PERFORMANCE OF SUBSURFACE DRIP UNDER DEFICIT IRRIGATION IN VEGETABLE PRODUCTION IN HUTTON SOILS FOR SEMI-ARID CONDITIONS

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ABSTRACT

The Gauteng province lies in a semi-arid zone and faces serious constraints of arable land and available water. High urbanisation rates pose serious threats to the remaining pockets of potential arable lands outside urban zones. Predominantly there are Hutton soils. Cash crops, nutritious African leafy vegetables (ALV) and flowers would require efficient irrigation methods such as subsurface drip irrigation (SDI). SDI places water and fertilizers directly to crop roots resulting in high application efficiencies, reduced evaporation and water saving. Several studies reported higher crops and vegetables yields with water saving using SDI compared to surface drip irrigation. Similarly, deficit irrigation has resulted in increased water productivity and higher crop yields. Significant potential therefore exists for higher crop yields and water saving from the combined application of deficit irrigation principles and SDI in the production of vegetables in Gauteng province. Carrots are produced in Gauteng mainly for consumption, export and for their high vitamin A content which is lacking in many children and women in South Africa. Likewise, ALV have received significant attention from researchers from Africa due to their nutritional and medicinal values reported to be superior to many exotic vegetables. In South Africa, amaranth offers greatest commercial promise. Local field information on the soil-water dynamics from buried laterals and the performance of SDI under deficit irrigation in the production of vegetables is not available. This proposal seeks to investigate the performance of SDI under deficit irrigation for the production of vegetables on Hutton soils. The expected results will be improved understanding of SDI in vegetable production, development of SDI engineering design guidelines, improved knowledge on soil-water dynamics and wetting patterns under SDI, improved knowledge in nutrient supply capacity and management in the root zone resulting in sustainable vegetable production, food security in peri-urban centers and small scale farmers of Gauteng province.

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1 INTRODUCTION

Several countries in Africa and the world already suffer from severe water shortage. Likewise, South Africa is experiencing acute water scarcity problems (UN-Water, 2007). Studies have shown that increased water productivity in agriculture holds the key to future water scarcity challenges (UN-Water, 2007). Subsurface drip irrigation (SDI) is an irrigation method which applies water and nutrients to crop roots through buried laterals. The emitter application rates are usually similar to the ones used in surface drip irrigation (ASAE, 2002). SDI is reported to be highly efficient as compared to all other irrigation methods (Camp, 1998; Ayars *et al*., 1999). The main advantages of SDI include the minimization of direct evaporation losses, overland runoff and deep percolation (Hanson and May, 2007; Safi *et al*., 2007). The accurate application of water and fertilisers results in increased water use efficiency, application uniformity and consequently improved crop yield and quality (Singh and Rajput, 2007).

SDI has been used successfully in vegetable production in the USA, Israel and other countries, and for sugar cane and lucerne production in South Africa, Zimbabwe and Swaziland. The yield response of several crops grown under different climatic and soil conditions across the world showed higher or similar crop yield for SDI compared to other irrigation systems (Camp, 1998). Using SDI, yields above average were obtained in tomatoes (Hanson and May, 2007), onion (Patel and Rajput, 2008), maize (Ayars *et al*., 1999; Enciso *et al*., 2007), soybeans, wheat and alfalfa (Ayars *et al*., 1999), and other crops (Qassim, 2003). In the Gauteng Province, carrots are produced using different forms of overhead sprinkler irrigation system whose efficiencies are lower than drip irrigation. Few studies on carrots production using SDI exist and are not conclusive. Dysko and Kaniszewski (2007) and Bucks *et al*. (1981) reported similar increased yields from carrots under surface and SDI. The amount of water was slightly lower in SDI compared to surface drip. Yields of carrots were similar for the daily and weekly SDI treatments in Arizona, unaffected by irrigation frequency under SDI system. However, the quality, colour, taste and length of carrots roots have been found to be greatly affected by soil moisture levels (Imtiyaz *et al*., 2000; Abdel-Mawly, 2004). For this reason, an opportunity may exist for further research to determine the response of carrots under SDI and deficit irrigation.

On the other hand, for several years now African leafy vegetables (ALV) have been growing on their own in the rural fields as wild weeds. Their consumption has largely been limited to the poor rural people of the world (Rensburg *et al*., 2007). However, due to their nutritional and medicinal values reported to be superior to several exotic vegetable, the ALV have attracted the attention of researchers. The most widely consumed indigenous leafy vegetables in many parts of South Africa and the African continent is the *Amaranthus* species (Maboko, 1999). Recent studies have focused on the nutritional and medicinal importance of ALV, their yield response to various organic and inorganic fertiliser rates, seed germination, population density, and temperature effects on vegetables growth, taxonomic characterisation and species identifications (Fasinmirin *et al*., 2009). Information about the growth response, yield and crop water requirements of ALV under drip irrigation using variable water regimes is not available.

In order to attain more understanding about the application and performance of SDI under deficit irrigation on vegetables production, further review of literature shall be done in the subsequent chapter. Particular focus will be on the engineering aspects of surface and SDI systems for vegetables production. Furthermore, carrots as an exotic vegetable and amaranth as an ALV will be reviewed.

2 SUBSURFACE DRIP IRRIGATION AND DEFICIT IRRIGATION

2.1 Introduction

This chapter presents an outline of the relevant literature studied on SDI as a method, the historical development in South Africa. The performance of SDI in field and vegetable crops, soil wetting pattern models, hydraulics of drip line pipes, drip line depth placements and application uniformity are covered. Deficit irrigation and water productivity of carrots and amaranth are covered, as well as the importance of the carrots and amaranth to South Africa.

2.2 Subsurface Drip Irrigation

2.2.1 Historical development of SDI in South Africa

SDI originated in Israel approximately in 1960 (Netafim SA, 2005) and has been practiced in the USA for over 40 years (Camp *et al*., 1997; Camp, 1998). The adoption of surface drip irrigation has increased extensively in many countries including South Africa (Netafim SA, 2005). In South Africa, SDI started approximately 10 years ago and presently covers about 12 000 hectares (Malan, 2008), while micro irrigation amounts to approximately 296 000 hectares of the total area under irrigation of approximately 1.4 million ha in country.

