GROWTH AND GRAIN YIELD RESPONSE OF MAIZE (*Zea mays*) TO WATER AND NITROGEN IN SMALL HOLDER IRRIGATION SCHEMES IN THE LIMPOPO PROVINCE

A THESIS
SUBMITTED TO THE SCHOOL OF AGRICULTURE AND ENVIRONMENTAL SCIENCES IN THE DEPARTMENT OF PLANT PRODUCTION IN THE FACULTY OF SCIENCES, HEALTH AND AGRICUTURE, UNIVERSITY OF THE NORTH, TURFLOOP, SOUTH AFRICA.

BY

MATLAKALA DINAH MODIBA
[B.Agric Admin, B. Agric Admin Hons. UNIN]

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SUPERVISOR:
Dr. KINGSLEY K AYISI

DECLARATION

I declare that the dissertation hereby submitted to the University of the North for the degree of Masters in Agricultural Management has not previously been submitted by me for a degree at this or any other university, that it is my own work in design and in execution and that all material contained therein has been duly acknowledged.

Signed:……………………………
DATE……27/09/2002……

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"Together we will prosper"

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Water and nutrients are the key factors that determine the productivity of crops and are the most limiting resources in the Limpopo province of South Africa. The effects of various irrigation regimes and nitrogen fertilizer application rates on water and nitrogen use efficiency of maize as well as on dry matter production, grain yield and physiological responses of maize crop have been examined. A randomized complete block design in a split plot arrangement was laid out with water applied at 12 and 6 mm irrigation regimes assigned as the main plot. Nitrogen applied as urea fertilizer at 0,50,100 and 150 Kg N ha^{-1} was a subplot treatment with four replications. Irrigation treatment positioning as the main plot imposed significant effects mainly on dry matter production and agronomic characteristics of maize such as physiological maturity, silking and flowering while similar results were evident for grain yields and yield components. 12mm application rate resulted in dramatic increase in dry matter production during the growing season. Nitrogen fertilizer application significantly affected most of the parameters measured at all locations although its effect was not consistent in increasing grain yield components and agronomic characteristics. Nitrogen fertilizer resulted in quadratic responses in grain yields (R^2 = 0.86 - 0.99), NUE, N uptake in dry matter yields at all locations. Linear relationships were evident between N uptake and dry matter yields at all locations with R^2 ranging from 0.04 - 0.98. Application rate of 100 and 150 Kg N ha^{-1} appeared to be the optimum levels for maize yields in this study for 6 and 12 mm application rates respectively.

CHAPTER 1

GENERAL INTRODUCTION AND LITERATURE REVIEW

GENERAL INTRODUCTION AND LITERATURE REVIEW

Maize (*Zea mays*) is an important cereal crop worldwide after wheat and rice, in terms of production and it is widely distributed. It is one of the highest yielding cereal crops providing food to meet the current and future needs of society. The United States is the world 's largest producing country, occupying double the area of any other crop. It is grown in more countries than any other cereal.

The crop is versatile and is endowed with tremendous genetic variability that enables it to thrive well under lowland tropical, subtropical and temperate climates and has become an important source of carbohydrate food for many societies. The crop is also a major component of the human diet and a livestock feed in many communities of the province and for various industrial purposes. Statistics shows that five hundred millions tons of maize are produced annually on 130 million hectares and developing countries account for 64% of the world's maize area and 43% of global maize production (Van Rensburg, 1978).

In parts of Africa, maize has replaced sorghum and millet particularly in South Africa, Malawi, Kenya and other countries. In South Africa, the crop occupies about four millions hectares of the country's arable land and about one third of South African farmers are maize farmers (Van Rensburg, 1978). In the Limpopo province, it forms a major component of the cropping systems for both commercial and small holder farmers. Maize is the principal summer crop grown by many smallholder farmers either in mixed cropping systems or as a sole culture in the Limpopo province of South Africa. In intercropping systems, it is commonly grown with cowpeas, groundnuts, watermelons, sweet sorghum, squashes and pumpkins. Despite the paramount importance of maize, its productivity is still marginal on farmers' fields, even in situations where farmers have access to irrigation. The major causes of declining maize yields in the province are irregular water supply during the growing season and the low soil fertility, particularly with respect to nitrogen and phosphorus.

Soil Moisture

Water is an important constituent of all living cells, comprising approximately 90% of the plant tissue and is a medium for proper nutrition and healthy growth in higher plants. It is also required for cellular activities and maintenance of turgor pressure within cells. The water in plant cells keeps the stem upright and maintains expanded leaves to receive sunlight for photosynthesis. Hence, any water stress during the course of growth constitutes a major limitation to crop growth and development and final yield (Chapin, 1991). A major impact of water stress on photosynthesis is the stomatal closure which inhibit gaseous exchange mainly carbon dioxide thereby reducing the photosynthetic rates (Gardner, 1983). In this regard, dry matter accumulation, final grain yield and several metabolic activities such as conversion of carbohydrates to lipids, nucleic acids, proteins and other organic molecules are also impaired during periods of stress. Other effects of water stress on crop productivity include: reduced transpiration, cell growth, cell wall synthesis, nitrogen and chlorophyll metabolism and the levels of growth substances, all of these leading to suboptimal developmental processes and final biological and economic yield in the crop (Hsiao, 1973). It is therefore crucial to effectively address seasonal water availability to crops if productivity is to be enhanced or maintained in the province. The initial effect of water stress could occur during the process of germination and emergence. Germination of maize seed, like that of many field crops is very sensitive to water shortage, and therefore reduced soil moisture potential during the germination process can limit moisture movement through the seed coat which is required for embryo activation and subsequent seedling growth.

Though low water availability during growth leads to reduced crop productivity, excess water application could be equally detrimental. Excess water, either due to over irrigation on farmers's fields or poor drainage of soil, results in waterlogging causing adverse effects on growth and metabolism of plants. Its physiological and biochemical effects includes disruption of respiratory metabolism, reduced root permeability, water and mineral uptake, nitrogen fixation and endogenous hormone (Germain *et al*., 1997). Uptake and distribution of essential nutrients are also perturbed in plants subjected to waterlogging (Trought and Drew, 1980; Muchow *et al*., 1990). Sadler and Turner, (1994) reported that water logging in peas causes inhibition in N uptake from the soil, thereby reducing the nitrogen concentration in vegetative and reproductive tissues. Muchow (1988) also reported retarded plant growth and lower productivity under waterlogged conditions due to purturbance in uptake and distribution of essential nutrients. An additional effect is increased leaching of mobile nutrient ions and pesticides into ground water when plants are overirrigated (Benjamin *et al.*, 1997). Pools of excess water on soil surface for a long period of time following irrigation is very typical in the current smallholder irrigation schemes in the limpopo province. There is therefore a pressing need to effectively manage water application and its efficient use in these schemes to minimize some of the negtive attributes associated with waterlogging.

Water use efficiency

Water use efficiency is defined as the amount of dry matter per unit evapotranspiration which is expressed as grams of dry matter per kilogram of water used by the plant (Helweg, 1991). This is expressed as the ratio of dry matter per evaporation or net photosynthesis or transpiration. Increased irriigation water use efficiency is desirable in the smallholder irrigation schemes of the Northern Province and in most areas where irrigation is a major user of water and where water availability is limited or declining.

Proposed approaches of reducing the amount of irrigation water required or increasing the water use efficiency while maximizing profit of the farmer include:

a) the usage of a shorter maturity cultivar, which has a short growing season and thus uses less water (Fjell *et al.*, 1993; Howell., 2001). However, the yield potential of short maturity maize is often less than that of their long season counterparts (Fjell *et.*, 1993; Howell., 2001).

b) improvement of plant growth through nutrient management to effectively utilize applied irrigation water (Clegg and Francis, 1994).

c) capturing more water from precipitation in the root zone of crop plants by i. improving infiltration rate and reducing percolation; ii. reducing consumptive use which is the sum of water lost through evaporation and amount contained in plant tissues (Kramer and Boyer , 1995)

d) improving irrigation systems to minmize leakages and ensure accurate delivery of the required amounts of water per application.

The plant's water use efficiency depends to a greater extent on the health and spread of the root system, species variety and nutritional status. Management of irrigation water influences the movement of mobile nutrients particularly nitrogen in soils and thus, its availability to plants roots, which ultimately affects the efficiency of nitrogen use. One way of doing this is to match irrigation water application to peak crop nitrogen demand during its growth cycle. Water use efficiency can also be improved if the fertility status of the soil is high since additional water will not necessarily improve crop yields in low fertile soils. Soil fertility is the ability of the soil to supply essential nutrients to crops through soil solution and ion complexes for maximum plant growth and productivity (Loomis and Connor, 1992). The concept of soil fertility includes not only the quantity of nutrients but how well nutrients are protected in the soil from leaching, how available the nutrients are and also the functional ability of roots to take up the nutrients (Plaster, 1992).

Improved soil fertility will enhance root and shoot growth, which enables plant to make use of available water. Thus, a thorough understanding of interaction between soil moisture availability and fertility status on farmers' fields is critical for improving crop productivity.

Soil Nitrogen

Plants obtain the bulk of their nitrogen requirements primarily as nitrate and ammonium from the soil. It is well documented that the mineral nutrition of plants is related, in many ways directly or indirectly to soil moisture since root hairs absorb dissolved plant nutrients in the soil solution by an active process that moves nutrients into root cells (Abrol,1990). Dry soils will obviously result in lower nutrient uptake since the lack of water impedes nutrient flow and diffusion whereas an increase in the amount of nutrient ions in the soil improves absorption. Nitrate is very water-soluble and its movement through the soil via the process of mass flow to plant roots, is reduced when soil moisture is low (Bennett *et al.*, 1986). A plant 's demand for mineral nutrients varies with growth conditions and its stage of growth. A well watered and therefore vigorously growing crop has a much greater nutrient uptake than the one in which growth is restricted for lack of water (Forbes and Watson, 1992). Thus, nutrient absorption is enhanced by the availability of moisture and hence, adequate soil water supply is critical for mineral uptake.

Apart from soil water content, the uptake of nitrogen by maize crop also depends on the amount of available soil nitrogen and the recovery of fertilizer nitrogen. Nitrogen, which is present in all proteins including enzymes and nucleic acids, is an element recognized as the first major nutrient ion that begins to limit normal growth in maize production under stress conditions (Ulger et al., 1997). Without nitrogen fertilizer application, N uptake depends on the mineral nitrogen reserve in the soil and the rate of nitrogen mineralization. The availability of nitrogen is determined by the balance between nitrogen supply and mineralization, nitrogen immobilization by microorganisms and losses either through leaching, volatilization or denitrification. Under Nitrogen limiting conditions, maize growth is stunted with smaller than normal leaves that are usually pale green or yellowish. Guardian *et al*., (1985) reported that nitrogen starvation decreases photosynthetic rate, respiration and chlorophyll formation while Brown and Bolton (1980) stressed that maize growth limitation by low nitrogen results mainly from decreased photosynthetic rate. Variations in nitrogen supply affect the growth and development in plants (McCullough *et al*., 1994, Hageman and Below, 1984)). Novoa and Loomis (1981), also found that, nitrogen supply can affect plant growth and productivity of maize crops by altering leaf area and photosynthetic capacity.

The ability of crops to translocate and mobilize stored nitrogen enables them to express visible symptoms when suffering a deficiency. Since nitrogen is mobile within the plant, lower leaves are the first to turn yellow and become necrotic. As deficiency becomes severe, chlorosis appears higher up on the plant and eventually the plant becomes entirely chlorotic and dies. In addition to the counter productivity resulting from low soil N on crop production fields, excess nitrogen in the soil which may arise from too much fertilizer application often subject the crops to lodging (Morgan, 1986) increased excessive vegetative growth at the expense of reproductive yields (Greenwood *et al.*, 1980). Nitrogen management is thus an important production constraint if maize productivity is to be improved or sustained in the small holder irrigation schemes of the Northern Province.

Nitrogen use efficiency

Due to the high cost of nitrogen fertilizer, it is important that applied nitrogen fertilizer to crops on farmers' fields be effectively utilized for biological productivity and economic returns. Biologically, nitrogen use efficiency is defined as the amount of dry matter or grain yield per unit of fertilizer applied to the soil. Other definitions include: biomass production per unit total above ground plant nitrogen (Borrel and Hammer, 2000) and also as grain production per unit total above ground plant nitrogen (Maranville *et al.*, 1980). Research aimed at N management on farmers' fields must consider improving nitrogen use efficiency especially in a situation such as the small holder irrigation schemes where farmers are too poor to purchase fertilizer.

Increased nitrogen use efficiency alone is not adequate in addressing the productivity problem on farmers' fields. However, efficient use of nitrogen must be accompanied by increased yields, which are necessary to meet the demands of the growing world population thus counteracting malnutrition problems. As the economic costs and environmental concerns associated with nitrogen fertilization rise, there is an increased emphasis on obtaining more efficient use of nitrogen in maize production systems. In rice production, optimum nitrogen fertilizer use efficiency has historically been found when urea was applied in split applications (Hargove *et al*, 1988). High crop nitrogen use efficiency is therefore desirable for reducing the cost and reliance on fertilizer nitrogen, it may also assist in reducing ground water pollution (Traore and Maranville, 1999).

It has been documented that when nitrogen fertilizer is applied at rates greater than required for maximum yield, plant biomass and long term soil organic carbon increase (Raun *et al.*, 1998) while nitrogen use efficiency decreases. Excessive use of nitrogen fertilizer is economically unfavourable, because yield diminish with increasing amounts of nitrogen applied (Miner and Sims, 1983). With appropriate nitrogen management practices it may be possible to limit the accumulation of nitrates in leaves, optimize fertilizer nitrogen use and reduce potential degradation of soil and water resources in these small holder irrigation systems. The proper use of nitrogen fertilizer is fundamental for farm profitability and environmental protection.

Nitrogen fertilizer must be used judiciously to maximize profits, reduce susceptibility to diseases and pests, optimize crop quality, save energy and protect the environment. Nitrogen use is an issue of great concern in maize production, as the negative impact of maize production on ground water quality has become a public issue (Cerrato and Blackmer, 1991, Klausner *et al*., 1993, Schlegel *et al*., 1996, Schroeder *et al*., 1998).

Higher energy cost of nitrogen and its mobility in agricultural systems mean that good opportunities exist to improve profitability by controlling losses and improving the efficiency of use. Single large dosages of nitrogen fertilizer are most likely to suffer losses by volatilization, denitrification and leaching than are applications more closely related to the uptake dynamics of the crop. Improvement of formulation and application of nitrogen fertilizer offer significant savings to inputs and environmental hazards. Due to the increase in costs of nitrogen fertilizer in general, there is a greater need in identifying nitrogen amendments that result in efficient nitrogen use. Apart from nutrients and water, maize also depends upon the availability of solar radiation for its growth, maintenance and reproduction.

Crop Growth

Growth is generally a function of environmental factors such as mineral nutrition, solar radiation, temperature along with genotype and production practices (Maman *et al*., 1999). Young maize plants require ample supplies of nitrogen for unconstrained growth (Van Dijk and Brouwer, 1998). Nitrogen is particularly associated with the growth of leaves and stems (Loomis and Connor, 1992) and has a more significant effect on crop yield than any other element (Kumar and Abrol, 1990). Effective leaf growth and canopy systems in plants have a positive impact on partitioning of carbohydrates and dry matter between shoots and roots and the overall productivity per unit area (Marschner, 1995 and Marschner *et al*., 1996). Nitrogen demand and also deficiencies vary with the growth stage at which nitrogen becomes limiting (Frederich *et al*., 1979, Mills and McElhannon, 1982). Usually when nitrogen is adequate in early stages of growth but becomes limited later, the yellowing occurs in older leaves while the new leaves appear almost normal. Thus, management of N fertillzer application through split doses might ensure adequate supply throughout the season.

Photosynthetically active radiation (PAR)

An important environmental factor that affects growth, development and yield of higher plants is solar radiation and heat units, which are required for effective photosynthesis (Delvin, 1975; Woodward, 1987). A crop intercepts light energy and through photosynthesis it is converted to carbohydrate, which is then used by the plant for growth and storage. The amount of light available for a crop varies seasonally and daily depending on latitude slope and cloud cover. Theses factors determine the total radiation received by the crops during the growing season (Clegg, 1972). From the plant's perspective, leaves are the key elements in light interception, and they should be supplied with adequate water and nutrients to stay efficient. Photosynthetically active radiation (PAR) is the amount of light energy in the visible range of about 400- 700 nM and it is the portion of the electromagnetic spectrum utilized by plants for photosythesis (Gardner *et al*., 1985). The amount of PAR intercepted by crop plants is expressed as follows:

$$PAR = (1 - Pb/Pa) \times 100$$

where Pa is the amount of incoming radiation and pb is the amount of light below the crop canopy (Clark, 1990). Plant growth is related to its ability to intercept solar radiation and to convert it to carbohydrates, or generally dry matter. The amount of radiation received and the efficieny with which it is used, sets the upper limit of biomass production in crop plants (Muchow *et al*., 1990).

