EXECUTIVE SUMMARY

The potato is an important source of food world wide. In South Africa the crop is primarily produced under irrigation (about 73% of the total area under potatoes) for the fresh market, for the processing industry as chips and crisps, and for seed potatoes.

In subtropical climates potato crops are often subjected to unfavourable conditions of high temperatures and water shortages during the growing season: heat- and water stress adversely affect growth, tuber yield and quality. In these hot, dry climates the high evaporative demand increases crop water requirements, which may compound the sensitivity of the crop to water stress, resulting in greater yield reductions than experienced with similar water deficits under cooler conditions.

Due to limited water resources and unreliable annual distribution of rain, water stress is a major constraint on potato production in South Africa. In some production areas the quantity and quality of water resources have deteriorated badly due to over exploitation. Two possible approaches could be followed by agriculture to achieve savings on water use without reducing the cultivated area. The first option is to cut down on current water use by the application of sound irrigation scheduling techniques as it has been shown that, although water stress is considered an important production limiting factor, only a few producers apply scheduling on irrigated crops. The negative attitude towards irrigation scheduling can be attributed to various factors. The lack of easy, quick and reliable scheduling methods seems to be one of the major reasons. The second option is to breed and select genotypes that are more efficient with regard to water use characteristics, which may be a long term solution to the problem. This alternative is well recognized for many crops and breeding for better adaptability to drought is an important objective of the local potato breeding programme at Roodeplaat.

Since little is known about the amounts of water required for optimum production and the effects of water stress on local potato genotypes, the following objectives were set to clarify these aspects:

1. To determine the water use of the most important potato cultivars and breeding lines to ensure maximum yield and quality.
2. To identify the critical growth stages of potatoes to water stress.
3. To determine the effect of water stress imposed in different growth stages on growth and development.
4. To determine the suitability of some physiological parameters to indicate the existence of plant water stress and to serve as early screening methods for drought tolerance in potàto genotypes.
5. To use collected data for the development of crop growth models and adapt irrigation scheduling models for potatoes.

Seven trials were conducted from the 1992 autumn planting until the autumn of 1995. The trials were planted under automated rain shelters and irrigation booms were used in combination with rain shelters.

Genotypic yield differences in response to levels of water stress were mainly confined to the spring plantings, when temperatures and the atmospheric evaporative demand are higher than in autumn. Some genotypes were clearly more adapted to water-stress conditions than others. Of the late genotypes Late Harvest and Mnandi performed best at the dry treatments, while Mnandi had the highest yields at the wetter treatments as well. The findings of this study contrast the suggestions of Jefferies & MacKerron (1993) that there is limited capacity for improved drought tolerance through breeding other than improving the yield potential. Genotypes such as Late Harvest, Vanderplank, 82-252-1 and 83-252-1 had low yield potentials under favourable conditions, but had of the highest yields when they were water-stressed.

The ranking of genotypes according to yields attained at different water treatments is an important contribution to the current state of knowledge and will be valuable to producers in assisting them to select genotypes most suitable to their specific growing conditions. The ranking order of genotypes as a result of water treatments only changed in spring plantings, indicating that in autumn genotypes can be selected purely according to yield potential or specific needs of the end user. If producers have a choice between spring and autumn planting seasons, the range of high-yielding genotypes to select from will be larger for the autumn planting. High yields can usually be expected from autumn plantings, while the saving on irrigation water will be substantial, compared to a spring planting.

Local potato genotypes were for the first time characterised according to drought tolerance. Drought-tolerant genotypes were regarded as those that showed the lowest reduction in tuber yield when exposed to water stress. Mnandi, Late Harvest, Vanderplank, 82-252-5 and 83-252-1 were the most drought tolerant of the genotypes evaluated. Genotypic differences in drought tolerance were less pronounced in autumn, because temperatures and atmospheric evaporative demand were lower. The drought-sensitivity index demonstrated in this study should be a valuable tool to plant breeders for the selection of drought-tolerant parental material in breeding programmes.

The negative effect of water stress on tuber size was most severe in spring plantings, when temperatures and the atmospheric evaporative demand were higher. The yield of medium and especially large tubers were damaged by water stress, but genotypes within the same trial did not respond differently to water stress.

Water regimes apparently had less effect than temperature on tuber internal quality in spring plantings. The effect of water regimes on tuber quality was not clear and, contrary to most reports in literature, no negative effects of water stress on tuber relative density and chip colour could be demonstrated in spring plantings, while chip colour improved as a result of water stress in autumn plantings. Firstly, the contradictory results are possibly attributable to the dominating effects of temperature on tuber quality. Secondly, the irrigation boom method used does not resemble field conditions, due to the regular application of small amounts of water to dry treatments.

Part one of the first objective, which was to determine the water regimes that will ensure maximum yield and quality of different potato genotypes, were only partly reached: although the intermediate regimes (W2 and W3) seemed to provide the most favourable compromise between highest yield and best quality, genotypic differences could not be identified. The irrigation boom system used is probably to be blamed for the fact that possible genotypic differences could not be found.

Photosynthetic rate (Pn) and stomatal resistance (Rs) were investigated as indicators of drought tolerance. Tuber yields correlated well ($r=0.87$ to $r=0.99$) with seasonal mean values of both these parameters for all the genotypes, but the regression functions that describe these relationships changed for seasons and genotypes. The magnitude of decline in Pn or increase in Rs in response to drought was found to be related to the magnitude of decline in tuber yield. These relationships are, however, not valid for heat-sensitive genotypes such as Up-to-date. These findings may be a significant contribution to early selection techniques for drought tolerance in crops, but the technique should be evaluated on independent data and on a wider range of more diverse material to prove its usefulness.

