PROJECT NUMBER		M121/ 81
PROJECT TITLE		Maize cultivar evaluation under different soil fertility conditions for resource-poor farmers
PROJECT MANAGER		MA Prinsloo
PROJECT STATUS		Complete
PROJECT DURATION		01/04/2001 - 31/03/2010
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	External	None

Abstract

The objective of the project was to identify maize genotypes that perform well under resource poor smallholder farmer conditions. Smallholder farmers are in most cases farming on poor soils and often do not know their soil chemical status. The trials were planted under researcher-managed conditions to identify varieties tolerant to low N or low P soil conditions. Results were combined in the end to identify genotypes tolerant to both low N and P. An *optimum* fertilised cultivar trial was planted adjacent to a trial that had a specific nutrient deficiency. The *low N* trials received no N, while the *optimum N* trials were planted with 20 kg N ha^{-1} and 100 kg N ha^{-1} applied as a side-dressing four to six weeks after emergence. The low P trials received no P, while the *optimum P* trials were planted with at least 50 kg P ha^{-1} according to the level of deficiency. All other nutrient elements were applied based on soil analysis results. A cultivar is identified as stress tolerant if its yield is above the mean yield of the corresponding stress trial. Commercial cultivars used on the South African market yielded much higher than most other genotypes. They, however, were also much more sensitive to low soil fertility levels. For resource poor farmers, it seems more appropriate for them to use genotypes that yield lower but are more stable under different fertility regimes. A number of entries, such as the DF-genotypes, showed promising results on tolerance to low N and P. From 2005 until 2010, open-pollinated varieties (OPV's) expressed much more tolerance to especially N-deficiency with CAP 311, SA3, Obatanpa, ZM 1523 and Kep being the most tolerant. In contrast to the 2001 - 2004 trial series, hybrids especially AFG 4611 and LS 8507 were more susceptible to N and P deficiencies. From the results it is evident that cultivars differ in their tolerance to different nutrient deficiencies. Although it is desirable for all farmers to plant hybrids in order to take advantage of their high yield potential, there will always be a portion of resource poor farmers who will not have the necessary funds to buy hybrid seed each year. This study has shown that there are stress tolerant OPV’s that can be used as an alternative to hybrids since the seed is cheaper and harvested grain can be used as seed.

Key words

Hybrids, maize, nutrient deficiency, open-pollinated varieties.

Introduction

Drought and low soil fertility are among the most important factors that are a threat to sustainable maize production and as a result food security and economic growth in southern Africa (Bänziger & Diallo, 2001). Soils have become depleted over time due to continuous and intensive cropping, tillage, burning of crop residue and little or no fertiliser application as a result of non-competitive inputs *versus* product prices (Kumwenda *et al*., 1997). Nitrogen (N) is the most important element required for plant growth and is an integral component for many growth processes. Although not as important as N, phosphorus (P) is also a very important element since it is associated with especially the DNA component of a plant. Bundy and Carter (1988) indicated that various research results concluded that maize cultivars differ significantly in their responses to sufficient or deficient soil fertility status. In the industrialised countries fertility deficits are alleviated by addition of inorganic fertilisers. Developing or resource poor farmers are often not able to apply inorganic fertilisers because they are not available or are too expensive (Mkhabela *et al*., 2001).

Maize yields of resource poor farmers are generally low because they cannot follow recommended agronomic practices, particularly the use of fertiliser, appropriate varieties and other management practices (Salasya *et al.*, 1998). This results in the destabilisation of maize production, income and food security in South Africa. Of these factors, low soil fertility was found to be the biggest constraint followed by suitable varieties (KARI, 1994). High fertiliser input is one of the requirements necessary for obtaining high yields in hybrids and many resource poor farmers have little or no access to fertilisers (Kogbe & Adediran, 2003). Hybrid vigour means three very important things for resource poor farmers. First, to sustain high yields they are reliant on a seed industry; second, a hybrid-based sector requires large-scale commercial seed enterprises whose profit can only be sustained through strong seasonal demand (Tripp, 2001) and temperate maize germplasm is not easily adapted to non-temperate environments as found in the developing world (Smale & Jayne, 2004). Resource poor farmers tend to consider the stability of returns more than well-off farmers (Hardaker *et al.*, 1997) and the shortage of acceptable seed varieties is one of the factors affecting risk (Blackie, 1994). Seed of OPV's is much cheaper than commercially available hybrids and resource poor farmers, therefore, resort to planting saved maize grain from the previous harvest (Anonymous, 2001), which can only be done with open-pollinated varieties (OPV's) if yields are to be sustained. In general, resource poor farmers need to have access to affordable seed that can be utilised for food and as a seed source for next year’s planting. Also, with high fertiliser prices, suitable varieties that are tolerant to low soil fertility conditions are required.

Bänziger & Diallo (2001) stated that maize breeding activities by national and international seed companies target commercial farming enterprises for which good performing cultivars are bred under optimal and well-managed conditions. The market among resource poor farmers proves, therefore, insufficiently attractive to private companies. For these reasons, Phiri *et al*. (2003) stated that resource poor farmers rely on low yielding cultivars that were developed decades ago and 50-70% of them rely on low productivity seed from local sources or from recycling grain (OPV’s). No or very little research has been done under low input agriculture since most research is aimed at optimal commercial conditions. Although information exists on the production of hybrids, very little information is available on the development, maintenance and adaptability of OPV’s. Such information would assist researchers, extension services and farmers to identify suitable OPV’s for specific environments and constraints, such as low soil fertility. Feedback from farmers regarding new cultivars should quantify the requirements of resource-poor farmers and should systematically influence breeding priorities. The project should have a direct and long-term impact on the sustainability of maize production for especially, small-scale and resource poor farmers. Identification of appropriate genotypes for specific soil deficiencies will in the long term not only improve yields but will more prominently stabilise yields and thereby increase income without increased inputs. Results from these trials can have profound effects insofar as sustainability, income and job creation are considered as a whole. In a sustainable way, especially resource-poor farmers will be able to produce reasonable maize yields without high additional input costs. Since land redistribution is having an effect on commercial farming enterprises, it is important that smallholder and resource poor farmers have the ability to produce maize in a sustainable manner otherwise South Africa could become a maize importer. OPV’s present the opportunity to smallholder and resource poor farmers to produce maize on a sustainable and cost-effective manner. The advantages of OPV’s include low seed costs and the use of seed obtained from a previous harvest and, although OPV’s in general produce lower yields than hybrids they are more stable particularly in stress prone environments. Factors such as ear size and kernel appearance (form, size and colour) are also important to small-scale farmers since harvested maize is utilised as green mealies.

