# AN EVALUATION OF POTENTIAL MANAGEMENT OPTIONS TO REDUCE WATER USE IN COMMUNAL GARDENS ON THE CAPE FLATS

**Jaqueta D. Keet**

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by

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Submitted in partial fulfillment for the degree of
**MASTERS IN SCIENCE**

In the Department of Earth Sciences
University of the Western cape



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May 2001

# DECLARATION

"I the undersigned hereby declare that
*AN EVALUATION OF POTENTIAL MANAGEMENT OPTIONS TO REDUCE WATER USE IN COMMUNAL GARDENS ON THE CAPE FLATS*,
is my own work, that it has not been submitted for a degree or examination in any other university, and that all the sources I have quoted have been indicated and acknowledged by complete references."



Jaqueta D. Keet May 2001

Signature......................................

## ABSTRACT

The aim of this project was to evaluate various potential management options in their ability to reduce the water use of small and medium scale vegetable gardens on the Cape Flats. The water use of these gardens has a considerable impact on the economic feasibility of vegetable gardening. Considering the importance of the Cape Flats aquifer, it is also preferable from an environmental point of view to reduce water usage on the Cape Flats. The potential management options discussed in this report are: (1) reducing crop water requirements by using windbreaks and changing planting or sowing dates, (2) improving irrigation techniques and (3) improving irrigation management practices.

The CROPWAT 7.0 model was used to quantify the effects of windbreaks and planting or sowing dates on crop water requirements. It was calculated that artificial windbreaks could reduce crop water requirements by 7-13%. Optimising planting or sowing dates could reduce the crop water requirements by 30-40%.

Different irrigation techniques were tested on Cape Flats soils. Abandoning the present sprinkler irrigation system for drip irrigation could result in a potential 35-50% reduction in water use, especially when commercial drippers with uniform flow rates are used in combination with other techniques to improve the sandy soils water holding capacity.

Poor irrigation management practices could lead to an estimated 30 % over-irrigation. The low-tech drip irrigation system proposed in this study proved to be an excellent tool in allowing gardeners to control irrigation application quantities. An irrigation scheduling programme permits farmers to control water applications depending on weather, crop type and growth stage.

Overall, it can be concluded that by reducing crop water requirements (windbreaks and changing planting), improving irrigation techniques (drip irrigation) and management practices (irrigation schedules) has a combined potential to reduce water use in small and medium scale gardens up to 70%. Windbreaks seem to be the least promising option with regard to water use reduction.

# PREFACE

This study formed part of a larger project namely " Urban Vegetable production in Khayelitsha: A case study of management options to improve the feasibility of vegetable gardening in deprived communities of the Cape Flats, South Africa, with an emphasis on Agroforestry. The Department of Water Affairs and Forestry (DWAF) funded this project as a community forestry project. Thus it was a prerequisite that trees be included in the study. Therefore the study initially focused on the effect of trees on the water use of communal gardens.

It was hypothesized that trees acting as windbreaks would reduce evapotranspiraton rates, simultaneously reducing irrigation water requirements and therefore water use of communal gardens. After determining the effect of artificial windbreaks on the water balance of the communal garden, the results indicated a small reduction in water use. In the case of real trees the reduction would be insignificant, or increase water consumption, as trees utilize water as well.

The option of using windbreaks to reduce water use is not viable in the study area, thus other water saving options were focused on, such as improving irrigation techniques, changing planting or sowing dates and irrigation management. The focus therefore shifted from trees reducing water use to evaluating potential management options in order to reduce water use.

## ACKNOWLEDGEMENTS

I would like to thank God, my heavenly Father for his grace, power and strength.

My Parents for being the foundation in my life.

My precious son Brent Keet, who is my driving force.

Dr Vincent Taylor for his support throughout my studies and making it possible for me to obtain my MSc.

Dr Jan Boelhouwers who's input and assistance has made it possible for me to complete my thesis.

Piet van Asten and Anneke Fermont who has provided valuable inputs, always kept me focused and committed to my studies.

The Department of Water Affairs and Forestry who provided me with funding during the period of masteral studies.

Rob Small, Landy Wright and Christina Kaba from the NGO Abalimi Bezekhaya for their assistance and support.

The SCAGA gardeners, especially Mrs Ngada.

ARC Infruitec-Nietvoorbij – For their ongoing support and funding.

Elton Jacquire, family and friends for continual encouragement.

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# 1. INTRODUCTION

## 1.1 BACKGROUND

In 1996 the University of the Western Cape (UWC), Earth Science Department became part of a Community Forestry Network initiated by the Department of Water Affairs and Forestry (DWAF, 1996). The network was a collaboration between three universities namely UWC, the University of Stellenbosch (US) and the University of the North (UN).

The Reconstruction and Development Program (RDP), introduced by the new South African government in 1994, formed the context for this collaboration. The RDP's function was to (a) mobilize disadvantaged communities and (b) the transformation of the agricultural sector. The RDP strategy identified the forestry sector as an important element of local natural resources development that can contribute to creating better living environments and economic opportunity (DWAF, 1996).

## 1.2 JUSTIFICATION OF THE RESEARCH

South Africa has experienced rapid urbanization (Spies, 1987). In South Africa the townships around and in Cape Town have developed since 1980 and have increased in size in the last 10 years (Fermont *et al.*, 1998). Khayelitsha, the largest township development along the coastline, had an official population of 320 000 by 1990 with an estimated population of approximately 750 000 by the turn of the century (Wright *et al.*, 1993). At present Khayelitsha have over 1 million residents (LTE, 2001)

The rural influx has contributed to the ethnic diversity and economic disparities found in South African cities (Wright et al., 1993). The preliminary results of the 1996 census suggested that more than half (54.4 percent) of the estimated population of South Africa lives in urban areas (Census, 1997). Furthermore, 47 % of the urban population in the Cape Town Township is poor (Central Statistical Services, 1995). The rapid expansion of settlements results in overcrowding, which leads to lack of sanitation or basic hygiene among the community (Wright *et al.*, 1993). In Khayelitsha, problems such as inadequate provision of services, lack of facilities, poor water quality of public open spaces poor environmental quality and various other problems are evident (Karaan and Mohammed, 1996).

Due to rapid expansion, unemployment and increasing food prices, living conditions have declined drastically. People have thus resorted to producing their own food to reduce food costs. Food production in urban and peri-urban areas is known as Urban Agriculture (UA) (Yeung, 1987).

*Communal Gardening*

This study looks at vegetable gardening on a larger scale namely communal gardening. Communal gardens are directed at feeding the family and possibly saving money on food costs. Money is generated through the selling of surplus produce (Kogi-Makau, 1995).

Communal gardening can become quite expensive if not managed correctly. Initially adequate fertiliser and other inputs need to be applied in order for these gardens to produce worthwhile crops during the first growing seasons. In order to start up a communal garden the starting cost is normally quite high. The main costs are normally installing the necessary infrastructure, possibly a borehole and pump (including labour), fencing to prevent theft of crops and tools and sheds to store tools and equipment (Fermont *et al.*, 1998).

This study was conducted at a communal garden in Khayelitsha on the Cape Flats, Western Cape. The focus of this study was to significantly reduce water usage of communal gardens in order to reduce excess expenditure and water cost. At present 1000L (1kL) of water costs R1.75 excluding VAT, which is relatively inexpensive. In the future with the expansion of the informal settlements, increased population and increased water scarcity, the water prices are bound to increase by 2 or even 3 fold, making water an extremely expensive commodity. But with proper water management, costs could be reduced significantly (Fermont *et al.*, 1998).

The Western Cape experiences harsh southeasterly and northwesterly winds, which could have devastating effects on communal gardens such as (1) sandblasting which results in direct damage to the vegetable crops and (2) increased evapotranspiration rates increasing irrigation requirements. Initially, it was presumed that incorporating trees as windbreaks into communal gardens would minimize windblasting and reduce irrigation water usage. It was therefore hypothesized that by incorporating trees as windbreaks into communal gardens, evapotranspiration rates and thus irrigation water requirements would be reduced.

This study eventually incorporated other options to reduce water usage of communal gardens, which included reducing crop water requirements, improving irrigation techniques and irrigation management.

Time limitation excluded the option of long-term experiments. Climatic limitations also resulted in fewer experiments. This study has mainly been based on theoretical considerations, which deems this a potential feasibility study of various techniques and methodologies on the Cape Flats and not so much an actual feasibility study.

## 1.3 OBJECTIVES

The overall goal of this study was to investigate the potential management options for water use in small-scale urban communal gardens on the Cape Flats in order to reduce water use yet to increase productivity and sustainability. Reducing water use can be done in 2 ways –

a) Reducing crop water requirements by means of (i) windbreaks (ii) changing planting or sowing dates and
b) Improving irrigation efficiency by (i) type of irrigation system (ii) irrigation management.

The objectives of the study are:

1. To determine and evaluate the effects of windbreaks on the water usage of communal vegetable gardens
2. To develop a model that could calculate crop water and irrigation requirements
3. To determine and evaluate the effects of irrigation techniques, optimal planting dates and irrigation management.
4. To identify the most promising water management strategy for communal vegetable gardening.

Examining the objectives of the study a theoretical approach was most appropriate. However, certain aspects of the research have been verified and quantified in the field (testing the irrigation systems in the Siyazama Community Allotment Garden Association (SCAGA) communal garden on the Cape Flats). An irrigation model was formulated and used to improve and verify the results obtained using the CROPWAT 7.0 model used in this study.

This chapter will be followed by a locality description with a brief overview of the socio-economic status of the SCAGA gardeners. After the study area description, chapter 3 will focus on reducing crop water requirements with regards to (a) trees as windbreaks and (b) changing planting or sowing dates. The crop water requirements were quantified by means of the FAO CROPWAT 7.0 computer based model. Chapter 3 will be followed by irrigation systems, which focuses on irrigation techniques (Chapter 4) and management (Chapter 5). 'Irrigation Techniques' will investigate the most efficient irrigation system for the Cape Flats, Khayelitsha area. 'Irrigation management' will focus on optimising irrigation by means of developing an irrigation schedule specifically for the SCAGA gardeners. The study will then be finalized with overall conclusions.

# 2. ENVIRONMENTAL SETTING OF THE STUDY AREA

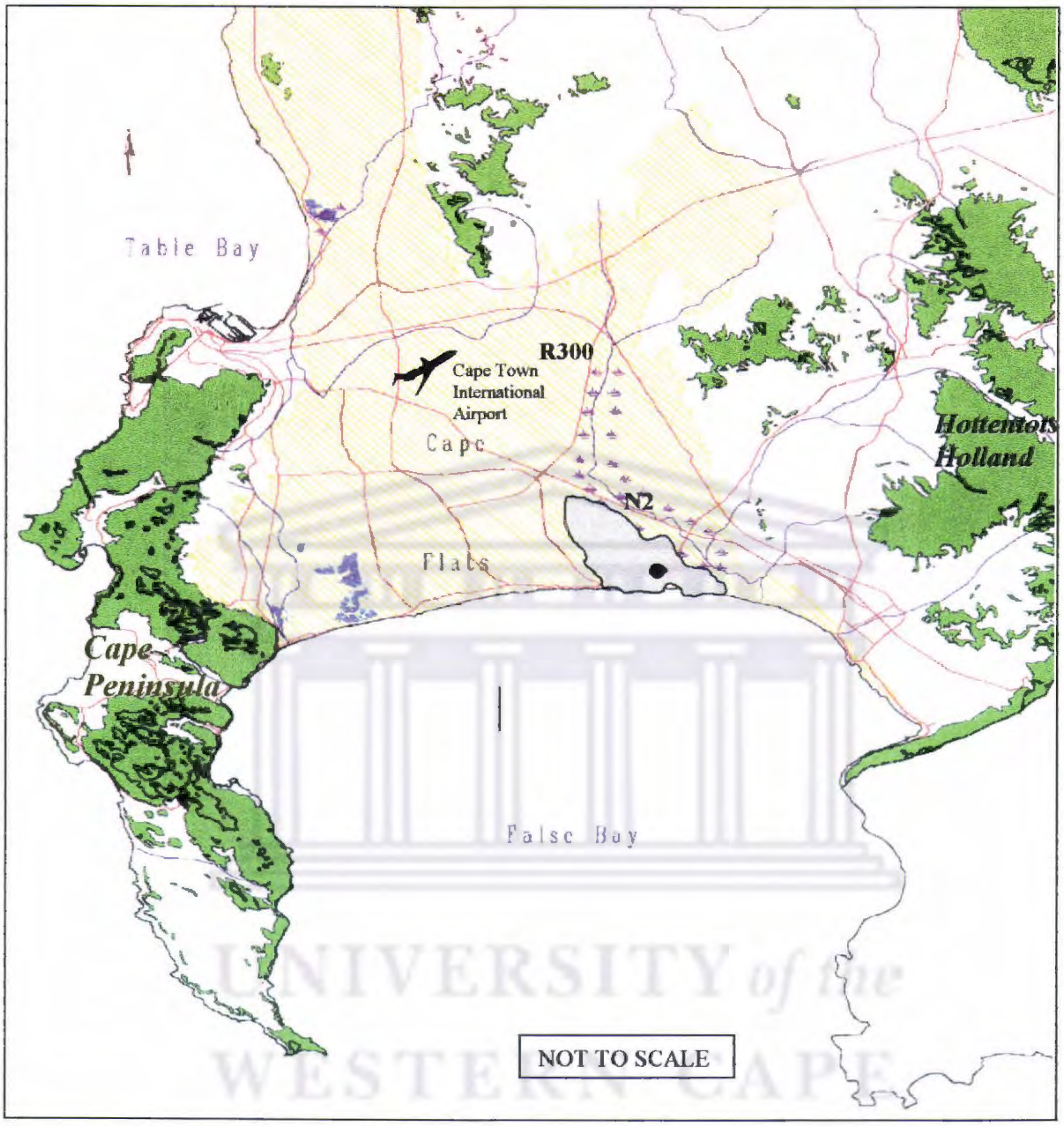
## 2.1 CAPE FLATS

The Cape Flats are located in Western Cape Province, which extends from the Cape Peninsula in the west to the Hottentots Holland Mountain in the east and Atlantis in the North. This Chapter gives a description of the Cape Flats, a township located on the Cape Flats (Khayelitsha) and the study site (SCAGA garden), which is located in Khayelitsha (Figure 1).

## 2.2 PHYSICAL ENVIRONMENT

### 2.2.1 Climate

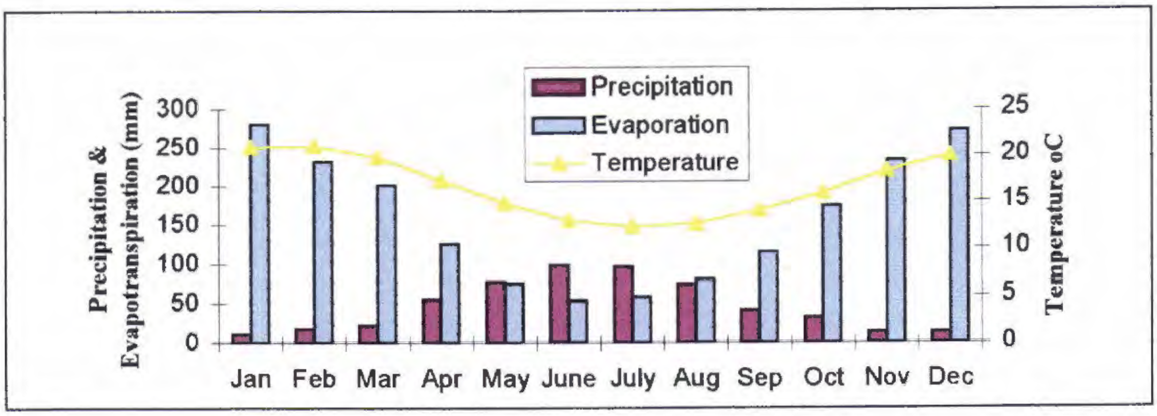
The Cape Peninsula climate experiences a typical Mediterranean climate with hot dry summers and cold wet winters. On average 97 rain days are experienced per annum with an annual average rainfall of 555mm. The Cape Town International Airport weather station is the closest meteorological station to the study area (Figure 1). Thus all the climatic data required for this study was obtained from the meteorological station located at the airport 10km northwest of the study site. According to the climatic data in Figure 2, the average daily temperature varies from 12$^{o}$C in winter (July) to 21 $^{o}$C in summer (January) (SAWB, Unpublished data).




| | |
|---|---|
| | Cape Flats |
| | Forestry |
| | Khayelitsha |
| ● | SCAGA garden |

Wright and Conrad, 1995

Figure 1: Location map of SCAGA garden in Khayelitsha on the Cape Flats




(SAWB, Unpublished data)

Figure 2: Average monthly temperature (1968-1996), precipitation (1959-1996) and A-pan evaporation (mm) (1957-1987) as measured at Cape Town International Airport

In winter, cold fronts coming from the Atlantic Ocean bring rain with regularly strong northwesterly winds. In summer strong, dry southeastern winds occur that frequently reach gale force but also brings cooler air to the Cape Flats (Fermont *et al.*, 1998). In summer temperatures are high, there is an abundance of sunlight and rainfall is almost absent. Therefore in summer water needs to be provided in the form of irrigation, while in winter there is sufficient water to meet crop water requirements.

### 2.2.2 Topography

The Cape Flats represents a large tombolo between the Cape Peninsula and the mainland (Wright and Conrad, 1995). The almost horizontal sandstones of Table Mountain were originally linked to the same formations capping the mountains on the Eastern fringes of the Cape Flats (Wright and Conrad, 1995). Khayelitsha is subdivided into sections of which the study site can be located in section 39 also known as Macassar Khayelitsha. This area was comprised of high-vegetated dunes with a large low-lying central area

(Wright and Conrad, 1995). Urbanising the catchment has leveled the terrain with dunes remaining only in the south (Wright and Conrad, 1995).

### 2.2.3 Geology

Fluvial and marine erosion have shaped the topography of the deeply weathered Malmesbury Group and Cape granite basement on the Cape Flats (Hartnady & Rogers, 1990). In more recent geological eras (Cenozoic), sands have been deposited on top of the latter two geological formations. The sand body is generally stratified horizontally and several lithostratigraphic units can be recognized (Wright and Conrad, 1995). The Sandveld lithostratigraphic unit is typical of the Cape Flats, which is comprised of the following Witzand, Langebaan, Veldrift, Varswater and Elandsfontein Formations (Table 1).

The Witzand Formation consists of very fine to very coarse calcareous sands and has abundant small shells and shell fragments (Wright and Conrad, 1995). These sands form an extensive system of parabolic, vegetation-bound dunes (Wright and Conrad, 1995).