2.2.2 Performance of subsurface drip irrigation in crop production

SDI has been used in many countries to irrigate high value crops by supplying moisture directly to the plant roots (Camp, 1998; Qassim, 2003). Qassim (2003) attributed the continued expansion of SDI to an increase in the need to conserve the available water resources. When compared to drip irrigation, the main advantages of SDI are: reduced or no loss of soil moisture through evaporation and deep percolation, and that it eliminates completely surface runoff (Safi *et al*., 2007; Hanson and May, 2007). The precise placement and management of water and nutrients has resulted in higher water use efficiency, application uniformity, improved crop yield and quality (Singh and Rajput, 2007; Enciso *et al*., 2007). Hanson and May (2007) observed better tomato yields under SDI when compared to surface drip on clay loam and silty loam soils. The depth of drip laterals depends mostly on the cultivation methods to be used and the irrigated crop (Sekellariou-Makrantonak *et al*., 2002). Dependent on the soil type and crop grown, the lateral depth has ranged between 0.02 m and 0.7 m, while the commonly used lateral spacing has ranged from 0.25 to 5 m (Camp, 1998). Camp *et al*. (1997) successfully cultivated maize, cowpea, green beans, yellow squash, muskmelon and broccoli for 8 years under SDI at lateral depth of 0.3 m spaced 0.76 m apart. Safi *et al*. (2007) grew onions for 3 years using SDI with laterals 0.1 m deep and spaced 0.8 m apart. Carrots, okra, tomatoes, cantaloupe and onions were successfully cultivated for 2 to 3 years under SDI with laterals placed at 0.1 – 0.18 m below ground, and spaced about 1.0 – 1.2 m and emitter spacing of about 0.30 m (Camp *et al*., 1997; Bucks *et al*., 1981).

Dysko and Kaniszewski (2007) working in Poland, obtained higher total and marketable yields of carrots using surface drip as compared to SDI. In 2005, the same authors reported no difference in yields from surface and SDI when carrots were cultivated on flat ground; however, higher yields of carrot were found on ridged ground when SDI was applied. Bucks *et al*. (1981) found that the yields of carrots were similar for the daily and weekly SDI treatments in Arizona, and were not affected by irrigation frequency under SDI system. Carrot cultivated on ridges is reported to have produced significantly longer roots as compared to carrots cultivated on flat ground (Dysko and Kaniszewski, 2007). The roots of carrot, onion and cantaloupe have not been found to plug the SDI lateral lines (Buck *et al*., 1981). Studies to evaluate irrigation scheduling for SDI mainly focused on determining whether reduced evaporation and improved irrigation efficiency would have a measurable effect on the irrigation requirement or its timing. The varying results on the performance of SDI illustrate the difficulty in making general guidelines for SDI. Sakellariou-Makrantonaki *et al*. (2002) concluded that more field experiments and studies on SDI lateral depth placements are required to supplement the conclusions that have been made about SDI performance

2.2.3 Soil hydraulic properties and the design of subsurface drip irrigation

A properly designed, operated and managed SDI system will improve nutrient supply and management in the crop root zone and reduce leaching. The system design should match the emitter spacing and flow rates with the expected wetted soil volume which depends on the soil characteristics and the crop roots water extraction pattern (Battam *et al*., 2003). The criteria currently used by the designers of surface drip and SDI are based on the broad soil texture ranges of sand, loam and clay. Based on soil texture, general guidelines of emitter spacing and discharge rates have been specified for designers (Battam *et al.*, 2003; Reinders *et al.*, 2005). Netafim SA (2005) recommends 2.0 ℓ/h drippers at 0.6 m interval with laterals 1.3 m apart for loamy to clayey soils; 1.5 ℓ/h emitters spaced 0.6 m and lateral at 1.0 m for sandy soils. However, Thorburn *et al.* (2003) disputed that soil texture can not be reliable for accurate prediction of the soil wetting pattern. They further argued that assigning particular emitter and lateral spacing values on the basis of different soil textures without acquiring actual site information on the wetting pattern may not be correct. The same authors stated that actual site information is crucial if satisfactory and efficient trickle irrigation systems can be designed.

The fact that SDI lateral design information can easily be obtained on the basis of soil texture does not make the procedure reliable in terms of the expected soil wetting patterns (Battam *et al.*, 2003). Therefore, a comprehensive understanding of the soil moisture movement in the root zone is essential for planning and management of SDI (Patel and Rajput, 2008). It is thus possible that a poorly designed SDI system may be produced if it was based on the soil texture alone (Battam *et al.*, 2003). Consequently, the actual information on the behaviour of water movement in the soil will be useful in designing trickle irrigation schemes and improving the efficiency of SDI. By way of direct field quantification or using analytical models, the accurate soil wetting pattern can be determined (Singh *et al.*, 2006). Several suitable simulation models exist in literature (Battam *et al.*, 2003; Patel and Rajput, 2008; Thorburn *et al.*, 2003).

Like other models, the accuracy of the results from soil water flow models depend on the quality of the input data of the soil hydraulic properties. However, Battam *et al.* (2003) stipulated that some form of training in soil physics may be necessary to effectively use most of the existing soil water models. For ordinary design purposes, the use of numerical flow models may be time-consuming (Battam *et al.*, 2003). According to Singh *et al.* (2006), “the width (W) and depth (Z) under SDI system with line source of water application at the end of an irrigation cycle was assumed to depend on discharge per unit length (q), total amount of water (V) in soil per unit length of lateral, hydraulic conductivity (K_s) and depth of lateral placement (Z)”. Schwartzman and Zur (1986) stated that the dimensions of the wetted bulb can be represented by “the wetting depth (Z), diameter of the wetted soil volume (W) measured at its widest points, emitter discharge rate (q_e) and saturated hydraulic conductivity (K_s) which describes the soil type and physical conditions". The functional relationship of the stated parameters is shown in Eq. (2-1):

$$W = f_1(V,\ q_e,\ K_s) \text{ and } Z = f_2(V, q_e, K_s) \tag{2-1}$$

Using dimensional analysis, Eq.(2-2) and (2-3) were obtained.

$$Z = 2.54V^{0.63}\left(\frac{K_s}{q_e}\right)^{0.45} \tag{2-2}$$

$$W = 1.82V^{0.22}\left(\frac{K_s}{q_e}\right)^{-0.17} \tag{2-3}$$

Eliminating *V* from Eq. (2-2) and (2-3) and taking account of the units through constant 0.0094 yields the following equation (Sne, 2006) which is applicable for surface drip irrigation system:

$$W = 0.0094Z^{0.35}q_e^{0.33}K_s^{-0.33} \tag{2-4}$$

Singh *et al*. (2006) modified Schwartzman and Zur (1986) method [Eq. (2-2) and Eq. (2-3)] and included lateral depth (*D*) for SDI system. *D* is related to the plant root zone depth and density. The resulting relationship is presented in Eq. (2-5) and (2-6).

$$W = 3.27V^{0.44}\left(\frac{K_s}{q_e D}\right)^{-0.06} \tag{2-5}$$

$$Z = 3.86V^{0.31}\left(\frac{K_s}{q_e D}\right)^{-0.19} \tag{2-6}$$

Similarly, getting rid of *V* from Eq. (2-5) and (2-6) produces Eq. (2-7) which is applicable for line source SDI system:

$$W = 0.4808Z^{1.42}\left(\frac{K_s}{q_e D}\right)^{0.21} \tag{2-7}$$

Results from these formulae do not always agree with results from field measurements. It is argued the difference is due to hydraulic conductivity that is determined in the laboratory on a disturbed soil sample (Sne, 2006). Insufficient understanding of how K_s influences the resultant dimensions of soil wetted bulb has often times resulted in low water use efficiency particularly in SDI systems. For this reason, Patel and Rajput (2008) indicated that more studies need to be carried out in order to comprehend the relationship between lateral depth placement and wetted bulb of the soil under SDI. Due to the laborious, time-consuming and expensive nature of work required to determine accurate soil moisture movement under SDI from direct field measurement, information is still lacking. Adequate study on the effect of SDI on crop yield compared to surface drip has been reported in literature (Camp, 1998; Patel and Rajput, 2008). Battam *et al.* (2003) compared the “soil pit method” with the soil texture based design. The soil texture based technique resulted in inadequate watering and water surfacing problems as compared to the “soil pit method”. Thorburn *et al.* (2003), Badr and Taalab (2007) successfully used the auger and gravimetric method for direct field measurements of the soil water volume from drip irrigation systems.

