmers used pair-wise ranking to evaluate performance of technologies. Plots were prepared for farmer and extension officer assessments. Maize cobs from one row in each plot were dehusked to allow assessment of grain size, grain colour and other attributes such as pest and/or disease infestation. At harvest, data on cob weight and shelling percentage were collected and used to calculate grain yield for each site. A Willey-55 grain moisture meter (GB) was used to standardise grain moisture content to 12.5%.

**Statistical analysis:** Data on grain yield was subjected to analysis of variance using SAS version 8.2 (SAS, 1999) on a per site basis. Bartlett's test (Gomez & Gomez, 1984) was performed to determine homogeneity of error variances before combining data across sites. Bartlett's test showed homogeneity of error variances for Kalawe and Sisando, but not for Nofemele. For this reason data from Nofemele site was analysed and presented separately whilst Sisando and Kalawe sites were combined. Least significant differences (LSD) were calculated at 5% confidence level and used to compare treatment means using Student's t-test (Ott, 1998).

## RESULTS

**Effect of agronomic factors at Sisando and Kalawe farms:** There was a significant ($p<0.01$) site × N rate × planting time interaction on grain yield. There were significant interactions between N rate × cultivar ($p<0.05$), planting time × plant population ($p<0.01$), N rate × planting time ($p<0.05$), site × N rate ($p<0.01$) and site × planting time ($p<0.05$). Main effects of N, planting time, cultivar and plant population were significant ($p<0.01$).

The site × N rate × planting time interaction showed that maize fertilised at 60 kg N ha$^{-1}$ and planted early produced similar yield regardless of site, but Sisando had higher yields with late planting at the same N rate (Table 2). The planting time × plant population interaction showed that increasing plant population from 40 000 to 90 000 plants ha$^{-1}$ resulted in significantly higher yield when planting was done early, but significantly lower yield with late planting (Table 3). The N rate × cultivar interaction showed that similar yield was obtained when the two cultivars were fertilised at 60 kg ha$^{-1}$, but PAN6777 produced significantly higher grain yield when 250 kg N ha$^{-1}$ was used (Table 4).

**Table 2:** Maize grain yield as affected by N rate and planting time at Kalawe and Sisando farms, Eastern Cape, South Africa.

| Site | 60 kg N ha$^{-1}$ | | 250 kg N ha$^{-1}$ | |
|---|---|---|---|---|
| | **Early planted** | **Late planted** | **Early planted** | **Late planted** |
| Kalawe | 4552*$_b$ | 1654$_c$ | 7306$_a$ | 2627$_{bc}$ |
| Sisando | 4712$_b$ | 4062$_b$ | 8297$_a$ | 4030$_b$ |
| LSD (0.05) | | 2191 | | |

* Grain yield (kg ha$^{-1}$)

**Table 3:** Maize grain yield as affected by planting time and plant population at Kalawe and Sisando farms, Eastern Cape, South Africa.

| | Planting density (plants ha$^{-1}$) | |
|---|---|---|
| **Planting time** | **40 000** | **90 000** |
| Early | 6 123*$_b$ | 7 297$_a$ |
| Late | 3 531$_c$ | 2 669$_d$ |
| LSD(0.05) | 723 | |

*Grain yield (kg ha$^{-1}$)

**Table 4:** Grain yields of maize cultivars DKC61-25 and PAN6777 fertilised at 60 and 250 kg N ha$^{-1}$ at Kalawe and Sisando farms, Eastern Cape, South Africa.

| N rate (kg ha$^{-1}$) | DKC61-25 | PAN6777 |
|---|---|---|
| 60 | 4 637*$_c$ | 3 853$_d$ |
| 250 | 5 445$_b$ | 6 684$_a$ |
| LSD(0.05) | 648 | |

* Grain yield (kg ha$^{-1}$)

**Effect of agronomic factors at Nofemele farm:** The N rate × planting time × plant population × cultivar interaction was significant ($p<0.05$). There was a significant ($p<0.05$) N rate × plant population × cultivar interaction. There were significant ($p<0.05$) N rate × planting time, planting time × plant population and planting time × cultivar interactions. N rate was the only significant ($p<0.01$) main effect. The four-way interaction showed that with early planting and at 60 kg N ha$^{-1}$, cultivars were not significantly different regardless of plant population but were different at 250 kg N ha$^{-1}$, with PAN6777 and DKC61-25 yielding significantly higher at 40 000 and 90 000 plants ha$^{-1}$, respectively (Table 5).