Table 1: Lithostratigraphy of the Cape Flats

| | | |
|---|---|---|
| | *Witzand Formation* | *Holocene* |
| | *Langebaan Formation* | *Pleistocene* |
| ***SANDVELD (lithostratigraphy of the Cape Flats)*** | *Velddrif Formation* | *Pleistocene* |
| | *Varswater Formation* | *Pleistocene* |
| | *Elandsfontein Formation* | *Miocene* |

From: Hartnady and Rogers, 1990

The Langebaan Formation consists of calcrete and very fine to fine calcareous sands, consisting of cross bedded, semi-consolidated aeolianites along the coast (Wright and Conrad, 1995). These calcrete layers could also be seen, at the study site after the soils had been ripped, the calcretions differ in thickness and shape and are commonly seen close to the surface. The high pH values (pH 8-9) are as a result of the high calcite concentration resulting in extremely poor soils. Massive sandy surface limestone, which forms a hard irregular layer, covers most of the eastern Cape Flats. This layer is only a few meters thick and consist of a hard, densely cemented zone of 25 – 30cm, resting on soft sandy calcrete, which grades into calcareous sand, the lime content gradually decreases with depth (Wright and Conrad, 1995) which is typical of the sands at the study site.

The Velddrif Formation is a patchy deposit of poorly consolidated intertidal and estuarine sediments, which is best seen at the foot of the coastal cliffs (Wright and Conrad, 1995). The Springfontein Formation is aeolian in nature and is comprised of fine to medium quartzose sand. In the Phillipi area on the Cape Flats, these sands attain an unusual degree of purity (99,5 % $SiO_2$) (Wright and Conrad, 1995). The Varswater Formation is of marine origin consists of high fossiliferous, phosphate bearing muddy, very fine quartzite sand (Wright and Conrad, 1995).

### 2.2.4 Geohydrology

Khayelitsha forms part of the Cape Flats coastal aquifer, which has been considered as a valuable groundwater resource (Vandoolaeghe, 1984). The aquifer is recharged from the precipitation in the catchment (Wessels and Greef, 1980). Due to the catchment being sandy in nature it results in high infiltration rates and no natural runoff occurs (Wessels and Greef, 1980). The aquifer is not homogeneous as the calcrete and clay horizons act as semi-pervious layers (Wright and Conrad, 1995). The occurrence of calcrete near the water table is a result of the abundance of shelly material throughout the aquifer resulting in groundwater saturated with calcium carbonate (Table 2). The exceptionally high groundwater levels during winter are due to the calcrete layers occurring throughout the area (Wright, et. al., 1993). At the SCAGA garden (study site), the groundwater level was 3 meters below the surface in August 1997.

### 2.2.5 Soils

The Cape Flats are characterized by deep calcareous sands of relatively recent geological origin. Older sand display more acidic soil, while sand of more recent marine origin tends to be alkaline (FAO, AGL, 2000). Sandy soils are generally well drained although there are areas that are underlain by laterites (iron oxides known colloquially as koffieklip) and calcrete layers, which result in poor drainage (FAO, AGL, 2000).



### 2.2.6 Vegetation

In the South Western Cape fynbos is classified as the dominant vegetation (White, 1997). Fynbos can be classified as either mountain or lowland fynbos, which is limited to clayey and sandy soils and limestone areas (White, 1997). Coastal fynbos forms part of the lowland fynbos much of which has been destroyed by increased agriculture and urbanization and is threatened by alien vegetation from other countries (White, 1997).

The most common alien plants are the Australian wattles like Rooikrans, Port Jackson and Black Wattle (White, 1997).

Table 2: Groundwater quality of the Cape Flats aquifer

| CHEMICAL | | CONCENTRATIONS | | |
|---|---|---|---|---|
| | | MEDIAN | MINIMUM | MAXIMUM |
| **Sodium** | **mg/l** | 57 | 20 | 760 |
| **Potassium** | **mg/l** | 1.5 | 0.9 | 12.0 |
| **Calcium** | **mg/l** | 95 | 36 | 150 |
| **Magnesium** | **mg/l** | 11 | 3.9 | 93 |
| **Ammonia (as N)** | **mg/l** | <0.5 | <0.5 | 1.2 |
| **Sulfate** | **mg/l** | 30 | 4 | 166 |
| **Chloride** | **mg/l** | 99 | 35 | 1317 |
| **Total alkalinity ($CaCO_3$)** | **mg/l** | 248 | 80 | 391 |
| **Nitrate (as N)** | **mg/l** | <0.1 | <0.1 | 2.6 |
| **Nitrite (as N)** | **mg/l** | <0.05 | <0.5 | 0.1 |
| **Total Phosphate (as P)** | **mg/l** | <0.1 | <0.1 | 0.35 |
| **pH** | | 7.7 | 7.0 | 8.2 |
| **Electrical conductivity** | **mS/m** | 78 | 43 | 499 |

From: Tredoux *et al.*, 1980

## 2.3 THE STUDY SITE – SCAGA GARDEN

### 2.3.1 Demography

The urban township of Khayelitsha is situated centrally along the northern shoreline of False Bay some 35 km southeast of Cape Town (Fermont *et al.*, 1998). The township is bound on the northern side by the N2 freeway and on the southern side by the Baden Powell Drive and False Bay (Fermont *et al.*, 1998). The locality of the study area can be seen in Figure 1. On the eastern side the township extends across Baden Powell drive to Macassar. The study site is located in Macassar Khayelitsha and is called Siyazama Community Allotment Garden Association (SCAGA) garden.

### 2.3.2 Background

The SCAGA communal garden, located in Macassar Khayelitsha, section 39 was selected as the most suitable study site. To start up a communal garden in Khayelitsha required that the community members had enough money and land to start a communal garden, which was not the case for the section 39 community members. A non-governmental organization (NGO) by the name of Abalimi Bezekhaya was approached by the members of section 39 for assistance. Six of these home gardeners were trained in January 1994. By mid-1994 Abalimi Bezekhaya and the community members of section 39 wrote a proposal for funding to initiate a communal garden. In October 1996, 2 years later they received funding. Early 1997 the SCAGA members were supplied with land underneath a set of powerlines (Figure 3). This was the beginning of the Siyazama

Community Allotment Garden Association. The garden initially started out with 18 members, 16 women and 2 men.

Figure 3: SCAGA garden underneath powerlines. Initial stage: fences and sheds were erected, ground ripped, pump installed and the vegetable plots demarcated.

After the allocation of the land by the City Council, the area was cleared and fenced; three sheds and a shade-house were erected. Overhead irrigation was installed throughout the garden, which uses borehole water. The mixed vegetable garden's water usage was calculated at 1566 kL/year while the cash cropping water use was calculated at 1754 – 3222 kL/year (Fermont *et al.*, 1998). The irrigation requirements for mixed and cash crops can be found in Table 3 (a), 3(b) and 4.

Table 3: Seasonal irrigation requirements for mixed cropping for SCAGA ($1800m^2$) (Fermont *et al.*, 1998)

a) Summer (planted 1 September), 100% efficiency

| VEGETABLE | IRRIGATION (mm) | AREA ($m^2$) | IRRIGATION (kL) |
|---|---|---|---|
| Cabbage | 500 | 300 | 150 |
| Spinach | 347 | 360 | 124.9 |
| Beetroot | 336 | 140 | 47 |
| Turnip | 336 | 140 | 47 |
| Potatoes | 528 | 160 | 84.5 |
| Carrots | 336 | 110 | 37 |
| Onions | 336 | 130 | 43.7 |
| Peas | 306 | 70 | 21.4 |
| Tomato | 600 | 130 | 78 |
| Pepper | 536 | 40 | 21.4 |
| Beans | 241 | 50 | 12.1 |
| Pumpkin | 419 | 40 | 16.8 |
| Mielies | 486 | 70 | 34 |
| Lettuce | 271 | 20 | 5.4 |
| Eggplant | 536 | 40 | 21.4 |
| TOTAL | | 1800 | **744.7** |

b)Winter (planted 1 April), 100% irrigation efficiency

| VEGETABLE | IRRIGATION (mm) | AREA ($m^2$) | IRRIGATION (kL) |
|---|---|---|---|
| Cabbage | 17 | 250 | 4.3 |
| Potato | 4 | 270 | 1.2 |
| Spinach | 19 | 400 | 7.6 |
| Carrots | 43 | 140 | 6.0 |
| Cauliflower | 20 | 90 | 1.8 |
| Onions | 43 | 180 | 7.7 |
| Peas | 3 | 130 | 0.4 |
| Turnip | 43 | 140 | 6.0 |
| Beans | 6 | 110 | 0.7 |
| Broccoli | 20 | 50 | 1.0 |
| Beetroot | 43 | 40 | 1.7 |
| TOTAL | | 1800 | **38.4** |

Sprinkler Irrigation in SCAGA garden is estimated to have an efficiency of 50%. Irrigation requirements for the SCAGA garden is therefore 745 * 2 = 1490 and 38 * 2 = 76 kL for the summer and winter season respectively

Table 4: Irrigation requirements for cash crops (sole cropping) for SCAGA ($1800m^2$) (Fermont *et al.*, 1998)

| VEGETABLE | CROP/ YEAR | IRRIGATION (mm) 1/1 – 1 January, 1/3 – 1 March, 1/4 - 1 April, 1/6 –1 June, 1/9 – 1 September, 1/12 – 1 December | TOTAL IRRIGATION (mm) | TOTAL IRRIGATION (kL) |
|---|---|---|---|---|
| Spinach | 3 | 374 (1/9) + 446 (1/1) +4(1/5) | 824 | 1483 |
| Cabbage | 2 | 500 (1/9) + 17 (1/4) | 517 | 931 |
| Beetroot | 3 | 336 (1/9) + 439 (1/1) +4(1/5) | 779 | 1402 |
| Turnip | 3 | 336 (1/9) + 439 (1/1) +4(1/5) | 779 | 1402 |
| Potatoes | 2 | 528 (1/9) + 4 (1/4) | 532 | 958 |
| Carrots | 3 | 336 (1/9) + 139 (1/1) +4(1/5) | 779 | 1402 |
| Onions | 3 | 336 (1/9) + 439 (1/1) +4(1/5) | 779 | 1402 |
| Peas | 3 | 306 (1/9) + 377 (1/1) +2(1/5) | 685 | 1233 |
| Tomato | 2 | 600 (1/9) + 76 (1/3) | 676 | 1217 |
| Pepper | 2 | 536 (1/9) + 134 (1/3) | 670 | 1206 |
| Beans | 3 | 241 (1/9) + 330 (1/1) +6(1/5) | 577 | 1039 |
| Pumkin | 3 | 419 (1/3) + 461 (1/1) +5(1/5) | 885 | 1593 |
| Mielies | 2 | 486 (1/9) + 1 (1/3) | 487 | 877 |
| Lettuce | 4 | 271 (1/9) +441(1/12)+176(1/3)+ 7(1/6) | 895 | 1611 |
| Eggplant | 2 | 536 (1/9) + 134 (1/3) | 670 | 1206 |
| Cauliflower | 3 | 384 (1/9) + 450 (1/1) +3(1/5) | 837 | 1507 |
| Broccoli | 3 | 384 (1/9) + 450 (1/1) +3(1/5) | 837 | 1507 |

Note : The irrigation efficiency is 100%. Irrigation requirements for sprinkler irrigation in the Cape Flats (50%) will thus be twice as high.

The entire garden is 170m x 35m and is divided into 30 plots, each consisting of 6 beds. Each bed is approximately $10m^2$. Fynbos hedgerows were planted in between every 6 plots and at the most southeastern side of the garden trees were planted (Figure 4, 5 and 6).

*Brachylena Discolor* trees were planted to act as windbreaks (although it will take a few years before they can serve their purpose) in order to protect the garden against the harsh southeasterly and northwesterly winds experienced on the Cape Flats.

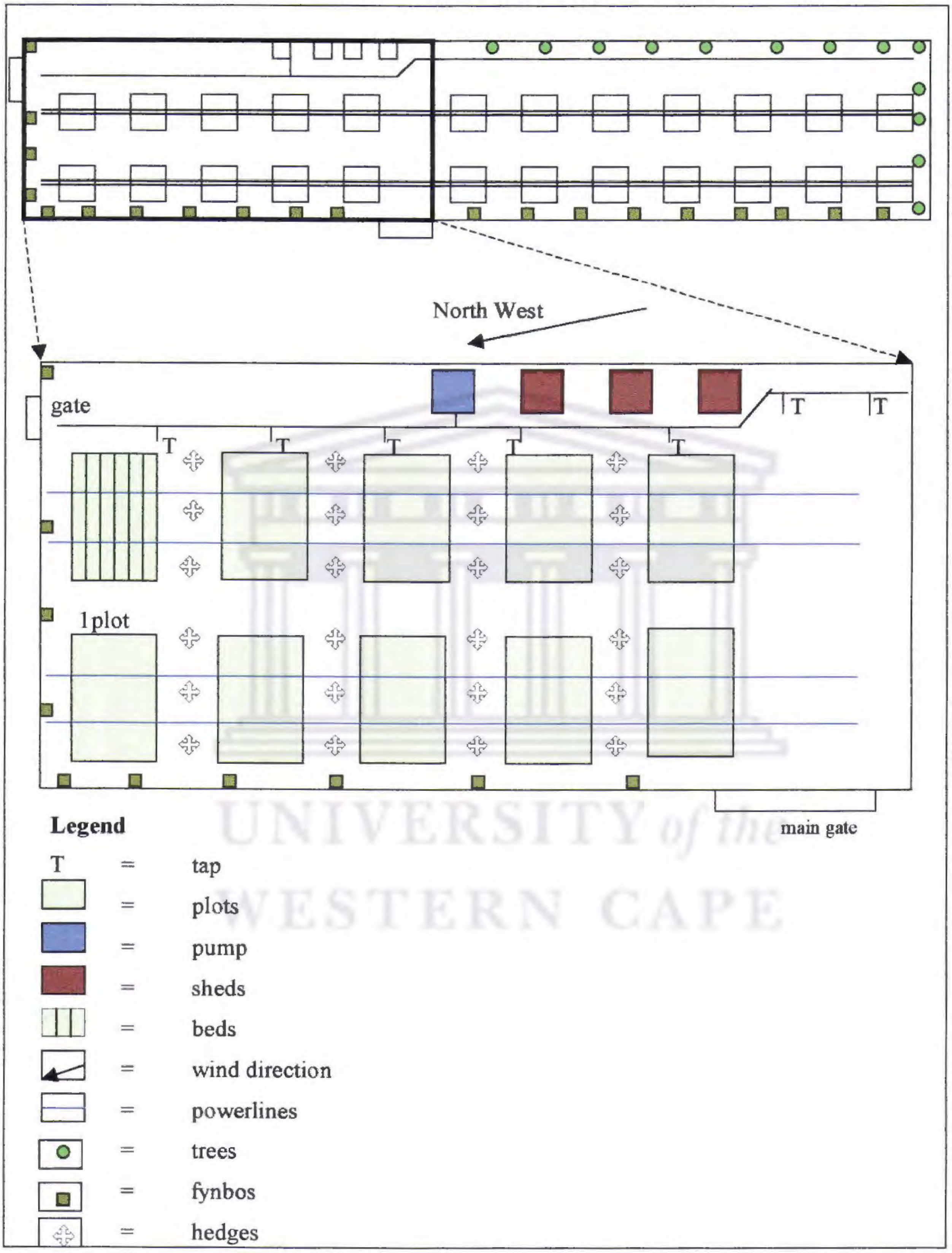



Figure 4: SCAGA garden layout (not to scale)

Figure 5: *Brachylena* trees planted as windbreaks on the southeastern border of the SCAGA garden.

Figure 6: First crops planted in April/May 1997, Port Jackson branches are used to protect seedlings against the harsh winds experienced. Various fynbos species were planted as hedgerows to protect the vegetable beds.

SCAGA's first crops were planted April/May 1997. The designated seasons for planting crops are from September to February (summer) and March to August (winter).

### 2.3.3 Socio-economic status of the SCAGA gardeners

*(The socio-economic information in this section can be verified in Fermont et al., 1998 of which J.D.Keet was co-author)*

All gardeners were growing vegetables at home before joining SCAGA, as owning a home garden was a prerequisite to joining the SCAGA group. The reasons put forward by SCAGA for having home gardens were:

1. Feeding a family, without having to buy vegetables
2. No money
3. No work/nothing else to do
4. Being used to it
5. Liked growing vegetables or have greenery in front of their houses.

These were the main reasons for joining the communal garden but there were social reasons as well, such as working together, getting to know the neighbours and learning new skills. A number of women mentioned the health aspect of gardening, both as exercise for themselves and as a vitamin source for their families (Fermont *et al.*, 1998).

#### 2.3.3.1 Gardening Practices

At present, the Cape Flats gardeners plant their crops in two main cropping seasons namely, the summer season (September – February) and winter season (March – August).

The crops planted in summer and winter are listed in Table 5 (Keet in Fermont *et al.*, 1998).

Table 5. Summer- and winter crops as planted on the Cape Flats

| **Summer Crops** | | | | **Winter Crops** |
|---|---|---|---|---|
| Beans (bush) | Eggplant | Melons | Squash | Beans (broad) |
| Beetroot | Herbs | Peas | Sweet potato | Cabbage |
| Cabbage | Pepper | Potato | Tomato | Lettuce |
| Carrots | Leek | Pumpkin | Turnip | Onion |
| Cauliflower | Lettuce | Radish | | Peas |
| Cucumber | Mielies | Spinach | | Potato |
| | | | | Spinach |

From: Keet in Fermont *et al.*, 1998

The gardeners each rented one or two plots depending on the numbers of gardeners. Each plot consists out of 6 vegetable beds. Abalimi Bezekhaya advises the gardeners to transform all their vegetable beds into so called trenched beds (Keet in Fermont *et al.*, 1998). As this transformation requires intensive labour, the SCAGA gardener's only converted one or two vegetable beds per season per person (Keet in Fermont *et al.*, 1998).

Irrigation took place twice daily during the first growing season. This was reduced to once daily after the gardeners learnt about the benefits of trenched bedding and mulching to conserve water (Keet in Fermont *et al.*, 1998). The gardeners also realized how important water is due to their fear of water shortages (Keet in Fermont *et al.*, 1998).

Abalimi Bezekhaya is responsible for supplying the seedlings and manure although the gardener's pay an annual fee and a weekly garden fee for the pump. Many gardeners feared that the seedlings would be too expensive to purchase if Abalimi no longer supplied inputs. At the time when the 1998 report by Fermont *et al* was published it was only an idea of the gardeners to start their own seedling nursery the following year. The idea of starting a nursery materialized in the beginning of 1999, and has proved to be extremely successful so far (Keet in Fermont *et al.*, 1998).

At the start of each new growing season SCAGA gardeners have to pay a fee of R12, plus an additional R2 monthly fee for the electricity used to run the electric pump. For some people it has proven to be difficult to fulfill this financial duty, as the garden expenditure has to compete with other more urgent expenditures (e.g. for food) (Fermont *et al.*, 1998)

#### 2.3.3.2 Economic feasibility of vegetable production

As mentioned in section 2.5 apart from providing fresh produce for their families, earning money by selling vegetables is one of the main reasons for gardening, but also the most important limitation. Thus people will not start or continue gardening if the inputs required are too high.