2.2.4 Head losses and pressure variation along buried drip laterals

The level of application uniformity (AU) obtained from micro irrigation laterals depends mainly on the variation in emitter manufacture, pressure changes due to friction head loss and elevation differences. For SDI tapes, Hills *et al.* (1989) noted that cross-sectional deformation of the lateral due to soil compaction is another potential factor. From a preliminary unpublished study conducted in 1986/87, the same authors reported that soil compaction had an effect on the geometric shape of the pressurized buried drip tapes. The laboratory study of four different drip tapes to determine the hydraulic effects of compression deformation of drip tape due to soil compaction reported a reduction in average emitter flow rate corresponding to the degree of drip tape deformation. From a study conducted in Iran, Safi *et al.* (2007) reported that inlet pressure head of 50 and 90 kPa applied to drip tapes 0.1 m under the soil proved low, probably due to an elliptical cross section of the tapes created from soil compaction, and resulted in lower emitter discharge rates. In order to evaluate the effect of drip tape compression due to soil compaction, the total head losses due friction and head loss due to drip tape compression has to be separated.

Soil compaction due to soil weight generally produces elliptically shaped drip tapes. For elliptical cross-sectional drip tape pipes, friction head loss can be evaluated using Eq. (2-8) (Hills *et al.*, 1989).

$$H_f = 1.9x10^4 \left[\frac{\left(a^2 + b^2\right)^{0.625}}{(ab)^3} \right] LQ^{1.75} F \tag{2-8}$$

Where, H_f, L, Q are defined above; a = length of longer axis of ellipse (m); b = length of minor axis of ellipse, $a^2 + b^2 = \frac{D_i^2}{2}$, where Di = internal pipe diameter and F = Jensen Fratini factor for multiple outlet pipes. Therefore, the variance between the measured head losses and the normal calculated friction head loss due to wall roughness and local losses at emitters will be attributed to head loss due to drip tape compression, and should be approximately equal to the value obtained from Equation (2-8).

2.2.5 Head loss due to wall roughness and emitters

Friction head loss due to pipe roughness, *f*, of a small inside diameter D_i [m] of polyethylene (PE) pipes can be obtained using the Darcy-Weisbach formula (Bagarello *et al.*, 1995). Experimental studies indicate that for small diameter PE pipes, *f*, for Reynolds number range of 2000 < R < 36000, varies according to the following relationship:

$$f = 0.302R^{-0.25} \tag{2-9}$$

Using Equation (2-9) and Equation (2-8), *f* can be eliminated. *R* depends on the average flow velocity, *V*, internal pipe diameter D_i, kinematic viscosity, ν [m^2/s]; H_f between the first and last emitter on the lateral can be evaluated using the following formula (Provenzano *et al.*, 2005):

$$H_f = 0.0235.\nu^{0.25} \frac{q_{av}^{1.75}}{D_i^{4.75}} L_e \sum_{i=1}^{N-1} (i)^{1.75} \tag{2-10}$$

Where q_{av} = average emitter flow rate (m^3/s),

L_e = emitter spacing (m);

N = number of emitters on the lateral, and

i = the i^{th} emitter on the lateral counted from the downstream end of lateral.

The significant contribution of local head losses due to emitter fittings has been recognized by Howell and Barinas (1980) and Bagarello *et al.* (1995). Total local losses due to emitter fittings, h_L, in which N emitters are installed is represented by, γ, related to kinetic head (Howell and Barinas, 1980 and Bagarello *et al.*, 1997) which was further re-arranged by Provenzano *et al.* (2005) as shown in Eq. (2-11):

$$h_L = \gamma \frac{V_i^2}{2g} = \gamma \frac{8Q_i^2}{g\pi^2 D_i^4} = \gamma \frac{8q_{av}^2}{g\pi^2 D_i^4} \sum_i^{N-1} (i)^2 \tag{2-11}$$

γ can be obtained from the following relationship (Provenzano and Pumo, 2004):

$$\gamma = 0.056 \left[\left(\frac{D_i}{D_g} \right)^{17.83} - 1 \right] \tag{2-12}$$

Where D_g = average inner diameter of in-line emitters (mm).

2.2.6 Lateral depth, emitter discharge rate and water application uniformity

For non-pressure compensating emitters, AU is affected by operating pressure, emitter spacing, land slope, pipeline size, emitter discharge rate and emitter variability (ASAE, 2002). Poor irrigation water application can be the reason for reduced crop yields (Gil *et al.*, 2008). To verify if water and nutrients are uniformly applied in the field, emitter discharge uniformity and system performance would require evaluation. AU of drip irrigation systems can be given by several uniformity parameters; however most require measurement of emitter discharge for a representative sample in a system (Camp *et al.*, 1997). From a field evaluation of surface and 3-year old SDI systems in Iran, Safi *et al.* (2007) obtained uniformity coefficient (UC) values of 96.9 % and 91.8 % for SDI and surface drip irrigation systems respectively. Gil *et al.* (2008) carried out an experiment under laboratory conditions, where they compared the AU of surface drip and SDI using plastic pipes buried in 5.5 liters pots under laboratory conditions and concluded that the AU of SDI would be higher than surface drip. They concluded that in uniform soils, the AU achieved from SDI laterals should be superior when compared with surface drip irrigation. The same authors indicated that there was evidence of significant influence of soils with low infiltration rate on emitter discharge. The soil overpressure (back-pressure) at emitter-soil interface moderates the discharge. In soils with low infiltration rates, drippers with larger discharge rates on the soil surface would experience elevated back-pressure when buried underground. Camp *et al.* (1997) reported that the measured emitter discharge uniformity for SDI was somewhat less and rated between "good" and "fair" based on ASAE (1996) guidelines. In direct field measurements, the AU for micro irrigation is normally defined by: emitter discharge variation (q_{var}), coefficient of variation (CV), statistical uniformity (U_s), uniformity coefficient (UC) and distribution uniformity (DU_{LQ}) (ASAE, 1996; Camp *et al.*, 1997). For SDI, additional parameters that capture the unique feature of SDI are used and these include "pressure uniformity" [$DU_{LQ\ \Delta P}$], coefficient of pressure variation [CV_P] (Mizyed and Kruse, 1989) and statistical uniformity due to hydraulics [U_{sh}] (ASAE, 1996; Safi *et al.*, 2007). These are:

$$q_{\mathrm{var}} = \frac{q_{\max} - q_{\min}}{q_{\max}} \tag{2-13}$$

$$CV_m = \frac{S_q}{\bar{q}} \tag{2-14}$$

$$UC = 100\left[\frac{\frac{1}{N}\sum_{i=N}^{N}\left|q_i - \bar{q}\right|}{\bar{q}}\right] \tag{2-15}$$

$$DU_{LQ} = \frac{\bar{q}_{25\%}}{\bar{q}}100 \tag{2-16}$$

$$U_s = 100(1 - CV_m) \tag{2-17}$$

Where S_q = standard deviation of emitter discharge rates,

q_{max} = maximum emitter flow rate, and q_{min} = minimum emitter flow rate;

$\bar{q}$ = mean emitter flow rate,

N = number of emitters in a lateral,

$\bar{q}_{25\%} = \bar{q}$ for lower 25 % of emitters.