The objective of this study was to identify maize genotypes that perform well under low N and/or P soil conditions.

Materials and Methods

The project started in 2001 in collaboration with CIMMYT. From 2001/02 until 2003/04 the best CIMMYT OPV's were selected and the poorest were replaced by South African hybrids. From 2004/05 until 2009/10, mainly South African OPV's and low-cost hybrids nominated by seed companies were evaluated with one or two easily obtainable and well performing CIMMYT OPV's. In the first three years 35 cultivars were planted at three localities (Bethlehem, Viljoenskroon and Potchefstroom) in a randomised complete block design with three replicates. Each plot was made up of four 20 m rows with a row width of 1.5 m. Treatments consisted of optimum fertility level, low N and low P. The optimum *N* trials were planted with 20 kg N ha^{-1} and 50 kg P ha^{-1} and 100 kg N ha^{-1} was applied as a side-dressing four to six weeks after planting. The low N treatments received no N but 50 kg P ha^{-1} at planting. Weeds were eradicated throughout the seasons and pests and diseases controlled with appropriate measures.

From 2004/05 South African OPV's and hybrids, as nominated by breeders and seed companies, were included in the trials. Low-cost hybrids nominated by seed companies served as controls. The Viljoenskroon site, however, had been terminated because the site was reclaimed by the farmer. All trials were planted in accordance to the respective production practices for the different regions. Plant responses to different treatments were recorded throughout the growth season and final yields were statistically analysed. Sensitivity of genotypes, giving an indication of the ability to tolerate low N-levels, was calculated as a percentage of the difference between grain yields at optimum and low N-levels divided by grain yields at optimum levels.

Results and Discussion

Results of optimum fertility and low N levels were averaged for Bethlehem, Viljoenskroon and Potchefstroom for the period 2001 until 2004 because in this period a large number of CIMMYT cultivars were included. At optimum fertility level, commercial hybrids as well as two DF varieties gave superior grain yields in excess of 4000 kg ha^{-1}. Although there was a notable reduction in grain yields due to low N-levels, differences between high and low yield genotypes were much smaller compared to optimum levels, indicating diverse sensitivity of genotypes towards fertility levels. Significant differences exist between genotypes within seasonal growth length clusters but also between clusters with some medium-late, medium and medium early genotypes performing better than late and early genotypes (Fig 1). The same trend, but with the exception of medium-late genotypes is observed at low N-levels (Fig 2). Sensitivity of genotypes is presented in Fig 3. In this case, the lower a value the more tolerant a genotype is towards N-level fluctuation. Although yielding high under optimum conditions the commercial cultivars seemed to be more susceptible to lower N-levels, especially for the medium-late cluster.

Trials for optimum fertility and low P levels were done at Potchefstroom where conditions were not as favourable compared to Bethlehem and Viljoenskroon. Yields were notably lower at optimum conditions but with the long season and medium-early season genotypes performing the best. There, however, was also a distinct decrease in grain yields at low P-levels although not as much as with low N-levels. Grain yields at optimum levels were notably higher for the long and medium-early clusters with 501/502 SR and some DF genotypes out-performing most other genotypes (Fig 4). At low P-levels the medium and medium- early clusters performed on average the best (Fig 5). Sensitivity towards low P-levels gave no indication of superiority between commercial cultivars and DF, SG and CIMMYT genotypes (Fig 6). There was, however, a tendency for the medium and medium-early clusters to be less sensitive towards low P-levels on average.

Combined tolerance responses to low N and P-levels are given in Figure 7. Based on above and below averages, the first quadrant indicates genotypes relatively tolerant towards low N-levels but susceptible to low P-levels. The second quadrant gives genotypes that are susceptible to both low N and P-levels. The third quadrant indicates genotypes relatively tolerant to low P-levels but susceptible to low N-levels. The fourth quadrant gives genotypes that are relatively tolerant to both low N and P-levels.

Cultivars used from 2005 until 2010 are presented in Table 1. In 2004/05 the trial consisted of five open-pollinated varieties and four hybrids that were planted at optimum fertility level, low N-levels and low P-levels at Potchefstroom. Trials consisting of optimum fertility levels and low N-levels were also planted at Bethlehem and Viljoenskroon. At Potchefstroom CRN 3549 yielded significantly higher than all the other cultivars (8 106 kg ha^{-1}) under optimal conditions. One hybrid, SC 513, yielded very poorly at all the localities which could be attributed to poor germination as a result of poor seed quality. Unlike at Potchefstroom, three OPV's at Bethlehem gave significantly higher yields than most hybrids at optimum fertility level (7 095, 6 199 and 6 095 kg ha^{-1} for ZM 1611, Nelson's choice and SAM 1037, respectively). Results at Potchefstroom indicate significant yield decreases from optimum fertility levels to N and P deficiencies. Although yields were lowest under N deficiencies there were no significant differences between N and P deficiencies. Yields of OPV's ZM 521 and ZM 1611, and hybrids SC 513 and CRN 3 549 were 61, 40, 44 and 40 % less under low N conditions respectively. Nelson's choice responded the worst to P deficiencies (60 % yield decrease) compared to optimum conditions. AFRIC, PHB 3253 and ZM 1611 were least susceptible to low N-levels. No results from Viljoenskroon were analysed due to overall poor germination that resulted in poor plant densities. Although not the highest grain yielder, AFRIC seems to be an OPV with good potential for use by resource-poor farmers under low fertility conditions.

Through identification of cultivars for their tolerance towards nutrient deficiencies, resource-poor farmers could have a much better chance of survival on soils of specific deficiencies without unnecessarily increased inputs. During the 2005/06 season 16 cultivars were evaluated for yield and tolerance to low fertility levels. In the eastern production areas, optimum fertility levels resulted in significantly higher yields compared to low N levels. Of the tested hybrids and OPVs, ZM 1523 (8 095 kg ha^{-1}) PAN 6549 (7 978 kg ha^{-1}), QS 7711 (7 932 kg ha^{-1}) and SAM 1107 (7 896 kg ha^{-1}) resulted in significantly higher average yields above Afric 1 (6 591 kg ha^{-1}) and LS 8507 (5 664 kg ha^{-1}). Although, responses to low N conditions were not as pronounced in the east as compared to western localities, hybrids AFG 4501, DKC 78-15B, LS 8507 and PAN 67 and the OPV Obatanpa-SR seemed most tolerant to low N levels. Other cultivars were all sensitive to low N levels, with yield decreases between 1 000 and 3 000 kg ha^{-1}. In the western production areas average yields differed significantly between optimum fertility (6 469 kg ha^{-1}) and low N levels (3 626 kg ha^{-1}). Low P levels (6 164 kg ha^{-1}) were on average not significantly different from optimum levels. Again AFG 4501 and PAN 67, with the addition of QS 7711 were most tolerant for low N levels, although yield decreases were approximately 2 000 kg ha^{-1}. Other hybrids and OPVs were all highly susceptible to low N levels, with yield decreases reaching 4 000 kg ha^{-1}. LS 8507 and DKC 78-15B and the OPV SAM 1101 were most susceptible to low P levels, with yield decreases between 1 000 and 2 000 kg ha^{-1}.