The objective of finding suitable physiological parameters as indicators of water stress and to serve as early screening methods for drought tolerance in potatoes was reached, since the regression functions obtained from this study can in future be used to estimate the expected yield reduction of a specific genotype, once the reduction in Pn or increase in Rs for that genotype is established.

The vast differences in total water use between plantings and years were mainly as a result of differences in atmospheric evaporative demand. Normalising the water-use data for seasonal vapour pressure deficits narrowed the gap between years, but differences between spring and autumn plantings were still evident for the same genotypes. The reason for the remaining differences should probably be attributed to the fact that evapotranspiration and not transpiration data was used for comparison.

The small differences observed between genotypes in water use can perhaps be explained by the way water use was calculated and by the method of irrigation used. Water use was mainly a function of water applied, as genotypes within the same maturity class received the same amount of water. Since genotypic differences in water use could not be determined with the irrigation method used, this second part of the first objective was not reached, as we are not sure that genotypic differences in water requirements were not present. The irrigation boom system is therefore not ideal for water use studies, although it is a valuable technique for drought tolerance screening.

Water-use efficiencies were the highest for autumn plantings, because less water was lost through evaporation without contributing to the production of dry matter. Highest water-use efficiencies were generally recorded at the intermediate treatments (W2 and W3) for both plantings. The high-potential cultivars Up-to-date, BP1, Mnandi, 81-163-40 and Mondial had the highest efficiencies in autumn plantings, independent of the water treatment applied, but in spring plantings the water-use efficiencies of genotypes were influenced by water treatments. Generally, Up-to-date, and 83-363-67 had the highest efficiencies at the wet to intermediate treatments, while the more drought-tolerant genotypes Vanderplank, Late Harvest and Mnandi had high efficiencies at all the water treatments in spring plantings. The medium-maturity genotypes 82-252-5 and 83-252-1 had the highest efficiencies at the driest treatments.

Rooting density in deep soil layers was not related to drought tolerance for the genotypes studied. Although root distribution was slightly changed by water regime, root development does not seem to be a suitable indicator of drought tolerance in potato genotypes. The majority of roots were located in the top 600 mm soil layer for all potato genotypes. The greatest portion of soil water was also extracted from this zone, which is suggested as the maximum rooting depth for irrigation scheduling calculations.

The Soil Water Balance model (SWB) was calibrated for the cultivar Up-to-date, using data sets of autumn plantings. SWB generally performed satisfactorily with regard to the simulation of dry matter production and water deficit of the soil profile for both well-watered and water-stressed conditions in autumn plantings. Simulations of crop growth and soil-water depletion were, however, not accurate in spring if the crop parameters determined for autumn plantings were used. Canopy size was under estimated and the date of senescence was too early, resulting in incorrectly simulated soil-water deficits. The reason for the poor results in spring plantings is probably attributable to the fact that the effects of photoperiod and high temperatures on development and assimilate distribution is not taken into account by the generic crop model. The model therefore needs further refinement to ensure better simulations of canopy development over seasons, possibly by accommodating the effect of day-length on growth, development and senescence. Alternatively, separate crop parameters should be determined for spring or summer plantings. Crop parameters should also be established for cultivars of other maturity classes, which will require complete growth analysis studies.

The objective to use data collected in this study for the development or adaptation of a simulation model for irrigation scheduling purposes was reached for the cultivar Up-to-date, a medium-maturity cultivar. Destructive growth analyses were not possible because of the limited number of plants that could be accommodated under the rain shelters. Sufficient crop data were therefore not available for the determination of crop parameters for specific genotypes. If the water requirements of genotypes within the same maturity class do not differ, as suggested by the results of this study, the first important step in future research would be to obtain crop parameters for the most important genotypes belonging to the early and late maturity classes. In spite of the research still needed to improve the model, it should already be a valuable tool which could assist both advisors and potato producers on a daily basis to decide when and how much to irrigate their potato crops.

A part of the first objective was to determine the water requirements for optimal production of different genotypes. The water use of genotypes within the same maturity class did, however, not differ, possibly due to the equal amounts of water applied to all the genotypes for the same water regime. It is therefore not known whether total water use would have been different if another method of irrigation was used instead of the irrigation boom.

The objectives set to determine the effects of water stress imposed in different growth stages on growth and development, and therefore the identification of critical growth stages, were not met in this study. Different levels of water stress could not be imposed at different growth stages, because the irrigation boom did not permit such treatments.

Reports from literature indicate the main effects of drought on growth and development to be the following: Drought usually reduces the canopy size, whereby the interception of solar radiation is reduced. Secondly, crop development and canopy senescence are hastened, which result in a shortened life cycle. Water stress during the tuber initiation phase will result in less tubers being initiated and therefore the potential yield is reduced. The most devastating effect of water stress on tuber yield is during the tuber bulking phase: drought reduces the number of harvestable tubers by reducing the number of tubers that grow into a certain minimum size. The downward shift in tuber size distribution result in a lower total yield.

Water supply may also have adverse effects on tuber internal quality. Tuber relative density and reducing sugar content are the two quality characteristics commonly affected by water supply. Tuber relative density is usually enhanced by water stress late in the growing season, while reducing sugar content will rise as a result of late water stress, resulting in unacceptably dark chip colours.

Recommendations for future water use studies on potatoes include the following: if the water requirements of individual genotypes are to be established, the irrigation boom should deliberately not be used, for the reasons already elaborated on in this section. These also apply to studies for determining the effect of water levels on tuber internal quality. The irrigation boom technique is, however, ideal when genotypes are to be screened for drought tolerance. The suitability of photosynthetic rate and stomatal resistance as early screening methods for drought tolerance should be evaluated on independent data sets before being applied. The SWB irrigation scheduling model should be refined to enable its use in any season. Crop parameters should also be established for potato cultivars of other maturity classes.