CV_P is determined from Eq. (2-14), replacing q by hydraulic pressure, H; U_{sh} from Eq. (2-18) substituting CV_m with CV_p. $DU_{LQ\ \Delta P}$ shall be calculated using Eq. (2-17) replacing q by H^x, where x is emitter discharge exponent from the power law emitter equation (Keller and Karmeli, 1974). The interpretation guidelines that outline the adequacy of the line-source irrigation system based on evaluation results are given by ASAE (1996) and Safi *et al.* (2007). Few studies have investigated the field measurement of water AU of SDI systems and no direct field method exist which outline the procedure for evaluating the discharge rate of buried emitters (Gil *et al.*, 2008). The methods followed involved the excavation of the buried laterals and emitter flow rates measured (ARC-IAE, 2007; Safi *et al.*, 2007). However, Sadler *et al.* (1995), Lazarovitch *et al.* (2006) and Safi *et al.* (2007) reported an increase in emitter discharge rates when the buried lateral is excavated.

2.2.7 Lateral placement depth and yield

Yield and quality variation with lateral placement depth has been studied for field and vegetable crops (Camp, 1998). Similarly, Machado and Oliveira (2005) observed that drip lateral placement depths of 0 (surface), 20 and 40 cm had no significant effect on dry matter production of processing tomato in Portugal. However, a crop yield variation as affected by drip lateral placement depth has been reported in literature as well. A 3-year study in central California recorded higher production of faba bean when drip laterals were located at 0.3 or 0.45 m as compared to laterals buried 0.60 m (Bryla *et al.*, 2003). Singh and Rajput (2007) evaluated the response of okra to drip lateral placement depth where highest yields of 13.5 % more were obtained from laterals 0.1 m deep compared to laterals at 0 and 0.15 m. Hanson and May (2007) evaluated how the yield and quality of processing tomatoes was affected by variations of drip lateral. They observed a variation of tomato production with lateral depth, obtaining highest yields from laterals buried 0.23 m compared to furrow method. Sakellariou-Makrantonaki *et al.* (2002) reported greater yield and higher sugar content of sugar beet when grown under SDI as compared to surface drip. Camp (1998) indicated that lateral depth was seldom a treatment variable in the studies carried out so far, hence little can be said about crop yield differences with lateral depth. No studies as yet have been carried out where lateral placement effect on carrot yield has been done, and such knowledge will be valuable to both farmers and engineers.

2.3 Water Productivity of Carrots and Amaranth

Water productivity (WP) is the ratio of the total quantity harvested to the total amount of water used per crop season (ASAE, 2002). Mathematically it can be represented as:

$$WP = \frac{Y}{\sum ET_c} \tag{2-18}$$

Where $\sum ET_c$ = cumulative crop evapotranspiration for the whole season (m^3), Y is the quantity (in kg) of the plant product from a certain area in a given growing season (Power, 1983). Since water use (ET_c) in Eq. (2-18) is the denominator, the management strategies that minimize ET_c will improve WP. Plant water use is regulated primarily by (i) the evaporative potential of the atmosphere, (ii) the amount of soil available water and (iii) certain plant characteristics. For a certain soil type in a given locality, irrigation method, tillage, residue management, fertilizer practices, cropping systems and other factors determine the amount of soil available water (Power, 1983).

If adequate soil moisture is available to provide reasonable growth, WP is known to increase with the increase of plant nutrients. When water availability is limited, optimum WP values are achieved at fertility levels considerably below those that provide maximum yield (Power, 1983). The adoption of irrigation systems with better water application efficiency increase WP. Studies have shown that SDI has great potential to increase WP. In their study carried out in Iran, they recorded significantly increased WP of potato, tomato and eggplant with laterals placed 0.15 m below the soil surface. In India, Singh and Rajput (2007) recorded higher WP of okra under SDI as compared to surface drip method. They reported a similar quantity of applied water for all the treatments (0 cm [surface], 5, 10 and 15 cm) except that yield only were affected. In a field experiment carried out in Cairo, Egypt Abdel-Mawly (2004) recorded high value of WP, increased dry matter, root yields and nitrogen uptake of carrots with water replacement levels of 75 % of A pan evaporation.

The reference evapotranspiration (ET_o) from irrigated crops is commonly determined using the Penman-Monteith formula (Allen *et al*., 1998). The actual crop evapotranspiration (ET_c) is the product of the crop factor (K_c) and ET_o.

2.4 Deficit Irrigation as a Management Strategy

Deficit irrigation is the "practice of using irrigation to maintain plant water status within prescribed limits of deficit with respect to maximum water potential for a prescribed part or parts of the seasonal cycle of plant development" (Kriedemann and Goodwin, 2001). Deliberately, a pre-determined magnitude of water stress at prescribed times is administered to a crop with the expectation of increased WP due to reduced water quantity, increased production area even though actual yields may be reduced (Nagaz *et al*., 2008). Several crops are reported to have performed satisfactorily under deficit irrigation management (English and Raja, 1996). Improved yields, WP and saving in water used has been reported in onion (Enciso *et al*., 2007), tomatoes (Machado and Oliveira, 2005), wheat (English and Raja, 1996), broccoli, rape, cabbage (Imtiyaz *et al*., 2000). Research on the performance of carrots under different levels of irrigation has been carried out. Batra (1990) reported higher values of the plant height, root length and diameter, weight of fresh leaf, root yield and leaf dry matter at irrigation water depth/cumulative evaporation ratios of 0.8 and 1.2 as compared to a 0.4 ratio of irrigation water depth/cumulative evaporation. Imtiyaz *et al*. (2000) recorded the highest mean marketable yield of broccoli, carrot, rape and cabbage at 80 % replenishment of the class A pan. The total root and marketable root yields (total root yield less split, cracked and bent roots) were highest with irrigation at 80 % pan evaporation replenishment. Irrigation at 100 % replenishment significantly reduced the irrigation production efficiency as the excess water applied simply percolated out of root zone without a significant contribution towards the root yield of carrots (Imtiyaz *et al*., 2000). The higher seasonal water applied at 100 % evaporation replenishment rather increased deep percolation, leaching of nutrients and poor aeration which could explain the quadratic nature of the resultant yield-applied water relationship obtained by Imtiyaz *et al*. (2000).