A basic cost analysis was done by E. van Boom in Fermont *et al.* 1998 using calculations based on the (potential) situation of the SCAGA garden (30 Gardeners, cropped area = $1800m^2$ (180 beds of 10 $m^2$) with mixed vegetables. A brief overview of the economic feasibility of small-scale vegetable gardening will be provided in the following section.

*Starting cost*

To start up a small-scale communal garden the initial cost is extremely high. For the SCAGA garden the start up cost amounted to R36 463.00, of which the main costs were infrastructure (see Table 6).

Table 6: Initial Cost (SGAGA)

| **Expenses** | **Costs (R)** |
|---|---|
| Fencing and gates | 14 969 |
| Borehole and pump | 9 839 |
| Sheds (3) | 5 762 |
| Tools | 2 704 |
| Irrigation fittings and hose pipes | 1 404 |
| Installing council water | 800 |
| Security gates/bars | 535 |
| Electricity box (for pump) | 450 |
| **Total** | **36 463** |

From: Keet in Fermont *et al.*, 1998

*Actual running costs of the first two seasons*

The costs were calculated using field- and Abalimi Bezekhaya's data. The cost included:

Fertilizer - R85/ton

Bonemeal - R120/ton

Tobacco dust - R4.10/bag

Guano manure - R50/bag

Water costs are based on the cost needed to run the pump (electricity cost).As indicated in Table 7 the running costs exceed income, due to high running cost and exceptionally low income.

Table 7: Actual running costs – season 1 & 2

| | Winter | Summer | Total |
|---|---|---|---|
| **Income** | **500** | **4 100** | **4 600** |
| **Costs** | | | |
| Fertilizer | 3 400 | 3 400 | 6 800 |
| Seedlings/seeds | 3 100 | 3 100 | 6 200 |
| Water | 250 | 500 | 750 |
| Sub-total | 6 750 | 7 000 | 13 750 |
| **Profits** | **- 6 250** | **- 2 900** | **- 9 150** |

From: Fermont *et al.*, 1998

The high running costs are attributed to (1) high fertilizer inputs resulting from the low soil fertility in the SCAGA garden and (2) the purchase of seedlings. The low-income generated is due to the poor produce obtained as a result of low soil fertility.

In the SCAGA garden the most successful money-making crop is spinach, followed by cabbage, tomato and carrots. It was found that spinach brought in 62% of the gardeners income, depending if it was favoured by the local community (Fermont *et al.*, 1998).

*Reducing input costs*

Water use and soil fertility of the Cape Flats vegetable garden are two areas that can result in a reduction of input costs. Improving water- and soil fertility management will significantly reduce these input cost, thus overcoming cash flow problems experienced by the gardeners. Water management for the reduction of water usage will be the focus of this study while information pertaining to soil fertility can be found in Fermont *et al.*, 1998.

Good marketing strategies are essential for the development of vegetable production on the larger scale on the Cape Flats townships. Not only is there a need to develop and facilitate the sales of locally grown vegetables, but there is also a need to locate special markets, such as for organically grown vegetables (Fermont *et al.*, 1998).

### 2.3.4 Abalimi Bezekhaya

Abalimi Bezekhaya (Meaning: Planters of the Home) assisted the SCAGA gardeners by giving them the support and the training necessary to start their communal garden. Abalimi's mission statement is "to provide opportunities for the poor, especially women, in the townships of the Cape Flats, to support each other, grow food for themselves and their families and to gain self-respect by creating household food security".

Activities to reach the above objectives are:

- Conducting the urban agriculture programme, which facilitates individual home food growers, neighbourhood gardening groups, community allotment gardens and urban agricultural associations.
- Conducting the Cape Flats tree project, which includes school greening programmes, park development, green streets, Arbour Day activities and general greening initiatives.
- Undertaking urban agriculture and greening in partnership with grassroots individuals and Community Based Organisations (CBO's).

The activities are especially directed towards the involvement of unemployed people, low-income households and women.

As explained earlier in section 2.3.2 Abalimi Bezekhaya was approached by the people of section 39 to assist them with the establishment of a garden project. The NGO's support consisted of both technical as well as financial support. It is Abalimi's intention to gradually decrease their input into the SCAGA garden. Abalimi's initial aims with regard to SCAGA were to have the garden run on its own, three years after the initiation of the project. The future will indicate if these three years are sufficient, or whether external input is still necessary to keep the garden functioning.

# 3. REDUCING CROP WATER REQUIREMENTS WITH REGARDS TO WINDBREAKS AND CHANGING PLANTING DATES

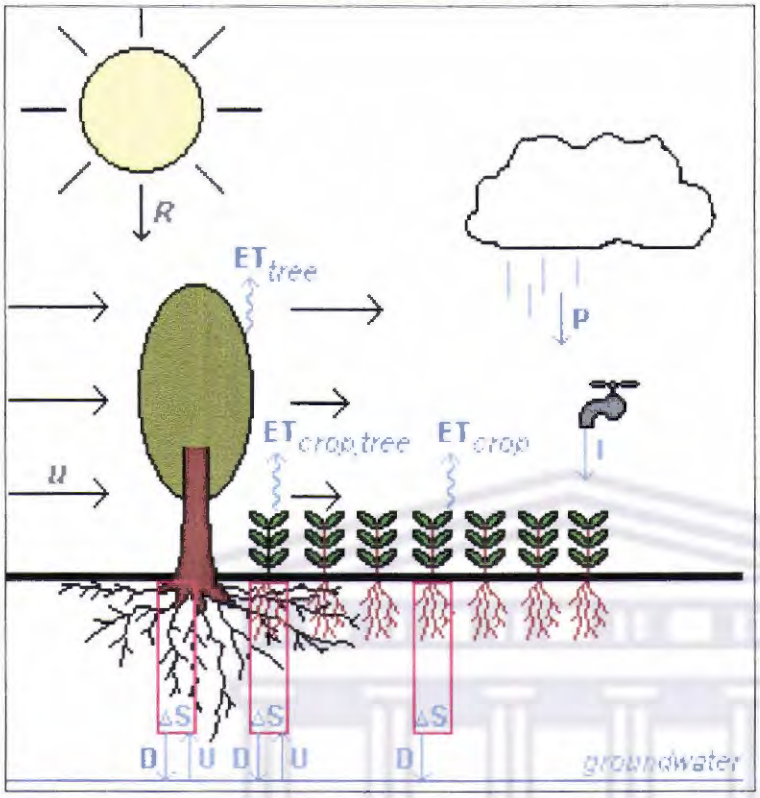
## 3.1 INTRODUCTION

The aim of this chapter is to highlight the potential of windbreaks and shifting growing seasons to reduce the crop water requirements of a garden. Any reduction in irrigation costs will contribute to the economic sustainability of communal gardens.

A large number of changes will occur when trees (as windbreaks) are introduced into a farmer's field. Those of particular interest to this chapter are changes in the water balance of the garden. These changes are due to the fact that the water balance of trees is different from the water balance of crops. Furthermore, trees will also indirectly affect the water balance of a garden, by changing the radiation balance and the surface wind pattern of the cropped area (Figure 7).



In the following paragraphs, a process-based approach will be followed to gain insight into the main water balance changes and related microclimate modifications, which occur when windbreaks are established in a vegetable garden. Paragraph 3.2 gives a literature review on the effect of windbreaks on the water balance of a garden. In subsequent paragraphs, these principles are then applied to the conditions as found in the Macassar-Khayelitsha garden, to calculate specifically the effects of trees on the irrigation requirements of the SCAGA garden. Paragraph 3.2.1 explains the major water




**Legend**

ΔS = change in soil water storage
P = precipitation
R = radiation
I = irrigation
U = upward capillary flow
H = Horizontal groundwater flow
D = downward drainage
ET = evapotranspiration

Figure 7: An agroforestry water balance

balance processes and the relationships between radiation, wind, air humidity and temperature including their effect on evapotranspiration.



## 3.2 LITERATURE REVIEW

### 3.2.1 The effect of windbreaks

Windbreaks play an important role in agricultural management systems (Marshall, 1967; Sturrock, 1984). It has been recognized that wind causes losses to crop yields (Bates, 1944; Caborn, 1957; Frank and Willes, 1972; Grace, 1977). Kort *et al* (1988) stated that studies have shown that crop yields are increased by shelterbelts and the degree of the positive effects varies with climate conditions, soil type, crop variety and the management practice. Thus, the use of trees as shelterbelts in areas that experienced high wind speeds or sand movement is a well-established example of improved yields resulting from microclimate alterations (Reifsnyder and Darnhover, 1989). Rosenberg (1966) concluded in an extensive literature review, that there appear to be few, if any published reports showing yield reduction caused by windbreaks or shelterbelts, except in the zone immediately adjacent to the barrier.

The effectiveness of a windbreak in reducing windspeed and altering the microclimate is as a function of windbreak's structure such as height, density, number of rows, species composition, length, orientation and continuity (Brandle., 2001). The most important factor determining the downwind area protected by a windbreak is windbreak height (H) (Brandle, 2001). Height is the most important factor governing a windbreak's effectiveness (Farm Forestry, 1999). Windspeed reductions are measurable for a distance of 2 to 5 times the height upwind of the windbreak (2H to 5H) whereas on the leeward side windspeed reductions are up to 30H downwind of the barrier (Brandle, 2001). Beyond 30 tree heights, windbreaks have little or no effect (Farm Forestry, 1999).

Within the protected zone, density of a windbreak is the main structural characteristic of a windbreak that determines the extent of the windspeed reductions (Brandle, 2001. A windbreak of 40 - 60% density provides the greatest downwind area of protection but if there are any gaps in the windbreak, its effectiveness diminishes (Brandle, 2001). A windbreak with the ideal windbreaks density of 40-60% (10H) could reduce windspeeds up to 50% (Brandle, 2001).

Windbreaks are normally positioned perpendicular to the prevailing wind and although wind may predominantly blow from one direction for a particular season it seldom blows exclusively from that direction (Brandle, 2001). If this is the case and wind direction are highly variable, a grid pattern of windbreaks will be the most effective protection (Farm Foresty 1999).

An important aspect of reduced wind velocity behind a windbreak in the protected area is in microclimate change (Brandle, 2001). Microclimate change usually increases the temperature and humidity levels while decreasing evaporation and plant water stress (Brandle 2001).

Evaporation measured in the lee of windbreaks by pans and piche evaporimeters indicate a reduction of evaporation of between 10 and 40% (Bates, 1911; Long and Persaud, (1988). Frank and Willes (1972) in the USA, Carr (1985) in Kenya and Reddi *et al.* (1981) in India reported increases in yield behind windbreaks when water was available, whereas shelter reduced crop growth if water was scarce. This is in line with the findings of Ong and Huxley (1996) who stated that while soil water supply is not limiting maximum benefit of shelterbelts is observed, especially where irrigation is possible. Radke and Hagstrom (1973) also found that, when sheltered soybeans were well watered, transpiration was lower than in the unsheltered plants, but as water availability decreased, transpiration increased in shelter when compared with the unsheltered control. The combined effect of irrigation and shelter can increase crop yields to a larger amount than the sum of their individual influences (Sturrock, 1984; Barker *et al.*, 1989). This increased crop yields may result from reduced evaporative loss of irrigated water and decreased stomatal resistance (Rosenberg, 1966; Frank and Willes, 1972). Thus when soil water is freely available to the crop the physiological restriction of stomatal closure is minimised (Rosenberg, 1966).

The above statements on the different effects of shelter on the evaporation of crops are functions of windspeed, net radiation, and vapour pressure gradient and air temperature (Rosenberg, 1966). Evapotranspiration is furthermore determined by the stomatal resistance ($r_s$) (Equation 3.3, pg 39), which is influenced by climate and water availability (Allen *et al*, 1998). If stomatal resistance is minimal (wet surface), then an increase in wind will increase evapotranspiration. However, a crop with drought stress and high stomatal resistance will transpire more water when wind speeds reduce.

From the above explanation, one can deduce that a windbreak has a beneficial effect especially in irrigated areas (e.g. the SCAGA garden). In these areas drought stress does not (or hardly) occur, so that the boundary layer resistance mainly determines evaporation. Shelter will also reduce evaporation from a wet surface (Jensen, 1954) (as found in irrigated areas), as this evaporation is only determined by the boundary layer resistance (and not stomatal resistance), which will increase with a reduction in wind.

Miller *et al* (1973) calculated that for a 1m high irrigated soybean crop shelter reduced transpiration by 20% because of a decrease in vapour deficit.

Experiments have shown that windbreaks can affect the plant physiology for example leaf stomatal apertures are larger on sheltered plants (Frank and Willis, 1972), which in turn affects the crop water requirements as larger apertures result in greater transpiration and more withdrawal of soil water (Frank and Willis, 1972). As shelter results in increased leaf area as well as an increase in transpiration per unit leaf area, sheltered crops may deplete water reserves earlier than an unsheltered crop (Jensen, 1954). Therefore in an environment where water is limited, sheltered crops could become stressed while unsheltered plants remain unstressed (Jensen, 1954). Alternatively, the rapid early growth of sheltered plants may stimulate increased rooting, enabling plants to access a greater soil volume, thereby increasing the availability of water and nutrients (Stoeckler, 1962). It is thus not easy to come to a general conclusion regarding the effect of windbreaks on the water consumption of crops.



In some cases a windbreak might be more important to protect crops from storm events, than to benefit from the cumulative microclimate changes (Brenner, 1996). Sandblasting, which is often observed on the Cape Flats may reduce growth, slowing down establishment and uprooting young seedlings (Brenner, 1996). Furthermore, a windbreak may also reduce erosion, which could reduce plant damage (Brenner, 1996).

### 3.2.2 Calculating crop water requirements - Theoretical background

The equations displayed in this section were also used to develop an independent crop water and requirement mathematical model. There are a number of ways in which agroforestry systems could use (irrigation) water more efficiently than sole agricultural crops, but a clear picture of how this actually happens in any system can be obtained through a comprehensive water balance study. Little is currently known about the water balance of agroforestry systems although techniques developed for sole trees, sole crops and intercrops have made a range of techniques and models available to examine agroforestry systems (Wallace, 1996).

The water balance is merely a detailed statement of the law of conservation of matter (Hillel, 1982). The water balance states that, in a given volume of soil, the difference between the amount of water added ($W_{in}$) and the amount of water withdrawn ($W_{out}$) during a certain period is equal to the change in soil water content (S) during the same period (see equation 3.1) (Hillel, 1982).

$$S = W_{in} - W_{out} \tag{3.1}$$

The water content change is positive when gains exceed losses and conversely when losses exceed gains S is negative (Hillel, 1982). The appropriate volume or depth of the soil for which the water balance is based on the soil depth and rooting depth. A water balance can thus be determined for a small sample of soil or for an entire watershed (Hillel, 1982).

Within an agroforestry system, one can basically distinguish three types of water balance: the water balance of a soil column underneath trees (T), a water balance for the cropped area (C) and a water balance for the area where both crops and trees compete for water (TC) (See figure 7). Differences in the water balance of trees and crops occur as a result of differences in infiltration, runoff and evapotranspiration (Wallace, 1996). Furthermore, physical characteristics of the soil, such as water holding capacity, can be altered as a result of management differences between the cropped and non-cropped area (Fermont *et al*, 1998).

The general water balance is expressed in an adapted equation 3.2 (Hillel, 1982) and Figure 8

$$\Delta S = (P + I + U + H) - (R + D + ET + \Delta V) \quad (3.2)$$

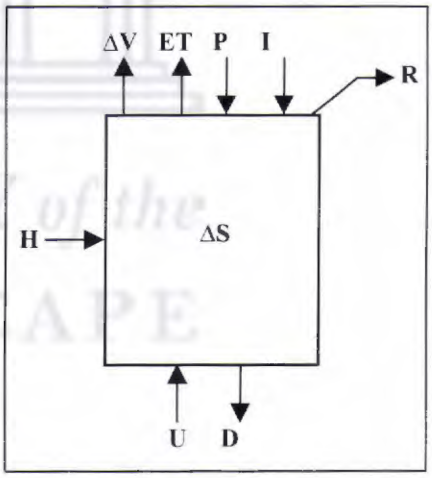


Figure 8: The water balance of a soil column

Where:

$\Delta S$ = change in soil water storage ($mm^3/mm^2$)

P = precipitation ($mm^3/mm^2$)

I = irrigation ($mm^3/mm^2$)

U = upward capillary flow ($mm^3/mm^2$)

H = horizontal groundwater flow ($mm^3/mm^2$)

R = runoff ($mm^3/mm^2$)

D = downward drainage ($mm^3/mm^2$)

ET = evapotranspiration (i.e. the combined effect of direct evaporation from the soil and wet leaves and transpiration via the plant's stomata) ($mm^3/mm^2$)

$\Delta V$ = change in water stored in plants ($mm^3/mm^2$)

All quantities are expressed in terms of volume of water per unit land surface area (equivalent units) during the period considered.

To see what the effect of changes in the water balance has on the irrigation requirements, we can express irrigation according to equation 3.2a, as follows:

$$I = \Delta S + R + D + ET + \Delta V - P - U - H \tag{3.2a}$$

Where:

| | |
|---|---|
| I | : irrigation ($mm^3/mm^2$) |
| $\Delta S$ | : change in soil water storage ($mm^3/mm^2$) |
| R | : runoff ($mm^3/mm^2$) |
| D | : downward drainage ($mm^3/mm^2$) |
| ET | : evapotranspiration (i.e. the combined effect of direct evaporation from the soil and wet leaves and transpiration via the plant's stomata) ($mm^3/mm^2$) |
| $\Delta V$ | : change in water stored in plants ($mm^3/mm^2$) |
| P | : precipitation ($mm^3/mm^2$) |
| U | : upward capillary flow ($mm^3/mm^2$) |
| H | : horizontal groundwater flow ($mm^3/mm^2$) |

To estimate the effect of windbreaks on the irrigation requirements of the garden, we need to calculate or estimate all the other parameters for a scenario with and without windbreaks. In these calculations it is assumed that irrigation water will be applied at the moment that the soil water content has decreased to a point where plant production is being limited, i.e. the critical soil water content. This means that crop transpiration (ET) will always be maximum, i.e. water supply to the plant is always optimal.

Horizontal ground water fluxes are relatively small compared to the other parameters of the water balance especially in sandy soils. This is due to the course texture and low water holding capacity and high infiltration rate of sandy soils (FOA, AGL, 2000). Therefore they are neglected in this study. The same accounts for runoff. Although runoff can have a substantial influence on the water balance of a soil column, it is assumed not to play an important role at the scale of a vegetable garden in the Cape Flats. This is also due to high infiltration capacity of the sandy soils and the absence of steep slopes. The water which is temporarily stored in the plants, or which is used to synthesize plant material ($CH_2O$), is only a very small fraction of the plant's total water consumption. In view of the disparity between water loss by transpiration and water built in plant matter, $\Delta V$ can be ignored.