Besides the role of solar radiation as a source of energy for photosynthetic reactions, Sawhney and Naik (1990) out that light influences the general metabolic activity in plants, such as photorespiration, chlorophyll synthesis, chloroplast development, protein and nucleic acids synthesis, degradation of fat and starch and the synthesis of secondary metabolites. However, production of organic matter by photosynthesis does not only depend on radiant energy but also on inorganic nutrients, adequate supplies of water, CO_2, favourable temperature and absence of toxic substances from the immediate environment which in turn affect productivity. In a review by Norman *et al.*, (1984), it was reported that crops growing under ordinary agricultural conditions, where moisture and nutrients are limiting do not convert greater than 0.1 - 0.3% of usable radiant energy into plant organic matter. Under conditions of intensive agriculture, where adequate moisture and nutrients were provided and where modern land management practices are followed, crop plants convert between 2 - 3% of usable radiant energy into plant material. It is important that crop canopies in the field are managed effectively for maximum capture of solar radiation to enhance dry matter accumulation and final yield improvement.

From the foregoing discussion, it is evident that water and nitrogen are major potential abiotic factors that can severely limit maize growth and grain yield production. Since the Northern Province of South Africa is relatively dry with suboptimal soil nutrient status on farmers' fields, particularly nitrogen, it is critical that these resources are effectively managed to enhance farmers' productivity and income. Although the effects of both water and nitrogen stress on crop growth and development, physiology and yield have been the subject of many studies, relatively little information concerning the interactive effects of these stresses, when imposed in combination, is available in smallholder farming systems of the province. Thus, research interventions that could efficiently maximize the use of these resources and improve maize productivity in the smallholder irrigation schemes are required. The objectives of this study therefore were to:

1. Determine optimum nitrogen fertilizer application under varying irrigation levels for optimal grain yield and its components in small holder irrigation systems.

2. Evaluate the effect of irrigation and nitrogen fertilization on plant growth, nitrogen uptake and nitrogen use efficiencies of maize in relation to the irrigation water applied.
3. Evaluate the influence of reduced water and nitrogen on the growth and agronomic traits of maize in the smallholder irrigation scheme.
4. Estimate profit margins resulting from nitrogen fertilzer application in the smallholder irrigation schemes.

CHAPTER 2

IRRIGATION WATER REGIMES AND NITROGEN FERTILIZER EFFECTS ON DRY MATTER PRODUCTION, LIGHT INTERCEPTION, NUTRIENT UPTAKE, NITROGEN AND WATER USE EFFICIENCIES IN MAIZE.

ABSTRACT [192 words]

Adequate water and mineral nutrient supply to a crop is an important factor determining its optimum growth, development and yield in areas characterized by water deficits. To increase the yield potential and maximize productivity for farmers in the province, a study was undertaken to assess the impact of water and nitrogen on maize crop. Significant responses of dry matter yield and agronomic traits were evident for both irrigation and nitrogen treatments at all locations. Nitrogen fertilizer application significantly increased dry matter yield at all locations. Initially intercepted PAR seemed to be increased by N fertilizer applications between 100 and 150 Kg N ha^{-1} while midseason PAR contributed a substantial increase during mid season. Quadratic responses of N uptake and NUE to nitrogen; and of nitrogen to phosphorus tissue contents were evident in dry matter yields while efficiency of N use steadily decreased with increased N fertilizer rates. Lower N uptake in dry matter yields was associated with limited soil moisture and lower N fertilizer status. The findings indicated that management of both water and nitrogen in this study can significantly influenced crop growth and development and also maintain the soil nutrient status.

INTRODUCTION

Maize (*Zea mays*) is the most important crop grown in summer by smallholder farmers in the Limpopo province of South Africa. It is also the staple food crop sustaining several rural communites in the province. In addition to its use as a crop for humans, the residue after grain harvest is the major feed for livestock during winter months when conditions of the natural grasslands are too poor for sustaining livestock production.

Despite its importance in the province, productivity of maize is low and continues to be marginal. The main identified reasons for low productivity are inadequate water and poor soil fertility, particularly in terms of nitrogen and phosphorous. Since smallholder farmers usually cannot afford adequate amounts of these resources, cost saving techniques on these resources is essential l for long-term sustainability in this farming system. South Africa is classified as a water-scarce country (Bruwer and Van Heerden, 1995) with most agroecological zones characterised by low and erratic rainfall, which subject crops to frequent water deficits during the growing season. In the Limpopo province, most parts receive an annual rainfall of about 500-mm. Thus, judicious use of water for agricultural production is essential for long-term sustainability.

The uncertainty about rainfall led to the development of several smallholder irrigation schemes for farmers in the province. However, even after the establishment of these schemes, maize production levels are still low and unsatisfactory. With rainfall being such a major limitation to crop production, full or supplementary irrigation remains an attractive technological approach to increase food and fibre production. Irrigation in South Africa uses approximately 51% of the total water resources (Backenberg and Oosthuizen, 1995). According to the Bruwer and van heerden (1995), 25 to 35% of the gross agricultural production in South Africa originates from irrigated agriculture. Since irrigation water is a scarce resource, increased output is feasible and sustainable only if the most efficient use is made of this resource in these irrigation schemes. Although, water is fundamental to plant growth and protection, excessive water can lead to certain unfavourable environmental conditions such as transport of herbicides and pesticides into surface waters, salt intrusion into the soil surface, leaching of mobile nutrients, particularly nitrate, soil erosion and overall land degradation (Fillery and Gregory, 1991; Sadler and Turner, 1994). Water use efficiency represents a given level of biomass or grain yield per unit of water used by the crop (Hatfield *et al.*, 2001). For improved water use efficiency, a proper co-ordination of water application and fertilizer management of these resources in crop production is critical (Cahudhury *et al.*, 1982). Russelle *et al.*, (1981), reported a considerable reduction in NO_3-N leaching with proper management of irrigation water application. Viets (1962) first described relationships between nutrients and water use efficiency and also observed that increases in water use efficiency come from improved plant growth and yield that are a result of a proper soil nutrient management.

Nitrogen is considered to be the most important plant nutrient due to its demand in greatest quantities by plants, and in the Limpopo province it is a major limiting nutrient in the smallholder farming systems. Given the economics of using N fertilizer in smallholder maize production systems, it is vital that the available N is used efficiently by the crop. An improvement of N use efficiency requires either an increase in crop use of applied N fertilizer or similar or improved crop productivity with a reduced application of N fertilizer. Appropriate management practices of inorganic fertilizer use can raise N-use efficiency (NUE). With sorghum production, Maranville *et al.*, (1980) defined NUE as biomass production per unit total aboveground plant nitrogen and as grain production per unit of total aboveground plants nitrogen. Response curves resulting from nitrogen fertilizer application are often used to derive

N requirements for crop growth. Van Keulen and Stol (1991) had suggested however, such recommendations, based on N fertilizer application alone have been found to be inadequate and an alternative procedure involving relationships between crop response to increased soil N availability (fertilizer application) as well as response to increase N uptake. With such an approach, differences in N supply from soil derived sources (the uptake at zero N application) and the differences in the recovery of applied N (the slope of N applied uptake regression) could be made. This is essential for making better nitrogen recommendations for farmers.

From the foregoing discussions, it is obvious that a clear understanding of the interactive effect of water and nitrogen is required if proper recommendations are to be made for farmers in these small holder irrigation schemes. The objective of this research was to:

1. assess the impact of reduced irrigation water application and nitrogen fertilizer on seasonal dry matter accumualation, nitrogen uptake and interception of photosynthetically active radiation.

MATERIALS AND METHODS

Study Area

Field studies were conducted during 1999 - 2000 growing season at three locations in the Limpopo province of South Africa: Adriaansdraai, Veeplaats both under smallholder irrigation schemes and at the University of the North experimental farm, at Syferkuil. The soil types were sandy loam of Orthic type at Adriaansdraai and Veeplaats and a sandy loam of Hutton form at Syferkuil. Before planting, land preparation was done by ploughing followed by disking and harrowing at all sites. The maize variety SNK 2147 was planted manually on 11 November at Adriaansdraai, 15 December at Veeplaats and 06 December 1999 at Syferkuil. To ensure plant density of 45 000 plants per hectare and even distribution of plants in the plot, plots were overseeded and later thinned out 10-12 days after emergence across locations.

Experimental Details

The experiments were laid out in a randomized complete block design (RCBD) in split plot arrangement with four replications. Water was assigned as the main plot factor with two levels of irrigation: (full =12 mm per application and half = 6 mm per application) while nitrogen was assigned to the subplot factor applied as Urea at rates of 0, 50, 100 and 150 Kg N ha $^{-1}$. At Adriaansdraai, the subplots consisted of 8 rows of 8 m length each while six rows of 6m length were maintained at Veeplaats and Syferkuil; all at 0.9 m inter-row spacing. Phosphorus was also applied to all experimental units at planting at a rate of 60 Kg P ha^{-1} using superphosphate fertilizer. The 12mm irrigation treatment was applied weekly for all the experimental units for 4 hours, whereas other plots were watered for 2 hours for the 6-mm treatment, using sprinklers. Total seasonal rainfall was also recorded at all locations. The total water applied for irrigation was 360 mm and 180 mm for full and half irrigation at Veeplaats, 336 and 168 mm at Adriaansdraai and 280mm and 140mm at Syferkuil for half and full irrigation treatments respectively. Irrigation treatments commenced 28 days after planting at Veeplaats and Adriaansdraai but 2 months later at Syferkuil due to rainfall received. Nitrogen was split-applied and incorporated into the soil using handhoe during planting and as side- dressing, 28 days after planting. Phosphorus was applied as superphosphate at 60 Kg P per hectare during planting. Hand weeding was done twice during the vegetative stage for each location while at Veeplaats pre-emergence herbicide was used. Parameters measured included: dry matter accumulation, photosynthetically active radiation (PAR), grain yields, yield components and stover yield.

Dry matter accumulation.

Above ground plant samples were taken at 56 and 78 DAP at Adriaansdraai ; 83 and 108 DAP at Veeplaats; 44 DAP and 66 DAP at Syferkuil during the growing season. Samples were taken from a total of 4 m^2 length per plot at Adriaansdraai and 12 m^2 at Veeplaats and Syferkuil respectively from each plot area from the ends of the middle rows, leaving two to three plants as borders. Plant samples were oven dried at 65 ^oC for several days. The samples were ground to pass through a 0.1 mm sieve and thereafter were analyzed for Nitrogen concentration using the Kjeldahl method (AOAC, 1990). Crop growth rate (CGR, $Kgha^{-1}\ d^{-1}$) was calculated as the difference in total above ground dry matter at two consecutive stages divided by the number of days elapsed between the two stages (Dwyer *et al*., 1993).

Soil analysis

Soil nitrogen, phosphorus and potassium contents were determined from samples taken prior to planting and also during the growing season from 0 -15 cm and 15 - 30 cm depths. Nitrogen was determined on an autoanalyzer by Kjeldahl while the Bray 1 (Molybdenum reagent) method was used to extract phosphorus from the soil at 1:5 soil water ratio. A spectrophotometer with light band was used to determine the concentration of phosphorus in the soil extract and potassium was determined by means of an atomic absorption spectrophotometer (Jackson, 1967). Soil pH for water and KCl was also measured using a pH meter.

Interception of Photosynthetically Active Radiation (PAR)

The amount of light intercepted by plant canopies was measured using an Accupar Linear ceptometer. Light measurements were taken from each plot at 63, 75 and 83 DAP at Adriaansdraai; 56, 75 and 83 DAP at Veeplaats and 44, 66, 83 and 106 DAP at Syferkuil once from above plant canopy and twice diagonally between adjacent rows from below the plant canopy. The readings were taken between 11am to 14h00 pm on days when clouds caused no interference. Mean values for each plot were then used to calculate the percentage PAR intercepted by the plant canopy of each treatment as follows: $\% \, PAR_i = (1 - [PAR_{a} / PAR_{a]})* 100$ (Carr *et al.*,1995) where the subscript i designates intercepted PAR, and subscripts a and b designate PAR above and below the plant canopy, respectively.

Stover yield

Stover yield was determined by harvesting five plants randomly from the harvested area and was weighed using a mass meter after drying in the field. The samples were ground to pass throgh a 1.0-mm sieve and were analyzed for nitrogen content in the laboratory using the Kjeldahl procedure.

Tissue N and P analysis

The adequacy of soil fertility is frequently evaluated by plant nutrient status. Total nitrogen concentrations in maize plant tissue were determined by the Kjeldahl method in digested samples. Before analysis, the plant tissue samples were dried at 65°C and ground to pass a through a 1.0 mm sieve. N uptake in individual treatments was calculated from nitrogen concentrations in the whole plant samples and the corresponding dry matter yield. Nitrogen use efficiency under the various treatments and its component traits were determined using the methods suggested by Maranville *et al.*, (1980), and was calculated as the total above ground dry matter divided by total nitrogen uptake in the dry matter. Phosphorus in each plant tissue was measured using a dry ash procedure (Hue and Evans, 1986).

Finally, all data were subjected to analysis of variance (ANOVA) using a statistical analysis program system (SAS) in order to detect the significant difference between treatment means (SAS, 1989). The means found to vary significantly ($P \leq 0.05$) were separated using Fishers protected Least significance Difference ($LSD_{0.05}$) test (Steel and Torrie, 1980). Regression analysis was used to examine models describing the effects of nitrogen rate and irrigation levels on the parameters previously mentioned (Moll *et al*., 1982)). Multiple regression was used to test the association among grain yield related traits. Nitrogen response functions were generated using the PROC REG procedure for linear and quadratic regressions (SAS. INST., 1995).

RESULTS AND DISCUSSION

Soil Nutrient status

Analysis of the soil samples taken prior to land preparation indicates that the experimental sites were very low in nitrogen and phosphorous at Adriaansdraai and Veeplaats whereas Potassium levels were adequate (Table 1). Nutrient levels were fairly high at the Syferkuil experimental station, particularly in nitrogen and this could be attributed to the long history of fertilization at the site. Soil pH status was within the range of neutrality at all locations, which is an important factor for nutrient availability to crop plants. The low soil fertility recorded at the farmers' fields, Adriaansdraai and Veeplaats is a common feature of major soils in the Northern Province and in South Africa as a whole. These low values are expected considering the sandy nature and low organic matter content of the soils as well as the general lack of external inputs in the farming system of smallholder farmers. Judicious use of inorganic fertilizer is an important management strategy for improved and sustained productivity of the soils.

Table 1 Soil pH and nutrient content during the 1999/2000 growing season.

Location	Depth	$pH_{(H_2O)}$	$pH_{(KCl)}$	Total N	P	K
	cm			....	$mg\ kg^{-1}$	....
Adriaansdraai	00-15	7.2	6.4	15.0	18.5	188.3
	15-30	7.4	6.5	20.0	25.9	99.5
Veeplaats	00-15	6.6	6.5	19.5	22.8	195.3
	15-30	7.0	6.6	20.0	25.9	103.5
Syferkuil	00-15	6.8	6.2	72.3	40	211.2
	15-30	7.1	6.5	69.6	38	110.5

Dry matter yield

Dry matter production was measured as an indicator of overall plant growth. Both irrigation and nitrogen fertilizer levels significantly ($P \leq 0.05$) influenced dry matter yields during the growing season at Adriaansdraai. Dry matter, sampled at 56 and 78 days after planting was increased by

12 and 20% respectively when plants received full irrigation compared to those that received half the amount of water (Table 2.1). Maize responds to N by increasing vegetative growth and the effect of nitrogen fertilizer on dry matter was evident. Under the half irrigation regime, the highest dry matter accumulations were generally attained under 100 and 150 kg N ha^{-1} at both sampling dates whereas at full irrigation, the highest dry matter yield accumulation at these dates occurred at 150 kg N ha^{-1} application. The highest response of dry matter to nitrogen under the full irrigation regime suggests that, further increase in maize growth response to an even higher N application than the maximum rate applied in this study might be possible. This assumption agrees with findings by Lemcoff and Loomis (1986) namely that higher maize dry matter yield could still be obtained with addition of nitrogen N even under conditions where neither nitrogen nor moisture was limiting.

At Veeplaats, the influence of irrigation on dry matter production at 63 and 83 days after planting were rather similar. However, the effect of nitrogen fertilzer application was fairly similar to that observed at Adriaansdraai (Table 2.2). Dry matter produced at 63 DAP generally increased with increasing N application under the full irrigation regime. With the exception of dry matter yield at 63 DAP under half irrigation, where nitrogen supply at 50 Kg N ha^{-1} improved dry matter production by 9% compared to 100 Kg N ha^{-1}, dry matter accumulation generally tended to increase with increasing N application as well. Both half and fully irrigated crops attained the greatest dry matter production at 150 Kg N ha^{-1}, which ranged from 36 to 54% and 36 to 38% higher respectively compared to the unfertilized plots. The lowest dry matter yields observed in nitrogen deprived plots, emphasizeds the importance of adequate nitrogen supply to the growth of maize plants in these irrigation schemes.

At Syferkuil, both irrigation and nitrogen influenced maize dry matter accumulation at 44 and 66 DAP. Pooled over nitrogen levels, plants receiving full irrigation produced 28 and 9% higher dry matter at the two sampling dates respectively than those receiving half the amount of water (Table 2.3). This is an indication of the significant role played by water on maize seasonal dry matter production. Regarding N fertilizer application, dry matter accumulation of all fertilized plots were similar under half irrigation but were on average 71 and 31% higher than the unfertilized plants at both 44 and 66 DAP respectively. Under full irrigation, the highest dry matter accumulation occurred at 100 and 150 Kg ha^{-1} at 44 DAP whereas dry matter accumulation at 66 DAP did not differ across the treatments. The lack of clear response of maize growth to nitrogen at Syferkuil comapared to the other locations could be attributed to the slightly higher levels of soil nitrogen levels at this location (Table 1).