Abdel-Mawly (2004) obtained significantly superior root yields with irrigation scheduled at replacement of 75 % and 100 % evaporation losses with 120 kg/ha nitrogen compared to yields obtained at lower irrigation frequencies of 50 % and 25 % and lesser nitrogen rates of 0, 40 and

80 kg/ha. An adequately accurate conclusion can thus be made that total carrot root and marketable root yields of carrot can be successfully produced under deficit irrigation with irrigation replacement levels of evaporation of about 75 % and higher.

However, the irrigation methods used in the several cited studies on carrot production under deficit irrigation were mainly surface drip (Abdel-Mawly, 2004; Dysko and Kaniszewski, 2007) and sprinkler systems (Gibberd *et al*., 2003; McPharlin *et al*., 1992). No information exists on deficit irrigation of carrots under subsurface drip irrigation. Abdel-Mawly (2004) stated that information on water requirement of carrots has received little attention and the irrigation practices followed are arbitrary. A study is therefore necessary that will determine the response of the vegetative growth, water relations and yield of carrots under deficit irrigation when SDI is used.

2.5 Vegetable Amaranth (*Amaranthus spp*.) and its Importance

African leafy vegetables (ALV) refer to crops, which originated from Africa and which either grow spontaneously or have been semi-cultivated in home gardens of many parts of Africa. In South Africa they are commonly referred to as *morogo* (Sesotho, isiPedi) or *imifino* (isiZulu, isiXhosa), which simply means leafy vegetables (Rensburg *et al*., 2007). The most widely consumed ALV in South Africa and Africa in general are the *Amaranthus* species (Maboko, 1999). Amaranth grows optimally under warm conditions, with enough light and nutrients. It grows best in loamy soils. It can tolerate soil pH from 4.5 to 8.0. It is known to be drought resistant, but prolonged dry spells induce flowering and reduce leafy yields (Palada and Chang, 2003). Under cultivated conditions, amaranth produces fresh leaf yields of up to 40 tons/ha. Fasinmirin *et al*. (2009) obtained highest and lowest *Amaranthus cruentus* yields of 13.94 and 4.2 tons/ha when grown under drip irrigation, with 11.16 and 3.39 tons/ha under sprinkler system in Nigeria. Amaranth has received considerable attention in many countries due to high nutritional value of some species that are important sources of food, either as vegetables or grain. In South Africa, amaranth has shown potential to be developed commercially (Rensburg *et al*., 2007). The Gauteng Department of Agriculture and Rural Development is encouraging farmers to grow more of indigenous vegetables. ARC-Vegetables and Ornamental Plant Institute in Pretoria, Morogo Research Institute (North West University), universities of Pretoria, KwaZulu-Natal, Tswane

University of Technology and other universities are currently engaged in research in many other aspects of ALV.

Considering their potential nutritional value, ALV could contribute in a significant way to the food security and balanced diet of rural households, peri-urban and urban dwellers. Rensburg *et al*. (2007) recommended that further research on the different aspects of ALV species is required. With the increasing need of this crop, it is necessary to accelerate and expand its production all year round (Fasinmirin *et al*., 2009), and this could mean improving the current subsistence production methods into modern commercial production using modern irrigation systems. Recent studies have focused on the nutritional and medicinal values of ALV, yield response to organic and inorganic fertiliser application, seed germination, vegetables growth as affected by growing temperature, taxonomic characterization and species identifications (Fasinmirin *et al*., 2009). Production under irrigated conditions needs to be investigated. Information about the growth response, yield and crop water requirements of amaranth under SDI using variable water regimes is not available.

2.6 Carrots (*Carrota Daucus*, L) and its Importance

Carrots are rich in beta carotene (Vitamin A) which is vital in the immune system, human skin, and in promoting a healthy body cell growth. Growth is optimal between 15 ^{o}C to 20 ^{o}C, producing the best colour and flavour at such temperatures. Soils should be deep, free draining and low in salts. Carrots are not particularly sensitive to winter cold and frost. Excessive soil moisture is harmful to the root development and gives rise to shorter, thicker roots with lighter colour and rotting (Abdel-Mawly, 2004). Conversely, soil moisture deficiency results in longer, woody and hard carrots with strong orange colour (Joubert *et al*., 1994; Abdel-Mawly, 2004) at times with thinner conical shaped shoulders (Nortje and Henrico, 1986).

In the Gauteng province, carrots are one of the most produced vegetable crops with 867 ha out of 300 360 ha arable is under carrot production in Gauteng. The average yield carrots is 31.75 ton/ha (SSA, 2006), which is below the potential carrot yield of 50 ton/ha in South Africa (Hygrotech, 2008), and lower than other world producers like Netherlands (57.4 tons/ha), United Kingdom (63.7 tons/ha) and USA (40 ton/ha) (FAO STATS, 2008). In 2008, the fresh produce consumption of carrots was about 110 000 tones making it the eighth most consumed vegetable after potatoes, onions, tomatoes, green mealies, pumpkins, squash and cabbage in their ranking order. Palada *et al*. (2008) admits that more studies on water requirements of drip irrigated vegetables is required under tropical conditions despite the fact that extensive studies on drip irrigated vegetables have carried out in different climatic conditions. The consensus exist that efficient water and nutrient utilization will be achieved through the development or adoption of water application methods with superior efficiencies.

A national survey carried out on South African children between 12 to 108 months and women between 16 and 35 years identified a serious health problem due to vitamin A shortage. The study concluded that measures need to be put in place to address the poor vitamin A deficiency in women and children in South Africa (Labadarios *et al*., 2008).

It is therefore critical that the recommended water levels for carrots production be carefully established and maintained to obtain satisfactorily long roots of good quality and shape. In the Gauteng province, carrots are mainly irrigated using centre pivots and sprinkler irrigation methods, no record exist of farmers in the province that use either surface drip irrigation or SDI methods. There is therefore need that carrots production using SDI under deficit irrigation in semi-arid zones be investigated.

3 DISCUSSION AND CONCLUSIONS

The rate of urban development in the province has reached high levels, causing serious threats to potential agricultural lands in the province. This has prompted urgent intervention by way of identifying, demarcating and protecting areas of medium and high potential agricultural production called agricultural hubs. These agricultural hubs are mainly on the outskirts of Gauteng urban and intensive utilization of these hubs on a competitive basis is expected through diverse but high value and flexible agricultural industry. This will be achieved by the production of niche, innovative and specialty crops for niche markets such as high value vegetable crops, herbs, essential oils, indigenous and exotic flowers, goat milk and others. Hutton soils constitute the greater part of these zones. In Gauteng, carrots rank highest in terms of total production area and are mainly produced using conventional sprinkler irrigation methods such as center pivots and quick coupling.

ALV recently received attention from researchers, mainly from the African continent. This is due to their nutritional and medicinal values reported to be better than many exotic vegetables. Of the seven prominent ALV entering the commercial market, amaranth offers greatest promise. However, there are still several unknowns with all ALV including amaranth, and these include the water requirement of the crop under drip irrigation systems.