Drainage is assumed only to take place in winter time, when the soil water content exceeds field capacity (pF 2) in sandy soils (Figure 9).

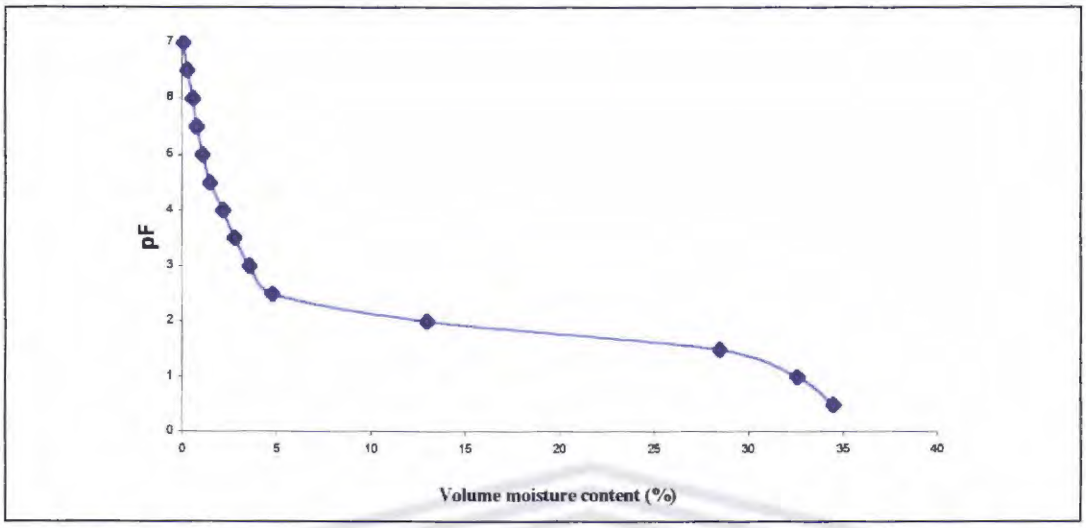



Figure 9: pF curve for sandy soils (Khayelitsha – Study site) based on laboratory determination

Precipitation is measured by rain gauges. For crops, upward capillary flow is assumed zero, as the effective rooting depth of most crops is not sufficient to make use of the groundwater. The water table is below 2.5 meters depth throughout the year in the SCAGA garden. However, trees are easily capable of reaching this groundwater level especially deep-rooted trees ability to exploit larger areas laterally and vertically (van Noordwijk *et al.*, 1996). Obtaining an estimate for the amount of capillary flux underneath trees is essential in order to create an insight into their effect on the irrigation requirement of the garden. Determining the capillary flux underneath trees is only possible by continuously measuring the changes in soil water content throughout a soil profile, or by obtaining all the parameters of the water balance, except for the capillary flux.

The latter option is not applicable for this study, since we want to determine the irrigation requirement as a result of changes in the other water balance parameters.

Therefore in this study, we will first focus on the effect of artificial windbreaks, so that the tree and tree-crop water balance (T and TC) will not have to be calculated. By calculating the effect wind reduction has on the water balance of the cropped area in case of artificial windbreaks, we will, however, also be able to create an insight into the potential of trees as windbreaks. From the above it can be deduced that the water balance of the cropped area (C) in the SCAGA garden can be simplified to:

$$I = \Delta S + D + ET - P \qquad (3.2b)$$

From equation 3.2b it follows that the determination of evapotranspiration is very important, as we expect a reduction in irrigation requirement due to a reduction in crop evapotranspiration. Numerous methods have been developed to calculate or measure evapotranspiration. In this study evapotranspiration rates were calculated via energy balance methods. In agro-meteorological studies, the Penman-Monteith formula is mostly applied.

The Penman-Montieth equation combination equation can be written as follows (Allen *et al.*, 1998):

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a c_p (e_s - e_a) / r_a}{\Delta + \gamma (1 + r_s / r_a)} \qquad (3.3)$$

Where:

$\lambda ET$ : latent heat flux of evaporation [kJ $m^{-2}$ $s^{-1}$ ]

$R_n$ : net radiation flux at surface [kJ $m^{-2}$ $s^{-1}$ ]

G : soil heat flux [kJ $m^{-2}$ $s^{-1}$ ]

$\rho_a$ : air density [kg $m^{-3}$ ]

$c_p$ : specific heat of moist air [kJ $kg^{-1}$ $C^{-1}$]

$(e_s-e_a)$ : vapour pressure deficit of air [kPa] ]( See Equation 1 in Appendix 1)

$r_s$ : surface resistance [s $m^{-1}$ ]

$r_a$ : aerodynamic resistance [s $m^{-1}$ ]

$\Delta$ : slope of vapor pressure curve [kPa $C^{-1}$]( See Equation 2 in Appendix 1)

$\gamma$ : psychometric constant [kPa $C^{-1}$ ]( See Equation 3 in Appendix 1)

$r_a$ is the transfer of heat and water vapour from the evaporating surface into the air above the canopy and is determined as follows (Allen *et al.*, 1998):

$$r_a = \frac{\ln[(z_m-d)/z_{om}]\ln[(z_h-d)/z_{oh}]}{k^2u_z} \qquad (3.4)$$

Where:

$r_a$ : aerodynamic resistance [s $m^{-1}$]

$z_m$ : height of the wind measurement [m]

$z_h$ : height of the humidity measurement [m]

d : zero plane displacement height [m]

$z_{om}$ : roughness length governing momentum transfer [m]

$z_{oh}$ : roughness length governing transfer of heat and vapour pressure [m] k : von Karman's constant [0.41 [-]

$u_z$ :windspeed at height z [m/s]

The resistance of vapour flow through the transpiring crop and evaporating surface known as the (bulk) surface resistance and is determined as follows (Allen *et al.*, 1998):

$$r_s = \frac{r_l}{LAI_{active}} \quad (3.5)$$

Where:

$r_s$ : (bulk)surface resistance [s $m^{-1}$]

$LAI_{active}$: active (sunlit) leaf area index [$m^2$ (leaf area) $m^{-2}$ (soil surface)]

The stomatal resistance of a plant is easily determined with a porometer and changes throughout the day as a function of solar radiation, leaf temperature, soil water content and vapour pressure deficit. The effect of windbreaks on the stomatal resistance also plays a key role in water consumptions of plants.

In order too define unique evaporation parameters for each crop and stage of growth, the concept of reference surface was introduced (Allen *et al.*, 1998). The FAO Penman Monteith method to estimate reference crop evapotranspiration ($ET_o$) has been derived from the Penman Monteith equation (Equation 3.3) , the aerodynamics (Equation 3.4) and surface resistance (Equation 3.5 ) referring to equation 3.6 (Allen *et al.*, 1998).

$$ET_o = \frac{0.48\,\Delta(\mathrm{Rn} - \mathrm{G}) + \gamma \dfrac{900}{\mathrm{T} + 273} U_2\,(e_a - e_s)}{\Delta + \gamma\,(1 + 0.34 U_2)} \qquad (3.6)$$

Where:

| | | |
|---|---|---|
| T | : | average temperature [$^{o}$C] |
| $U_2$ | : | windspeed measured at 2m height [m $s^{-1}$ ] |
| 900 | : | conversion factor |

If measured radiation data is not available, the net radiation can be estimated as follows (Smith, 1990):

$$G = 0.14\,(T_{month\ n} - T_{month\ n-1}) \qquad (3.7)$$

$$R_{nl} = 2.45\ .\ 10\text{-}9\,(0.9\frac{n}{N} + 0.1)(0.34 - 0.14\,\sqrt{ed})\,(T^{4}_{kx} + T^{4}_{kn}) \qquad (3.8)$$

$$R_{ns} = 0.77\,(0.25 + 0.5\frac{n}{N})\,R_a \qquad (3.9)$$

$$R_n = R_{ns} - R_{nl} \qquad (3.10)$$

Where:

| | | |
|---|---|---|
| $R_n$ | : | net radiation [MJ $m^{-2}$ $d^{-1}$ ] |
| $R_{ns}$ | : | net shortwave radiation [MJ $m^{-2}$ $d^{-1}$ ] |
| $R_{nl}$ | : | net longwave radiation [MJ $m^{-2}$ $d^{-1}$ ] |

$R_a$ : extraterrestrial radiation [MJ $m^{-2}$ $d^{-1}$ ](See Equation 4 in Appendix 1)

n/N : relative sunshine fraction

$T_{kx}$ : maximum temperature [°K]

$T_{kn}$ : minimum temperature [°K]

$e_d$ : actual vapour pressure [kPa]

G : soil heat flux [MJ $m^{-2}$ $d^{-1}$ ](See Equation 5 in Appendix 1)

The reference evapotranspiration can also be calculated by using pan evaporation measurements (class A) (formula 3.11) (Allen *et al.*, 1998).

$$ET_0 = K_p * E_{pan} \qquad (3.11)$$

Where:

$K_p$ : pan coefficient (-)

$E_{pan}$ : pan evaporation (mm/day)

Both Penman and the pan (class A) method give you an estimate of the reference evapotranspiration (Doorenbos and Pruit, 1977). Evapotranspiration rates of various crops are related to the evapotranspiration rate from the reference surface ($ET_0$) by means of the crop coefficient formula 3.12. (Allen *et al.*, 1998).

$$ET_{crop} = K_c * ET_0 \qquad (3.12)$$

Where:

$ET_{crop}$ : crop evapotranspiration

$K_c$ : crop factor

The value of the crop coefficient ($K_C$) is affected by factors such as crop characteristics, crop planting or sowing date, rate of crop development, length of growing season and climatic conditions (Doorenbos & Pruitt, 1977 and Allen, 1998). Wind will affect the transpiration rate of taller crops more than shorter crops as a result of air turbulence above the rougher crop surface (Doorenbos & Pruitt, 1977). This is more pronounced in dry than in humid climates thus $K_c$ values for rougher crop surfaces are greater in dry climates (Doorenbos & Pruitt, 1977).

$ET_{crop}$ is determined as a product of $ET_o$ and $K_c$, whereby $ET_o$ incorporates all climatic conditions and $K_c$ incorporates crop characteristics and averaged effects of evaporation from the soil (Allen *et al*, 1998). During full groundcover, evaporation is negligible, just following sowing and during the early growing period when the soil is hardly covered, evaporation from the soil surface ($E_{soil}$) may be considerable, particularly when the soil surface is wet for most of the time from irrigation and rain (Doorenbos & Pruitt, 1977). For the sake of simplicity, the coefficient relating $ET_0$ to $E_{soil}$ is given herein by the appropriate 'crop' factor ($K_c$)(Equation 3.13).

$$(ET_{crop} \approx E_{soil}) \qquad (3.13)$$

During the initial growth stage, $K_c$ can vary largely, depending on the rate of irrigation or significant rainstorm events (Doorenbos & Pruitt, 1977). To cope with the changing $K_c$ value throughout the season, the following different crop development stages are distinguished as can be found in Table 8. While $k_c$ of the different crops, development stages, depth and depletion levels can be found in Appendix 2. Table 9 gives an indication of the range of seasonal crop water requirements for various vegetables.

Table 8: Crop development stages

| GROWTH STAGES | DESCRIPTION |
|---|---|
| 1. Initial stage: | Germination and early growth when the soil surface is hardly covered ($ET_{crop} \approx ET_{soil}$) |
| 2. crop development stage: | From the end of the initial stage to attainment of effective full ground cover (groundcover 70 – 80 %) |
| 3. mid-season stage: | From attainment of full effective Ground cover, to time of start of maturing as indicated by discolouring leaves or leaves falling |
| 4. late season stage: | From end of mid season stage until full maturing or harvest |

From: Doorenbos and Pruitt, 1977

Table 9: Seasonal $ET_{crop}$ values

| **Vegetable** | **$ET_{crop}$ (mm)** |
|---|---|
| Tomato | *300 – 600* |
| Potato | *350 – 625* |
| Onions | *350 – 600* |
| Maize | *400 – 750* |
| Beans | *250 – 500* |
| Vegetable, general | *250 – 500* |

From: Doorenbosch and Pruitt, 1977

### 3.2.3 FAO CROPWAT 7.0

Irrigation requirements in this report were eventually quantified by means of the FAO CROPWAT 7.0 model, which has been modified from the CROPWAT 5.7 model issued in 1992 (Smith, 1992). The model was developed to facilitate irrigation planning and management (FAO, 2000). It is based on the methodologies presented in FAO Irrigation and drainage papers for crop water requirements and yield responses to water (FAO, 2000).

The main Function of CROPWAT 7.0 is to calculate reference evapotranspiration, crop water requirements and crop irrigation water requirements (FAO, 2000). CROPWAT 7.0 is based on a water balance where soil water status is determined on a daily basis from calculated evapotranspiration and inputs of rainfall and irrigation. FAO methodologies for crop water requirements and yield responses to water are used. Input data required for the model include monthly climatic data ($ET_o$, rainfall), generalized crop data (growth stages, crop factor, rooting depth, critical soil water levels, yield response factor, soil data (total available soil water) and information on field irrigation method and supply system.

The model thus uses the conventional reference evapotranspiration and crop coefficients, which are used to calculate the crop water requirements. In combination with crop water requirements effective precipitation and the soil water balance are used to determine the output of irrigation water requirements, which can be seen in Figure 8. The equations explained in section 3.2.2 are used in the CROPWAT 7.0 model in order to obtain crop water requirements.

Within the garden the windspeed varies as a function of height, density and distance from a windbreak. The irrigation requirements of SCAGA garden will depend among others tings on crop type and windspeed. The irrigation requirements for the garden will be calculated using several windspeeds and several crop types and thus irrigation reductions will be calculated. The results can be extrapolated according to crop windbreak layout of the garden.

The FAO CROPWAT 7.0 model and the mathematical model developed to calculate irrigation requirements were done according to following steps:

The first step in the CROPWAT 7.0 model and the developed Excel model is the calculation of reference evapotranspiration ($ET_o$), which uses average monthly data of temperature relative humidity, sunshine and wind.

The second step in the CROPWAT 7.0 model and the developed Excel model is calculating the crop water requirements ($ET_{crop}$).

The third step for CROPWAT 7.0 and the developed model would then be to determine the crop irrigation requirements ($I_{crop}$), from monthly $ET_o$, rainfall data, effective rainfall estimates and crop information. $ET_o$, $ET_{crop}$ and $I_{crop}$ were calculated with stepped reductions in windspeed of 25% namely at windspeeds 100%, 75% and 50%. The process that CROPWAT 7.0 follows to determine crop irrigation requirements can be seen in Figure 10.

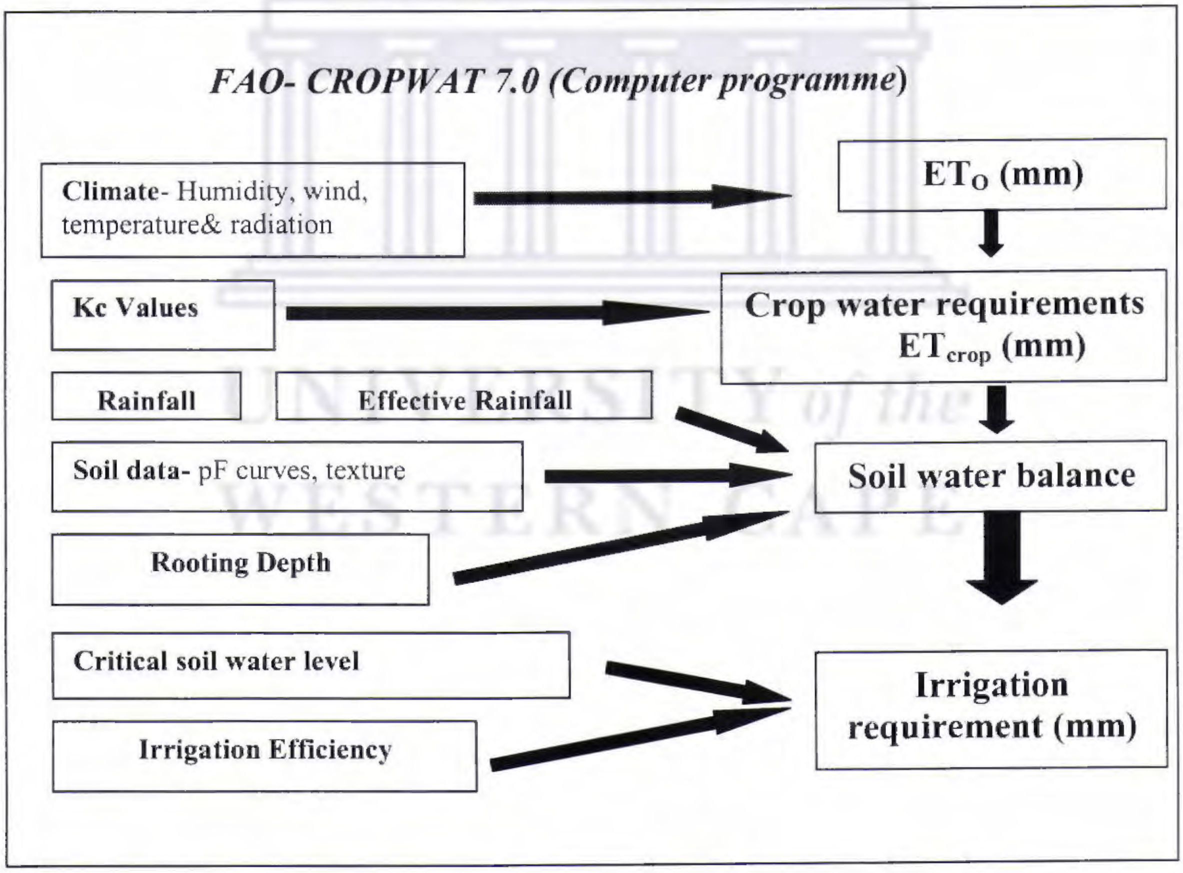



Figure 10: Flow chart of CROPWAT 7.0

The data generated using the Excel mathematical model was calculated on a daily basis in order to determine $ET_o$ values. The data generated using the Excel mathematical model was then modified to obtain data on a monthly basis in order to calculated irrigation requirements using the CROPWAT 7.0. model. The CROPWAT 7.0 model requires monthly input data in order to determine irrigation requirements. Refer to Appendix 3 for daily $ET_0$ values generated using the Excel mathematical model also displaying average daily and monthly $ET_o$ values. This information was imported into CROPWAT 7.0 as well as the calculated monthly mean average rainfall data.

## 3.3 RESULTS

### 3.3.1 Developed Model vs. CROPWAT 7.0

One of the objectives of this study was to develop an Excel mathematical model that could determine crop water requirements, and crop irrigation requirements. Using the equations mentioned in section 3.2.2 a mathematical model calculating crop water and irrigation requirements was developed. The development of this model took place over a few months. Various computer functions had to be learnt, understood and applied in order to perform certain mathematical functions. The results obtained using the mathematical model were calculated manually to verify the results.