With late planting, cultivars differed at both populations when fertilisation was applied at 250 kg N ha$^{-1}$ with PAN6777 yielding significantly higher at 40 000 plants ha$^{-1}$, but lower than DKC61-25 at 90 000 plants ha$^{-1}$. For DKC61-25, there was no difference in grain yield at 40 000 plants ha$^{-1}$ whether planting was done early or late and regardless of N rate. The response to N rate for this cultivar was apparent at 90 000 plants ha$^{-1}$ whereby higher grain yield was obtained at 250 kg N ha$^{-1}$ regardless of planting time. For PAN6777 there was a significant increase in grain yield with increase in N rate from 60 to 250 kg ha$^{-1}$ when maize was grown at 40 000 plants ha$^{-1}$ regardless of planting time and when maize grown at 90 000 plants ha$^{-1}$ was planted late (Table 5).

**Table 5:** Maize grain yield as affected by N rate, planting time, plant population and cultivar on grain yield at Nofemele farm, Eastern Cape, South Africa.

| Planting time | Plants $ha^{-1}$ | N rate ($kg\ ha^{-1}$) | Cultivar | Grain yield ($kg\ ha^{-1}$) |
|---|---|---|---|---|
| Early planting | 40 000 | 60 | DKC61-25 | 5 484$_{bc}$ |
| | | | PAN6777 | 4 507$_{c}$ |
| | | 250 | DKC61-25 | 6 467$_{b}$ |
| | | | PAN6777 | 9 788$_{a}$ |
| | 90 000 | 60 | DKC61-25 | 5 153$_{bc}$ |
| | | | PAN6777 | 4 065$_{c}$ |
| | | 250 | DKC61-25 | 8 862$_{a}$ |
| | | | PAN6777 | 6 617$_{b}$ |
| Late planting | 40 000 | 60 | DKC61-25 | 4 434$_{c}$ |
| | | | PAN6777 | 4 286$_{c}$ |
| | | 250 | DKC61-25 | 5 317$_{bc}$ |
| | | | PAN6777 | 7 671$_{ab}$ |
| | 90 000 | 60 | DKC61-25 | 3 806$_{cd}$ |
| | | | PAN6777 | 3 435$_{cd}$ |
| | | 250 | DKC61-25 | 8 672$_{a}$ |
| | | | PAN6777 | 5 654$_{bc}$ |
| LSD(0.05) | | | | 1 835 |

**Farmer evaluations:** Farmers preferred early-planted PAN6777 grown at 40 000 plants $ha^{-1}$ and fertilised at 250 kg N $ha^{-1}$, citing big size of cob and grains which would supposedly translate to higher yield. Late planted maize of both cultivars fertilised at 60 kg N $ha^{-1}$ had similar appearance to farmers' maize crop and as a result farmers were able to link performance of their crop to their management of N. Planting time caused poor performance compared to early planting, but farmers were unable to separate performance of cultivars at the vegetative stage in the late planting treatment though the difference became apparent at harvesting. At harvesting, poor grain fill of PAN6777 relative to DKC61-25 was observed as a negative attribute. However, even with late planting, farmers still preferred PAN6777 because of the bigger cob size relative to DKC61-25. With early planting observation of the extension officers was similar to that of the farmers and both preferred the lower plant population of 40 000 plants $ha^{-1}$ irrespective of cultivar, planting time and N rate. However, unlike the farmers, the extension officers preferred DKC61-25 when fertilisation was done at the lower rate and planting was done late.

Farmers were able to attribute the low productivity of their maize as being caused by low N fertilisation and late planting. However, both farmers and extension workers were not able to link plant population with the different management factors. They preferred the lower plant population regardless of the levels of the other three factors. Thus, they tended to look at individual factors in isolation without looking at possible interaction among factors.