The critically low water levels in South Africa and Gauteng province demands a major shift in the water use practices. One way of improving water productivity in the province will be the adoption of irrigation methods with high water and nutrients application efficiencies. Researchers concur that SDI achieves efficiencies higher than the surface drip irrigation method. In addition, studies have proven that deficit irrigation as a management strategy increases water productivity. SDI system has been used successfully in several field and vegetable crops. So far, the few studies that have been carried out on carrots production under SDI have not been conclusive in terms of marketable yield with respect of lateral depth placement for SDI system. Furthermore, the performance of SDI in comparison to surface drip under deficit irrigation in Hutton soils requires field study.

Local information on the soil moisture patterns resultant from buried laterals in SDI in the field production of carrots and amaranth vegetables is not available, and such knowledge will be valuable in the determination of the financial viability and engineering applicability SDI in South Africa. Furthermore, local users will benefit in terms of the best and acceptable management practices of SDI irrigated carrots and amaranth vegetables that will be generated from the study. The varying results from reviewed literature on the performance of SDI illustrate the difficulty in making general guidelines for SDI, and therefore its suitability, at minimum, may need to be assessed. Therefore, more field experiments and studies on SDI lateral depth placements are required to supplement the conclusions that have been made about SDI performance. Such studies may need explicit examination of the performance and applicability of SDI in comparison with surface drip irrigation, using various design criteria and deficit irrigation (DI) as a water management strategy.

From the conclusions made above, it is proposed that a study be carried out evaluate the SDI system performance under deficit irrigation.

4 PROJECT PROPOSAL

4.1 Introduction

This chapter presents a proposal to investigate the performance of SDI in comparison to surface drip under deficit irrigation for vegetables production in the Gauteng province.

4.2 Problem Statement

It is proposed that a specific need exists to substantiate the performance of SDI under deficit irrigation for the production of carrots and indigenous vegetable amaranth in the semi-arid conditions of Gauteng province on Hutton soils. Hutton soils are the predominant agricultural soils in the province and country, deep and well drained. Optimum management of water and nutrients within the root zone in Hutton soils will be valuable to farmers and the country. SDI has received wide adoption for the irrigation of high value crops by supplying moisture and nutrients directly to the plant roots (Lamm *et al*., 1997; Qassim, 2003). Vegetables production using SDI has continued to expand globally (Hanson and May, 2007; Safi *et al*., 2007), but 12 000 ha of the 1.4 million ha under irrigation in South Africa is under SDI (Malan, 2008) since surface drip irrigation was introduced in the country in 1969 (Reinders, 2000).

Accurate design of SDI systems requires the proper placement of lateral lines in the soil profile, emitter spacing and laterals intervals. Soil-moisture dynamics and extraction pattern of the irrigated crop largely determine lateral placements. The best position will therefore be the result of careful understanding of the soil type and the irrigated crop (Gilley and Allred, 1974). After a 3 year study on lucerne, Reinders *et al*. (2005) concluded that further investigation on the impact of design procedures, operation and maintenance of SDI is necessary for South African conditions.

The soil type-irrigation frequency-crop extraction pattern interaction needs further studying to determine the nature and extent of water movement away from the emitter (Ayars *et al*., 1999). Studies on irrigation scheduling for SDI assumed that reduced evaporation and improved irrigation efficiency would have a considerable effect on the irrigation requirement. The results have not answered the question conclusively. In some cases irrigation water was reduced and in others it was not (Camp, 1998). The varying results on the performance of SDI illustrate the difficulty in making general guidelines for SDI. Further experimentation and extensive field research coupled with the existing knowledge thus far about SDI performance will enable the production of useful guidelines for both farmers and designers (Sakellariou-Makrantonaki *et al.*, 2002). Camp (1998) acknowledged that the realization of increased application efficiency from SDI will depend on matching applications to crop water and nutrient requirements. It can be observed from various studies that there is need for research that explicitly examines the performance and applicability of SDI, using various design criteria and deficit irrigation as a water management strategy (Ayars *et al.*, 1999). Information on the soil moisture patterns resultant from buried laterals in SDI in the field production of carrots and amaranth vegetables is not available, and such knowledge will be valuable in the determination of the financial viability and engineering applicability SDI in South Africa. Furthermore, local users will benefit in terms of the best and acceptable management practices of SDI irrigated carrots and amaranth vegetables that will be generated from the study carrots and amaranth vegetables. The objectives of this study shall be as indicated below.

4.3 Objectives

The main objective of the proposed study is to investigate the performance of SDI under deficit irrigation for the production of carrots and indigenous amaranth vegetables in semi-arid conditions of Gauteng province on Hutton soils. Surface drip irrigation shall be used as the control. The specific objectives of the research are:

a) To evaluate the effect of hydraulic properties of Hutton soil on emitter discharge rate.
b) To determine the design requirements of SDI in a Hutton soil and its influence on deficit irrigation applicability to carrots and amaranth production.
c) To investigate the impact of drip lateral placement depth on the SDI system performance under deficit irrigation in semi-arid conditions for Hutton soil.
d) To determine crop water requirements, crop coefficient and water productivity of carrots and amaranth under SDI system for semi-arid conditions in a Hutton soil.
e) To assess the problem of emitter clogging and how it varies with lateral depth placement.

4.4 Hypotheses

It is hypothesised that deficit irrigation strategies enhance the performance of subsurface drip irrigation and will improve the production of indigenous amaranth and carrots vegetables under semi-arid conditions of Gauteng province on predominant Hutton soils.

1.1.1 The emitter discharge rate of buried laterals in Hutton soils may be lower than for surface drip system.

1.1.2 The width and depth of the soil wetting pattern diminishes with the increase of water stress levels on Hutton soils while productivity levels of carrots and amaranth increase.

1.1.3 The SDI system performance improves with lateral placement depth increase.

1.1.4 Crop water requirements and crop coefficient of amaranth and carrots are lower for SDI than for surface drip irrigation, while their water productivity increases with lateral placement depth under deficit irrigation in semi-arid conditions for Hutton soils.

1.1.5 Emitter clogging and root intrusion decrease with lateral depth placement.

In order to test the above objectives, the following chapter proposes the methodology that should be pursued.

5 MATERIALS AND METHODS

5.1 Introduction

This chapter describes the necessary procedures that should be followed to achieve the objectives set out above. It highlights the equipment to be used in the study. The optimal combination of deficit irrigation and SDI for vegetable production in Hutton soils will be assessed. Soil wetting pattern from different lateral depths, moisture regimes and extraction patterns will be investigated. The application uniformity and related parameters, problems of emitter clogging and root intrusion will also be assessed. Furthermore, crop coefficients of amaranth and carrots under SDI will be determined

5.2 Experimental Site Location

A field experiment shall be conducted at the Agricultural Research Council's Institute for Agricultural Engineering (ARC-IAE) in Pretoria. The actual geographical position of the study area is 25° 43' 45.2" S, 028° 16' 37.1" E at an altitude of 1337 m above sea level. The soils on the experimental site are Hutton soils which form the backbone of agriculture in Gauteng and the country. Therefore, the results of this study will be useful to drip irrigation users, peri-urban and small-scale farmers in the province in terms of vegetable production, food security, nutrition and medicinal requirements. In addition, the results will be useful to irrigation designers.