In the 2006/07 season significant differences existed among the three fertility treatments (i.e. low N, low P and optimum fertility levels). At Potchefstroom grain yields at optimum fertility averaged 3 688 kg ha^{-1} for 16 low priced hybrids and OPV's compared to 3 008 kg ha^{-1} at low P and 2 518 kg ha^{-1} at low N levels. At Bethlehem grain yields at optimum fertility levels were 2 941 kg ha^{-1} compared to 1 988 kg ha^{-1} at low N-levels. This clearly indicates that N is the dominant nutrient in grain yield production of maize. On average most hybrids, as would be expected, performed significantly better than the OPV's. Reduction in grain yield due to N deficiency ranged from 56 % to 15 %, with PAN 6671 being the most sensitive hybrid and CAP 341 NG the least sensitive OPV. The highest yielding cultivars under low N conditions were SNK 2551, CRN 3549 and RO 413, which are all hybrids and with yield decreases between 24 and 30 % at low N-levels. The lowest yielding cultivars, under low N levels, at both localities were PAN 6671, Nelson's choice and ZM 1523 with decreased yields between 31 and 56 % compared to optimum conditions. With the exception of Afric 1 and Zama the real yield decline from optimum conditions to low N levels are much less compared to hybrids, indicating that most OPV's, although not having the high yield potential of hybrids, are more stable under low N fertility conditions. Responses to low P conditions were not as profound as for low N levels. Yield decreases due to low P levels ranged between 0 and 41 % compared to optimum conditions with ZM 1523, Afric 1 and AFG 4611 the most sensitive to low P levels. In general, the OPV's seem more sensitive to low P levels compared to hybrids although yield decreases are not as pronounced due to the lower yielding OPV's in general. Results from these trials can have profound effects insofar as sustainability, income and job creation are considered as a whole. In a sustainable way, especially resource-poor farmers will be able to produce reasonable maize yields without high fertiliser input costs. This in turn will increase general income and could lead to hiring of people as area planted and labour required for harvesting and processing increase. Correct choice of cultivars will benefit not only resource-poor farmers in the long term, but also the country as a whole.

At Potchefstroom during the 2007/08 season significant differences in yield between optimum fertility and low N and P levels were observed. Although low N levels resulted in lower yields compared to low P levels no significant differences were observed between deficiencies of both elements. The hybrids PAN 6053 (7.19 t ha^{-1}) and RO413 (6.34 t ha^{-1}) produced significantly higher yields than the OPV's and other low-cost hybrids under optimum conditions. SAM 1107(F1) (5.33 t ha^{-1}) was the best performing OPV, followed by SAM 1107 (F2) (5.24 t ha^{-1}). Under low N conditions, however, SAM 1107(F2) (4.12 t ha^{-1}) out-performed the hybrids. The OPV's SAM 1109 QPM and ZM521 tolerated low N-conditions but PAN 6053 was affected resulting in a yield decrease of 3.6 t ha^{-1}. Under low P conditions SAM 1107 (F2) was again least affected but the hybrid PAN 6053 was affected to a 2.7 t ha^{-1} reduction in yield. At Bethlehem the hybrids PAN 6053 (5.89 t ha^{-1}) and AFG 4501 (5.37 t ha^{-1}) performed well under optimum conditions compared to the OPV's SAM 1109 QPM and ZM521, with yields of 3.75 and 4.30 t ha^{-1}, respectively. At low N levels a significant difference between the OPV's Nevada (3.49 t ha^{-1}) and ZM521 (1.91 t ha^{-1}) were observed. The hybrid PAN 6053 was most susceptible to low fertility conditions, with a yield decrease of 3.37 t ha^{-1}. SAM 1109 QPM and Nevada were more tolerant to low fertility levels. In conclusion it was found that hybrids performed better under optimal conditions but they were more sensitive to low fertility conditions. Overall OPV's do not perform as well as hybrids but are more tolerant to low fertility conditions.

In 2008/09 the hybrids CAP 341 NG (5.28 t ha^{-1}), DKC 80-31 (3.00 t ha^{-1}), DKC 80-33 (4.56 t ha^{-1}), RO 413 (5.37 t ha^{-1}) and SNK 2147 (5.94 t ha^{-1}) gave significantly higher yields at optimum fertility levels than at low N levels. Only DKC 80-33 gave a significantly higher yield at optimum fertility level compared to low P-levels. For the six OPV's only Nevada (4.42 t ha^{-1}) and SA1 (5.18 t ha^{-1}) performed better under optimum fertility levels compared to low N-levels. Although the differences were smaller compared to the previous seasons' results this could be attributed to the good amount and distribution of rainfall throughout the season. Average increase in yield for the hybrids and OPV's were 0.89 t ha^{-1} at optimum fertility levels. SNK 2147 (5.94 t ha^{-1}) was the best-performing hybrid and SA7 (5.98 t ha^{-1}) the best OPV. At Bethlehem only two hybrids (DKC 80-33 at 6.57 t ha^{-1} and PAN 6671 at 5.72 t ha^{-1}) performed better at optimum N levels. Nelson's choice (5.72 t ha^{-1}) was the only OPV that performed better at optimum N levels. On average DKC 80-33 (5.17 t ha^{-1}) performed the best among the hybrids and SA1 (5.68 t ha^{-1}) and SA7 (5.53 t ha^{-1}) among the OPV's. In general it could be concluded that the new improved OPV's out-yield the older hybrids.

In 2009/10 there was a significant average yield decrease for the N–deficiency plot of 65% at Bethlehem. Of all the cultivars tested DKC 80-33 and PAN 6671 had the largest yield decreases of 71% compared to the optimum fertility level. N 5919 yielded much lower at optimum level (4946 t ha^{-1}) but the yield reduction due to N-deficiency was much smaller. DKC 80-33 performed the best under optimum conditions with 8845 kg ha^{-1} and PAN 6053 was the best performer with 3419 kg ha^{-1} under N-deficiency conditions. Yield reduction under P-deficiency was not significant. Yields of N-deficient plots were also significantly lower at Potchefstroom but only at an average of 12%. This could be attributed to the higher clay content which in time releases additional nutrients to the soil. The same tendency as with Bethlehem was observed at Potchefstroom where DKC 80-33 was the best performer and NS 5919 the worst.