**Cultivar performance at Kalawe and Sisando farms:** There was a significant ($p<0.01$) difference in performance amongst the cultivars across the three sites. At Kalawe and Sisando farms there was a significant ($p<0.01$) interaction between cultivar and site, with DKC61-25 and PHB33A14 yielding higher than PAN6568 and PAN6479 at Kalawe. At Sisando, there was no significant difference between PAN6568, PAN6479, DKC61-25 and PHB33A14 (Table 6). With the exception of the difference in performance of the four cultivars at the two sites, the maize cultivars yielded generally lower at Kalawe than at Sisando site. Cultivars SC701 and Okavango were consistently the lowest yielding at both sites. At Kalawe site, cultivar SC701 produced 3.8 t $ha^{-1}$ less yields than cv. DKC6125 whilst the same cultivar yielded 4.5 t $ha^{-1}$ less than cv. PAN6568 at Sisando. The yield of cv. Okavango was 4.1 t $ha^{-1}$ lower than that of cv. DKC61-25 at Kalawe and 5.6 t $ha^{-1}$ lower than that of cv. PAN6568 at Sisando (Table 6).

**Table 6**: Maize grain yield (kg ha$^{-1}$) as affected by site and cultivar in the Eastern Cape, South Africa.

| Cultivar | Kalawe farm | Sisando farm | Nofemele farm |
|---|---|---|---|
| DKC61-25 | 6 691$_b$ | 7 695$_a$ | 9 294$_a$ |
| PHB33A14 | 6 582$_b$ | 7 699$_a$ | 9 210$_a$ |
| CRN3505 | 6 397$_b$ | 6 569$_b$ | 9 953$_a$ |
| PAN6479 | 6 261$_b$ | 6 989$_{ab}$ | 8 389$_{ab}$ |
| PAN6777 | 5 546$_{bc}$ | 6 413$_b$ | 8 400$_{ab}$ |
| PAN6568 | 6 536$_b$ | 8 571$_a$ | 9 055$_{ab}$ |
| SC701 | 2 914$_e$ | 4 066$_d$ | 6 952$_{bc}$ |
| Okavango | 2 632$_e$ | 2 997$_e$ | 4 952$_c$ |
| LSD(0.05) | 883 | | 2 145 |

**4.2.2 Cultivar performance at Nofemele farm:** At Nofemele farm all the hybrids were significantly ($p<0.01$) better than Okavango and yielded up to 5 tonnes ha$^{-1}$ more than the OPV Okavango. Cultivar SC701 yielded lower ($p<0.01$) than DKC61-25, PHB33A14 and CRN3505 but was similar to all the three PANNAR cultivars (Table 6).

Orthogonal contrasts showed significant differences between cultivars commonly used by farmers and the new cultivars tested, with new cultivars yielding higher across sites (Table 7**)**. Short season cultivars yielded significantly higher than both medium and long season cultivars across sites. Whereas medium season cultivars were significantly higher yielding than the long season at Kalawe and Sisando, there was no difference at Nofemele site (Table 7).

**Table 7:** Orthogonal contrasts comparing maize cultivars used by farmers to new cultivars and comparing maturity classes at three trial sites in Eastern Cape, South Africa.

| Characteristic of comparison | Significance (P value) | | Superior cultivar |
|---|---|---|---|
| | Nofemele | Kalawe and Sisando | |
| Okavango & SC701 versus new cultivars | 0.01 | 0.01 | New cultivars |
| Short versus long season cultivars | 0.01 | 0.01 | Short |
| Short versus medium season cultivars | 0.01 | 0.05 | Short |
| Medium versus long season cultivars | NS | 0.01 | Medium |