During vegetative growth, nitrogen supply had a marked influence on dry matter production. Higher rates of dry matter production have been observed where nutrients and soil moisture were not limiting. On average dry matter was 25% higher in full irrigation regime at all locations relative to reduced irrigation. These results agree with findings by Frederick and Camberato (1995), where the authors reported that vegetative weights of wheat were generally higher under irrigated conditions, particularly at higher nitrogen rates.

Crop growth rate (CGR)

Crop growth was significantly influenced by both irrigation and nitrogen levels applied ($P \leq 0.05$) at Adriaansdraai. On average, CGR of fully irrigated plants were increased by 21% relative to those receiving half the amount of water (Table 2.1). With regard to nitrogen, a trend of increasing CGR with an increase in N supply was observed with the highest rate of 319 to 328 Kg ha^{-1} day^{-1} being achieved at 100 to 150 Kg N ha^{-1} application rates under half irrigation. The results support findings by Greef *et al.*, (1998) that 150 Kg N ha^{-1} of nitrogen resulted in the highest crop growth rate in maize production. However, under fully irrigated conditions, a clear linear trend in CGR could not be established even though plants receiving 150 Kg N ha^{-1} produced a very high growth rate but this was also similar to that of plants receiving 50 Kg N ha^{-1}. Regardless, nitrogen promoted CGR by 19% for both irrigation regimes respectively compared to where no nitrogen was applied. Stimulated growth rate by both water and nitrogen is likely due to enhanced photosynthetic activities under optimum conditions of these resources and hence higher biomass accumulation as reported earlier. The results support other research evidence that limited nitrogen conditions in maize resulted in minimum crop growth rate compared to nitrogen fertilized conditions (Greef *et al.*, 1998).

At Veeplaats, (Table 2.2) the effect of both irrigation and nitrogen was non-significant on crop growth rate and linearity with N application was inconsistent at both irrigation regimes. However, there was a general tendency of higher growth rate with increasing N application under both irrigation regimes.

At Syferkuil, (Table 2.3) crop growth rates of plant receiving half irrigation were more accelerated compared to fully irrigated crops. In terms of nitrogen fertilizer application, CGR increased linearly with additional N fertilizer applied with the greatest rate of 463 Kg ha^{-1} d $^{-1}$ occuring at 150 Kg N ha^{-1} under half irrigation. This was different with full irrigation where the highest rates occurred at both 100 and 150 Kg N ha^{-1}. Without nitrogen fertilizer, CGR was significantly lower than with the application of any rate of N fertilizer.

Stover yield

Both irrigation and nitrogen treatments significantly influenced stover yield at Adriaansdraai and Veeplaats (Table 2.1 and 2.2). Stover yield was siginificantly hiher at 150 Kg N ha^{-1} at both locations under full irrgation regimes. At Syferkuil (Table 2.3), similar amounts of stover yields were produced regardless of irrigation and fertilizer N application levels. Comparing late season dry matter accumulation and stover yields at Veeplaats and Syferkuil under both irrigation and nitrogen levels, stover yields were significantly lower, suggesting the possibility of carbohydrate remobilization during the grain filling stage at these locations. Movement of stored carbohydrate from maize shoots during the linear stage of grain fill had been reported (Shanahan and Nielsen, 1987). Similar to dry matter yields, stover yields tended to be higher under full irrgation relative to half irrigation regime. Since maize grain is an outstanding feed for livestock, high in energy, low in fibre and easily digestible (Purseglove, 1972), production of more stover can be used for this purpose in the irrigation schemes and other parts of the province.

Percentage light interception

Photosynthetically active radiation (PAR) is an essential measurement for assessing the health status of the plant canopy. PAR measurements indicate the extent of useful light that is available to plants for photosynthesis. At Adriaansdraai, significant effects ($P \leq 0.05$) of both irrigation and nitrogen on amounts of light intercepted by the maize crop were detected at 44 DAP (Fig 2.1). On average, plants receiving half irrigation intercepted more solar radiation than those receiving full amount at this date but the percent interception between these two groups of plants were similar by 83 DAP (Fig 2.1). This is an indication of rapid canopy development of the fully irrigated plants after 44 DAP to cover the ground surface and capture maximum amounts of light. The influence of nitrogen on the interception of photosynthetically active radiation at this location differed with the level of irrigation water applied. Under half irrigated condition, significant N effect was only detected at 83 DAP with unfertilzed plants intercepting about 20 percentage point lower than the average interception of all the fertilized plants (Fig 2.1). Under fully irrigated conditions, differences in light interception due to nitrogen was recorded at 44 DAP and not at 83 DAP. The highest PAR interception at 44 DAP occurred at 150 kg N application under this irrigation regime.

At Veeplaats, the effect of irrigation on PAR interception was nonsignificant at both 56 and 83 DAP whereas nitrogen influenced the interception at 56 DAP but not at 83 DAP. At 56 DAP the highest PAR interception generally occurred in plants receiving 100 kg or more nitrogen per hectare (Fig 2.1).

At Syferkuil, (Fig 2.1), the effects of both irrigation and nitrogen were similar at each sampling date even though there was a tendency of higher interception at 100 Kg N ha^{-1} application rate at both 44 and 83 DAP except under half irrigation at 44 DAP. Lack of significant effect of nitrogen could again be attributed to the relatively higher levels of soil nitrogen at this location compared to Adriaansdraai and Veeplaats.

The generally high levels of PAR interception due to N at Adriaansdraai and Veeplaats emphasize the importance of this factor to crop canopy development. Nitrogen is essential for chlorophyl development, which is required for the conversion of light energy to chemical energy during photosynthesis and subsequent dry matter accumulation (Lemcoff and Loomis, 1986). Higher PAR interception could partially explain the high dry matter accumulation recorded under well-fertilized plants. Leaf senesce is also another plant characteristic that is tightly linked to nitrogen stress. Less illuminated leaves tend to senesce earlier and thus contribute much less to overall plant productivity (Marshner, 1995).

On average, light interception increased between 44 to 83 DAP, at all locations, namely: 25, 164 and 52% at Adriaansdraai, Veeplaats and Syferkuil respectively. The primary effect of lower light interception earlier in a growing season is reduced photosynthesis, which could also reduce assimilate supply for yield development. The amount of light intercepted during the midseason, however, enhanced additional accumulation of dry matter. The findings support the conclusion that light plays a critical role in promoting growth (Liang and Mackenzie, 1994). Increased dry matter and solar radiation absorption were observed when water and fertility were not limiting, suggesting that canopy photosynthesis and dry matter partitioning is dependent upon solar radiation.

Nitrogen uptake

Plant nitrogen uptake at the end of the vegetative growth stage was significantly influenced by applied fertilizer nitrogen at the irrigation schemes. Linear responses to increasing N supply for above-ground plant N content were observed under full irrigation regimes whereas under reduced irrigation the responses were quadratic at all locations (Fig. 2.2). Janzen and Schaalje, (1992) reported a strong linear relationship between N uptake and N fertilizer application. No strong relationship was however observed at Syferkuil, (Fig 2.2), under full irigation. Generally the coefficient of determination (R^2) across these locations ranged from 0.85 to 0.99 which indicates very strong relationships between nitrogen fertilizer application and plant N uptake in maize.

Under half irrigation, the peak N uptake occurred at 100 Kg N ha^{-1} at Adriaansdraai, (Fig 2.2) and Syferkuil (Fig 2.2) and at 100 and 150 Kg N ha^{-1} at Veeplaats showed a positive response to nitrogen with the highest uptake attained at 150 Kg N ha^{-1}. The linear relationship observed under full irrigation indicates that additional application of nitrogen beside 150 Kg N ha^{-1} could have increased N uptake levels. In contrast, N uptake was higher under nitrogen-deprived conditions in fully irrigated crops indicating that N uptake is enhanced by ample supply of moisture. N uptake was also lower at nitrogen deficient plots under both irrigation regimes indicating that the availability of plant nutrient to crops depends on nitrogen availability in the soil. Thus, a thorough understanding of interaction between soil moisture availability and nutrient status on farmers' fields is critical to improve crop productivity.

Nitrogen Use Efficiency (NUE)

NUE response to nitrogen fertilizer application at the onset of the reproductive stage generally declined linearly or quadratically with increasing levels of applied fertilizer nitrogen for both irrigation regimes at Adriansdraai and Veeplaats (Fig. 2.3. NUE was enhanced under nitrogen deprived crops for both irrigation regimes. Related studies have also reported that NUE was at maximum at low levels of applied N and declined rapidly with increasing amounts of applied N (Hatfield *et al.*, 2001; Eagle *et al.*, 2000; Buah *et al.*, 1998; Fischer, 1993).

At Syferkuil, (Fig. 2.3) there was an increasing response of NUE with added nitrogen fertilizer rates under both irrigation regimes. The most fertilized crops resulted in a maximum use of nitrogen particularly under full irrigation. NUE was greatest at each level of added nitrogen fertilizer under full irrigation relative to half irrigation indicating that nitrogen was used more efficiently in well-watered plants at this location. However, reports of increasing NUE with increasing N supply are rare.

Generally, these results demonstrated that limited moisture was associated with lower values of N uptake and NUE that resulted in contrasting response on both N uptake and NUE (Fig 2.3 and 2.4). The gradual increase in NUE might be the result of a reduction in N uptake. The decrease in NUE with increasing fertilizer N rates is consistent with other research studies (Zweifel *et al*., 1987). These findings tend to support the fact that NUE is the inverse of plant N content whereby more plant N results generally in lower NUE values. This relationship occurs because plant N content increases proportionally more than dry matter production with increased fertility.

Relationship between N uptake and dry matter yield

There was a positive effect of N uptake on dry matter yields at all locations. Under both irrigation regimes, N uptake rose linearly as the application of nitrogen fertilizer rate increased (Fig. 2.5). The magnitude of variation among R^2 of the regression equations was small, indicating that the relationship between N uptake and dry matter yield was highly consistent across these locations. Full irrigation regime at Adriaansdraai (Fig 2.4) enhanced vegetative growth with more N uptake than in half irrigated conditions. Surely, nutrient absorption is enhanced by the availability of moisture and hence adequate soil water supply is critical for mineral uptake. The tendency of improvement in dry matter yields with rising N uptake was an indication of transfer of nitrogen fertilizer application to the vegetative parts. Thus, total N uptake was largely a reflection of dry matter accumulation at all locations. According to Pan *et al*., (1986), and Osaki, (1995), enhanced N uptake during grain filling might reflect the ability of the plant to supply the root system with assimilates that assist in both root growth and N uptake.

Relationship between NUE and dry matter yield

Lower levels of NUE promoted dry matter yields at both irrigation regimes whereas the highest NUE suppressed growth at Veeplaats (Fig 2.5). At Adriaansdraai (Fig 2.5), NUE was sustantially higher under half irrigation regime ($R^2 = 0.79$) compared with that for fully irrigated crops ($R^2 = 0.41$). However, the ($R^2 = 0.74$ and 0.80) implies that NUE had a remarkable impact on dry matter production under half and full irrigation regimes at Veeplaats. There was no apparent response of dry matter to NUE under half irrigation regime however, fully irrigated crops showed reduced dry matter with an increase in NUE at Syferkuil (Fig 2.5). NUE for total biomass production decreased linearly as N application rate was increased like in the sorghum study by Buah *et al.*, (1998). Consequently, lower NUE crops had higher yields than the high NUE crops averaged across the fertility levels.

Dry matter tissue P concentration and Nitrogen fertilizer

Dry matter P concentration showed a quadratic response as fertilizer N rates increased (Fig. 2.6). P content in maize plant tissue gradually increased with added nitrogen fertilizer at all locations. The highest P content at each level of N fertilizer applied was evident at Syferkuil. The regression R^2 values are relatively higher at Veeplaats ($R^2 = 0.\ 99$) and Syferkuil ($R^2 = 0.\ 98$) than at Adriaansdraai ($R^2 = 0.\ 55$). These results are supported by findings of Kamprath (1987) who reported that N supply was the main factor affecting P content of maize plants on soils that were low in available Phosphorus. Thus, enhanced phosphorous uptake in plants occurs when avialable N to the plants is not limiting. The P content values observed in this study are comparable with those reported by Gordon and Whitney (1995) which ranged from 0.35 to 0.37%. Lower dry matter yields were associated with lower P values. Numerous studies have also demonstrated a reduction of photosynthesis when plants are subjected to P stress (Foyer and Spencer, 1986; Freeden *et al.*, (1989); Rao and Terry, 1989; Usada and Shimogwara, 1991).

CONCLUSIONS

Application of adequate amounts of water stimulated maize growth by increasing dry matter production and accelerating the crop growth rate. Nitrogen fertilizer also played a dominant role in dry matter production of maize at all locations. Thus, with irrigation, nitrogen appeared to have been more efficiently used. Application of nitrogen fertilizer, 150 Kg N ha^{-1}, resulted in more dry matter production that can be useful as a livestock feed after harvest or alternatively, if left in the field, will maintain organic matter as soil cover in this province. Research has shown that leaving cereal stover in fields provides a physical barrier to soil movement, allows soil organic matter to accumulate and increases soil pH, total N and crop yields (Mokwunye and Batiano, 1991). The data demonstrated that mineral N could substantially enhance dry matter and N uptake when applied in abundance.

Additional N from nitrogen fertilizer caused appreciable increases in tissue N and P content, N uptake under both half and full irrigated conditions; however, additional N from the highest rates of fertilizer application led to a decline in NUE. Therefore, optimizing N application rates with soil test levels and crop needs are crucial, to avoid high levels of nitrate in the profile. Nevertheless, with continuos cropping, addition of N may be necessary to obtain acceptable yields at the irrigation schemes. Management of nitrogen and water availability to satisfy maize demands was important for attaining desired yields goals and influencing the crop water and nitrogen use efficiency, plant tissue nitrogen content and uptake. Overall, the results of this study support the well-established idea that there is a tendency for the N concentrations in maize grain to increase in response to additions of N that increase yields.

Both nitrogen fertilizer and availability of moisture enhanced growth parameters of maize with an increase in crop growth rate, dry matter production, agronomic characteristics and crop growth height. Regarding the importance of water and nitrogen in the irrigation schemes for crop productivity, management practices should be strictly followed to avoid overirrigation and minimize leaching of nutrients for sustainable environment. Application of fertilizers, especially nitrogen, should match the crop's requirements. Furthermore, appropriate timing of application should be taken into consideration.

Table 2.1 Effects of irrigation water and nitrogen fertilizer rate on dry matter yield, crop growth rate and stover yield at Adriaansdraai in 1999/2000 growing season.

Irrigation	Nitrogen	Seasonal Dry matter 56 DAP	 76 DAP	Crop Growth Rate	Stover yield 146 DAP
		Kg ha^{-1}		Kg ha^{-1} d^{-1}	Kg ha^{-1}
Half	0	3099.b	7311c	153d	9967g
Half	50	2410.c	89150c	2446c	10639e
Half	100	4000b	9647b	319b	11799cd
Half	150	3307b	9340b	328ab	10289fg
$\bar{x}$		3204	6703	261	10674
Full	0	2373c	9425	281bc	12794b
Full	50	2984c	9985	328ab	11806c
Full	100	3823b	10336b	284bc	11128de
Full	150	5215a	12493a	374a	1306a
$\bar{x}$		3599	10560	317	12197
LSD(0.05)		988.1	1494	53	624
CV(%)		28	15	189	23

LSD= Least significant difference

CV = Coefficient of variation= nonsignificant ($P \leq 0.05$.)

DAP = Days after planting

Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$.)

Table 2.2 Effects of irrigation water and nitrogen fertilizer rate on dry matter yield, crop growth rate and stover yield at Veeplaats in 1999/2000 growing season.

		Seasonal Dry matter		Crop Growth Rate	Stover yield
Irrigation	Nitrogen	63 DAP	83DAP		134 DAP
		Kg ha^{-1}		Kg ha^{-1} d^{-1}	Kg ha^{-1}
Half	0	8026e	10868d	135	6397c
Half	50	11009ab	13235b	106	8272b
Half	100	10062c	13069b	155	8883b
Half	150	12318a	14872a	122	8428b
$\bar{x}$		10354	13011	130	7995
Full	0	8954d	11051c	94	8717b
Full	50	9408d	12512b	112	7889bc
Full	100	11296b	12812b	109	9033b
Full	150	12355a	15014a	168	11300a
$\bar{x}$		10503	12847	121	8985
LSD$_{(0.05)}$		660.6	1312.3	ns	1495
CV(%)		9.1	9.7	44.8	16.5

LSD= Least significant difference

CV = Coefficient of variation

ns= nonsignificnt ($P \leq 0.05$.)

Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$.)

Table 2.3. Effects of irrigation water and fertilizer nitrogen rate on drymatter yield, crop growth rate and stover yield at Syferkuil in 1999/2000 growing season.