Shortly after developing the Excel mathematical model the CROPWAT 7.0 model was discovered, which could perform the same calculations as the mathematical model developed. Many parameters used to calculate crop water requirements and irrigation requirements are incorporated into the CROPWAT 7.0 program. And only input data such as soil type and planting dates are required to obtain crop water and irrigation requirements. With the developed Excel model all parameters had to be entered manually into the model to obtain results. The developed model serves the same purpose as CROPWAT 7.0 and the same results are obtained, except that the developed model is time consuming as all input parameters need to be entered manually.

The Excel model developed also calculated all crop water and irrigation requirements on a daily basis. Therefore the model requires large amounts of data to obtain results. This model is therefore time consuming and not user friendly.

The CROPWAT 7.0 program requires climatic data such a temperature, rainfall and evpotranspiration on a monthly basis. The developed model was thus used to calculate average daily data. The data generated using the Excel mathematical model was manipulated into monthly data and imported into the CROPWAT 7.0 model as input data. The $ET_o$ values calculated using the Excel mathematical model can be seen in Appendix 3.

### 3.3.2 The effect of windbreaks

As discussed in section 3.2.1 windbreaks (not too dense & decreasing porosity with height) can reduce windspeeds with up to 50 % (Rosenberg, 1966). Crops benefit from this effect, not only because they are less prone to damage from the wind and sand blasting, but also because their transpiration rates decrease. The reduction in wind furthermore results in lower evaporation rates of the soil. Consequently, irrigation requirements are decreased. To quantify this effect CROPWAT 7.0 was run, using 3 different climatic input files. The first contained the Cape Town Airport original wind data, the second file contained wind data reduced by 25% and the third reduced by 50 %. Using these input files, irrigation requirements of mixed crops (crops listed in Table 3) and cash crops (turnips, mielies, peppers and spinach) were determined. Previous gardening practices indicated that the summer cropping started in September and winter cropping beginning in March. The results obtained from determining the effect of windbreaks on irrigation requirements are presented in Figures 11a and 11b. Note that irrigation requirements in these graphs were calculated with 100% irrigation efficiency. The calculations executed in this section are simplistic due to CROPWAT 7.0 not taking real trees into consideration. If windbreaks were present then the temperature and humidity would also be affected.

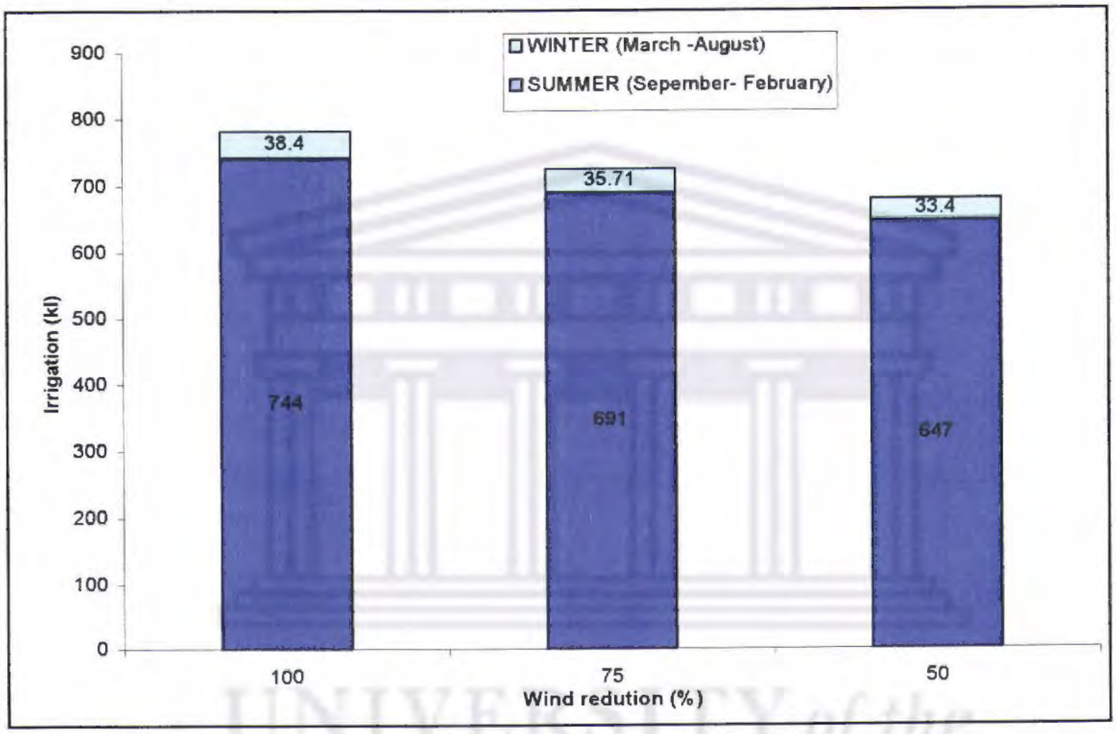



Figure 11a: Effect of wind reduction on yearly irrigation requirements for mixed crops

The irrigation requirement-ranges for each crop differ due to each crop possessing unique crop factors, this results in differing crop water requirement. For some individual cash crops (e.g. turnips and mielies) irrigation reduction might be lower (4 - 10%). While for other crops (e.g. peppers and spinach) the irrigation reductions are higher (12 – 18%) (Figure 11b). These irrigation ranges have been calculated using CROPWAT 7.0.

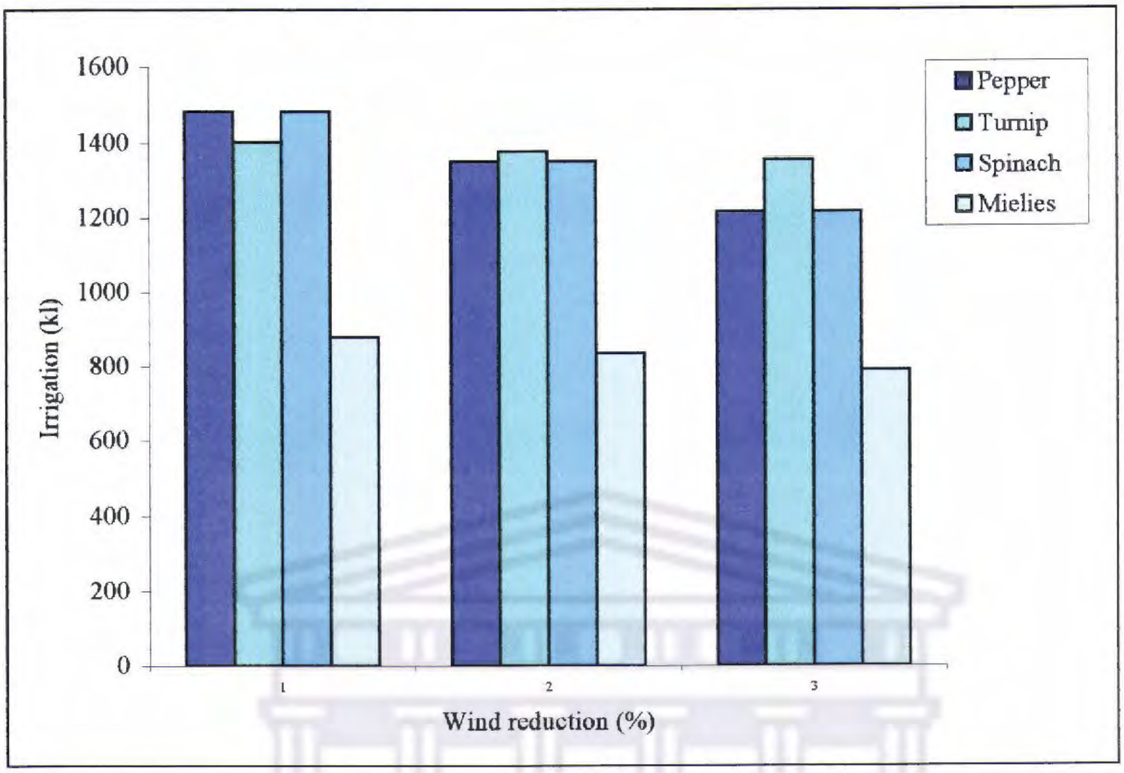



Figure 11b: Effect of wind reduction on yearly irrigation requirements for cash crops

In the previous section crop growth and development was mentioned. When crops are sheltered they develop faster and more abundantly, but a larger crop also transpires more. The improved growth conditions, however, might have stimulated root development and resulted in increased water uptake from the soil. Neither process is easy to quantify. As the one increases irrigation requirements the other decreases it. It is assumed that the sum of their effects can be neglected.

The second aspect, deals with the nature of the windbreaks. In the above quantification windbreaks are assumed to be artificial. Living windbreaks on the other hand require water. As trees and shrubs generally root much deeper than vegetables one assumes that they would utilize groundwater to a certain extent. It is, however, most likely that trees in close vicinity to vegetable beds would benefit from the irrigated vegetable beds. Although the trees would benefit from the irrigated water supply the crops would be deprived, thus resulting in competition between trees and shrubs with the vegetables for irrigated water. The competition will result in an increase in irrigation water to the entire garden. The degree of competition will depend on the type of trees or shrubs used as windbreaks, the distances of the windbreaks from the vegetable beds, the depth of the groundwater and the soil type.

This leads to the conclusion that using artificial windbreaks could lead to a reduction in irrigation requirements by 7-13 % on average (Table 10). Anticipating the use of trees and shrubs as a windbreak, the reduction in irrigation requirements would be smaller. Therefore the calculated reduction can only be applied to artificial windbreaks as real windbreaks could increase the water use of the garden and a significant water reduction will not be obtained.

Table 10: Reduction of irrigation requirements with reduction in windspeed (Artificial Windbreaks) for the mixed crops

| **Growing Season** | **100% wind** | **50 % wind reduction** | **25% wind reduction** |
|---|---|---|---|
| Summer | 744.7 kL | 691.0 kL | 647.0 kL |
| Winter | 38.4 kL | 35.7 kL | 33.4 kL |
| **Total** | 783.1 kL | 727.0 kL | 681.2 kL |
| **% reduction in irrigation requirements** | 0 | 7% | 13% |

### 3.3.3 The effect of changing planting or sowing dates

Weather conditions are the major factors influencing irrigation requirements of a crop. Because the weather changes throughout the year, the choice of planting or sowing dates influences the irrigation requirements of a crop. Using CROPWAT 7.0, the effect of changing planting or sowing dates for the mixed vegetable gardening was studied. Garden divisions (crop type and area) in the summer and winter season is the same as used in the Table 3. Irrigation efficiency is assumed to be 100%. Results are presented in Figure 12.

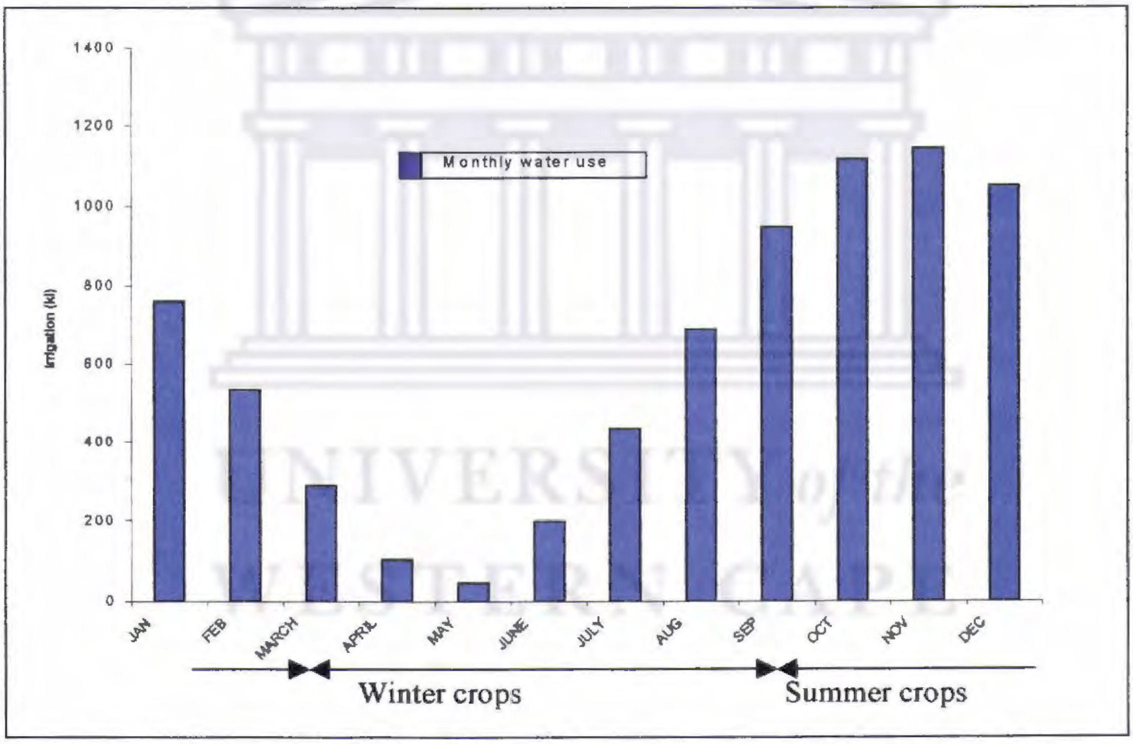



Figure 12: Irrigation requirements of mixed crops if planted on traditional planting dates for summer and winter seasons

Figure 12's calculated irrigation requirement displays a similar pattern to the evapotranspiration rates represented in Figure 2. In the winter months, temperature is low and rainfall is high. This results in low evapotranspiration rates and thus a minimum need for irrigation. The opposite is true for hot, dry summer months when evapotranspiration is much higher than rainfall and producing vegetables on sandy soils without irrigation is impossible.

Using the CROPWAT 7.0 model irrigation requirements were calculated for different growing periods in summer and winter. Planting dates were shifted on a monthly basis and irrigation requirements tabulated accordingly. Irrigation reductions were compared after determining irrigation requirements for different growing periods in summer. Comparing crops grown earlier in summer i.e. in September when precipitation is still available and temperatures relatively low compared to planting in October, November and December when evapotranspiration could exceeds precipitation up to 100% and temperatures are higher. During the winter growing season irrigation requirements were compared for different growing periods. Planting later in the winter growing season for example May when precipitation starts to increase and possibly exceed evapotranspition and temperatures are lower than if the were planted in March and April when precipitation is less and temperatures higher.



CROPWAT 7.0 calculations indicate that planting vegetable crops at the beginning of the planting season (September), when there is still ample rainfall and temperatures have not yet reached their maximum (instead of planting in October, November or December), respectively saves 19, 26, and 22% of irrigation water refer to Table 11a. Planting the winter crops in April or May instead of March reduces the irrigation requirements by

84% in April and 93% in May refer to Table 11b. On an annual basis, optimizing planting dates can contribute to 39% reduction in irrigation water. Changing planting dates will affect the length of the crop-growing season. This was however not taken into account during this study. The effect of changing planting dates might therefore differ somewhat from the values presented in this study.

Table 11a: Seasonal water use for changing planting dates (summer)

| Planting dates | Growing seasons | Irrigation requirements kL | % increase in irrigation requirements |
|---|---|---|---|
| 1 September | September – January | 1489.4 | |
| 1 October instead of 1 September | October – February | 1772.3 | 19 |
| 1 November instead of 1 September | November – March | 1876.5 | 26 |
| 1 December instead of 1 September | December - April | 1817.0 | 22 |

Table 11b: Seasonal water use for changing planting dates (winter)

| Planting dates | Growing seasons | Irrigation requirements kL | % increase in irrigation requirements |
|---|---|---|---|
| 1 March instead of 1 May | March - July | 80.8 | 93 |
| 1 April instead of 1 May | April – August | 76.8 | 84 |
| 1 May | May – September | 41.8 | |

Optimizing planting dates for cash cropping demands very careful planning, as the whole garden plan is much tighter. Although percentile reduction will be less, absolute savings of water might be more than with mixed vegetable cropping, due to the higher irrigation requirements of cash cropping.

## 3.4 DISCUSSIONS AND CONCLUSION

The effect of trees and changing planting dates on crop water requirements were determined by means of the FAO CROPWAT 7.0 computer model. The weather data required by CROPWAT 7.0 was manipulated using the irrigation model developed for this study. The CROPWAT 7.0 model made use of a water balance to execute all calculations. The real effects of trees was not determined as allowance for other parameters that would apply to trees were not included in the CROPWAT 7.0 model.

Using the model made it possible to calculate crop water requirements with reductions in wind speeds using artificial windbreaks. A 25% reduction in windspeed allowed for a 7% reduction in irrigation water requirements i.e. a 256.kL saving of water to the value of R448.70. While with a 50% reduction in windspeed a 13% reduction in irrigation requirements was obtained i.e. a 483.5kL saving of water to the value of R846.13 could be obtained on an annual basis. These reductions for a small-scale communal garden of $1800m^2$ are barely significant. If real windbreaks (trees) were introduced into the equation the water balance would have to take into account the water consumption of trees. It is assumed that trees extended rooting system will utilise groundwater and surface roots will compete with crop rooting systems for water. In these situations trees consuming water would transpire as well, therefore increase the water usage of the gardens, increasing the irrigation requirements. Thus using real windbreaks (trees) would probably not be beneficial to communal gardeners where water savings are concerned, lowering the percentile water reduction to less than the 13%.

It is clear that independently growing trees will not reduce water requirements significantly. The option of changing planting or sowing dates was investigated, yielding satisfactory results. Planting dates were also assessed using the CROPWAT 7.0 model. On an annual basis optimizing planting or sowing dates can contribute to a 39% reduction in irrigation water requirements. Changing planting or sowing dates will affect the length of the growing season. This was however not taken into account in this study. The effect of changing planting dates might therefore differ somewhat from the values presented in this study.

Changing planting or sowing dates by 30 days from the 15$^{th}$ of March to the 15$^{th}$ of April could result in not having to irrigate at all, as precipitation could exceed evapotranspiration during the last month of the growing season in winter. Proper planning will lead to optmisation of available rainwater. Optimising planting dates for cash cropping requires careful planning. The percentile reduction will be less, but the absolute savings of water might be more than with mixed vegetable cropping, as irrigation requirements are higher for cash cropping.



Out of the two options mentioned namely windbreaks and optimising planting dates the latter is by far the better option yielding a reduction of 39% in irrigation water requirements.

# 4. OPTIMISING IRRIGATION TECHNIQUES

## 4.1 INTRODUCTION

In Chapter three, it was shown that windbreaks could potentially reduce the irrigation requirements up to 13% and growing periods and changing planting dates up to 39%. However, there are methods to reduce irrigation cost other than reducing the crop water requirements. This chapter focuses on optimising irrigation techniques as a cost reduction option.

At present the SCAGA gardeners use a combination of sprinkler and hand irrigation (using a watering can or hose). The system poses many problems such as excessive water usage, high labour intensity, leaking pipes and high maintenance cost.