In combining results from 2004 to 2010 it is clear from Figures 8 and 9 that maize cultivars are much more susceptible to N-deficiency than to P-deficiency. CAP 311 and SA 3, which both are OPV's are least susceptible towards low N and P nutrients. In general, although the OPV's yielded on average lower grain yields than the hybrids the OPV's seem to be more tolerant towards especially N-deficiencies. Of the 44 cultivars evaluated 14 out of a total of 18 OPV's fell below the average susceptibility level. This tendency is not the same as for P-deficiencies where it seems as if there is not quite a difference in tolerance between hybrids and OPV's.

Conclusions

There is a clear tendency from results that commercial hybrids used on the South African market yield much higher than most other genotypes. They, however, are also much more sensitive than OPV's to low soil fertility levels, especially nitrogen.

For the period 2001 to 2004 a number of genotypes consistently proved their tolerance towards low fertility levels. Of these, CRN3549, PAN6053, CRN3505 and PAN6335 showed relative high tolerance towards low N-levels. KEP and Pan 6671 showed tolerance towards low P-levels whereas ZM521 and ZM302 also showed reasonable tolerance. CRN3760 and SNK2472 showed high tolerance towards both N and P deficiencies. A number of DF-genotypes showed promising results on tolerance to fertility deficiencies.

From 2005 until 2010, OPV's showed much more tolerance towards especially N-deficiencies with CAP 311, SA3, Obatanpa, ZM 1523 and Kep being the most tolerant. In contrast to the 2001 – 2004 series, hybrids, especially AFG 4611 and LS 8507, were more susceptible to N and P deficiencies. From the results it is evident that cultivars differ in their tolerance to different nutrient deficiencies. Although it is desirable for all farmers to grow hybrids there always will be a portion of resource poor farmers who will not have the necessary funds to buy new hybrid seed each year. This study has shown that there are stress tolerant OPV's that can be used as an alternative to hybrids since the seed is cheaper and harvested grain can be used as seed.

Acknowledgement

First and foremost the Maize Trust is acknowledged for their fund contribution towards the project and the technical team who conducted the trials is thanked for their contributions.

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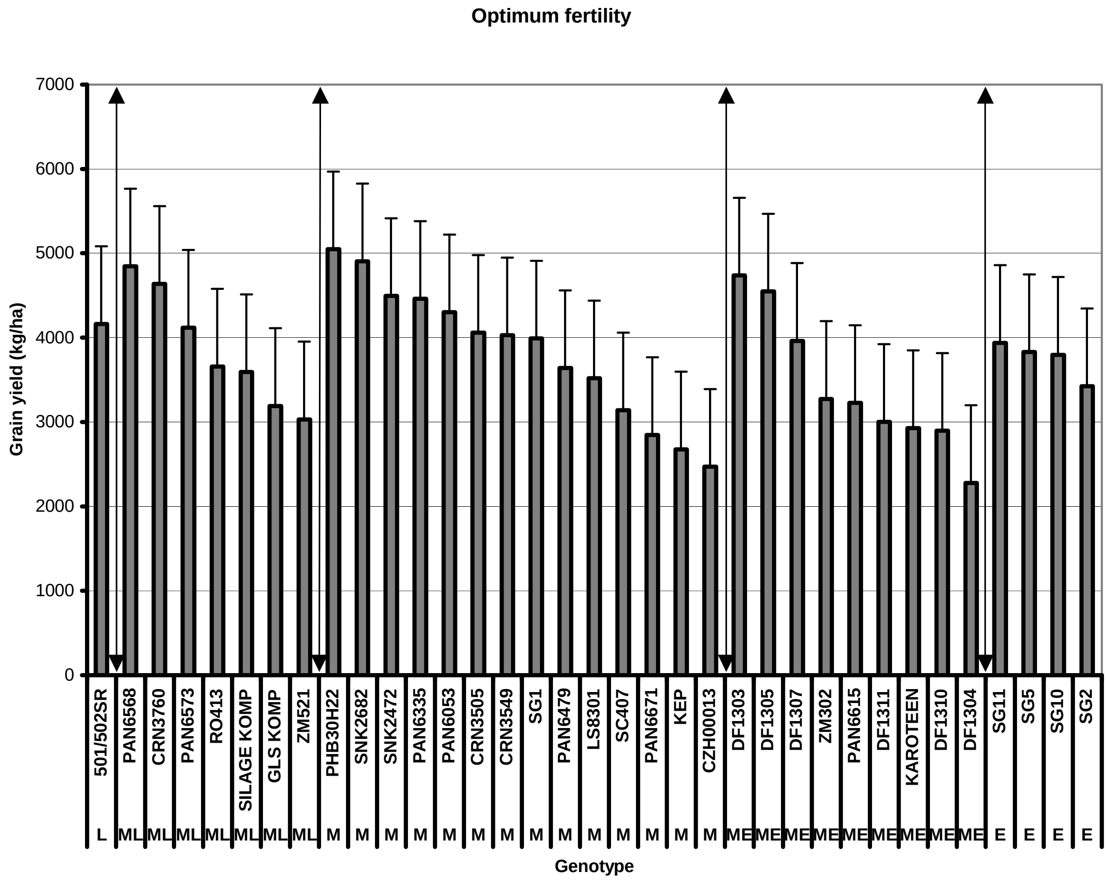

Figure 1. Average genotype response to optimum N-levels according to growth length period at three localities for the 2001 - 2004 seasons (lines on top of bars indicate least significant differences at 95 % certainty, L = long seasonal, M = medium seasonal and E = early seasonal)