		Seasonal Dry matter		Crop Growth Rate	Stover yield
Irrigation	Nitrogen	44 DAP	66 DAP		154 DAP
		Kg ha^{-1}		Kg $ha^{-1}d^{-1}$	Kg ha^{-1}
Half	0	1830d	9287c	308	6919
Half	50	2443cd	11238ab	375	7617
Half	100	3058c	11992ab	418	7303
Half	150	3875c	13317ab	463	7019
$\bar{x}$		2805	11459	391	7215
Full	0	1905d	10472ab	280	7611
Full	50	3274c	11093ab	339	8869
Full	100	4229ab	11058ab	412	7561
Full	150	4967a	13646a	398	8175
$\bar{x}$		3594	11567	357	8054
$LSD_{(0.05)}$		1900.8	27786	ns	ns
CV(%)		26.8	1.5	2.1	27.2

LSD= Least significant difference

CV = Coefficient of variation

ns= non significant ($P \leq 0.05$.)

DAP= days after planting

Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$.)

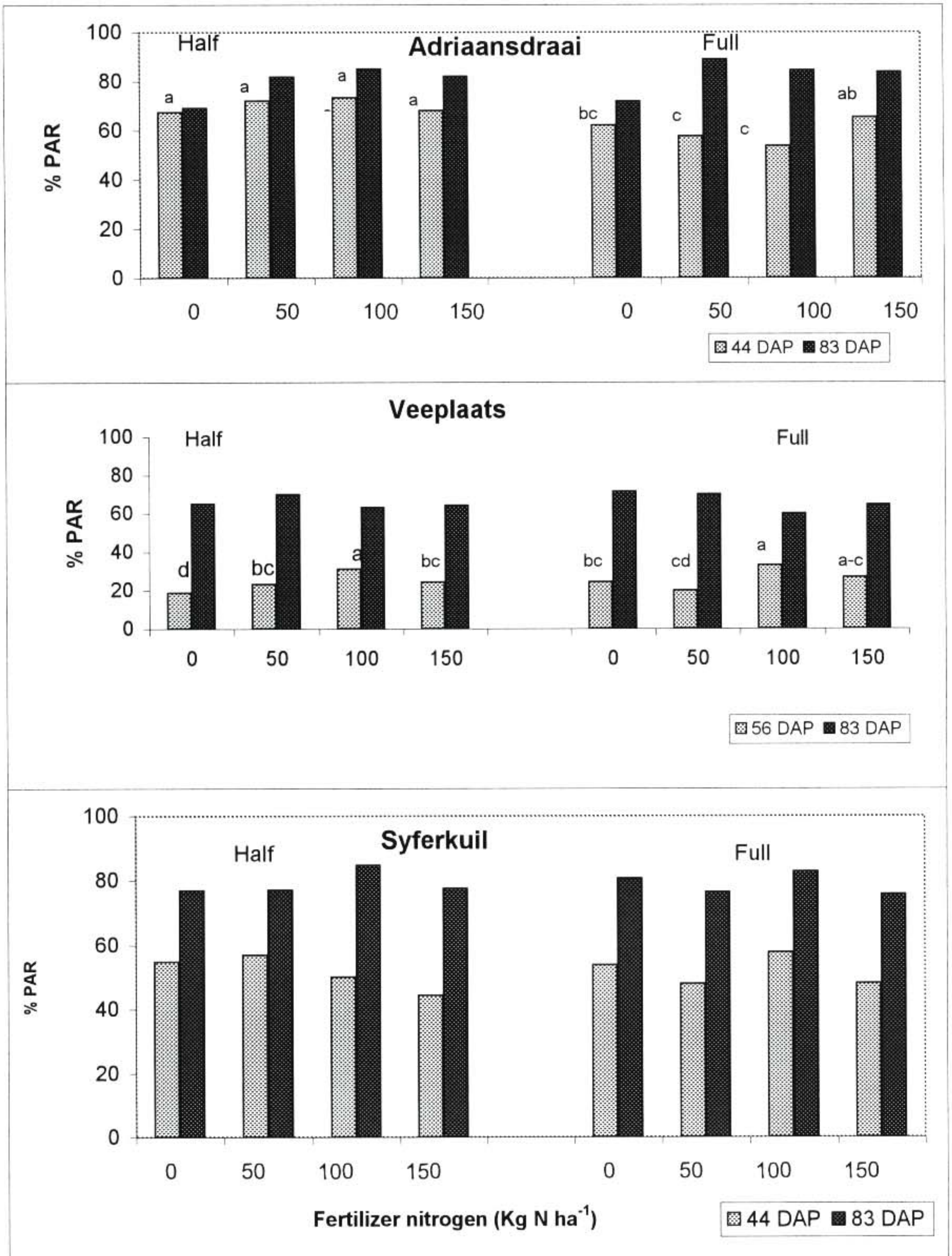

Fig 2.1 Fertilizer nitrogen rate effects on % PAR in maize under two irrigation regimes at Adriaansdraai, Veeplaats and Syferkuil in 1999/2000.

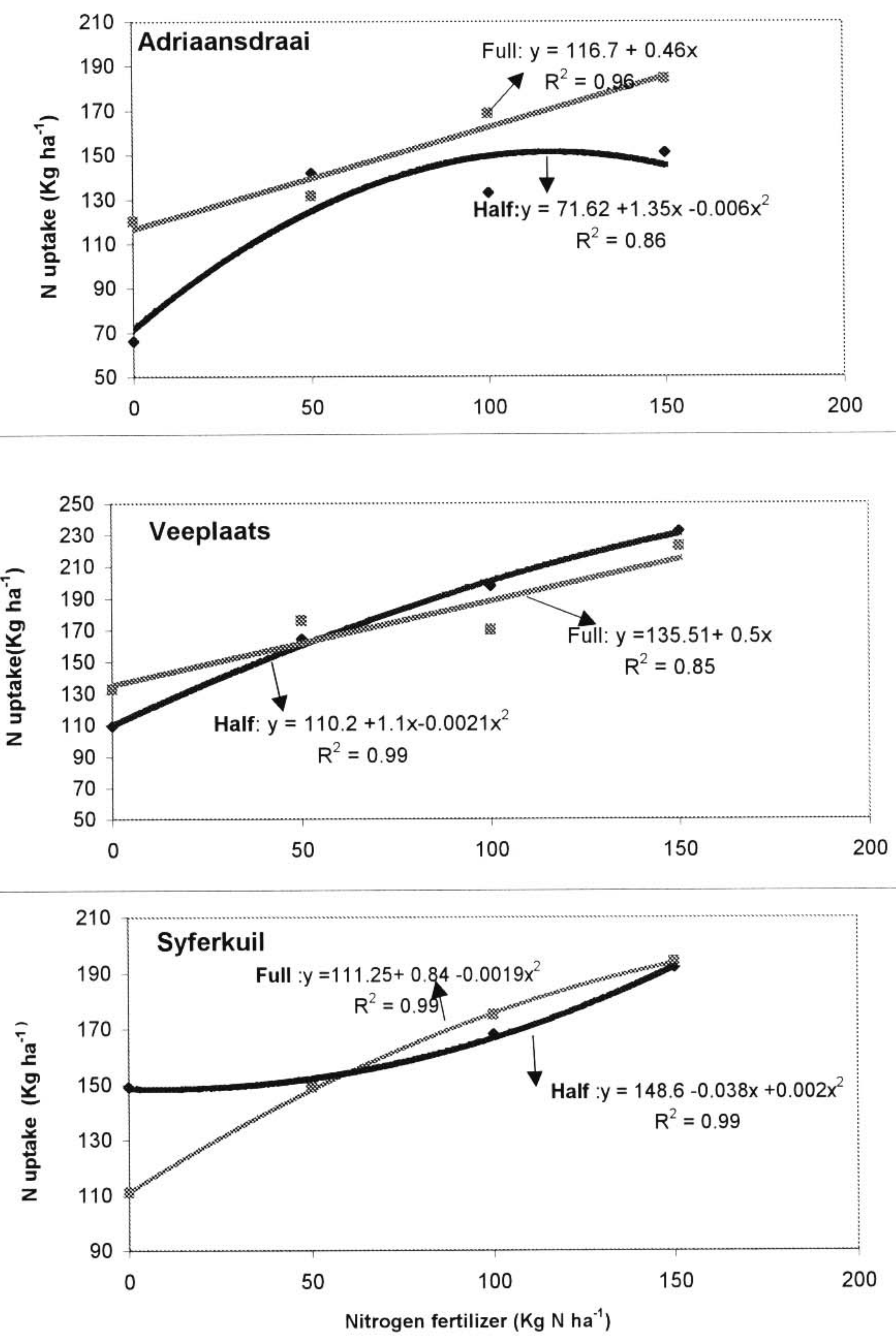

Fig 2.2 Nitrogen fertilizer application rate effects on N uptake in maize dry matter under two irrigation regimes in 1999/2000.

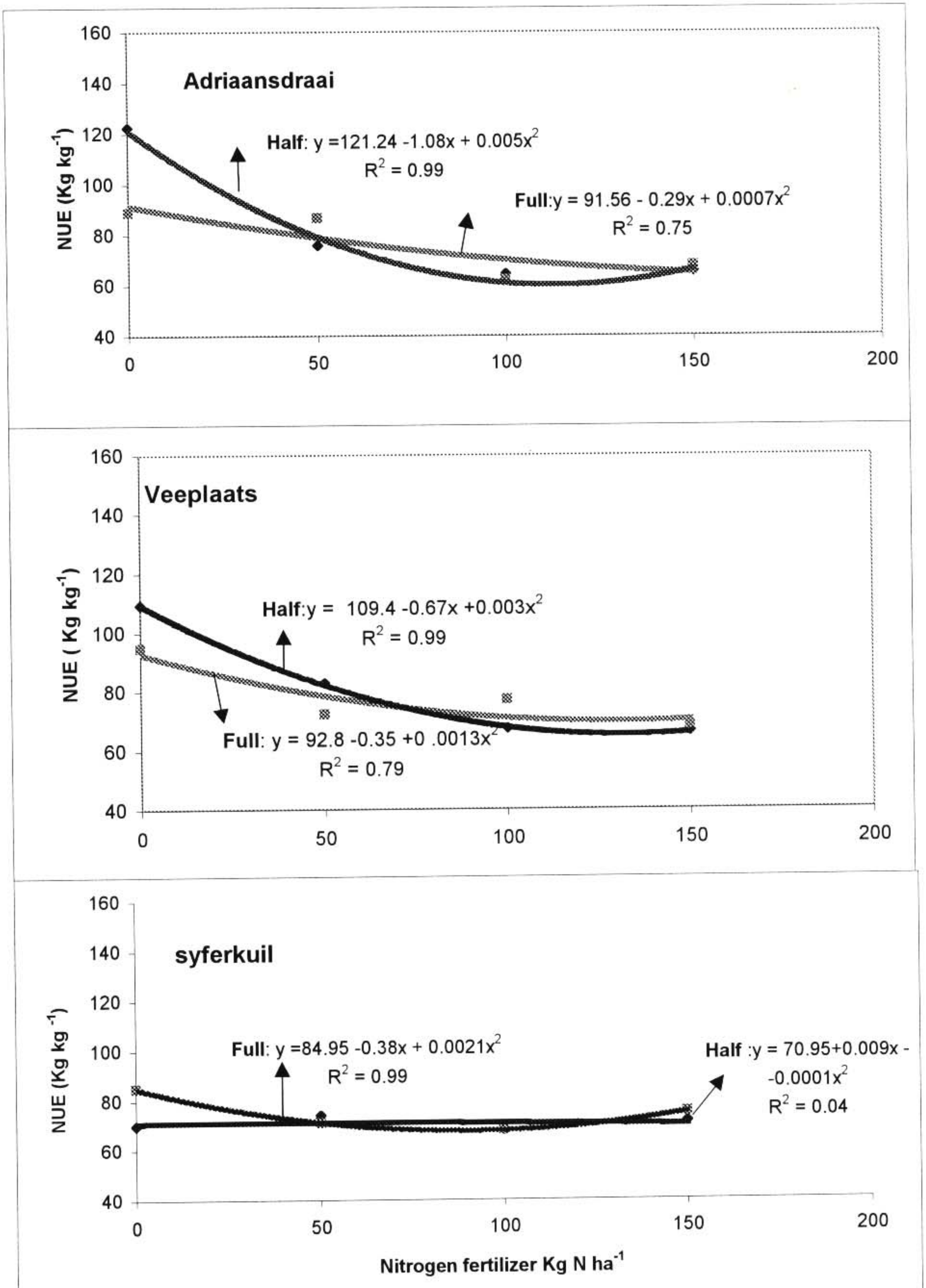

Fig 2.3 Nitrogen fertilizer effect on nitrogen use efficiency in dry matter under two irrigation regimes in 1999/2000.

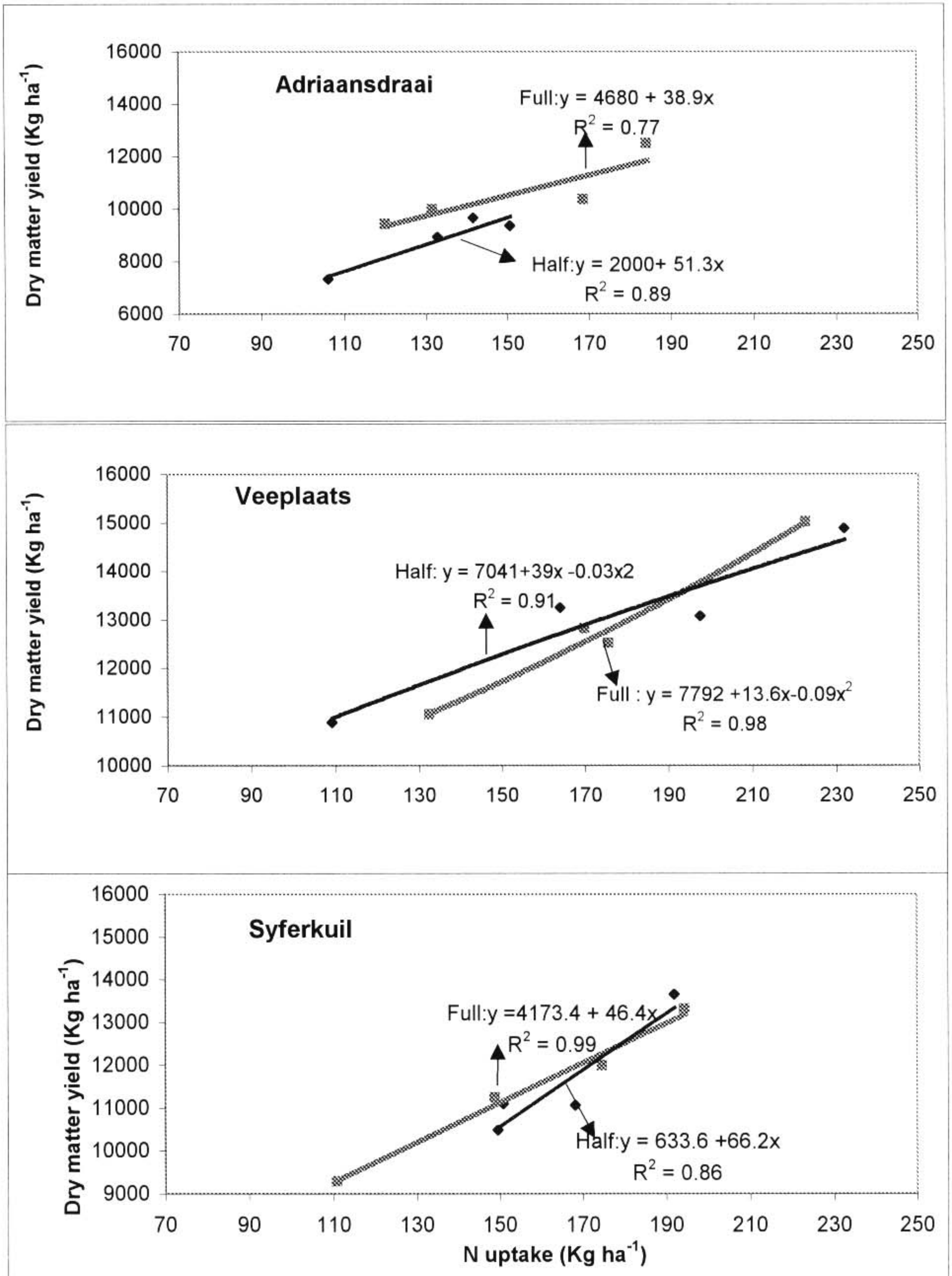

Fig 2.4 Relationship between N Uptake and dry matter yield under two irrigation regimes at Adriaansdraai, Veeplaats and Syferkuil in 1999/2000.