Water loss from irrigation systems is a typical phenomenon experienced, which in this case is due to high evaporation rates resulting from high temperatures and high wind speeds, which result in a non-uniform distribution of water. The sprinklers are placed too high (attached to 1m poles), which result in both the vegetable beds and paths being watered. The paths comprise approximately 40% of the garden surface area.

The system being labour intensive is owing to the irrigation system being physically transported from one point to the next in the garden. Furthermore hand watering is time consuming and the force and amount of water could do plant damage. Hand watering is normally done on beds, which are located outside the sprinklers wetting zone. Leaking pipes result in water wastage and due to high maintenance cost the system cannot be repaired.

Due to the magnitude of the factors mentioned above sprinkler irrigation efficiency at SCAGA garden is much lower than the attainable irrigation efficiency of between 65 and 75% (Solomon, 1988). It is estimated that the efficiency reached is approximately between 40 to 50%. Due to the problems experienced with sprinkler irrigation and the low irrigation efficiency, other irrigation options where considered that would be more suitable for the Cape Flats, SCAGA garden.

## 4.2 LITERATURE REVIEW

### 4.2.1 Dominant Irrigation Techniques in South Africa

The basic irrigation practices in South Africa are flood, furrow, sprinkler, centre pivot, micro, and drip/trickle irrigation. Of these, sprinkler irrigation is most commonly used on modern irrigation schemes, while furrow irrigation is very popular and used widely on older schemes and in community vegetable gardens by independent farmers (de Lange, 1994). More emphasis will be placed on the sprinkler, as this is the system currently being used in the SCAGA garden and drip irrigation, which is the system proposed for the garden.

*Flood* schemes designed for extreme flooding have been replaced by sprinkler or furrow irrigation (de Lange, 1994). Flood irrigation in beds requires specialized management without which over irrigation and soil erosion is more than likely to occur (de Lange, 1994).

*Furrow irrigation* is used in many forms such as long furrow, short furrow, small basin, and community garden furrow plots. de Lange (1994) states that suitable soils, with the correct layout and adequate flow rate, water losses may be as low as 5%, but in the extreme it is possible to have 100% loss, i.e. water infiltrates completely into the supply furrow and does not reach the irrigation furrows.

*Sprinkler irrigation* is the most common system and practiced on a larger scale than the rest. When irrigation is applied by the sprinkler method, water is sprayed through the air and is distributed over the irrigated areas (Solomon, 1988). High water uniformity is due to overlapping the spray patterns from adjacent sprinklers. While high water losses could be due to direct evapotranspiration from wet soil surfaces, wind drift, and evaporation losses from spray, system drainage and leaks (Solomon, 1988).

*Center pivot* is doubted to be suitable for small-scale farmers. de Lange (1994) states that moveable center pivot installations have not been successful in South Africa. Farmers who have access to pivot irrigation rarely entertain the idea of reverting to other types of irrigation systems although some farmers experience problems with center pivot irrigation, especially with the running and maintenance cost of the system (de Lange 1994).

*Micro irrigation* includes all methods of frequent water application, in small flow rates, on or below the soil surface (Hammon, 1989). Micro irrigation systems are classified by their emitter used in the system (Hammon, 1989). These are drip, bubbler, spray jet, and subsurface (EP 405.1, 1999). Microjet or microspray is an under-tree method of irrigation (Verbeeten, 1998). While drip irrigation applies water directly to the plant root (Verbeeten, 1998). Micro irrigation has a potential advantage when compared with other irrigation methods. The majority of which are related to the low rates of water application (Hammon, 1989).

Reviewing the systems mentioned above it is clear that many of these systems are not suitable for small-scale agriculture. Drip irrigation appears to be the most viable option for the Cape Flats, SCAGA garden due to the high wind speeds experienced, low water holding capacity of the sandy soils and minimal labour required to operate the drip irrigation system.



**4.2.2 Irrigation efficiencies**

Water application efficiency is an irrigation concept that is very important both in irrigation system selection, design and management. It is expressed as the percentage of irrigation water that is used by a crop. The ability of an irrigation system to apply water uniformly and efficiently to the irrigated area is a major factor influencing the agronomic viability of a farming system. A lack of uniformity in application or large water losses results in low irrigation efficiencies. If either the water losses are large or the application uniformity is poor, efficiency will be low. Although system design and management influence both components of efficiency, management predominantly affects losses, while uniformity is predominantly affected by system design (Solomon, 1988).

The three major irrigation types are distinguished as surface irrigation, sprinkler irrigation and drip irrigation. Attainable water applications efficiencies vary greatly with the irrigation system and management. The ranges in Table 12 give an indication of the attainable efficiencies that may be achieved with reasonable design management.

Table 12: Water application efficiencies (Solomon, 1988)

| TYPE OF SYSTEM | ATTAINABLE EFFICIENCIES |
|---|---|
| **Surface Irrigation** | |
| Basin | 80 – 90% |
| Border | 70 – 85% |
| Furrow | 60 – 75% |
| **Sprinkler Irrigation** | |
| Hand Move or Portable | 65 – 75% |
| Travelling Gun | 60 – 70% |
| Center Pivot &Linear move | 75 – 90% |
| Solid Set or Permanent | 70 – 80% |
| **Trickle Irrigation** | |
| With point source emitters | 75 – 90% |
| With line source products | 70-85% |

Although reasonably high efficiencies can be obtained with each type of system, surface irrigation is not an option due to the high infiltration rates of the Cape Flats sandy soils. Sprinkler irrigation also displays high efficiencies but due to the weather conditions such as exceptionally high wind speeds, this system's attainable efficiencies will be almost impossible to reach. Drip irrigation being the most suitable option, if operated correctly, could yield the highest efficiency.

### 4.2.3 Sprinkler irrigation: System and efficiency

Sprinkler irrigation is the system most frequently used on irrigation schemes, but because of the high standards in the design criteria, pumping installations are often too expensive, making irrigation unaffordable for small-scale farmers (de Lange, 1994). Besides being too expensive sprinkler irrigation presents many other problems as discussed below.

#### *4.2.3.1 Disadvantages of sprinkler irrigation*

A) Water losses due to the following:

1) Over watering, is probably the most significant cause of water loss. The proper irrigation scheduling is important (this will be discussed in the following chapter) for high efficiencies to be achieved (Solomon, 1988).

The primary water losses associated with sprinkler irrigation are:

2) Direct evaporation from wet soil surfaces

3) Wind drift, which occurs when wind carries water droplets away from the irrigated area resulting in unnecessary wetting of the non cropped area as

the water droplets may fall outside the irrigated area (Smajstrla and Zazueta, 1994).

4) Evaporation losses from spray, as water evaporated from droplets sprayed through the air (Smajstrla and Zazueta, 1994). Kohl *et al* (1987) stated that ±40% of water loss by evapotranspiration is by water droplets that have not reached the soil surface within 60 m of the sprinkler lateral[1].

5) System drainage and leaks (Solomon, 1988).

B) Uneven distribution and Distortion

Large quantities of water do not reach the vegetable beds due to the high windspeeds resulting in water spray drift as stated by Seginer *et al* (1991). This phenomenon results in uneven water distribution. Ali and Barefoot (1984) state that wind is probably the principal factor, which cause undesirable water distribution. Under windy conditions, windspeed and direction affect droplet size and distribution patterns (Smajstrla and Zazueta, 1994). Ali and Barefoot (1984) observed that under low windspeed, the individual distribution pattern is a doughnut shape, which could be reduced as a result of increased operating pressure. This pattern could be distorted, elongated, slightly enlarged and shifted towards the increasing pressure under high windspeeds (Han *et al*, 1994). Figure 13 depicts the water distribution and distortion of a sprinkler irrigation as observed on a windy day in the SCAGA garden.

[1] Lateral refers to the water delivery pipeline that suppliers water to the emitters from the manifold ( water delivery pipeline that supplies water from the main to the laterals) pipelines (EP 405.1, 1999)

C) Wetted leaves

The susceptibility of certain crops to leaf damage from sprinkling and the risk of fungus disease (Solomon, 1988)

D) Portable systems

Portable sprinkler systems require manual operation under wet field conditions (Solomon, 1988).

#### *4.2.3.2 Possible methods to reduce water losses*

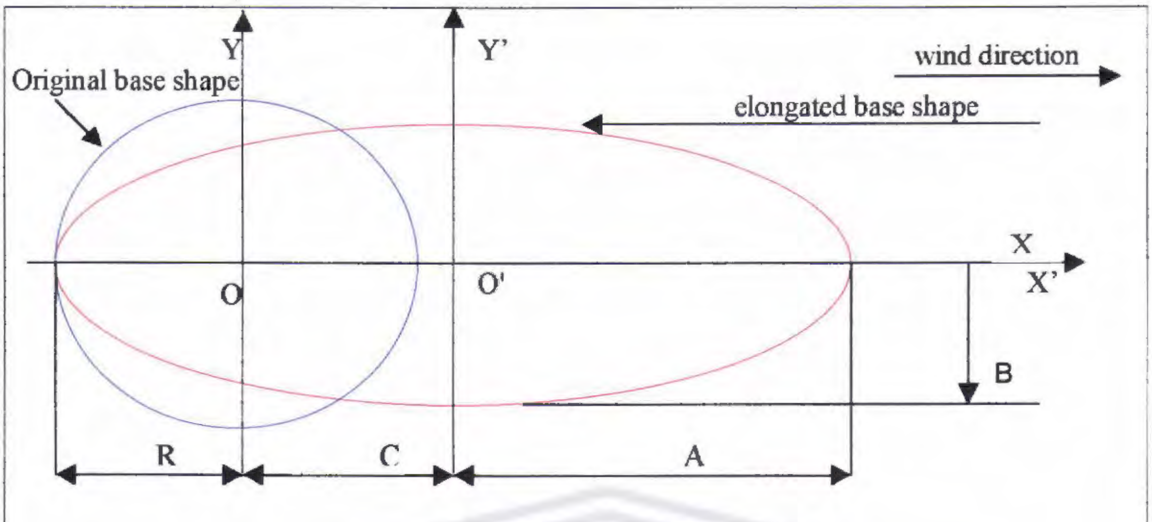
a) Reducing evaporation loss

Changing the sprinkler operating conditions to increase the size of water droplets or irrigate when water conditions are low (Smajstrla and Zazueta, 1994).

1) Changing the nozzle diameter or
2) Decreasing the operating pressure

b) Reducing wind drift loss

Irrigation systems should not be operated when wind speeds are high (Smajstrla and Zazueta, 1994). A sprinkler should always be operated within the operating pressure range for which it was designed (Smajstrla and Zazueta, 1994).




**Legend**

O - Sprinkler origin
X, Y - co-ordinates of the base shape
A - major axis of ellipse
B - minor axis of ellipse
C shift of the pattern
R - Pattern Radius in no wind condition (also called the wetted radius)
O - Radially symmetric distribution pattern
- elongated distorted distribution pattern

Figure 13: The base shape of the sprinkler distribution pattern as affected by wind as seen in the SCAGA garden, adapted from Han *et al* (1994) Patterns Base-Shape



### 4.2.4 Drip Irrigation: System and efficiency

Table 12 suggests drip irrigation to be an efficient irrigation method. Its high efficiency is as a result of the following:

1) Direct and slow application of water to crops (Solomon, 1988). This will result in no water lost on non-cropped areas, minimal losses due to evaporation and promotion of lateral distribution of irrigation water and reduction of vertical

losses (Solomon, 1988). With good management, losses should not exceed 1% (Solomon, 1988).

2) Minimisation or avoidance of deep percolation (Hammon, 1989)
3) Improved crop performance due to reduced foliar diseases and control of pest and weeds is easier as foliage and soil surface are not wetted (Verbeeten, 1998).
4) The application of drip irrigation also avoids leaf burn (Verbeeten, 1998).

#### *4.2.4.1 Potential problems and concerns with drip irrigation*

The disadvantages associated with drip irrigation are related to the high equipment cost, the lack of sound technical knowledge to operate the systems, the need for irrigation schedules and people's lack of awareness for the system. With specific regard to vegetable production, it is also important to realize that certain vegetables don't like drip irrigation and that one has to be careful when using drip irrigation with germinating seeds (A. Chalmers, pers. com.). In addition to the above reasons, de Lange and Crosby (1995) identified the following problems concerning the use of drip irrigation systems by small-scale farmers: It is difficult to spot the blockages which cause malfunctioning of the system; maintaining and monitoring the system is time consuming.

An aspect of drip irrigation, which needs some special attention, is the water distribution of drip irrigation systems on the soil. Because crop roots will grow towards water, a 100% uniform distribution of irrigation water is not essential. However, the irrigation water should stay within the rooting zone of the crops. It is therefore important that the lateral water movement underneath a dripper should at least be 80% when compared to the vertical water movement (see Figure 14) (Piaget, 1991). To obtain this more or less homogenous water distribution in sandy soils, such as on the Cape Flats, is not easy. The physical soil characteristics enhance vertical water flow and impede lateral water movement. This problem can (partially) be overcome by reducing the drip rate and decreasing the spacing of the drippers, e.g. 20 cm spacing (Streutter, 1996). The uniformity of the water distribution will be especially important to shallow (30 – 40 cm) rooting crops such as onions, lettuce and pumpkins – as drainage from the crop rooting zone can easily take place. The rooting depths for most vegetables range between 46 – 61 cm. Therefore the depth of penetration of the plant roots, and the infiltration rate of water into a specific soil type will determine the drip rate for a specific soil.

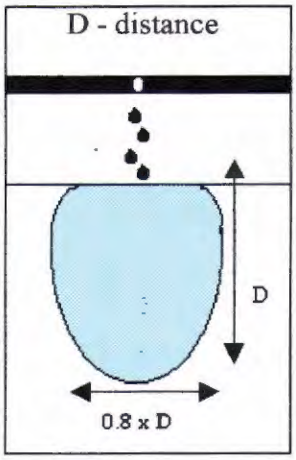


Figure 14: Required water distribution underneath a home made dripper line (Piaget, 1991)

It was stated by Davies and Day (1998) that drip irrigation is useless on coarse soils as the water leaches through the soil and does not spread out in the root zone. This statement is valid if the flow rates are high and does not allow the irrigated water to wet the soil adequately and only vertical wetting takes place. A concern about drip irrigation is that the wetted area beneath the dripper (lateral distribution) is at least 80% of the rooting depth.

The drippers should be reasonably close to each other so as to allow and overlap with the wetted areas beneath the drippers (Figure 15). The perfect wetting can be created with a suitable flow rate for a specific soil while taking the rooting depth into consideration as well.

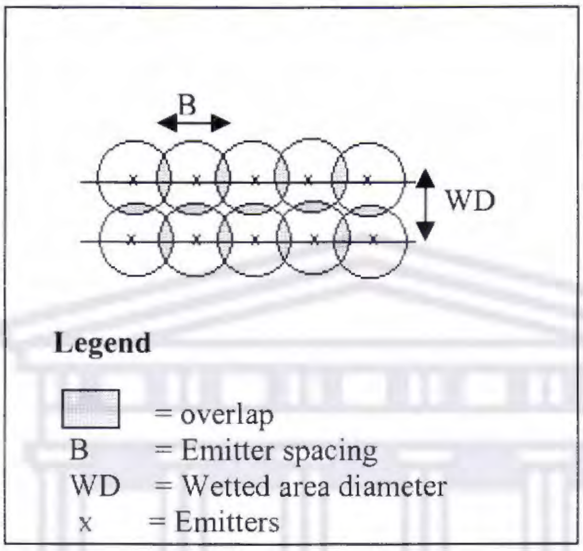



Figure 15: Ideal wetting patterns created by drip irrigation

It is hypothesized that drip micro-irrigation systems do not have the ability to wet sandy soils adequately and only vertical wetting can occur. But with a slow enough flow rate in the range of 1- 4 l/h it is possible to achieve a rounded wetting front (vertical and lateral) which will make the optimal amount of water available to the plant in the rooting zone.

#### *4.2.4.2 Low Tech Drip Irrigation Systems*

Although drip irrigation has high irrigation efficiency, due to the disadvantages mentioned earlier it is predominantly used for commercial agriculture. The development of a low cost drip irrigation system that fits the needs of small-scale farmers in developing countries has long been recognized as a critical need (Pollak, *et al*). Attempts have been made to simulate commercial drippers, by constructing home-made dripper lines simply using polyethylene pipes and a pin to pierce holes into the polyethylene pipe to act as emitters/drippers. According to van Niekerk, (1988) the following problems resulted:

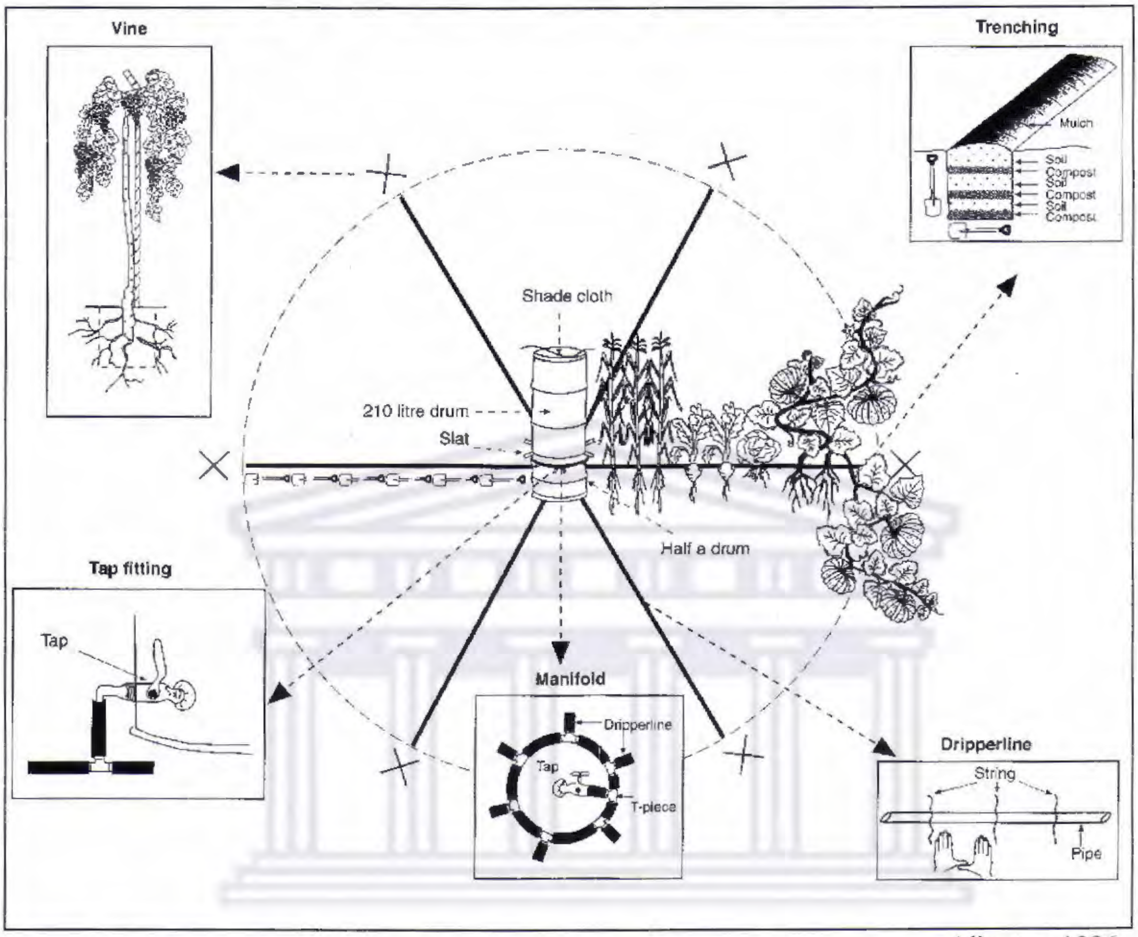
(a) The high variations in flow rate along the line (more than 30 %, while only variations smaller than 10 % are acceptable according to the coefficient of variation).