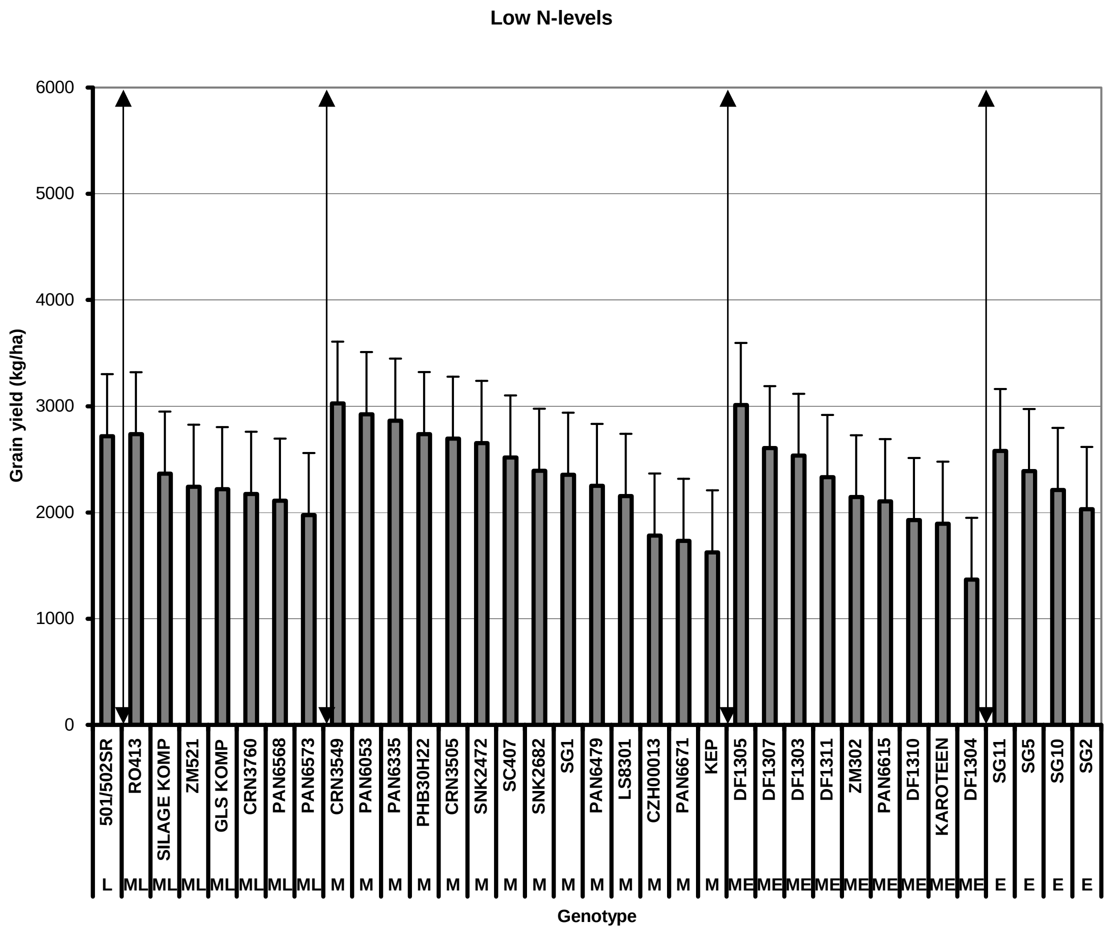

Figure 2. Average genotype response to low N-levels according to growth length period at three localities for the 2001 - 2004 seasons (lines on top of bars indicate least significant differences at 95 % certainty)

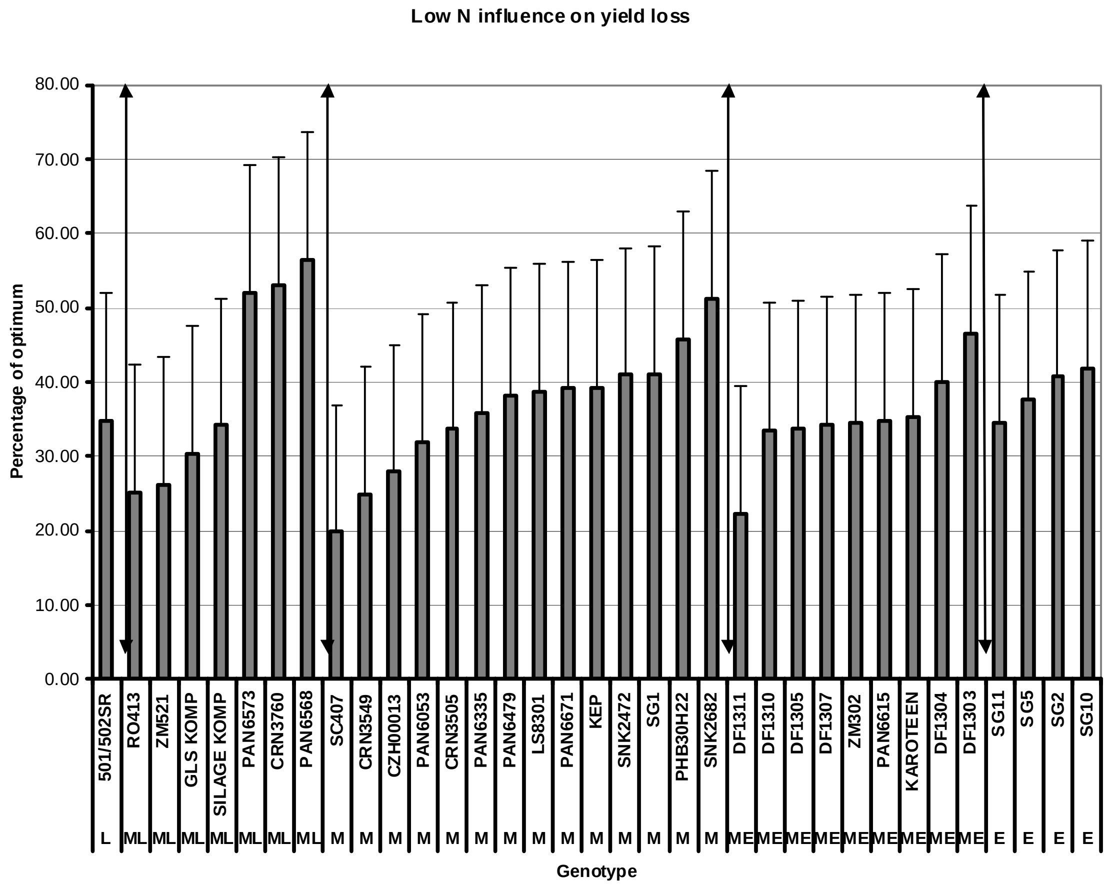

Figure 3. Average genotype response between optimum and low N-levels according to growth length period at three localities for the 2001 - 2004 seasons (lines on top of bars indicate least significant differences at 95 % certainty)