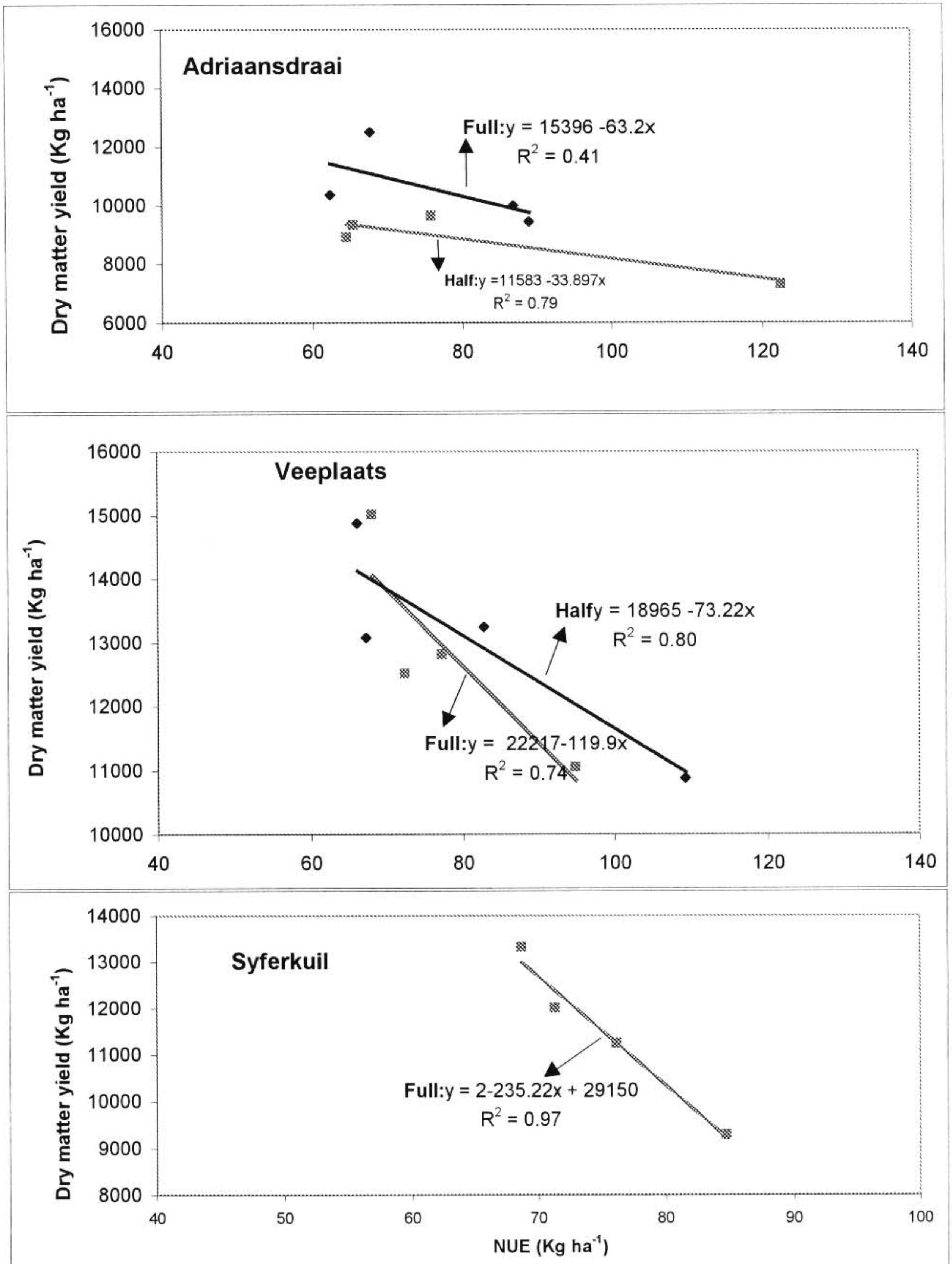

Fig 2.5 Relationship between NUE and dry matter yields under two irrigation regimes at Adriaansdraai, Veeplaats and Syferkuil in 1999/2000.

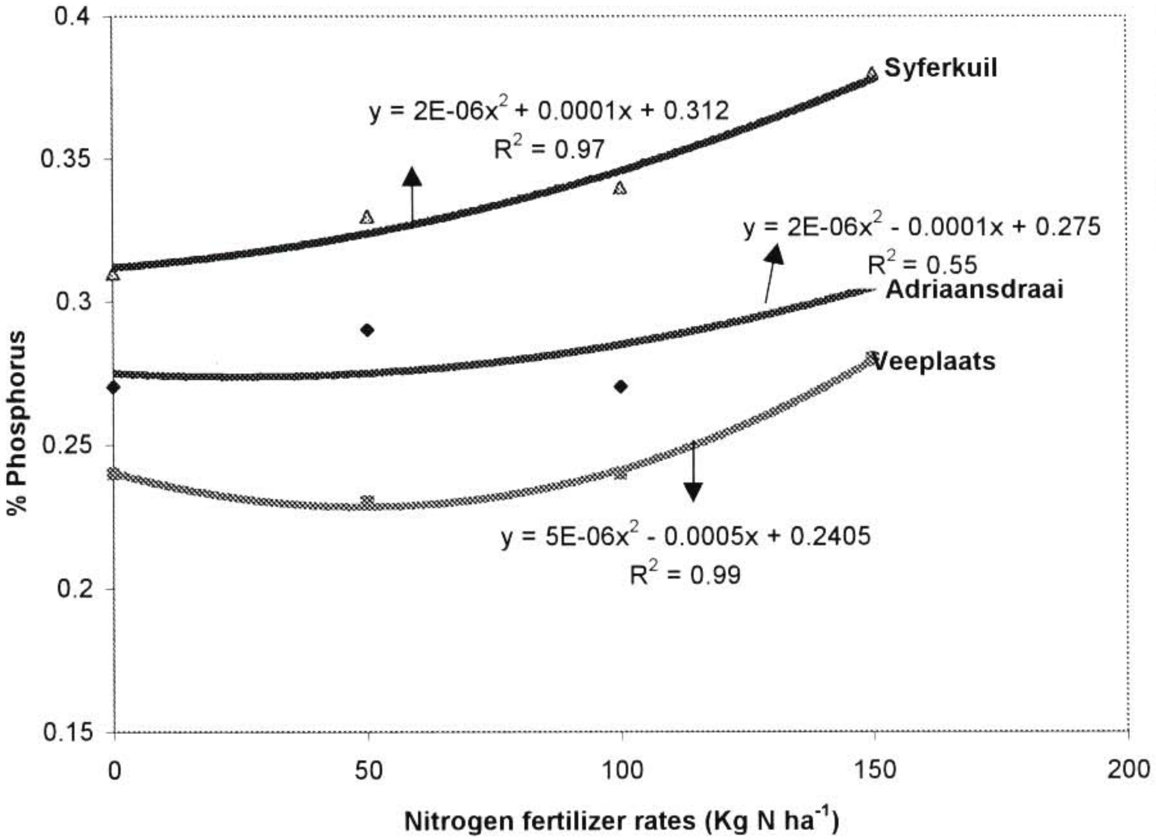

Fig 2.6 The relationship between nitrogen fertilizer rate and tisssue phosphorus concentration at Adriaansdraai, Veeplaats and Syferkuil in 1999/2000.

CHAPTER 3

INTERACTIVE WATER AND NITROGEN EFFECTS ON GRAIN YIELD, YIELD COMPONENTS AND AGRONOMIC TRAITS OF MAIZE.

ABSTRACT [259 words]

The Limpopo province of South Africa is a semi arid region and it is vital for farmers to optimize water and nutrient use and minimize input cost to enhance and sustain productivity. Irrigated experiments on maize at three locations were conducted to determine optimum nitrogen fertilizer levels and assess the impact of reduced irrigation grain yield and its components, agronomic characteristics and efficiency of water use in the schemes. The effect of irrigation water was nonsignificant for grain yield at all locations, though more water appeared to be efficiently used under a reduced irrigation regime. Quadratic grain yield responses to N fertilizer were observed at all locations under both irrigation regimes, and the highest maize yields were obtained between 100 and 150 Kg N ha^{-1}. Without nitrogen fertilizer, maize crops depicted severe chlorotic stress symptoms, which reduced crop growth, dry matter production and grain yield. Several grain yield components responded significantly to both irrigation and nitrogen treatments at all locations. The increase in grain yield was mainly connected to N fertilizer applied and the response of plants to increase kernel number and number of cobs. Dry matter accumulation due to increased N uptake and PAR interception during grainfill, also contributed significantly to increased grain yields. The economic optimum N rate appeared to be 100 and 150 Kg N ha^{-1}. Applying up to 150 Kg N ha^{-1}, could be beneficial for increasing grain yield in the studied areas. Optimal management of irrigation water usage as well as nitrogen fertilizer application is essential for obtaining maximal returns in the areas studied.

INTRODUCTION

Among environmental factors, water availability is the most limiting factor for crop production on a global basis due to its direct effect on crop productivity. Nitrogen application is a known necessity in crop production and water shortages can enhance the negative impact on N shortages on productivity. Sound management practices in terms of N application and water usage are essential to sustain crop growth and yields in the smallholder irrigation schemes under investigation.

Rainfall variability constitutes the uncertain characteristic of agriculture in South Africa, while adequate precipitation does not always coincide with critical crop growth stages. The demand for irrigation therefore is increasing in most of the crop production areas in South Africa in order to remove some of the risk involved. However, water is becoming scarcer and more expensive to farmers. Hence, efficient use of water is becoming a more important consideration in crop production systems than the availability thereof.

In agricultural terms, water use efficiency is generally defined by Viets, (1962) as WUE = crop yield (usually the economic yield)/water used to produce yield. Water use efficiency can be improved through nitrogen management, which in turn, influences yield components like grain number per unit area. In a study conducted by Gardner, (1983) water use efficiency was found to increase with the addition of nitrogen fertilizer. Varvel (1995) found that adding N fertilizer increased water use efficiency in grain sorghum. Smika *et al.*, (1965) found a similar response for native grasses as did Campbell *et al.*, (1992) for wheat and Varvel, (1994) for maize.

To increase and maintain sustainability of crop yields in this province, available water should be efficiently utilized. Water use efficiency which provides a simple means of assessing whether yield is limited by water supply or other factors (Angus and Van Herwaarden, 2001). Increased water use efficiency is of greatest interest to growers when yields are maximized for the available water supply during the growing season. Sinclair and Muchow, (2001) documented that economic benefits from increased water use efficiency under limited water conditions are usually achieved only if yield is maximized for available water

In addition to water, mineral nutrition is also a major determinant of maize productivity in the smallholder irrigation systems. Maize is a popular crop forming a wide range of local dishes in the province and with the availability of nitrogen fertilizers it enjoys a boom as a cash crop because it is more nitrogen responsive than the other cereals, millet and sorghum (Winslow, 1991). Nitrogen is the major nutrient required by maize crop for higher grain yields, the key resource in influencing the phytomass and grain productivity of maize (Bratia and Mitra, 1990) and also a dominant factor affecting plant chlorophyll, a content which is generally related to yield (Reeves *et al*., 1993). Because the available nitrogen is limited in most soils, inorganic nitrogen fertilizers are usually applied to maize (Sallah, 1991).

The application of inorganic fertilizers to crops therefore provides a more direct means of using nutrition to reduce the severity of many diseases and thus increases yield. All cultivated crops respond to nitrogen fertilizer by increase in grain yield especially in the presence of ample supply of water, which depends on the level of water availability (Pala *et al*., 1997). In a maize field study yield increase induced with nitrogen supply was the result of either increased partitioning to the grain, increased total dry matter production, decreased percentage of aborted kernels or increased number of ovules at anthesis (Simiciklas and Below, 1992). Surely, high crop yields require high levels of nitrogen and without adequate nitrogen, crop yields will not meet the food requirements of the human population resulting in poverty and of malnutrition.

Numerous investigations on maize yield responses to nitrogen treatments (Lemcoff and Loomis, 1986; Muchow and Sinclair, 1998) verified that nitrogen plays a dominant role in enhancing crop yield. Growth and yield components of maize are enhanced by nitrogen fertilization with an increase in kernel number, number of ears per plant, plant height, dry matter production and grain/stover ratio (Ulger *et al*., 1997). When other factors are not limiting, particularly water, grain yields are approximately proportional to the amount of nitrogen made available to the plant (Chatterjee and Nair, 1990). It has been emphasized by Sinclair, (1990); and Sinclair *et al*., (1995), that increasing maize yields has been closely associated with increasing amounts of nitrogen applied to the crop.

On the other hand, Rengel and Graham (1995) noted that nutrient deficiency shortens the time to maturity and may decrease the length of the physiological stage. Nitrogen deficiencies seriously reduce yield and economic returns for farmers in these small holder irrigation schemes. Bacci *et al*., (1991) reported that nitrogen shortage diminished grain yield by reducing both kernel number and kernel weight by 9 and 25 % and 14 and 80 % respectively relative to unstressed plants.

The poor maize yields in the province due to the low and unstable yield potential of the available production technologies as well as dominant unfavorable climatic and soil conditions need serious research interventions. To increase maize grain yields and maintain sustainability in crop production through judicious use of available resources, in particular water and nitrogen, accentuated the need for this study. The objectives of the research therefore were:

1. To determine optimum nitrogen for maximum maize grain yields and
2. To assess the impact of reduced irrigation on maize yields and efficiency of water use in these smallholder irrigation schemes.

MATERIALS AND METHODS

Study area and experimental details are the same as reported in chapter 2.

Grain yields and yield components.

Grain was harvested after physiological maturity at 167, 170 and 187 days after planting at Adriaansdraai, Veeplaats and Syferkuil respectively. At final harvest 25 m^2 at Adriaansdraai, 12 m^2 area at Veeplaats and Syferkuil was manually harvested from each experimental unit to determine grain yield, cob weight, number of kernels per cob, kernel number per row and 100 seed mass. Plant height in each plot was measured right after harvest (Ulger *et al*., 1997). Harvested area for each location had a minimum distance of 0.9 m from the plot border to minimize border effects. Each grain bearing ear was machine shelled and oven dried at 65°C.

Water Use Efficiency (WUE)

Water Use Efficiency is generally defined (Viets, 1962) as:
WUE= Crop yield (usually economic yield)/ water used to produce yield, but in this study WUE was calculated as WUE= Crop yield (usually economic yield)/ applied irrigation water.

Harvest index (HI)

Harvest index was computed as the ratio of economic yield to biological yield *100 where economic yield = grain yield and Biological yield = grain yield + stover yield (Donald and Hamblin, 1976)

Agronomic traits

Days to tasseling, assessed by the emergence of tassels from the upper most leaves; anthesis, measured as the emergence of anthers from the spikelets of the tassel; silking indicated by the appearance of silks at the tip of the husks of the ear were recorded when 50 % of the plants in each plot had reached these stages.

Plant height

Maize crop height was measured during vegetative stage at 75 DAP (Adriaansdraai), 83 DAP (Veeplaats) and at 66 DAP (Syferkuil) and right after harvest. Measurements were taken from an average of ten plant samples from each experimental unit using a measuring tape.

Chlorosis

A major symptom of nitrogen deficiency that is mainly depicted by the yellowing of leaves was visually scored for all plots.

Scores	Description
1	No chlorosis
5	Severe chlorosis

Finally, all data were subjected to analysis of variance (ANOVA) using a statistical analysis program system (SAS) to detect the significant differences between treatment means (SAS, 1989). The means found to vary significantly ($P \leq 0.05$) were separated using Fisher's protected Least significance Difference ($LSD_{0.05}$) test (Steel and Torrie, 1980). Regression analysis was used to examine models describing the effects of nitrogen rate and irrigation levels on the parameters previously mentioned (Moll *et al*, 1982).

RESULTS AND DISCUSSION

Grain yield

Irrigation did not influence grain yields significantly at Adriaansdraai and Syferkuil as the impact of irrigation on grain yields was similar regardless of irrigation levels at these locations. The effect of irrigation at Veeplaats (Fig 3.1) could not be determined due to the premature harvest of the fully irrigated treatment by a farmer. As such, the Veeplaats results only focus on the nitrogen fertilizer effect on yield parameters measured. The lack of a significant irrigation effect is contrary to results obtained on seasonal dry matter accumulation where irrigation had a significant effect at all locations. However, highly quadratic significances ($P \leq 0.05$.) in grain yield responses to nitrogen fertilizer were observed at all locations irrespective of the amount of irrigation water applied. At Adriaansdraai and Syferkuil (Fig 3.1, peak grain yields of 3200 to 3299 and 4222 to 4246 kg ha^{-1} under full irrigation was obtained at 100 and 150 Kg N ha^{-1} nitrogen fertilizer applications respectively and the mean yields were statistically similar at these levels of application. On average, addition of 100 and 150 kg N ha^{-1} nitrogen under full irrigation resulted in yield increases of 34 and 9%, relative to unfertilized plants at Adriaansdraai and Syferkuil, respectively. Under half irrigation, nitrogen fertilizer application for optimum grain yield production occurred at 100 Kg N ha^{-1} at Adriaansdraai whereas at Veeplats and Syferkuil, the optimum level was observed between 100 and 150 Kg N ha^{-1}. Yield increase under 100 Kg N ha^{-1} at Adriainsdraai was 40% relative to the unfertilized control and at Veeplats and Syferkuil, the average yield increases of 100 and 150 Kg N ha^{-1} application were 28% and 5% respectively. Russelle *et al.*, (1981), also obtained maximum grain yields of maize at about 150 Kg N ha^{-1} in an irrigation-nitrogen fertilizer study on all irrigation treatments however yield differences induced were comparatively small. The lack of yield difference between 100 and 150 Kg N ha^{-1} application is an indication that economical yields of maize could be obtained at 100 Kg N ha^{-1} application of fertilizer at these irrigation schemes. An application rate of 150 Kg N ha^{-1} could lead to excessive consumption which result in excess nitrogen uptake for carbohydrate synthesis at the expense of grain yields (Woodward, 1987). The lack of significant irrigation effect on grain yield at the experimental sites also indicates that maize can be successfully cultivated under half the amount of water currently being applied by farmers. Maize is probably the field crop most responsive to irrigation but the lack of significant effects of irrigation agree with findings of *Lehrscher et al*., (2001) and Hatfield *et al*., (2001) that irrigation water positioning as a main effect, did not influence maize grain yield at all locations studied by the farmers. On the contrary, Bitzer *et al*., (1983), reported an increase in maize yields with increments in irrigation although the author concluded that yields were not influenced as much by the total amount of water the crop received, as by distribution of the water.