5.3 Experimental Design and Treatments

The experimental design and layout will consist of 36 field plots in a 3 x 3 factorial on a split plot randomized complete block design replicated four times, where the water stress levels are the whole plots and drip lateral depth placement as sub-plots. Each field plot will be 29 m long which is the maximum length of experimental site and 6 m wide. Amaranth will be planted in summer and carrots in winter. The plots will consist of a set of three drip laterals 29 m long spaced 2 m to allow for adequate space for measurements of lateral soil moisture movement from each lateral. The drip laterals shall be equipped with 2 ℓ/h emitters spaced 0.6 m to create continuous line wetting. The main treatments will consist of a set of three drip laterals installed at 0 (surface drip as control), 0.1 and 0.2 m depths in relation to root zone depth and density of carrots, known to be 0.3 – 0.4 m (Hygrotech SA, 2008) and an average depth of 0.18 m (Dysko and Kaniszewiski, 2007). The root depth of amaranth is still not known. Each plot will be treated with deficit irrigation strategies in the form of imposed water stress based on irrigation 100 %, 80 % and 60 % of cumulative ET_c, after Nortje and Henrico (1996) and Dysko and Kaniszewiski (2007). The whole design will be replicated three times. An in-depth soil analysis will be conducted to establish the spatial and depth variations of the soil on the experimental site.

Two rows of the vegetable crops per drip lateral at 0.1 m from lateral position shall be transplanted and established using overhead irrigation. Carrots shall be thinned out to have a uniform spacing of about 3-5 cm 10 days after sowing (DAS), and amaranth shall be transplanted at an inter-row spacing of about 0.3 m. Based on soil analysis results, fertilizer requirements shall be determined and fertigated by a Dosatron injector. All other agronomic requirements shall be observed. Weather data shall be obtained from an automatic weather station located at the Botanical Gardens, approximately 1 km from the experimental site and monitored by ARC Institute for Soil, Climate and Water. Forecast weather data shall be obtained from Dacom services.

5.4 Instrumentation and Measurements

Objective 1: To evaluate the impact of hydraulic properties of Hutton soil on emitter discharge rate.

Lazarovitch *et al.* (2006), Shani *et al.* (1996) and Safi *et al.* (2007) reported reduced emitter discharge rates due to soil physical properties. The authors reported that a positive water pressure (backpressure) is developed at the emitter-soil interface, reducing design emitter discharge rate. The soil hydraulic properties determine the magnitude of backpressure. To evaluate the effect of soil properties on emitter discharge rates, one of the two outer laterals for each of the 36 plots shall be selected and five emitter flow rates measured by inserting containers at 5 m intervals under emitters adjacent to pressure measuring points. Emitter discharge measurements will be done three times per crop season. At the end of each crop season, two laterals chosen at random shall be excavated and inserted through 20-litre buckets with known total weight of soil and bucket. After 20 minutes of operation, the buckets shall be re-weighed to obtain discharge rates of buried emitters (Safi *et al.*, 2007). Such information will be valuable to designers, evaluators and farmers.

Objective 2: To determine the design requirements of SDI in Hutton soil and its influence on deficit irrigation applicability to carrots and amaranth production.

The design requirements that are critical for SDI systems are lateral spacing and depth placement which are dependent on soil characteristics. These requirements affect the initial investment costs of SDI systems, water application uniformity, system capacity, risks of deep percolation and overall system performance in crop production. In order to determine these, three access tubes at 0.3 m interval from the lateral shall be installed at 15 m point on one side of each of the 36 laterals. A 1.0 m Mobi-Check probe which scans and records at 5 depths (0.1, 0.3, 0.5, 0.7, 0.9 m) shall be used to obtain soil moisture content measurements down the soil profile. Soil moisture curves shall be drawn to determine the actual field soil wetting pattern (depth, width) for one lateral side. The total wetting pattern in terms of the width and depth of the wetting shall be determined for Hutton soil in semi-arid conditions for each of treatments. This procedure shall be done three times per irrigation cycle; immediately after irrigation, half-way of the irrigation interval and just before the next irrigation. Incidences of deep percolation and capillary effects shall be evaluated in the form of moisture measured beyond 0.5 m. Eq. (2-4) and (2-5) shall be used to estimate the soil wetted pattern. Comparison shall be made with predictions from existing empirical formula of Schwartzman and Zur (1986) and the soil-texture based techniques (Reinders *et al.*, 2005). Similarly, comparison shall be made between design requirements under deficit irrigation (60 % and 80 %) replenishment and those under 100 % ET_o replenishment.

Objective 3: To investigate the impact of drip lateral placement depth on the SDI system performance under deficit irrigation in semi-arid conditions for Hutton soil.

Samples of new drip tapes shall be selected at random and emitter flow rates and pressure variation parameters determined in the ARC-IAE Hydro laboratory. The application uniformity of new laterals as defined by q_{var}, CV, U_s, UC and DU_{LQ} shall be determined using Eq. (2-13) to (2-17). Three times per season, at the same time when discharge measurements will be done, water pressure in the lateral shall be measured at 5 m intervals. The field pressure variation along buried laterals will be measured using pressure gauges coupled with needles and inserted into the 5 mm polyethylene micro-tubes connected permanently to buried laterals at 5 m interval, modifying the procedures followed by Bagarello *et al*. (1995) and Provenzano and Pumo (2004). The application uniformity of the operating SDI system shall be computed and its performance compared to the values for the new drip tapes. The normal pressure variation due to friction for surface and SDI lateral shall be computed using Eq. (2-8) to (2-10), and comparison between computed and the observed pressure variation shall be made. Three places along the middle buried lateral tubes shall be excavated to observe the effect of tape deformation due to compression, and Eq. (2-11) shall be used to evaluate the effect of tape deformations. The difference between pressure variations shall be attributed to compression due soil weight.

Objective 4: To determine crop water requirements, crop coefficient and water productivity of carrots and amaranth under SDI system for semi-arid conditions in Hutton soil.

Irrigation treatments shall begin 20 days after planting (Allen *et al*., 1998) and will consist of 100, 80 and 60 % of cumulative ET_c, accounting for rainfall. ET_c will be estimated using $ET_c = K_c*ET_o$, where K_c shall be determined on site. Amaranth K_c values are unknown and those of carrots under SDI shall be compared with the existing values of 0.7, 1.05, 0.95 and 0.3 (Allen *et al*., 1998). ET_o shall be estimated using Penman-Monteith equation (Allen *et al*., 1998). The K_c values shall be determined using a modified pot experiment established on site. For each of the lateral depth variations, two uPVC pipes units 200 mm diameter and 0.8 m deep shall be filled with soil from the experimental site and one plant sown in each. For each set of units, water shall be applied at 0, 0.1 and 0.2 m depth. An average ET_c shall be obtained gravimetrically as the difference between pots weight measured using a digital scale and K_c values computed as stated above. Flow meter readings shall be taken at the beginning and end of irrigation season in order to determine the total water applied to the vegetable crop for each treatment. From each treatment, the total and marketable yield (ton/ha) of vegetables shall be determined. This will enable the identification of the lateral depth placement that optimizes the performance of deficit irrigation techniques under SDI in carrots and amaranth production in semi arid conditions for Hutton soils. Using the total yield (kg) and total amount of applied water as measured from flow meters, WP shall be calculated using Eq. (2-18) and comparison amongst treatments done. The quality of carrot shall be determined from the root lengths, diameter, colour and if possible from sugar levels as well. The quality of amaranth shall be determined from the edible portions, which are leaves and soft branches.