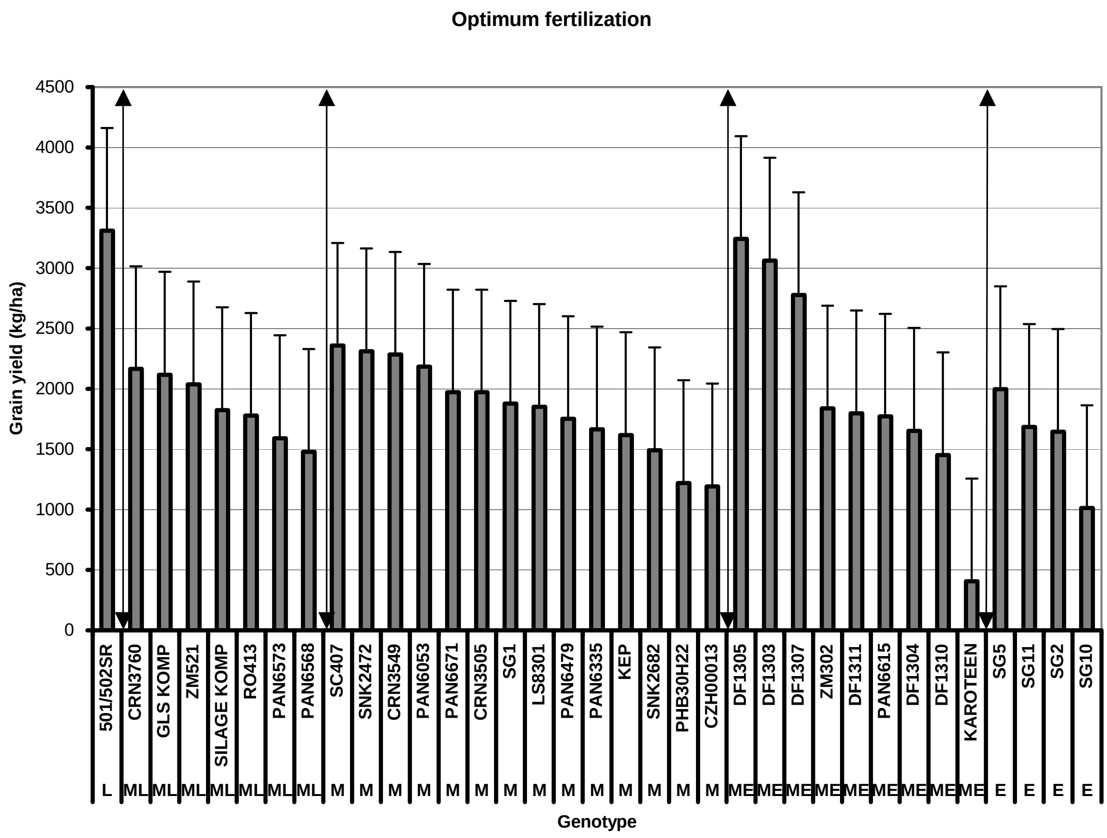

Figure 4. Genotype response to optimum fertility levels according to growth length period at two localities for the 2001 - 2004 seasons (lines on top of bars indicate least significant differences at 95 % certainty)

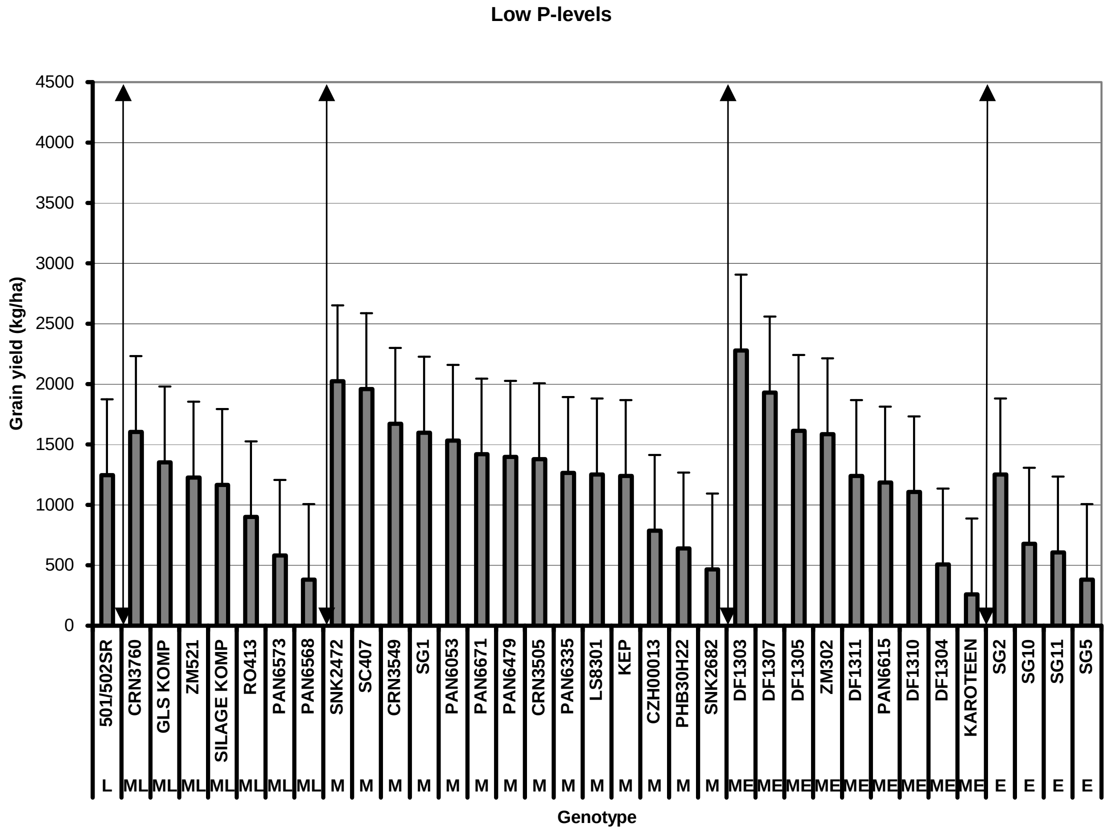

Figure 5. Genotype response to low P levels according to growth length period at two localities for the 2001 - 2004 seasons (lines on top of bars indicate least significant differences at 95 % certainty)