**Farmer evaluations:** The most important criteria used by both farmers and extension officers in evaluating cultivars were cob size, number of cobs per plant and utilisation (green or dry grain maize). "White-grained cultivars were preferred over yellow because of their superior consumption quality and customer preference for green maize (fresh corn on the cob/table maize/green mealies) while yellow cultivars could only be used for grain. The other criterion used by farmers was grain size while additional criteria used by extension officers were disease resistance, height or size of plant, husk coverage and uniformity of cobs. At the vegetative stage, both farmers and extension officers noted increased susceptibility of cv. Okavango to stalk borer attack and to lodging but no scores were recorded. Size of the plant relative to the cob, where a small cob was borne high on the plant was also a negative attribute observed with regards to Okavango. Cultivar DKC61-25 was the most popular at the vegetative stage because of its earliness and uniformity of plants. Despite having more evaluation criteria, extension officer assessments were in agreement with assessments by farmers at harvest. Cultivar SC701 was scored the best, followed by PAN6777 while PAN6568 was scored as the best among the yellow cultivars. Contrary to its popularity during the vegetative stage, cv. DKC61-25 was ranked as the worst at harvest mainly due to the relatively smaller size of the cobs and grain, which would supposedly translate to lower yields; and poor husk coverage which resulted in birds feeding on substantial portions of the cob.

## DISCUSSION

Results of this study indicate that grain yield was significantly affected by cultivar, N rate, planting time and plant population and there were interactions among these factors. Between 45 000 and 90 000 plants $ha^{-1}$ are required to achieve best yields under irrigation in SA, depending on maturity class (Department of Agriculture, 2003). Being a long season cultivar, PAN6777 was more sensitive to nutrient stress than DKC61-25 which only responded to increased N rate when it was planted at 90 000 plants $ha^{-1}$ and not at 40 000 plants $ha^{-1}$. Thus, with timely planting and optimum N rate, PAN6777 would be favoured over DKC61-25 while the latter would be a better option when planting is delayed as long as it is grown at the higher plant population of 90 000 plants $ha^{-1}$ and well fertilised. This contradicts extension officers' choice of late planted DKC61-25 at 60 kg N $ha^{-1}$ at a plant population of 40 000 plants $ha^{-1}$. It can, therefore, be deduced that when maize is grown at a higher plant population it requires more nutrients due to increased competition for the limited nutrients, and this applies irrespective of cultivar. With nutrients and season length non-limiting, the higher plant population would yield more for short season cultivars whilst a lower plant population would be favourable for long season cultivars as shown by this study. Short season cultivars need to be grown at a higher plant population in order to generate the leaf area index that provides maximum interception of solar radiation, an essential step to maximize grain yield (Sangoi, 2000).

Findings of this study indicated that various maize hybrids differ markedly in grain yield response to N fertilisation. Similar results were obtained by Mkhabela *et al*. (2001). This means that the optimum N requirements for maize differ from one cultivar to another, largely due to differences in yield potential. Long season cultivars generally yield higher with timely planting and would require higher rates of N fertilisation than short season cultivars. N rate followed by planting time had the greatest influence on grain yield. Effects of late planting were more apparent at Kalawe and Sisando which were generally planted later than at Nofemele farm.

The decline in grain yield with delayed planting could be attributed to reduced growing degree day heat units for grain development as the season progressed as observed by USDA (2006) and Pannar (2009). As a result, yield components such as grain number (Fisher and Palmer, 1983; Quayyum and Raquibullum, 1987) and grain weight (Tanaka and Hara, 1974; Cirilo and Andrade, 1996) are reduced, thereby decreasing yield potential as the total radiation accumulated during the development stage from floral initiation to flowering diminishes. Also, with late planting, assimilate translocation from the leaves to the cob are reduced because of low temperatures during grain fill as reported by Pannar (2009).

Pisani *et al.* (1982) developed a model for predicting planting time and reported that for much of the maize-growing areas in SA, the best time to plant ranged from mid-November to mid-December. However, monitoring studies done in ZIS during the same season when the reported studies were conducted showed that farmers planted their maize from December until as late as mid-March. With such a delay in planting, yields can be adversely reduced. Since farmers in ZIS are more interested in green maize, it would be important to test the effect of planting time on green maize production as well.

Statistical analysis indicated that factors interact and choice of plant population to use should depend on cultivar, N rate and planting time. However, unlike farmers, extension officers rightly interpreted the interaction between cultivar, planting time and N rate, resulting in their opting for DKC61-25 with late planting and low N fertilisation. The appropriateness of this choice has been confirmed by results of statistical analysis. Upon conduct of the information days, it became apparent that both farmers and extension officers lacked technical skills on basic agronomic aspects of maize production and would benefit from training courses on maize agronomy.