Objective 5: To assess the problem of emitter clogging and how it varies with lateral depth placement.

A flow meter shall be installed to each of the 36 treatments to measure the actual total flow rate of all the emitters in each treatment, and the average emitter discharge shall be estimated by dividing the total discharge rate by the total number of outlets in the treatment. An average value of K for all emitters in the lateral shall be calculated. The difference between the field K and the value for unused tubing shows the net effect of emitter plugging or water losses from the system because of leakage (Mizyed and Kruse, 1989). Also, the difference between the initial total lateral flow rate and the total lateral flow rate at the end of the season shall be indicative of emitter clogging. The effect of root intrusion will be evaluated at ARC-IAE HydroLab. One lateral from different depth treatments shall be carefully removed from the ground at the end of each season and physically assessed and evaluated at the ARC Hydro Lab.

5.5 Statistical Analysis

The two main effects, and all interactions between treatments shall be analysed by analysis of variance methods (ANOVA) using the statistical programme GenStat for Windows® (Payne *et al.*, 2007). The entire field experiment will be repeated for a three year period.

5.6 Equipment Requirements and Estimated Budget

1. Complete SDI system pipes, fittings and accessories, Soil moisture sensor (e.g. Mobi Check), data loggers, sensitive pressure gauges equipped with needles, digital scale, micro-lysimeters
2. The estimated budget is **R309, 800**

5.7 Summary of Deliverables

The results from this study will thus contribute to the:

1. Improved understanding of the use of SDI for vegetable production. The potential exist for SDI to be the best method for use of wastewater in vegetable production in the water-scarce South Africa.
2. Development of the engineering design, installation and management guidelines for SDI.

3. Improved knowledge of soil-water dynamics and wetting patterns under SDI. This will greatly improve the knowledge in nutrient supply capacity and management in the root zone resulting in sustainable vegetable production and food security in peri-urban and small scale farmers of Gauteng province.
4. Determination of crop water requirements and crop coefficients of amaranth vegetable.

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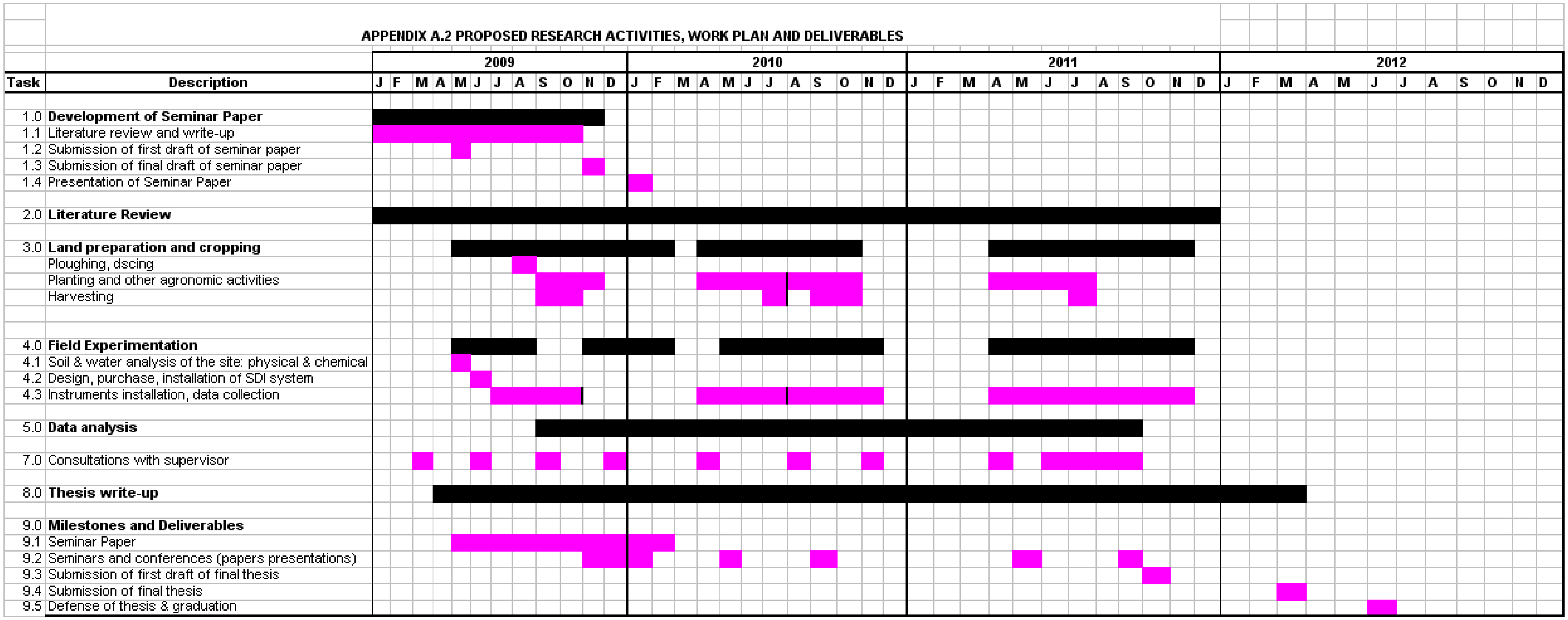
APPENDIX A.2: PROPOSED RESEARCH ACTIVITIES, WORK PLAN AND DELIVERABLES



APPENDIX A.2 PROPOSED RESEARCH ACTIVITIES, WORK PLAN AND DELIVERABLES

Task	Description
1.0	**Development of Seminar Paper**
1.1	Literature review and write-up
1.2	Submission of first draft of seminar paper
1.3	Submission of final draft of seminar paper
1.4	Presentation of Seminar Paper
2.0	**Literature Review**
3.0	**Land preparation and cropping**
	Ploughing, dscing
	Planting and other agronomic activities
	Harvesting
4.0	**Field Experimentation**
4.1	Soil & water analysis of the site: physical & chemical
4.2	Design, purchase, installation of SDI system
4.3	Instruments installation, data collection
5.0	**Data analysis**
7.0	Consultations with supervisor
8.0	**Thesis write-up**
9.0	**Milestones and Deliverables**
9.1	Seminar Paper
9.2	Seminars and conferences (papers presentations)
9.3	Submission of first draft of final thesis
9.4	Submission of final thesis
9.5	Defense of thesis & graduation