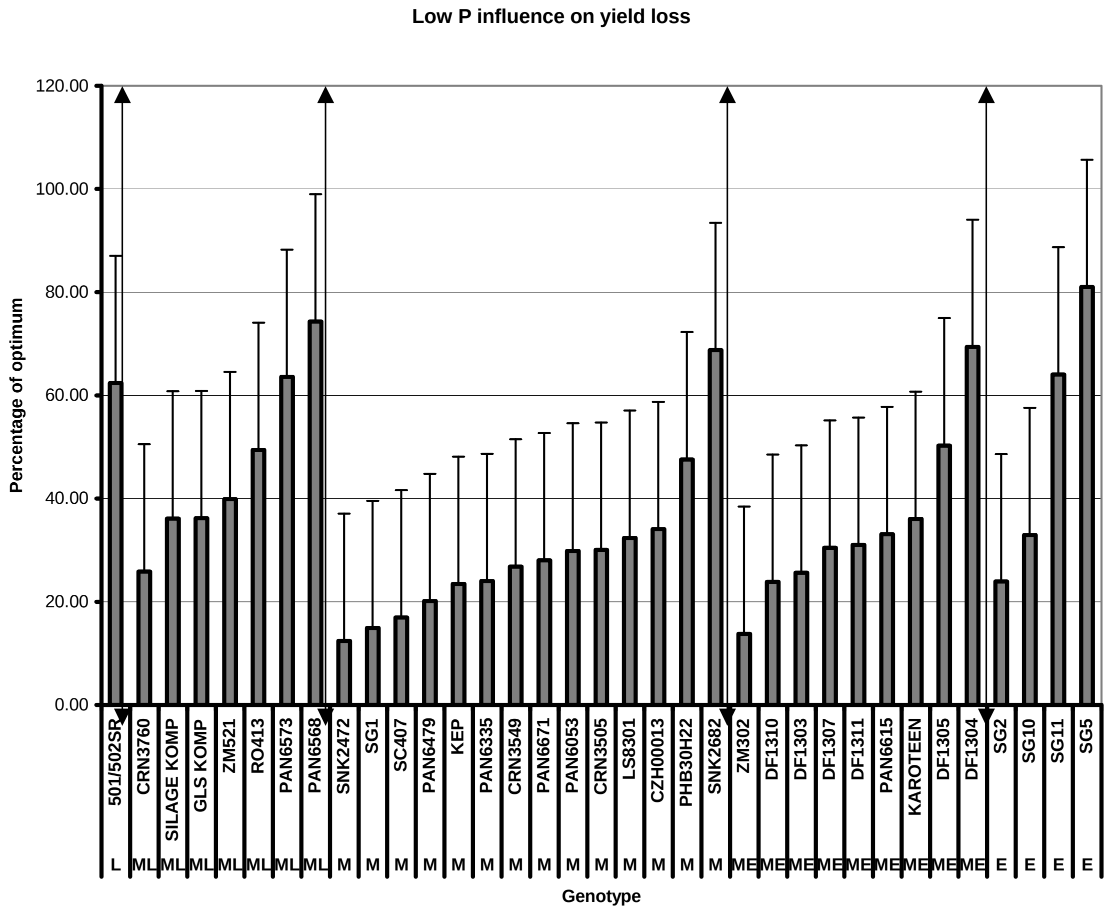

Figure 6. Average genotype response between optimum and low P-levels according to growth length period at two localities for the 2001 - 2004 seasons (lines on top of bars indicate least significant differences at 95 % certainty)

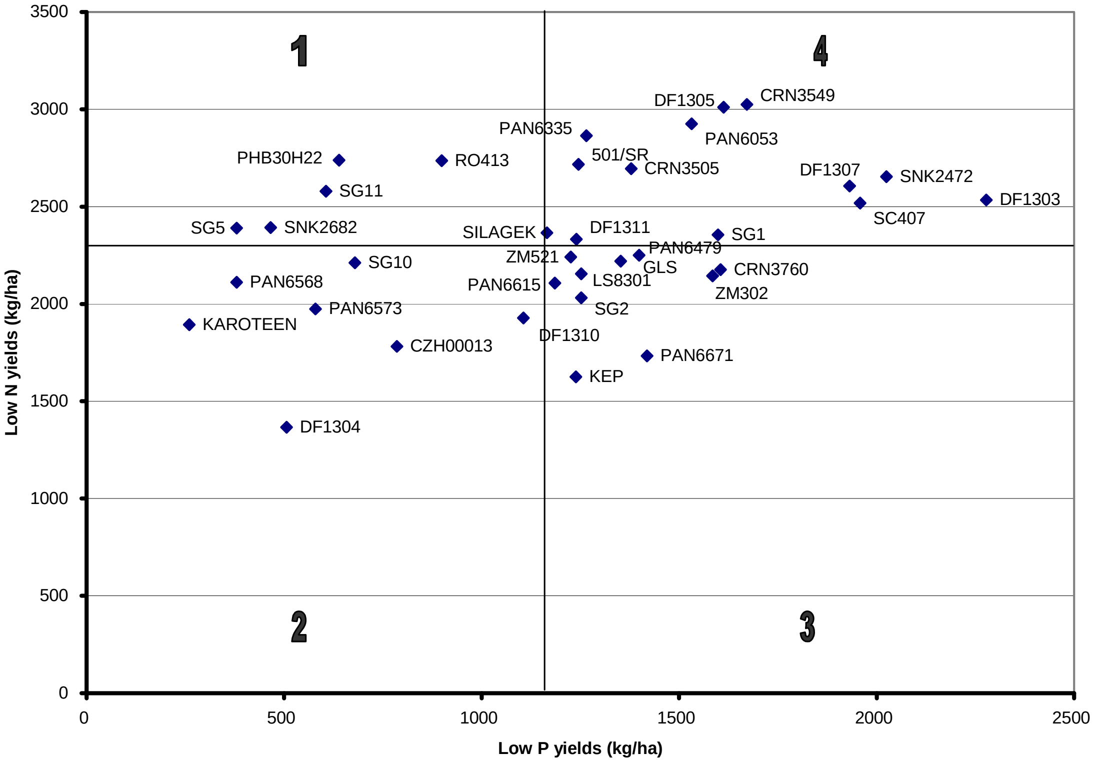

Figure 7. Genotype sensitivity to fertility deficiencies at three localities during the 2001 - 2004 seasons