(b) The small dripper holes (needed to obtain low flow rates) are susceptible to clogging and blockages.

(c) As a consequence of the "memory" of the plastic material; the drip holes tend to decrease in size affecting the flow rates. Bigger holes cannot be made, as it would then act as a micro-spitter line instead of a dripper line.

In order to overcome the problems described by van Niekerk, commercial drip lines were used by Chapin Watermatics who developed the "bucket drip irrigation system" (Chapin, 1998). This system consists of 2 buckets, hung from a stand, at the one end of the vegetable bed, each bucket is connected to a commercial drip line. This system is especially viable for home gardeners.

The ARC-Nietvoorbij and the Institute for Soil, Climate and Water have specifically developed a low-tech drip irrigation system for medium scale vegetable production, called the "waggon wheel" (Figure 16).




Albertse, 1996

Figure 16: Waggon Wheel developed by ARC - Nietvoorbij

This system was tested on loamy soils of Namaqualand and worked satisfactorily. It consists of a 210 liter drum and polyethylene pipes attached to the drum, as spokes of a wheel. Holes were burnt into the polyethylene pipes with a heated nail. 15mm braided nylon string was used as drippers. The string was threaded through the holes in the polyethylene pipe and knotted on either end. To prevent clogging the string can be shifted back and forth. This system requires only very little pressure therefore the drum could be elevated approximately 45cm above the ground.

The lifespan of the drip irrigation system depends on the quality of the material (thickness of the drip hose) and on the maintenance of the system. However, it is expected that the lifespan of the medium hose thickness class 3 is between five and ten years. Deterioration of the drip lines mainly occurs as a result of relocation and exposure to the sun.

Trials indicated that the waggon wheel low-tech irrigation system yielded 500kg of vegetables and 60 kg of grapes on a $113m^2$ plot per year in Stellenbosch, Western Cape (Appendix 3). Although the yields obtained from this system were good the system was not tested for efficiency, uniformity (flow rates) and water distribution patterns.

Due to the high vegetable yields obtained it was assumed that this system would be ideal on any soil on the Cape Flats in particular the sandy soils of Macassar Khayelitsha. The trials at Nietvoorbij (Stellenbosch) were done only on clay soils (high water holding capacity. Therefore the system needed to be tested for its effectiveness on sandy soils with a low water holding capacity.



#### *4.2.4.3 Prerequisite for the low-tech drip irrigation system*

In order to reduce or eliminate the irrigation problems experienced using sprinkler irrigation in the SCAGA garden an alternative system, was decided on. Drip was chosen mainly on the basis of its water saving characteristic. In order to determine drip irrigation effectiveness on sandy soils of Khayelitsha, SCAGA garden the system would have to conform to the following:

1. High irrigation efficiency (minimal water losses)
2. Good soil water distribution
   2a. Low flow rate variations between drippers
   2b. Low flow rates
3. Cost effective
4. Easy to operate
5. Not labour intensive
6. Minimal susceptibility to clogging

The Nietvoorbij waggon wheel system being (a) low cost @ R130 to R170/system (Appendix 4) and (b) easy to operate with minimal labour seemed to be the most suitable low tech drip irrigation system to be tested on the Cape Flats soils. In Namaqualand the system proved to be easy to operate with minimal labour. The only major downfall of the system is that the original dripper lines emitters yielded flow rates of up to 20 l/h. This is totally unsuitable for sandy soil with a low water holding capacity, vertical water movement will inevitably occur resulting in excessive drainage. An Agriplaas consultant, advised flow rates of 1 to 4l/h for sandy soils (A. Chalmers, pers. com.). The waggon wheel system would therefore have to be adjusted in order to yield flow rates of 1to 4 l/h before it could be tested and used on the Cape Flats.

The original design of the waggon wheel would not be practical in a communal garden situation on the Cape Flats as land is limited and this system would result in wasted space This would leave the system design unsuitable for the farming space provided. In order to test the waggon wheel system in the SCAGA the original design was adapted to accommodate the layout of the garden as can be seen in Figure 17.

Bearing in mind that SCAGA garden is rectangular in shape it would be appropriate to have a system design such as that in Figure 17 for optimal use of the land. If necessary it is possible for the system to include extra dripper lines to accommodate extra vegetable beds or vegetables per bed.

Figure 17 : Parallel layout of low-tech home-made drip irrigation system

## 4.3 METHODOLOGY

The experiments carried out to adapt the waggon wheel system into a more appropriate system for the Cape Flats consists of 4 steps as described by J.Keet in Fermont *et al*, 1998:

1. Developing dripper lines with flow rates between 1 and 4 l/hr
2. Testing the variation in flow rates between drippers
3. Determining the wetting patterns of the drip lines in the field
4. Observing the performance of the systems with respect to clogging

Two types of dripper lines were tested: homemade drip lines and commercial drip lines. The spacing between each dripper for both lines was 60 cm (Figure 18). This spacing was chosen to see the individual wetting patterns without any overlapping. The construction of low-tech dripper lines with sufficiently low flow rates was done according to the method developed by the ARC-Nietvoorbij (Appendix 4), i.e. burning holes in the polyethylene pipes with a heated nail and using nylon string as drippers. Using various nail sizes and string thickness, the flow rate was adjusted. Varying nail sizes of 1.5mm, 2mm, 2.5mm, 3mm and 1.5mm braided string were used to obtain flow rates of 1-4 liters/hour. In addition nails sizes of 2mm and 2.5mm were used in combination with varying string sizes of 1.5mm, 1.75mm and 2mm in order to create flow rates between 1 and 4litres/hour

To test the variation in flow rates between the low-tech and commercial dripper lines, the drum irrigation system was set up at the University of the Western Cape, Geography

Department. Buckets were placed below each dripper line and allowed to run for an hour in order to determine flow rates per hour per dripper (Figure 18).

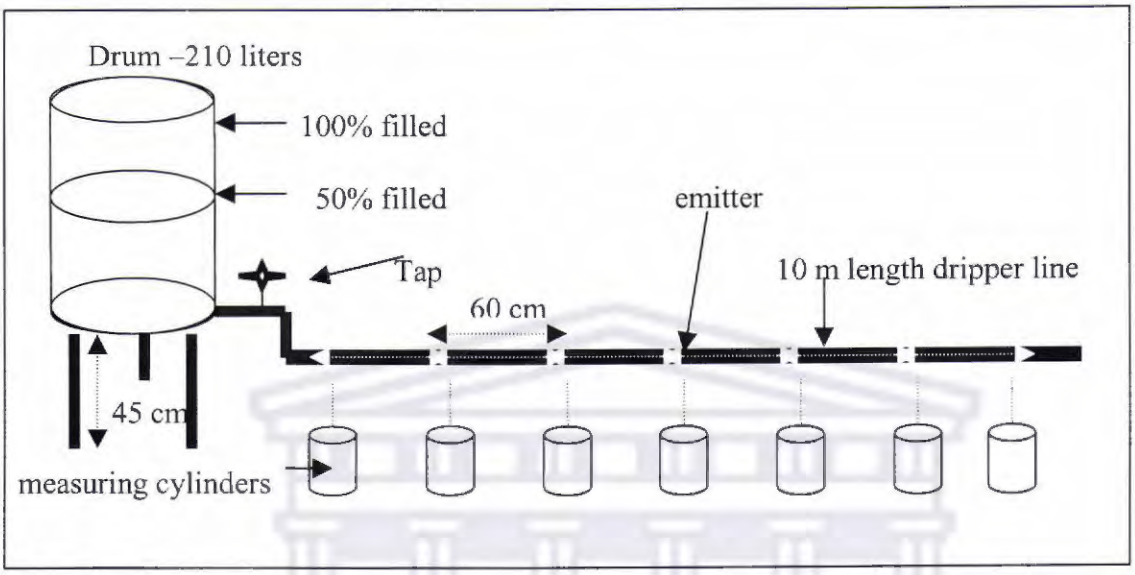



Figure 18: Flow rate experiments

To test the sensitivity of the system to variations in water pressure, the system was tested with both full and half filled drums. The intercepted water in each bucket was measured and the variation in the flow rates was calculated according to formula 4.1. The acceptable norms for the coefficients of variation (C.V). are presented in Table 13.

$$\text{C.V. (\%)} = \frac{\text{Standard deviation of discharge}}{\text{Average discharge}} \times 100 \qquad (4.1)$$

Table 13: C.V. Norms

| Acceptable norms for CV | |
|---|---|
| 0 - 5 | Good |
| 5 - 10 | Acceptable |
| > - 10% | Unacceptable |

Observations were made of all wetting patterns created under the tested dripper lines. The dripper lines were tested on virgin soils, trenched- and non-trenched [1]beds over periods of 1, 3 and 16 hours. Each test executed was done with one dripper line, 10 m in length to compliment the length of one vegetable bed in the SCAGA garden.

Visualising the wetting profiles created beneath each drip was difficult. The indicators used were namely food colouring and ink, which did not emphasize the wetting profiles. Potassium permanganate, used in experiments on loamy and clay soils, did not work in the sandy soils because the purple permanganate ion needs to bind to clay particles to keep its colour. The method used to enhance wetting profiles in sandy soils was to run the system on dry soil. Given an extra half an hour allowed a wetting profile to develop in the soil. A soil pit was then dug facing the sun. The profile was left for another 20 minutes allowing the soil surrounding the wetting front to dry out further. The enhanced wetting profile then appears as a dark imprint in the soil.

The disadvantage of this method is that it is impossible to observe the wetting profile in a soil, if the soil is not dry at the start of the experiment. It was therefore impossible to use the same beds for multiple experiments or to run test during the winter season. A limited

[1] Non-trenched vegetable beds are prepared by mixing a layer of manure into the topsoil

number of vegetable beds were available as the SCAGA gardeners utilised the remaining beds to grow their seasonal crops. Due to these limitations very few experiments could be executed.

## 4.4 RESULTS AND DISCUSSION

### 4.4.1 Flow rates

In order to obtain flow rates between 1 and 4 l/h various combination of different nail diameters and strings thickness were tested (Table 14).

Table 14: Combinations of nail diameters with 1.5mm string

| Nail size (mm) | Braided nylon string(mm) | Actual flow rates l/hr |
|---|---|---|
| 1.5 | 1x1.5 | 3.0 |
| 2.0 | 1x1.5 | 4.0 |
| 2.5 | 1x1.5 | 27.0 |
| 3.0 | 1x1.5 | 27.0+ |

The results obtained using increasing nail diameters and one string thickness showed increased flow rates from an acceptable 3 & 4 l/h to an unacceptable 27 l/h. Thus larger nail diameters would not be an option if 1.5mm string were used as drippers, as it would result in a spitting instead of dripping action.

Varying nail sizes and string thickness as can be seen in Table 15 indicates that the flow rates obtained ranges between 0 and 5 l/h. Flow rates below 1l/h are too low while that above 4l/h are too high to obtain optimal wetting of sandy soil.

Table 15: Combination of nail diameters and string thickness

| Nail size (mm) | Braided nylon string(mm) | Actual flow rates l/hr |
|---|---|---|
| 2.0 | 1x1.5 | 4.7 |
| 2.0 | 2x1.5 | 2.1 |
| 2.5 | 2x1.5 | 3.5 |
| 2.5 | 3x1.5 | 0.8 |

It was therefore decided to run experiments using low-tech dripper lines constructed according to the prescribed nail size of 1.5mm and string thickness of 1.5mm. The drippers were placed 60 cm apart and tested for flow rate uniformity. The results obtained can be seen in Table 16.

Uniformity of hole sizes along the low tech dripper line could not be obtained as burning holes in the polyethylene pipe allowed the plastic to move back as the heated nail was removed from the burnt hole. This resulted in each hole differing in size. The degree to which the hole-sizes differed resulted in the range of flow rates (1 to 4 l/h) as presented in Table 16. The C.V along the dripper lines were evaluated according to the acceptable norms for CV (Table 16). The C.V. values obtained indicated strongly that the low-tech dripper system was unacceptable due to the irregular flow rates along the dripper line.

In order to obtain a constant flow rate appropriate for sandy soils two commercial dripper lines were also tested. These commercial dripper lines were manufactured to obtain flow rates of 2 and 4 l/h under a high-pressure system, typically used for commercial farming. Tests done using the commercial dripper lines under extremely low pressure created by the elevated drum resulted in a 75% difference in flow rates (Table 16). Although the flow rates decreased due to the low pressure, the flow rates remained relatively constant along the dripper line as can be seen in Table 16. Test also indicated that changing the volume in the drum affected the performance of the dripper lines as the half-full drum (4b and 5b) compared with the full drum (4a and 5a) yielded significantly lower flow rates than that of the full drum (Table 16).

Table 16: Flow rates (1/h) and C.V.(%) of 6 drip lines (3 replications of each)

| Line | Average flow rates (l/hr) | | | | | | | | | | | C.V. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Ave. | (%) |
| 1 | 1.90 | 0.70 | 1.50 | 1.00 | 0.70 | 1.50 | 1.20 | 1.30 | 0.50 | 0.60 | 1.0 | 45.30 |
| 2 | 0.50 | 1.70 | 3.50 | 1.20 | 3.70 | 1.80 | 2.90 | 0.60 | 0.90 | 2.00 | 1.90 | 61.40 |
| 3 | 0.40 | 2.70 | 3.90 | 3.30 | 4.60 | 3.10 | 4.30 | 4.40 | 3.30 | 0.30 | 3.00 | 51.60 |
| 4a | 0.41 | 0.41 | 0.44 | 0.43 | 0.42 | 0.43 | 0.43 | 0.39 | 0.38 | 0.36 | 0.41 | 6.30 |
| 4b | 0.59 | 0.60 | 0.59 | 0.59 | 0.59 | 0.55 | 0.57 | 0.55 | 0.55 | 0.58 | 0.58 | 3.40 |
| 5a | 0.9 | 0.91 | 0.93 | 0.98 | 0.99 | 1.1 | 0.98 | 0.92 | 0.92 | 0.98 | 0.96 | 6.20 |
| 5b | 1.20 | 1.25 | 1.10 | 1.20 | 1.22 | 1.11 | 1.22 | 1.10 | 1.22 | 1.22 | 1.18 | 4.90 |
| Line 1, 2 and 3: Home made dripper lines, 100% filled drums<br>Line 4a and 4b: Commercial dripper (2l/h), 50 % and 100% filled drum<br>Line 5a and 5b: Commercial dripper (4l/h), 50 % and 100% filled drum | | | | | | | | | | | | |

From Table 16 it is clear that the homemade dripper lines yielded unacceptably high coefficients of variation, while the commercial dripper line remained within the acceptable 0-10 % range. Although the C.V of both commercial dripper lines were acceptable, the 2l/h drippers had reduced dripper flow too low for sandy soils. Only the 4l/h dripper was used in the garden.

### 4.4.2 Low-tech dripper line experimental results

In spite of some variation in flow rates, the low-tech dripper lines were tested in the SCAGA garden. Only surface wetting occurred to a depth of 1-5cm after a 1 hour wetting period. All tests that were run over a period of 1 hour revealed that longer periods of wetting is crucial if the soil is to be sufficiently wetted

**A) 3-hour tests on virgin, non-trenched and trenched soils**

The importance of striving for drippers with low coefficient of variation (C.V.) values was confirmed after 3-hour tests were executed on virgin soils, non-trenched beds (manure mixed into topsoil), and trenched beds.

Testing the dripper lines on virgin soil, the wetting patterns created where irregular and wetting depth varied due to either dripper holes being to large (Figure 19a) or clogged drippers (Figure 19b).

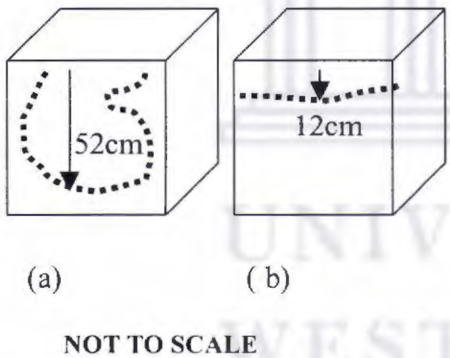
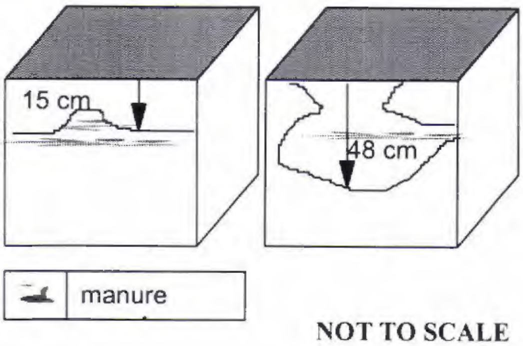



Figure 19: Wetting profiles of homemade drip lines on virgin soils – 3hr tests as observed in the SCAGA garden,

a) excessive penetration due to large dripper hole and
b) limited penetration due to clogged hole.

Figure 20 gives an example of the large variation in wetting profiles that were found on non-trenched beds. While some drippers created a good wetting profile others hardly wetted the soil at all. In some instances layers of manure hindered water movement.




NOT TO SCALE

Figure 20: Wetting profiles of homemade drip lines on non-trenched beds – 3hr tests as observed in the SCAGA garden

Testing the home made dripper lines on the trenched bed over a 3-hour wetting period indicated and overall wetting of the vegetable bed to a depth of approximately 70cm. This is about 20cm deeper than the depth of the trenched vegetable bed. This depth of wetting could be due to the trenched vegetable bed being wetted before the experiment was done.

Additional problems of clogging were observed which manifested in the home-made dripper lines. Sand grains lodge themselves in-between the wetted nylon threads, making it impossible to unclog. This problem increased the variability in flow rates and uneven wetting of the soil. Instead of the nylon strings being the solution to unclogging the blocked drippers they are the primary cause.

#### 4.4.3 Commercial dripper line experimental results

**A) 3-hour tests on virgin, non-trenched and trenched soils**

The next set of experiments was done with the commercial drip lines (Table 16 - Line 5). Three-hour tests were carried out on virgin soil and non-trenched beds.