Water Use Efficiency (WUE)

Water use efficiency, estimated as grain yield per unit of water applied, was significantly influenced by irrigation at both Adriaansdraai and Syferkuil. At these locations the WUE of partially irrigated crops were twice or more than that of plants receiving full irrigation (Table 3.5). The effect of nitrogen on water use efficiency was significant at Adriaansdraai and Veeplaats and not at Syferkuil. At Adriaansdraai the highest WUE were recorded at 100 and 150 Kg N ha^{-1} of application under reduced irrigation level whereas at Veeplaats, WUE was similar at all nitrogen fertilizer application rates. Unfertilized plots tended to have lower WUE than highly fertilized plots at these locations. At Veeplaats, fertilized crops resulted in 25% more efficient water use than unfertilized crops. When plants were fully irrigated, no differences in nitrogen application rates on WUE were observed. Half irrigated crops appeared to have used water more efficiently to produce grain yield resulting in over 100% more water use efficiency than fully irrigated crops. Excessively lower WUE mostly arise from water stress imposed during grain fill due to the unreliability of water supplies (ITPRID, 1999).

Even though, no significant differences were apparent at Syferkuil on water use efficiency due to nitrogen, N fertilizer appeared to have enhanced efficient water use compared to unfertilized plots. Nitrogen supply generally improved WUE at all locations which is in accordance with research findings by Varvel, (1995) (grain sorghum), Campbell *et al*., (Wheat), (1992) and Varvel, (1994) (Maize). The results further support Hatfield *et al*., (2001) who reported that increases in WUE come from improved plant growth and yield that are a result of a proper soil nutrient status. Because water is a scarce resource, it is important to use it efficiently in the small holder irrigation schemes.

Economic comparisons

Net returns from N were determined from the difference between the value of yield increase due to N rates and the cost of N fertilizer (Vannotti and Bundy, 1994). Similar to grain yields, quadratic responses were also evident for net returns of maize grain yields at all locations (Fig. 3.2). At Adriaansdraai and Syferkuil, full irrigation resulted in higher net returns at each applied fertilizer N compared to half irrigation except at 150 Kg N ha^{-1} at Syferkuil. Maximum returns were observed at 100 Kg N ha^{-1} under full irrigation while in half irrigation maximum was never reached at Adriaansdraai and it was vice versa at Syferkuil. In contrast, under both irrigation regimes, negative returns were evident where nitrogen was never applied indicating the importance of nitrogen supply in maize productivity at Adriaansdraai. Both irrigation regimes had a similar response of net returns to applied nitrogen fertilizer rates. At Veeplaats, half irrigation also had a gradual increase of net returns with increasing fertilizer nitrogen application rates thus N was consistent in increasing the net returns. Also, there was a similar response of net returns at all locations which is confirmed by the coefficient of determination values ($R^2 = 0.99$). The results indicate that, for all locations, it is usually profitable to supply fertilizer nitrogen to a maize crop. These findings also support that nitrogen fertilizers are essential for profitable production of maize (Binford *et al*., 1990). By maximizing returns to the most limiting factor, producers can maximize the overall profit.

Harvest index

Harvest index is defined as the ratio of economic yield, that is, grain to the total biological productivity of a crop (Ayisi, 2000) which gives an indication of how plants partition dry matter into reproductive organs relative to vegetative parts. Harvest index provides an estimate of the conversion efficiency of dry matter yield (Gebeyehou *et al.*, 1982). Harvest index was neither influenced by irrigation nor nitrogen levels at Adriaansdraai and Syferkuil. However, plants under reduced irrigation, appeared to partition more of its photosynthates to grain yield than fully irrigated ones at Adriaansdraai (Table 3.2). Harvest index tended to be lower at low yield levels under both irrigation regimes but the decrease was much less than the decline in grain yield indicating the dominant effect of nitrogen supply on dry matter production across irrigation levels. The lack of significant differences at Adriaansdraai and Syferkuil agree with findings of Ofori and Stern, (1986) who reported that nitrogen and water had no effect on harvest indices measured at harvest maturity.

In contrast, the proportion of dry matter to grain yield was significantly ($P \leq 0.05$) influenced by nitrogen fertilizer application at Veeplaats. Irrespective of nitrogen fertilizer levels, harvest index was statistically similar among the plots. The highest harvest index value (39.8) was achieved at 50 Kg N ha^{-1}.

GRAIN YIELDS COMPONENTS

Total weight of cobs

Irrigation effect on cob weight (grain plus cob) was nonsignificant at all locations but the effect of nitrogen was significant ($P \leq 0.05$) at these locations. There was also a linear increase in cob weight per hectare with additional nitrogen fertilizer application irrespective of irrigation regimes at all locations. At Adriaansdraai, the highest cob weight appeared to occur at 100 and 150 Kg N ha^{-1} rates of application whereas the minimum weights were evident in nitrogen deficient plots (Table 3.3). Nitrogen deficiency dramatically reduced total cob weight by 30 and 36%, compared to fertilized crops at 150 Kg N ha^{-1} fertilizer rate under half and full irrigation regimes respectively.

At Veeplaats (Table 3.4), maximum cob weight of 6464 Kg ha^{-1} was also attained at 150 Kg N ha^{-1} with minimum of 4142 Kg ha^{-1} weight in nitrogen deprived plots with a decrease of 39%. Nitrogen appears to have had a greater positive impact on the weight of maize cobs produced at all locations.

The maximum weight at Syferkuil (Table 3.5) was obtained at 100 and 150 Kg N ha^{-1} (Table 3.4). The nitrogen deprived crops had lower mean weights of 11184 and 11528 Kg ha^{-1} with 17 and 36% decrease relative to fertilized crops at this location.

Weight per cob

The effects of both irrigation and nitrogen on weight per cob were not significant at Adriaansdraai and Syferkuil. However, at Veeplaats, the effect of nitrogen on weight per cob was significant. Nitrogen fertilizer rate of 150 Kg N ha^{-1} again resulted in the highest cob weight at this location.

Number of cobs per hectare

Significant ($P \leq 0.05$) differences in number of cobs per hectare was only recorded for nitrogen fertilizer rates and not irrigation levels at all locations. Additional nitrogen supply increased number of cobs up to 100 Kg N ha^{-1} at Adriaansdraai, which was 99%

higher than unfertilized plot. Nitrogen deficient plots resulted in the lowest number of cobs per hectare. At Veeplaats, application of 100 Kg N ha^{-1} again resulted in a higher number of cobs per hectare relative to plants receiving no nitrogen fertilizer. The highest number of cobs at Syferkuil, was obtained at 100 and 150 Kg N ha^{-1} rates of application. The high number of cobs per hectare generally obtained under higher levels of nitrogen fertilizer applications could partially explain the greater grain yields recorded at 100 and 150 Kg N ha^{-1} application rates (Abrol, 1990).

Number of kernels per row / Number of kernels per cob / Rows per cob

The effects of irrigation on these measured yield parameters were nonsignificant at all the locations studied (Table 3.3, 3.4 and 3.5). The lack of significant effect is an indication that these parameters are generally not environmentally dependent but rather genetically controlled (Goldsworthy and Fischer, 1984).

Number of kernels m^{-2}

The effects of irrigation and nitrogen on the number of kernels per square meter were nonsignificant at Veeplaats (Table 3.4) and Syferkuil (Table 3.5). At Adriaansdraai (Table 3.3), nitrogen fertilizer application imposed a significant effect on number of kernels per square meter. However, there was an inconsistent trend of nitrogen in increasing number of kernels per square meter

Number of cobs per plant.

No significant irrigation and nitrogen effects were detected on the number of cobs per plant ($P \leq 0.05$) at Adriaansdraai (Table 3.3) and Veeplaats (Table 3.4). Significant nitrogen effects were only detected for nitrogen supply on the number of cobs per plant at

Syferkuil (Table 3.5) but the differences were only apparent between 150 and 0 Kg N ha^{-1}. However, additional nitrogen levels were not consistent in increasing number of cobs per plant under both irrigation regimes.

Seedmass

Seed mass was not affected by irrigation and nitrogen treatments at all locations. However, at Veeplaats the application of nitrogen fertilizer appeared to have increased seed weight relative to unfertilized plots.

AGRONOMIC CHARACTERISTICS

Flowering

Flowering is an important phenological stage of crop development because it signals change of growth of annual crops from vegetative to fruit and seed, essential for yield of most crops. It involves the conversion of apical meristem of the shoot to the reproductive structure. Significant differences ($P < 0.05$) in days to flowering resulting from both irrigation and nitrogen levels were recorded almost at all locations. Irrespective of irrigation levels, tassel emergence tended to be earlier in fertilized crops than unfertilized ones at all locations (Table 2.3, 2.4 and 2.5). This is an indication that nitrogen deficiency delayed tasseling and lengthened days to flowering at this location. Such delay in flowering periods due to stress was reported by Muchow, (1989) where four days difference were observed. Our findings were contrary to the findings of Rengel and Graham, (1995) that stress plants flower earlier.

Silking

Similar to flowering, silking in maize was significantly influenced by both nitrogen and irrigation levels ($P \leq 0.05$) at all locations. Nitrogen deficiency delayed the development of silks in maize plants under both irrigation regimes and at all locations (Table 3.6,3.7 and 3.8). Without nitrogen fertilizer, the period from planting to silking was lengthened by 1 to 2 days across irrigation levels and locations. Days to silk appearance relative to tasseling period are an important yield determinant.

Anthesis silking interval (ASI)

The period a crop takes from pollen shed to silking, is one of the most important drought parameters (Hall *et al*, 1981). Significant ($P \leq 0.05$) responses of ASI to both irrigation and nitrogen levels were recorded at all locations (Table 3.6). Nitrogen deprived crops had six days longer ASI than fertilized plots. Thus, nitrogen deficiency prolonged the days from flowering to silking. Full irrigation regime reached silking stage eight days later relative to reduced irrigation. Fully irrigated crops had four days shorter ASI compared to half irrigated crops which implies that full irrigation enhanced the days to silking at Veeplaats. Nitrogen fertilizer increased ASI particularly with half irrigated crops. In contrast to flowering and silking, ASI was prolonged under fertilized crops by two days relative to unfertilized crops. Since the effect on ASI is similar at all locations, that is an indication of consistency.

Physiological maturity

In annual plants, physiological maturity refers to the stage of growth at which there is no addition of dry matter into seeds. Thus, at this stage the crop has acquired maximum seed dry weight. The effects of irrigation on physiological maturity of the maize crop were significant only at Adriaansdraai whereas that of nitrogen was significant at both

Adriaansdraai and Syferkuil. Neither of the two parameters studied influenced physiological maturity at Veeplaats. At Adriaansdraai, fully irrigated crops matured about five days earlier than plants receiving half the amount (Table 3.6). Nitrogen deficiency generally increased days to maturity at both Adriaansdraai and Syferkuil irrespective of irrigation water application (Tables 3.6 and 3.8). These findings are contrary to the report by Rengel and Graham, (1995), that nutrient deficiency shortens time to maturity and in the process may decrease the length of the physiological stage.

Chlorosis

No clear-cut effect of irrigation on chlorosis were observed at Adriaansdraai and Veeplaats but at Syferkuil exhibited more chlorosis than half irrigated crops. Significant differences due to nitrogen fertilizer application rates on chlorosis were rather more observable at all locations under study. Without nitrogen fertilizer application or when plants received 50 Kg N ha^{-1} crops generally showed severe chlorosis compared to adequately fertilized crops at all locations irrespective of irrigation levels (Table 3.6, 3.7 and 3.8). Yellowing of leaves usually depicts a major symptom of nitrogen deficiency in most crops. This is common to many nutritional deficiencies particularly nitrogen and it is a condition that result from the impairment of the ability of the crop to synthesize chlorophyll (Binder *et al*, 2000). Chlorosis can lead to a loss in potential yield and has also a growth reduction effect. The higher deficiency of N at lower levels of N application in this study contributed to significant losses in vegetative growth, which had a negative impact on dry matter accumulation and other agronomic characteristics under limited N conditions.

Plant height

This parameter is the most manifestation of growth in most plants and its increase may enable the plant an advantage in competing with other plants in a community. Plant height significantly ($P \leq 0.05$) responded to both water and nitrogen levels at Adriansdraai at both 75 DAP and at harvest. The height of fully irrigated plants was 9.0% and 8.3% higher than plants receiving half irrigation at these sampling periods respectively (Table 3.4). Regarding N fertilizer effect, plants receiving 100 and 150 kg N ha^{-1} was an average, 12 to 13% taller than unfertilized plants during mid season and 7 to 9% taller at harvest at this location.

At Veeplaats, irrigation again influenced plant height at 83 DAP and at harvest whereas the effect of nitrogen was only significant during mid-season. The height of fully irrigated plants was 5.6% higher than plants receiving half irrigation at mid-season and at harvest, the height for fully irrigated plants was 4.0% higher (Table 3.5). During mid-season, the tallest plants were observed under plants receiving 100 and 150 Kg ha^{-1} under full irrigation whereas under half irrigation, the tallest were at 50 and 150 kg ha^{-1}. This observation again emphasizes the importance of nitrogen in influencing plant height in maize. Increase in plant height might have benefited the crop by displaying leaves in the most favorable positions for interception of photosynthetically active radiation and subsequent enhanced canopy photosynthesis.

Unlike Adriaansdraai and Veeplaats, plant heights measured during the growing season 83 DAP and at maturity responded nonsignificantly to both nitrogen and irrigation levels at Syferkuil (Table 3.6).

Although the use of nitrogen fertilizer significantly affected grain yield, the effect of nitrogen fertilization on yield components did not follow the same trend. Nitrogen fertilizer was not consistent in increasing most of the yield components, indicating that the fertilizer levels generally exerted little influence on the relative performance of these traits. While no single yield component was predominant in determining grain yield, cob weight and number of cobs per hectare showed that large number of grains per unit area was significantly correlated with higher yields. Thus, the major effect of nitrogen in increasing yields in all locations was through increasing cob weight and number of cobs per hectare. Reductions in grain yield due to stress during grain filling were reflected in seed weight and not seed numbers at Adriaansdraai and Veeplaats irrigation schemes, which was also supported by Eck, (1984).

Water and fertilizer effects on residual soil chemical properties.

The analysis of variance did not indicate any significant interaction between effects on fertilizer and water on soil pH, P and K (Table 2.7, 2.8 and 2.9). In conclusion, soil pH, available P and K were the greatest in subsoil at all locations except K at Adriaansdraai, which was similar in both top and subsoil. Soil pH appeared to stabilize between 6 and 7. At Veeplaats P and K were greater in top than sub soil. In contrast to the study by Powell and Fussell, (1993) it was concluded that soil pH and available P levels were greatest in the topsoil while N was the same in both top and sub soil. High pH and P in subsoil might have allowed roots to exploit the available soil water and N stored in the soil to enhance crop growth and yields.

CONCLUSIONS

The study has shown that water and nitrogen played a crucial role in improving maize grain yields. The linear responses of N fertilizer indicate that the highest yields were attained with applications of 150 Kg N ha^{-1} at all locations under full irrigation, whether higher rates of N would have further increased yields is not known. However, the increase in yield at 150 Kg N ha^{-1} was not significantly different from that for 100 Kg N ha^{-1} with the increase in irrigation beyond optimum water needed by the maize crop. The quadratic responses detected under half irrigation indicated that optimum nitrogen rates for highest yields were 100 Kg N ha^{-1}. Thus, limited irrigation made more efficient use of irrigation water and was also more profitable than full irrigation. Improvement in yields was related to water use efficiencies where grain yield production of 6mm of water applied was greater than when irrigation rate was kept at 12 mm. Therefore exceeding water requirements not only leads to water wastage, but also can affect the plant performance and soil environment. The lack of minimal differences of grain yield between full and half irrigation might probably be related to potential deep percolation and nutrient loss to ground water.

Although more research is needed, results presented in this study indicate that with water management and sustained soil fertility, crop production with reasonable higher yields are possible at these irrigation schemes. The results suggest that, for optimum yields, farmers should not substantially decrease their N fertilization of maize because when compared with other crop nutrients, N is required in relatively high quantities in maize for optimum vegetative and reproductive growth. Both nitrogen fertilizer and availability of moisture enhanced growth parameters of maize with an increase in enhanced agronomic characteristics and crop growth height. Both water and nitrogen stresses lengthened the time from tassel emergence and silking to physiological maturity which contributed to a substantial loss in grain yield under limited N conditions. The superior yields attained at Syferkuil in this study could be attributed to well distributed rainfall throughout the growing season and higher soil nutrient status of the soil. The unreliability of water supplies has contributed significantly to poor performance of small holder irrigation schemes in terms of productivity and profitability.