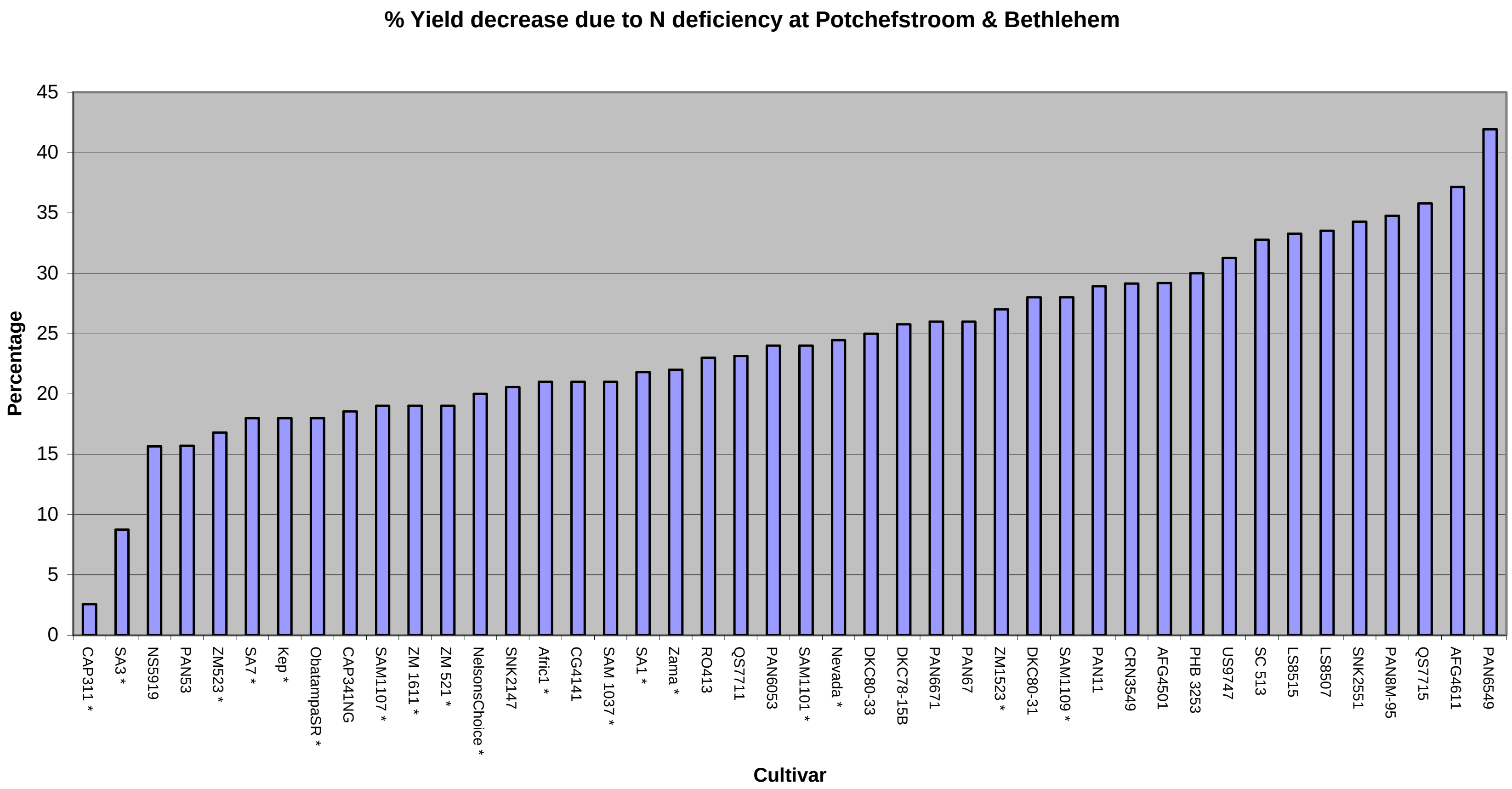

Figure 8. Average percentage yield decrease due to N-deficiencies at two localities for 2005 - 2010 seasons

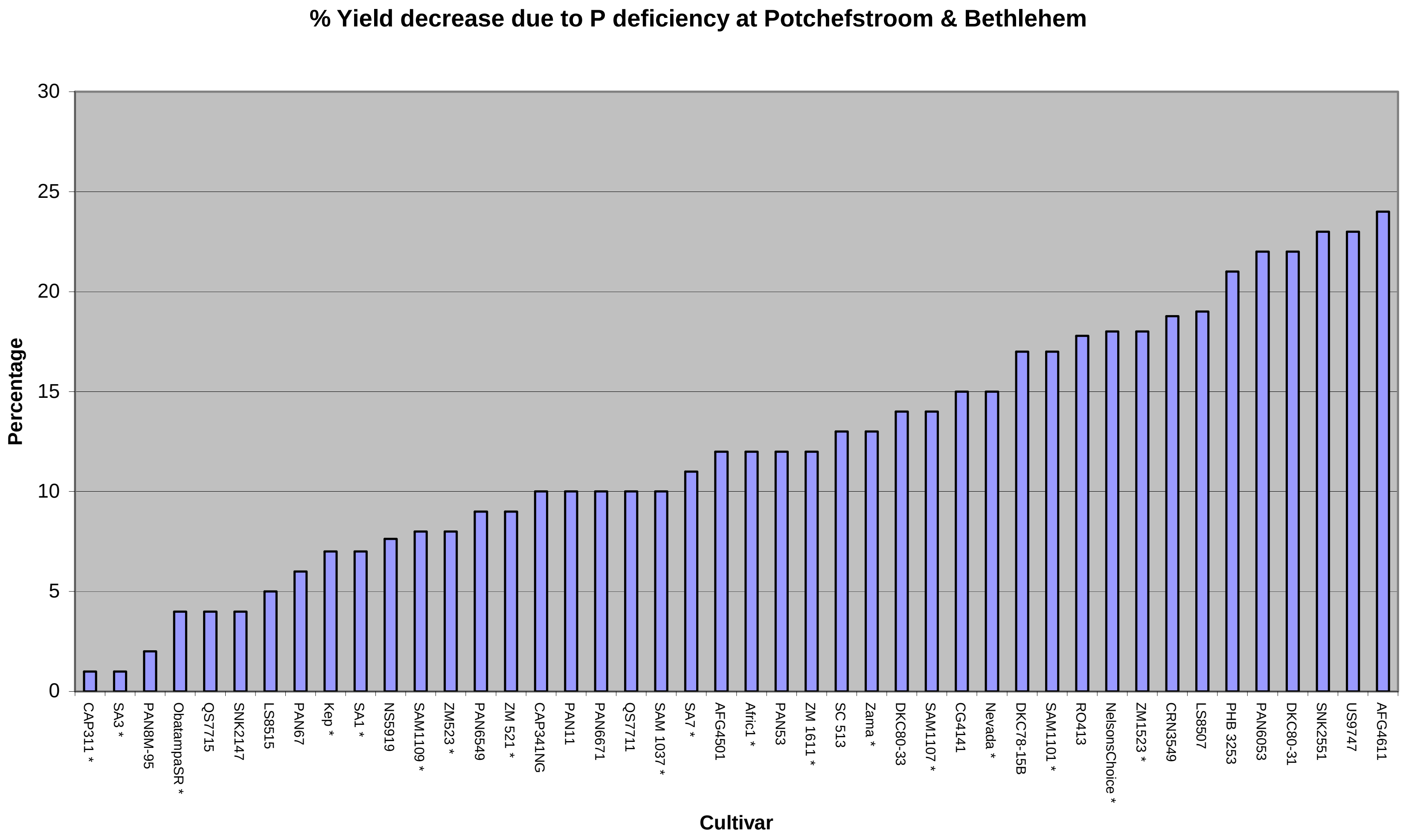

Figure 9. Average percentage yield decrease due to P-deficiencies at two localities for 2005 - 2010 seasons