New cultivars generally performed better than the two cultivars (SC701 and Okavango) commonly grown by farmers and short season cultivars out-yielded medium and long season cultivars. The yield of 4.95 t $ha^{-1}$ obtained from Okavango at Nofemele is within its yield potential of 4 to 5 t $ha^{-1}$ (du Plessis & Bruwer, 2004). This means that improvement in management of the OPV Okavango will not result in any higher yield than that obtained in the study, yet it is low under irrigation. OPVs are known to perform better than hybrids in below optimum conditions of low rainfall, but they cannot compete with hybrid maize in high potential areas (Belsitio, 2004). These findings suggest that proper selection of maize cultivars alone could almost double grain yields at ZIS.

Maize planting in the scheme is mostly done in the month of December, and planting of the cultivar evaluation trials was done at the same time that farmers were planting their own maize. Results of this study indicated that season length during this study could have been shorter for both SC701 and Okavango which are long season cultivars taking about 160 days to physiological maturity. Slightly extended season length was probably the reason why the two cultivars performed a bit better at Nofemele where planting was done about two weeks earlier than at Kalawe and Sisando. This suggest that with current practices in terms of planting time, farmers would obtain higher yields with short season cultivars like DKC61-25 rather than the long season cultivars that they seem to prefer.

Cultivar DKC61-25 was favoured by both farmers and extension officers during assessments at flowering, which agreed with results of statistical analysis of grain yield data whereby this cultivar was among the top yielding cultivars. However, at harvesting the same cultivar was scored as the worst cultivar while SC701 was scored as the best. SC701 was favoured mainly because of a larger cob size relative to the other cultivars. Cob size, cited as the most important selection criteria by farmers and extension officers, does not necessarily translate to higher grain yield. The most important grain yield determinant in maize is grain number (Otegui & Bonhomme, 1998). Other important grain yield determinants include number of cobs per unit area (Mkhabela *et al*., 2001) and grain weight (FAO, 1980; Anderson *et al*., 1984). The criteria used by farmers and extension workers in assessing a cultivar are not in line with agronomic aspects of grain maize production. However, cob size would be one of the most important selection criteria when producing for the green maize market.

Farmers have traditionally grown OPVs Okavango and/or Sahara for grain maize and SR52 or SC701 for green maize. Farmers were right in their choice of SC701 for purposes of green maize production, since the cob is of very good size and this sells very competitively on the market. ARC (1998) recommends this particular cultivar and SR52 as some of the best cultivars for production for green maize. While the study focused on improving grain yield, farmers preferred producing white-grained cultivars for the green maize market, which fetched higher prices at the market. It can therefore be said that farmers' assessment criteria was well-informed since their interest was for green maize rather than dry grain maize. Management practices to improve productivity of SC701 need to be explored.

It is apparent from the results that farmers and extension officers agree in terms of their choices of cultivars. Although extension officers used more criteria for selection of cultivars than farmers, the ultimate choices were the same. Yields obtained for all the new cultivars tested are comparable to those obtained from ARC evaluations (planted between 19 November and 8 December) for the early planted at Nofemele site but lower for Kalawe and Sisando sites. This means that planting time had a significant effect on yield with later planted sites yielding less. The shorter growing season favoured short season cultivars. However, as pointed out above, the new cultivars tested were not preferred by the farmers and thus their adoption is less likely.

## CONCLUSIONS

The findings of this study suggest that poor agronomic management practices by farmers are some of the reasons for the low grain yields obtained in ZIS. Late planting, low N fertiliser rates, and inappropriate choice of cultivar and plant population, as well as the interaction among these factors tend to limit grain yield. Though the focus of the research was on dry grain maize, farmers were more interested in green maize. Therefore, further research will be needed to include investigations on options to increase productivity of green maize. As a result of the preliminary studies in the scheme, focussed research should dwell more on investigating options to improve on planting time, fertiliser and plant population management, and cultivar selection to optimise on both green and grain yield.

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