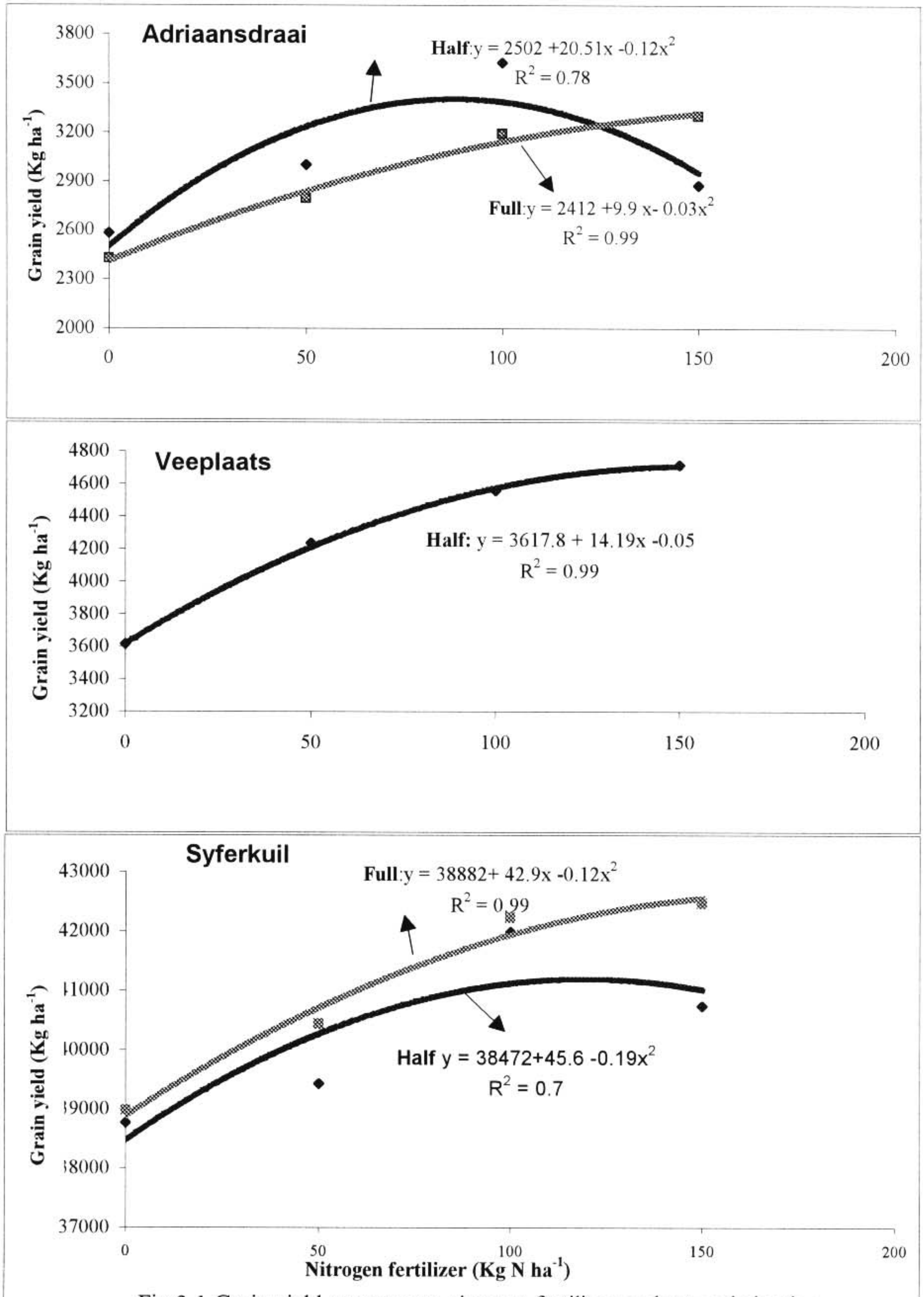

Fig 3.1 Grain yield response to nitrogen fertilizer under two irrigation regimes at Adriaansdraai, Veeplaats and Sferkuil in 1999/2000.

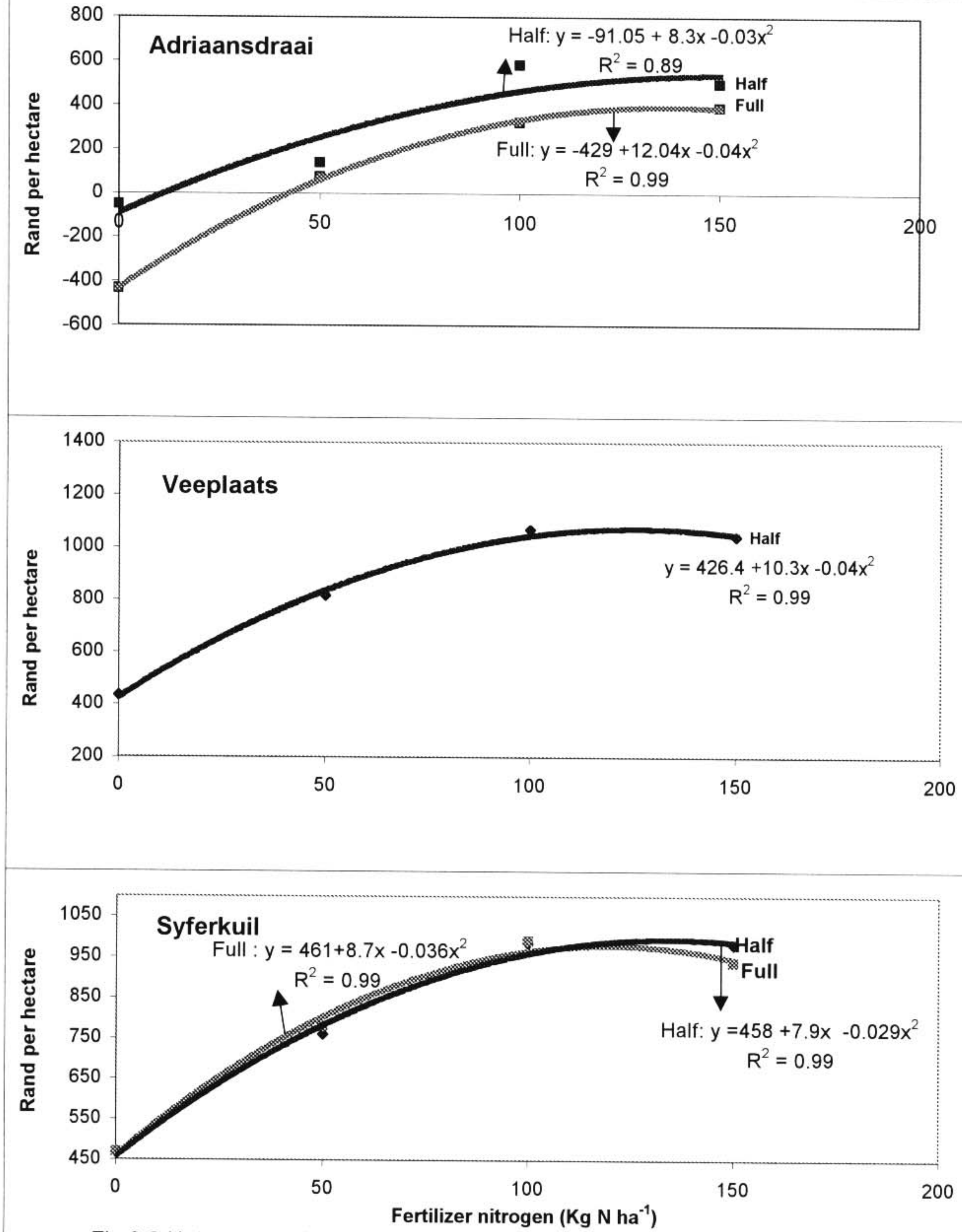

Fig 3.2 Net returns of maize in response to nitrogen fertilizer application rates under two irrigation regimes in 1999/2000.

Table 3.1 Effects of nitrogen fertilizer application rates on water use efficiency of maize grain yield under two irrigation regimes in 1999/2000 growing season.

		Adriaansdraai	Veeplaats	Syferkuil
Irrigation	Nitrogen Kg ha^{-1}		WUE Kg mm^{-1}	
Half	0	15.4b	21.5b	27.6
Half	50	17.1b	25.2ab	28.2
Half	100	21.5a	27.1a	30.0
Half	150	17.9ab	28.1a	29.1
$\bar{x}$				
Full	0	7.2c	-	13.9
Full	50	8.3c	-	14.4
Full	100	9.5c	-	15.4
Full	150	9.8c	-	15.2
$\bar{x}$				
$LSD_{(0.05)}$		3.9	4.0	ns
$CV_{\%}$		13.0	2.26	14.51

LSD= Least significant difference
CV = Coefficient of variation
ns= nonsignificant ($P \leq 0.05$.)
Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$.)

Table 3.2 Effects of nitrogen fertilizer application rates on Harvest index of maize under two irrigation regimes at in 1999/2000_growing season.

		Adriaansdraai	Veeplaats	Syferkuil
Irrigation	Nitrogen		Harvest Index	
	Kg ha^{-1}		%	
Half	0	20.6	22.81b	39
Half	50	21.9	39.8a	41.9
Half	100	24	34.2ab	42.5
Half	150	23.0	36.6ab	43.4
$\bar{x}$		22.4	33.3	41.7
Full	0	18.1	-	39.7
Full	50	20.1		41.1
Full	100	22.7	-	42.4
Full	150	20.2	-	42.7
$\bar{x}$		20.8	-	
LSD$_{(0.05)}$		ns	15.7	ns
CV$_{(\%)}$		27.26	29.3	5.7

LSD= Least significant difference
CV = Coefficient of variation
ns= nonsignificant ($P \leq 0.05$.)
Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$).

Table 3. 3 Grain yield components of maize response to irrigation and nitrogen fertilizer levels at Adriaansdraai,1999/2000 growing season.

Irrigation	Nitrogen	weight of cobs	weight per cob	rows per cob	kernels per row	kernels per cob	cobs per hectare	kernels m^{-2}	cobs per plant	seed mass
	Kg ha-^{1}	g		no						g
Half	0	2952d	154	12	39.1	475.2	2447.6e	913.9d	1.07	34.2
Half	50	3364cd	141	11	39.4	445.4	3304.3de	10645d	1.96	37.2
Half	100	3970bc	141	12	38.8	480.6	6028.7bc	1380.4a-c	1.31	32.1
Half	150	4168bc	157	13	39.9	505.5	3207de	1361.4a-c	1.53	36.0
$\bar{x}$		3614	148	12	39.3	477	3747	1180	1.5	35.0
Full	0	2745d	132	12	39.2	455.5	3234.4de	950.2d	1.29	35.2
Full	50	4002bc	162	12	38.3	439.4	6724.4ab	1136.1cd	1.24	36.4
Full	100	4571ab	156	13	40.7	488.8	7863.2a	1521.4a	2.081	38.1
Full	150	5184a	198	11	41.8	456.3	7374a	1128.7b-d	2.00	38.6
$\bar{x}$		4126	162	12	40	460	6254	1184	1.65	37.1
LSD$_{(0.05)}$		961.5	ns	ns	ns	ns	1635.8	242.1	ns	ns
CV(%)		16.7	26.6	16.7	8.5	5.9	11.8	17.65	19.3	28.8

LSD= Least significant difference
CV = Coefficient of variation
DAP=Days after planting
ns= non significant ($P \leq 0.05$.)
Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$.)

Table 3. 4 Grain yield components of maize response to irrigation and nitrogen fertilizer levels at Veeplaats in 1999/2000 growing season.

Nitrogen	weight of cobs	weight per cob	rows per cob	kernels per row	kernels per cob	kernel m^{-2}	cobs per hectare	cobs per plant	seed mass
	Kg ha^{-1}	g	no						g
0	4142c	171.4b	13.45	39.3a	528.8a	1281.2a	24228b	1.07a	36.1ab
50	4936b	174.7b	12.85	39.1a	501.4a	1419.4a	28472ab	0.99a	39.5a
100	5660b	195.1b	12.4	37.5a	465.3a	1351.4a	29166a	1.12a	39.5a
150	6464a	268.2a	12.4	38.8a	481.3a	1192.1a	24691ab	1.08a	41.4a
$LSD_{(0.05)}$	750.28	60.2	ns	5.4	100.8	345.6	597.7	0.38	2.2
$CV_{(\%)}$	8.84	18.6	5.34	8.7	12.7	16.5	10.79	22.05	2.3

LSD= Least significant difference
CV = Coefficient of variation
ns= non significant ($P \leq 0.05$.)
Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$.)

Table 3.5 Grain yield component response to irrigation and nitrogen fertilizer levels at Syferkuil in 1999/2000 growing season.

Irrigation	N fertilizer	Weight of cobs	weight per cob	cobs per hectare	rows per cob	kernels per row	kernels per cob	kernels m^{-2}	cobs per plant	Seed mass
	Kg ha^{-1}		no					g	no	g
Half	0	11184b	214	45837c	13.15b	43.45	571	28402	1.0d	43
Half	50	12526b	275	50467bc	13.05ab	44.55	582	31930	1.2cd	42
Half	100	13376a	232	59727a	13.20b	41.75	551	35757	1.3a-d	45
Half	150	14476a	263	63894a	13.4b	43.2	578	540302	1.6ab	44
$\bar{x}$		12890.5	1.3	54981	13.2	43.2	570.5	37530	1.3	43
Full	0	11529b	236	49773c	13.15b	42.85	572	30761	1.1cd	36
Full	50	12802ab	244	52782bc	13.9a	43.95	611	34874	1.3bcd	38
Full	100	13067a	223	62505a	14.15a	43.95	623	42002	1.4abc	39
Full	150	14141a	181	63431a	13.1b	42.6	559	38132	1.7a	39
$\bar{x}$		12885	221	57123	13.6	43.3	591.3	36442	1.4	38
$LSD_{(0.05)}$		1905.3	ns	11656	0.5	ns	ns	ns	0.4	ns
CV(%)		14.1	19.1	19.8	4.7	6.2	4.7	23.1	26.7	4.6

LSD= Least significant difference
CV = Coefficient of variation
ns= non significant ($P \leq 0.05$.)
Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$).

Table 3.6 Effects of irrigation an nitrogen fertilizer levels on agronomic characteristics of maize at Adriaansdraai in1999/2000 growing season

Irrigation	Nitrogen	Flowering	Silking	ASI	Physiological maturity	Chlorosis	Plant height cm	
	Kg ha^{-1}		DAP				75 DAP	At harvest
Half	0	63.3a	78b	10.5b	125a	4.3a	123d	163e
Half	50	62.5a	76c	12.5a	124a	3.3a	127cd	178cd
Half	100	61.3a	76c	13.5a	121b	1.8b	1379bc	175d
Half	150	61.3a	75c	13.5a	121b	1.8b	1393b	172cd
$\bar{x}$		62.1	76.3	12.5	122.8	2.8	131.5	172
Full	0	62.3ab	80a	10bc	120bc	4.0a	131cd	182b-d
Full	50	59.0bc	78b	7.3d	120b	3.8a	147b	186ab
Full	100	60.3b	79ab	9.3bc	115d	1.8b	134bc	185abc
Full	150	57.0c	760c	8.5cd	118c	2.0b	1615a	192a
$\bar{x}$		59.7	78.3	8.8	118.3	2.9	143.3	186.3
LSD$_{(0.05)}$		2.1	1.7	1.6	2.2	1.2	11.7	7.5
CV(%)		3.3	2.1	20.5	1.8	39.9	11.7	5.6

LSD= Least significant difference
CV = Coefficient of variation
ASI= Anthesis silking interval
DAP = Days after planting
Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$.)

Table 3.7 Effects of nitrogen fertilizer and irrigation levels on agronomic characteristics of maize at Veeplaats in 1999/2000 growing season.

Irrigation	Nitrogen Fertilizer	Flowering	Silking	ASI	Physiological maturity	Chlorosis	Plant height cm	
	Kg ha^{-1}	DAP					83 DAP	At harvest
Half	0	78a	89.0a	10.5 b	133	4.8a	158d	173.6
Half	50	73c	86.3b	11.5a	135	3.0b	166bc	166.1
Half	100	71de	85.3bc	13.5a	135	2.0c	157d	176.6
Half	150	70e	83.8c	13.5a	129	1.5cd	160cd	170.4
$\bar{x}$		73	86.1	13	133	2.8	160	171.7
Full	0	75b	85.8c	10.0bc	134	4.8a	167bc	180.2
Full	50	72cd	80.0d	10.0bc	133	7.3e	166bc	165.3
Full	100	71de	80.3d	9.3cd	134	2.0c	175a	188.1
Full	150	67f	76.0e	8.5d	132	1.3d	169ab	180.0
$\bar{x}$		71.25	80.5	9.45	133	2.7	169	178.4
LSD$_{(0.05)}$		1.5	2.5	1.3	ns	0.71	7.3	ns
CV(%		1.9	2.9	20.5	2.3	21.1	5.8	11.6

LSD= Least significant difference
CV = Coefficient of variation
ASI= Anthesis silking interval
DAP = Days after planting
Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$.)

Table 3.8 Effects of irrigation and nitrogen fertilizer levels on agronomic characteristics of maize at Syferkuil in 1999/2000 growing season.

Irrigation	Nitrogen	Flowering	Silking	ASI	Physiological maturity	Chlorosis	Plant height cm	
	Kg ha^{-1}		DAP				66 DAP	At harvest
Half	0	65.3a	76.0a	10.8c	135.3b	3.5a	88.1	186.4
Half	50	63.3b	75.3a	12bc	131.8e	2.5c	89.7	188.8
Half	100	59.0c	74.9a	15.8a	133.8c	1.5e	93.5	190.3
Half	150	61.5d	74.3a	12.8bc	133.5c	1.5e	93.8	185.5
$\bar{x}$		62.3	75.1	12.9	133.6	2.3	91.3	187.8
Full	0	65.3a	75.5a	11.5c	137.3a	3.3ab	93.5	179.9
Full	50	64.0b	74.8a	10.8c	132.8d	2.8bc	90.9	187.5
Full	100	61.5c	74.3a	13.0bc	135.5b	1.8de	89.6	192.2
Full	150	60.5d	74.0a	13.5b	133.8c	2.3cd	91.3	186.5
$\bar{x}$		62.8	74.7	12.2	134.9	2.6	91.3	186.5
LSD$_{(0.05)}$	2.5	0.7	2.4	2.4	0.6	ns	ns	ns
CV(%)	3.9	0.8	18.3	1.8	24.3	9.3	2.6	3.7

LSD= Least significant difference
CV = Coefficient of variation
ASI=Anthesis silking interval
DAP=Days after planting
ns= non significant ($P \leq 0.05$.)
Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$.).

Table 3.9 Effects of irrigation and nitrogen on residual soil pH and mineral nutrients after crop harvest at Adriaansdraai in 1999/2000.

Irrigation	Nitrogen	pH				Phosphorus		Potassium	
		H_2O		Kcl					
		A	B	A	B	A	B	A	B
	Kg ha^{-1}					mg Kg^{-1}			
Half	0	6.8	7.2	6.7	6.7	50.4	45.8	9.3	8.9
Half	50	6.9	6. 9	6.5	6.7	42.2	48.2	8.1	9.5
Half	100	7.1	7.1	6.5	6.7	45.5	43.7	9.6	8.0
Half	150	5.5	6.9	6.5	6.5	50.4	48.5	7.4	8.8
$\bar{x}$		6.4	7.1	6.5	6.6	47.0	46.7	8.6	8.7
Full	0	6.7	7.1	6.5	6.5	48.7	39.1	12.4	8.9
Full	50	6.4	6.9	6.2	6.7	80.8	52.6	11.8	10.1
Full	100	6.7	7.1	6.4	6.7	76.2	29.6	9.8	8.9
Full	150	6.9	7.2	6.5	6.8	39.3	53.7	9.1	12.5
$\bar{x}$		6.6	7.1	6.4	6.6	66.4	41.6	11.5	11.5
LSD$_{(0.05)}$									
Irrigation		ns	ns	ns	ns	ns	ns	ns	ns
Nitrogen		ns	ns	ns	ns	ns	ns	ns	ns
CV$_{(\%)}$		16.3	4.1	6.9	2.9	37.1	32.0	40.9	36.1

LSD= Least significant difference

CV = Coefficient of variation

ns= non significant ($P \leq 0.05$.)

A = 0-15cm, B = 15- 30cm

Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$.)

Table 3.10 Effects of irrigation and nitrogen fertilizer application rate on residual soil pH and mineral nutrients after crop harvest at Veeplaats in 1999/2000.

Irrigation	Nitrogen	pH				Phosphorus		Potassium	
		H_2O		Kcl					
		A	B	A	B	A	B	A	B
	Kg ha^{-1}					mg Kg^{-1}			
Half	0	6.7	6.8	5.8	6.1	48.6	39.1	4.2	1.8
Half	50	6.7	7.1	6.1	6.5	49.2	44.8	5.4	3.1
Half	100	6.3	6.9	5.6	6.3	48.3	41.9	3.6	3.5
Half	150	6.3	6.9	5.5	6.1	62.2	48.1	3.8	5.3
$\bar{x}$		6.5	6.9	5.9	6.3	52.1	43.5	4.3	3.4
Full	0	6.4	7.1	5.8	6.3	44.0	43.2	6.0	9.2
Full	50	6.4	6.9	5.7	5.7	59.2	65.2	4.5	5.2
Full	100	6.6	6.9	5.8	6.1	50.6	48.0	4.5	10.1
Full	150	6.3	7.1	5.7	6.3	51.0	45.8	9.1	5.6
$\bar{x}$		6.4	7	5.8	6.1	51.2	50.6	6.0	7.5
LSD$_{(0.05)}$									
Irrigation		ns	ns	ns	ns	ns	ns	ns	8.03
Nitrogen		ns	ns	ns	ns	ns	ns	ns	ns
CV$_{(\%)}$		5.9	4.7	5.9	7.2	24.1	21.8	62.9	76.72

LSD= Least significant difference
CV = Coefficient of variation
ns= non significant ($P \leq 0.05$.)
A = 0-15cm, B = 15- 30cm
Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$.)

Table 3.11Effects of irrigation and nitrogen fertilizer application rate on residual soil pH and mineral nutrients after crop harvest at Syferkuil in 1999/2000.

Irrigation	Nitrogen	pH				Phosphorus		Potassium	
		H_2O		Kcl					
		A	B	A	B	A	B	A	B
						mg Kg^{-1}			
Half	0	6.7	6.9	5.9	6.1	35.6bc	26.4	6.8	8.9
Half	50	6.6	6.9	6.0	6.3	26.2c	31.9	12.0	7.9
Half	100	6.2	6.9	5.5	6.3	58.3a	23.5	8.7	8.1
Half	150	6.3	7.0	5.5	6.1	30.9bc	22.9	8.0	10.6
$\bar{x}$		6.45	6.9	5.7	6.2	37.8	26.2	8.9	8.9
Full	0	6.4	7.1	5.8	6.3	35.6bc	23.4	10.1	6.2
Full	50	6.4	6.9	5.7	5.7	32.7bc	22.9	13.1	12.2
Full	100	6.2	6.9	5.8	6.1	43.1ab	14.1	12.7	8.7
Full	150	6.4	7.1	5.7	6.3	25.5c	31.7	25.3	7.1
$\bar{x}$		6.3	7	5.8	6.1	34.2	23.	15.3	8.6
$LSD_{(0.05)}$									
Irrigation		ns	ns	ns	ns	ns	ns	ns	ns
Nitrogen		ns	ns	ns	ns	15.9	ns	ns	ns
$CV_{(\%)}$		5.8	4.9	6.1	6.74	42.2	69.1	97.6	40.2

LSD= Least significant difference
CV = Coefficient of variation
ns = non significant ($P \leq 0.05$.)
A = 0-15cm, B = 15- 30cm
Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$.)

GENERAL SUMMARY AND CONCLUSIONS

The application of irrigation water imposed significant effects mainly on dry matter accumulation at all locations without affecting grain yield. However, there was evidence in the results that nitrogen management is linked to water use rates in cropping systems since higher WUE values for grain yield were observed at higher soil N supply. Both WUE and NUE were higher in reduced irrigation relative to full irrigation. Irrigation could have stimulated N uptake and increased crop growth rate, which would account for both high dry matter yield and N concentration in N fertilized plants.

At higher levels of nitrogen supply (N uptake ≤ 150 Kg) dry matter yield was greatest under both irrigation regimes at all locations. At higher rates of N fertilization, dry matter yields tended to increase linearly with increases in rates of N fertilization. The greater response of yield to N fertilization was due to increased N uptake when N was limiting and increased N uptake at high N fertilizer rates due to increased growth. N fertilizer enhanced plant N content, dry matter and grain yields but generally decreased NUE. The results demonstrated that all sites were responsive to both N and P fertilizers. This stresses that when P is banded, N is also needed in the band for stimulation of P uptake (Engelstad and Allen, 1971). Crop residues are vital animal feeds, and they stabilize food availability during the years of low rainfall when crop production is reduced or fails. Thus, the increase in stover production may be an added advantage in crop production since it can be used as an on-farm feed for livestock particularly during winter months where there is excessive feed shortage. The contribution of N fertilizer to maize crop determined in our study is comparable with other research findings.

Because N fertilizers are applied with the primary objective of increasing profitability economic analysis is clearly needed to detect the net returns of production. The grain yield response to N fertilizer was dependent on N availability. Borell *et al*., 1998; Olson *et al*., 1976 also had similar results. Fertilizer N management has become increasingly critical in crop production for both economic and environmental stand points (Timmons and Cruse, 1990). Thus, more efficient resource use can lead to reduced production costs, less impact on the off-farm environment and more sustainable food production.

Higher maize yields mean more food and income for farmers; as such more efficient resource use can lead to reduced production costs, less impact on the off-farm environment and more sustainable food production. The results indicated that there is an enormous potential to improve maize production and rural livelihoods for small holder farmers in South Africa through water and soil nutrient management strategies. The main results obtained in this study should now be tested in a wider range of field situations.

RECOMMENDATIONS

Maize production in semi - arid climate areas like in the small holder irrigation schemes in the Limpopo province can be improved significantly by using proper irrigation scheduling and fertilizer recommendations. Irrigation scheduling can improve irrigation and water use efficiencies especially in areas where water management is critical to crop yield and water quality. In an effort to produce more food for expanding populations, proper fertilizer recommendations are a necessity in order to improve soil fertility levels and maintain soil nutrient status while increasing crop growth and yields.

Where rainfall is low and water scarce, people have to make the best use of what is available. This means not only to improve water supplies, but taking measures to conserve land, which will dry out and become eroded; and growing the most suitable crops. The future research should continue to develop soil management practices with the goal of improving WUE and NUE for a range of cropping systems by incorporating knowledge on light interception patterns during the growing season to reveal how management practices affect dry matter accumulation and grain yields.

Regarding the importance of N for plant nutrition, applications of nitrogen fertilizer are required for improved maize growth and grain yields in the irrigation schemes. An application of 100 Kg ha^{-1} appears to be feasible in this study. However, subsequent studies should focus on demonstration trials on farmers' fields where large areas of maize, fertilized mainly on 100 Kg N ha^{-1} are compared with unfertilized controls under both irrigation schemes, before final recommendations are drawn for optimal nitrogen fertilizer application rates for the irrigation schemes.

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APPENDIX

Table 4.1.Grain yield response to varying irrigation and nitrogen levels at Adriaansdraai, Veeplaats and Syferkuil,1999/2000 growing season.

		Adriaansdraai	Veeplaats	Syferkuil
Irrigation	Nitrogen	Grain yield		
		Kg ha^{-1}		
Half	0	2581cd	3611b	3942c-e
Half	50	2999a-d	4232ab	3876de
Half	100	3622a	4555a	4198ab
Half	150	2872cd	4713a	4074bc
$\bar{x}$		3019	4278	4023
Full	0	2428d	-	3898e
Full	50	2794b-d	-	4044b-d
Full	100	3200a-c	-	4222a
Full	150	3299ab	-	4246a
$\bar{x}$		2930		4102
LSD$_{(0.05)}$		625	672.2	164.4
CV(%)		20.0	2.26	3.85

LSD= Least significant difference
CV = Coefficient of variationns= non significant ($P \leq 0.05$.)
Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$.)

Table 4.2 Irrigation and nitrogen fertilizer effects on N concentration, uptake and use efficiency in dry matter yield at Adriaansdraai.

Irrigation	Nitrogen	Tissue N	N uptake	NUE
			Dry matter	
	Kg ha^{-1}	%	Kg ha^{-1}	
	0	0.87c	66	122
Half	50	1.43ab	142	76
Half	100	1.49ab	133	65
Half	150	1.60a	151	65
$\bar{x}$		1.4	123	82
Full	0	1.25b	120	89
Full	50	1.32ab	132	87
Full	100	1.63a	169	62
Full	150	1.48ab	184	68
$\bar{x}$		1.4	151	77
LSD$_{(0.05)}$		0.34	ns	ns
CV$_{(\%)}$		23.1	28.2	29.5

LSD= Least significant difference
CV = Coefficient of variation
NUE= Nitrogen use efficiency
ns= nonsignificant ($P \leq 0.05$.)
Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$.)

Table 4.3 Irrigation and nitrogen fertilizer effects on N concentration, uptake and use efficiency in dry matter yield at Veeplaats.

Irrigation	Nitrogen	Tissue N	N uptake	NUE
			Dry matter	
	Kg ha^{-1}	%	Kg ha^{-1}	
Half	0	1.03c	109	109
Half	50	1.23a-c	164	83
Half	100	1.51ab	198	67
Half	150	1.56a	232	66
$\bar{x}$		1.3	176	81
Full	0	1.17bc	133	95
Full	50	1.40ab	176	72
Full	100	1.31a-c	170	77
Full	150	1.48abe	223	68
$\bar{x}$		1.3	176	78
LSD$_{(0.05)}$		0.35	ns	ns
CV$_{(\%)}$		17.4	18.5	25.1

LSD= Least significant difference
CV = Coefficient of variation
NUE = Nitrogen use efficiency
ns= nonsignificant ($P \leq 0.05$.)
Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$.)

Table 4.4 Irrigation and nitrogen fertilizer effects on N concentration, uptake and use efficiency in dry matter yield at Syferkuil

Irrigation	Nitrogen	Tissue N	N uptake	NUE
		Dry matter		
	Kg ha^{-1}	%	Kg ha^{-1}	
Half	0	1.43	149	70
Half	50	1.38	151	74
Half	100	1.50	168	68
Half	150	1.41	192	71
$\bar{x}$		1.43	165	71
Full	0	1.19	111	85
Full	50	1.34	149	76
Full	100	1.46	175	71
Full	150	1.46	194	68
$\bar{x}$		1.4	157	75
LSD$_{(0.05)}$		ns	ns	ns
CV$_{(\%)}$		13.8	17.8	13.4

LSD= Least significant difference
CV = Coefficient of variation
NUE= Nitrogen use efficiency
ns= nonsignificant ($P \leq 0.05$.)
Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$.)

Table 4.5 Effects of nitrogen fertilizer application on phosphorus content in dry matter production of maize at Adriaansdraai, Veeplaats and Syferkuil in 1999/2000.

		Adriaansdraai	Veeplaats	Syferkuil
Nitrogen	Phosphorus		Phosphorus content	
	Kg ha^{-1}		g kg^{-1}	
0	60	0.27	0.24	0.31
50	60	0.29	0.23	0.33
100	60	0.27	0.24	0.34
150	60	0.31	0.28	0.38
LSD$_{0.05}$		ns	ns	ns
CV$_{\%}$		2.18	2.18	3.01

LSD= Least significant difference
CV = Coefficient of variation
ns= non significant ($P \leq 0.05$.)
Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$.)

Table 4.6 Effects of nitrogen fertilizer on percentage light interception by maize under two irrigation regimes at Adriaansdraai, 1999/2000 growing season .

		Photosynthetically Active Radiation		
Irrigation	Nitrogen	44 DAP	75DAP	83 DAP
	Kg ha^{-1}	%		
Half	0	68a	55	69b
Half	50	72a	63	82a
Half	100	74a	63	85a
Half	150	68a	63	82a
$\bar{x}$		70.5	59	79.5
Full	0	62bc	69	72a
Full	50	58c	62	89a
Full	100	54c	69	85a
Full	150	65ab	66	84a
$\bar{x}$		60	67	83
LSD$_{(0.05)}$		8.6	ns	8.4
CV(%)		17.9	18.5	9.9

LSD= Least significant difference
CV = Coefficient of variation
DAP=Days after planting
ns= non significant ($P \leq 0.05$.)
Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$.)

Table 4.7 Effects of nitrogen fertilizer on percentage light interception by maize under two irrigation regimes at Veeplaats in 1999/2000 growing season.

		Photosynthetically Active Radiation		
Irrigation	Nitrogen	56 DAP	75 DAP	83 DAP
	Kg ha^{-1}	%		
Half	0	18.7d	74.5	65.3
Half	50	23.7bc	62.9	70.1
Half	100	31.1a	64.8	63.4
Half	150	24.3bc	69.5	64.6
$\bar{x}$		25	67.9	65.9
Full	0	24.9bc	57.5	70.1
Full	50	19.9cd	69.4	70.1
Full	100	33.1a	58.4	60.2
Full	150	26.9a-c	62.8	64.4
$\bar{x}$		26.2	62.0	66.2
LSD$_{(0.05)}$		7.8	ns	ns
CV$_{(\%)}$		29.7	14.6	14.3

LSD= Least significant difference
CV = Coefficient of variation
DAP = Days after planting
ns= non significant ($P \leq 0.05$.)
Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$.)

Table 4.8. Effects of nitrogen fertilizer on percentage light interception by maize under two irrigation regimes at Syferkuil in 1999/2000 growing season.

		Photosynthetically Active Radiation			
Irrigation	Nitrogen	44 DAP	66 DAP	83 DAP	106 DAP
	Kg ha^{-1}	%			
Half	0	55	81	77	74
Half	50	57	78	77	84
Half	100	50	80	85	79
Half	150	44	82	78	78
$\bar{x}$		52	80	79	79
Full	0	55	81	81	81
Full	50	48	78	77	69
Full	100	58	81	83	79
Full	150	49	74	76	72
$\bar{x}$		53	79	79	75
LSD$_{(0.05)}$		ns	ns	ns	ns
CV(%)		17.7	6.5	10.7	7.5

LSD= Least significant difference
CV = Coefficient of variation
DAP=Days after planting
ns= non significant ($P \leq 0.05$.)
Means followed by the same letter or letters within a column are not significantly different from each other ($P \leq 0.05$.)