Optimal rounded wetting profiles (15 cm – 17 cm) were obtained on virgin soils as shown in Figure 21. Little variation in the size of the wetting patterns was noted. Although good wetting patterns were obtained crop-rooting depths are between 0.4 and 0.6 m depth. The wetting pattern created is not sufficient to supply crops with an optimal amount of water.

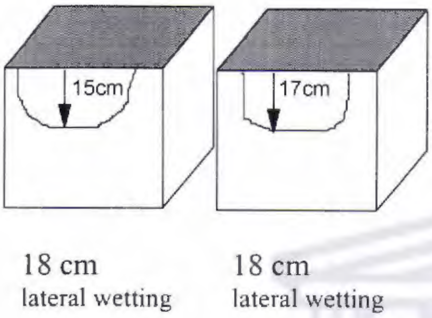
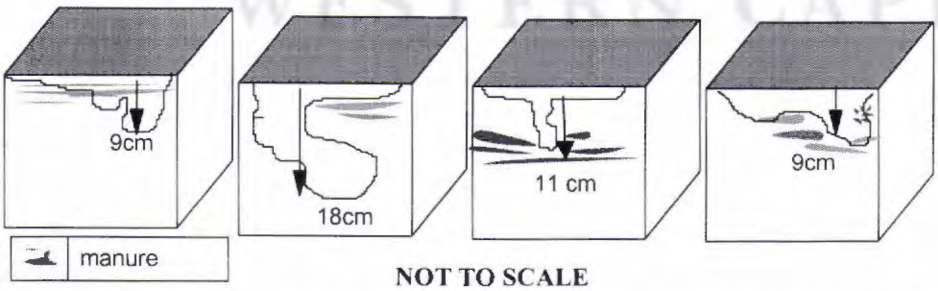



Figure 21: Wetting profiles of commercial drip lines on virgin soils – 3hr tests

**NOT TO SCALE**

Examples of wetting profiles created by the 4 liter /hour commercial dripper lines on non-trenched beds are shown in Figure 22. A few drippers created good wetting patterns as could be seen from the cross profile, but the development of good wetting patterns was inhibited at other places, due to the presence of lumps of manure, which was spread unevenly throughout the soils impeding water movement. The manure acted as a barrier, hindering water distribution.




**NOT TO SCALE**

Figure 22: Wetting profiles of commercial dripper lines on non-trenched beds – 3hr tests

In the SCAGA garden the initial moisture content of the trenched bed was too high making observation of the wetting profile impossible. Thus trenched beds retain moisture. The high initial moisture content resulted in the soil being wetted deeper than the trenched beds. It was impossible to dig any deeper than a few cm's below the trenched beds due to calcrete layers.

An example of a wetting front created after testing the commercial dripper line (4 l/h) on a trenched bed prepared at the University of the Western Cape can be seen in Figure 23, 24 and 25. After allowing a full drum of 210l of water to empty onto the trenched bed a wetting depth of 45 – 60 cm was obtained. The wetting depth varied according to the layer of rubble in the bed. Emptying of the drum lasted at least 16hrs. The trenched bed depth was approximately 60cm. The rubble and litter layer in the vegetable bed acted as a barrier allowing the water to be trapped in the trenched area of the vegetable bed.


1. Wetted trenched bed (45-60cm depth)
2. Rubble and litter layer
3. Dry soil

Figure 23: Wetting profile of a commercial drip line on a trenched bed –overnight test

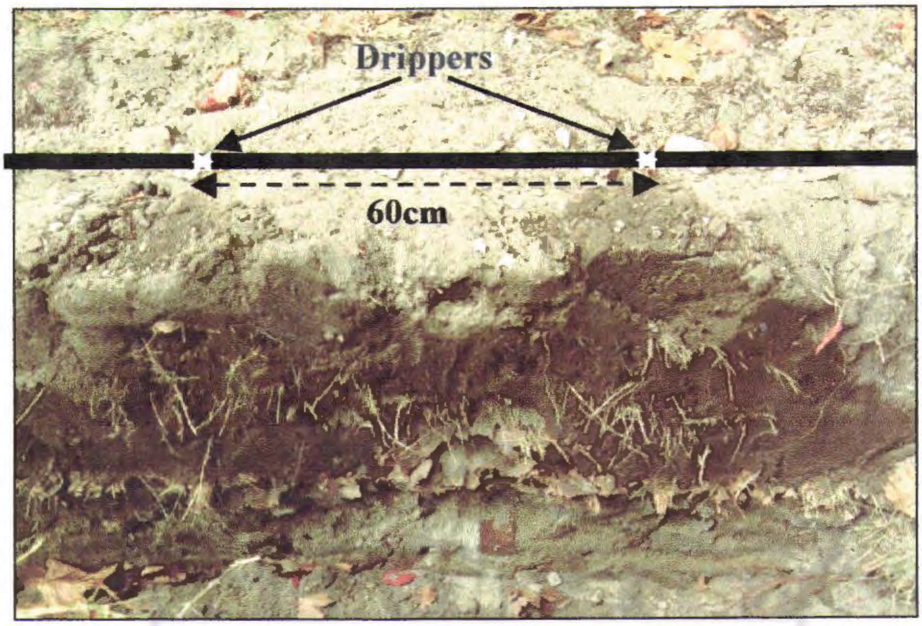



Figure 24: Commercial dripper line spacing

Figure 25: Diagonal view of Figure 24

The rubble and litter layer at the bottom of the trenched bed acted as a sponge, restricting the water from passing through the litter layer, preventing penetration of irrigation water to the lower soil layers. In the trenched bed mentioned earlier wetting was 20 cm deeper, possibly due to the bed having a higher initial moisture content or the rubble and litter layers may have been thinner. At no time was clogging observed during the experiments with the commercial drip lines.

## 4.5 CONCLUSION

The waggon wheel system developed by Nietvoorbij has produced relatively good yields and showed no signs of clogging on Namaqualand loamy soils and the clay soils of Nietvoorbij, Stellenbosch. Thus it was assumed that the homemade drip system would yield the same results on the Cape Flats sandy soils. However, sandy soils require an exceptionally low flow rate in order to obtain optimal wetting of the soil. A flow rate of 2-4 l/h is adequate for optimal wetting of sandy soils, as faster flow rates would result in excessive drainage and mainly vertical water movement. If lateral water movement is restricted due to high flow rates, rounded wetting patterns will not occur and thus overlapping of wetting profiles will not take place. If this were the case dry patches would remain in between the wetted areas beneath each dripper. It is therefore advised that dripper lines display slower flow rates in conjunction with more frequent water applications of shorter durations for overall wetting of sandy soils. The dripper spacings along the dripper line also play and important role in overlapping wetting patterns.

Only vegetable yields were examined in Namaqualand and Stellenbosch while all parameter relating to optimisation of water use was neglected. In order to determine if the system is feasible for the Cape Flats the system was adapted and tested in the SCAGA garden.

After testing the home-made and commercial dripper lines, it was clear that the home made dripper lines, produced according to the ARC-Nietvoorbij method, were unsuitable for the Cape Flats situation, owing to the following reasons:

1. Flow rates obtained varied between 0.4 and 4.6 l/h if the dripper holes are made carefully. If not, flow rates could reach 20l/h under these methods. High variation between discharge rates along the dripper line (high C.V.) is therefore inevitable.
2. Blockages were observed along the home-made dripper lines due to rapid accumulation of sand between the wet nylon threads, which was impossible to remove.

Commercial dripper lines have shown much better results. Commercial dripper lines delivering flow rates of 2 and 4 l/h under high pressure were tested using the drum system. The low pressure of the drum reduced flow rates from 2l/h to 0.5l/h and 4l/h to 1.2 l/h, indicating a 75% reduction in flow rates. Flow rates remained within the acceptable CV level of 10%. Although it does not fall within the desired range of flow rates for sandy soils acceptable results were obtained.

Tests of different duration were carried out in order to obtain wetting profiles. One-hour test with the 4l/h (reduced to 1.2 l/h) drippers showed profiles of surface wetting ranging from 1-5 cm in depth. Thus a lengthier time period was necessary to obtain deeper wetting. Three-hour tests with the reduced 1.2l/h dripper lines on non-trenched beds indicated that water penetration depth depended on the depth of the manure layers.

Vertical wetting was restricted at certain points due to the manure acting as a barrier inhibiting the development of desired wetting profiles.

An overnight test with a full drum of water (210l) showed that the tested drip line with the reduced flow rate of 1.2 l/h is capable of wetting the complete rooting zone. These tests show that the manure and organic matter in the trenched beds are capable of preventing deep drainage of irrigation water as long as they are not over-saturated. In the normal every day situation the soil is not permitted to dry out or even reach wilting point as it would have a detrimental effect on crops and crop yield. Thus moist manure will decrease water inhibition to a lesser extent than was found in these experiments. The high absorption capacity of manure as well as the litter layers increases the water holding capacity of the soils, which is advantageous for sandy soils whose water holding capacity is very low. As plant roots grow towards the water and nutrient sources, the concentrations of water in manure can only have a positive effect on crops.

The trenched vegetable bed consists of a litter layer at the bottom of the bed (Figure 23). This litter layer acts like a sponge absorbing all water applied to the vegetable bed. Over time this layer diminishes due to disintegration. The litter layer prevents drainage of irrigation water to deeper soil layers beyond the trenched vegetable bed. Non-trenched beds will thus be subject to excess drainage as the litter is not present.

The overnight test on the trenched vegetable bed was executed with only one dripper line. Under normal circumstances two dripper lines would be used per vegetable bed decreasing the amount of water per dripper line by half. The soil profile indicated that the entire $10m^2$ bed was wetted after emptying a full drum overnight. If irrigation is scheduled the same result can be obtained if 2 lines are used on one bed. Two full drum applications could even be given in one day to obtain a totally wetted trenched bed. If the same amount of water is applied to a previously wetted vegetable bed, it is however more than likely to cause excessive drainage. The solution to how much and when to apply water can be solved by developing a good irrigation schedule. This will be dealt with in the next chapter focusing on irrigation management.

It is apparent that the commercial drip lines fall below the acceptable flow rates for sandy soils i.e. (2-4l/h), but display overall wetting of the trenched beds. The low-tech dripper line also displays a range of flow rates (0-5l/h) that deviates minimally from the acceptable flow rates for sandy soils. The advantage of using the commercial dripper lines is that clogging never occurred, the C.V. values remained constant and within acceptable norms, and overall wetting of the trenched beds was obtained. While the home-made dripper lines clogged, the C.V. were totally unacceptable and flow rates of 20l/h is more than likely. Thus, the commercial dripper line is the most efficient and reliable dripper line.

The extremely high water losses as experienced by SCAGA garden due to sprinkler irrigation are caused by excessive evapotranspiration, strong winds and wetting of paths. Sprinkler spacing should be selected which allows sufficient overlap of the distribution pattern (Scott, 1998). In SCAGA garden the sprinklers are placed at random locations, the irrigation time is either too long or too short resulting in over- or under- irrigation. All of these reduce the sprinklers irrigation efficiency.

It has been estimated that over a 90 days growing period, SCAGA garden will utilize approximately 1 822.5 kL of water over a $1257m^2$ assuming that the garden is irrigated 3hrs/day everyday. Of the $1257m^2$ 60 % is vegetated area and 40% paths. If the 60%, which is comprised of the vegetable beds, is irrigated with the low tech-drip irrigation system only 955.5 kL will be utilized. This implies that a 47.6% water saving could be obtained if drip irrigation is utilized. This also implies a R1517 saving over 90 days or R505 over 30 days. This example gives a clear indication of the running cost saving that could be realized if drip irrigation were utilised.

Minimising or preventing water loss with the application of a drip irrigation system can optimise water usage. The commercial dripper lines with its low flow rate, low coefficient of variation, sufficient water distribution in the soil and it's low susceptibility to clogging, makes this system the most efficient. The commercial dripper lines cost only R 0.45 per meter hardly more expensive than the polyethylene pipes for the home made dripper. This is by far the most cost effective, and seemingly reliable system, suitable for the sandy soils of SCAGA garden in Khayelitsha, on the Cape Flats.

# 5. IMPROVING IRRIGATION MANAGEMENT

## 5.1 BACKGROUND

In Chapter 4 drip irrigation displayed much lower water losses than sprinkler irrigation. An up to 47.6% reduction in water requirements could be achieved if drip irrigation were used. On sandy soils however, excessive drainage due to over-irrigation can nullify these benefits. This chapter focuses on the development of an irrigation scheduling guideline for small-scale farmers, which would allow optimal irrigation of crops and reduce excessive drainage.

The SCAGA gardeners were found to irrigate their vegetable beds almost daily, sometimes twice daily because they feared their crops would not have sufficient water. A lack of knowledge among gardeners about the water needs of crops seems to be the most important reason for over-irrigation. Optimising irrigation management could prevent over-irrigation, excessive drainage and high water cost.

Supplying the grassroots gardener, agricultural NGO's and extension agencies with information on how much water crops need will help them to prevent over-irrigation. This information should be presented to the different groups in workable formats (illustrations). Information for gardeners should be simple and easy to understand, while information for NGO's can be more detailed.

The adapted waggon wheel drip irrigation system used in this research forms the ideal basis for the development of simple irrigation schedules, as one can precisely determine the amount of irrigation water required and thus supplied to a crop. The option of improving irrigation management in conjunction with the low-tech drip irrigation system will decrease water usage to an even greater extent.

## 5.2 LITERATURE REVIEW

### 5.2.1 Introduction

Due to the shortage of water in the summer months an alternative water supply is necessary (Fermont *et al*, 1998). Thus the importance of a good water supply to vegetables is obvious, as yields in general will directly be affected by any stress occurring during growth (Smith, 1989). For this reason supplementary irrigation should be successfully introduced for crops, even in regions with normally adequate rainfall (Smith, 1989).

All farmers who irrigate are faced with the decision of when to irrigate and how much water to apply. The farmer must consider not only when to start irrigating, and how much to apply, but also whether to stop irrigating after rainfall, so as not to waste resources or to over-irrigate the soil and risk excessive leaching (Hess, 1989). These are the primary irrigation management decisions that need to be made and can have the most effect on crop yield and efficient water use (Reicosky, 1989).

An adequate and timely water supply is a first condition to optimise production (Smith, 1989) as quantities and qualities are affected when water excess or deficit occur

(Linsalata and Linsalata, 1989). Adequate irrigation techniques for vegetable production are an essential condition to achieve the potential yield levels under irrigation (Smith, 1989).

Various other factors need to be taken into account when developing an efficient irrigation schedule such as crop type/s and soil water holding capacity. An accurate evaluation of the water reservoir available for plant growth is essential to develop management strategies for rain fed crop production, irrigation scheduling and for the minimization of groundwater pollution (Ritchie, 1972). The soil physical properties are not sufficient to determine the amount of water that can be removed from the soil but rather plant extractable soil water by plant roots and their distribution play a role (Ritchie, 1972).

### 5.2.2 Need for irrigation management

The sensitivity of vegetables to any stress has led to the common practice of "rather too much water than too little" (Smith, 1989). This unfortunate practice leads to over-irrigation and excessive water losses (Smith, 1989). Low irrigation efficiencies up to 30% are therefore not an uncommon characteristic of many irrigated vegetable crops (Smith, 1989). In order to overcome the problem of over-irrigation and high water losses, which results in excessive water usage and nutrient loss due to high leaching rates, irrigation scheduling should be applied in conjunction with the type of irrigation system in use (Fermont *et al.*, 1998). Producing scheduling for irrigation is essential for maximizing yields when irrigation water supplies are limited, and for reducing energy costs even where irrigation water is plentiful (Ciollaro *et al.*, 1989).

*Reasons for irrigation scheduling* as stated by Stegman *et al.* (1980) are:

1) Maximising yield per unit area
2) Maximising yield per unit of area
3) Minimising energy requirements

Rijks and Gbecker-Kove (1989) stated that for the acceptance of an irrigation schedule the following *benefits* should be made available to field irrigation practitioners:

1) avoidance of water stress resulting in better yield and quality of produce
2) better economy of scarce water
3) less excess deep drainage and a smaller risk of pollution by lost fertilizer, reduced risk of soil deterioration
4) better possibilities for weed control
5) higher efficiency of fertilizer applied
6) reduced spread of water borne diseases/pests
7) reduced plant heat stress

*Effects of excessive drainage* as stated by Smith (1989)

1) Excessive loss of nutrients and fertilizer due to high leaching rate
2) The excessive growth of hydrogenic pest and diseases
3) The high water table and salinisation hazards

## 5.3 METHODOLOGY

The aim of developing a schedule is to provide guidelines to prevent over-irrigation, yet provide an adequate amount of water in the soil for optimal plant growth. Crop water requirements depend on crop type, crop development stage, soil type (water holding capacity) and climate. As radiation was found to be the dominating climatic factor for crop water requirements on the Cape Flats, it was decided to categorise weather conditions into 3 classes: sunny, half overcast and overcast. Developing an irrigation schedule for specific crops was done according to the following steps:

1. Using the climatic data of a regular year (1985), daily radiation data were categorized into a typical sunny, half-overcast and overcast day.
2. Using CROPWAT 7.0 reference evapotranspiration ($ET_o$) was calculated on a daily basis, for the development stages of each crop.
3. Using the growing period of a specific crop and its crop coefficient ($K_c$)-values, the crop evapotranspiration ($ET_c$) was calculated for every day of each development stage.
4. A water balance (spreadsheet format) was formulated to determine the irrigation requirements as part of the irrigation model used to verify CROPWAT 7.0.
5. Using the 85% efficiency of drip irrigation systems, the net irrigation requirements of the crop in the various conditions were calculated.

## 5.4 RESULTS

The purpose of developing an irrigation schedule is to provide the SCAGA gardeners with guidelines on how to apply the optimal amount of irrigation water to prevent over-irrigation yet increase crop yield. The amount of irrigation required by crops depends on the climatic conditions. Therefore the climatic conditions were used as a guide to determine how much water should be irrigated and when. This was done in a sketch format using the three classes of climatic conditions: sunny, half overcast and overcast as indicators for irrigation scheduling.

Irrigation schedules were developed for a range of vegetables such as beans, potatoes, pulses, peppers, tomatoes and other vegetables but cabbage and spinach are highlighted in this chapter being the dominant crops on the Cape Flats. The illustrated schedules for the other crops mentioned can be found in Appendix 6. The procedure used to calculate irrigation requirements can be found in Appendix 7. The calculated irrigation requirement for cabbage and spinach can be found in Appendix 8 and 9. The irrigation requirements were determined on the basis of how often to apply 100l of water per crop per vegetable bed under differing climatic conditions. By using 100l of water per vegetable bed implies that 2 vegetable beds can be irrigated with one 210l drum. The number of dripper lines per vegetable bed range from 2-4 depending on the type of crop and the spacing requirements of the crop/s. The illustrated irrigation schedules for cabbage and spinach can be seen in Figures 26 and 27.

Figure 26. Illustrated irrigation schedule developed for cabbage in SCAGA garden

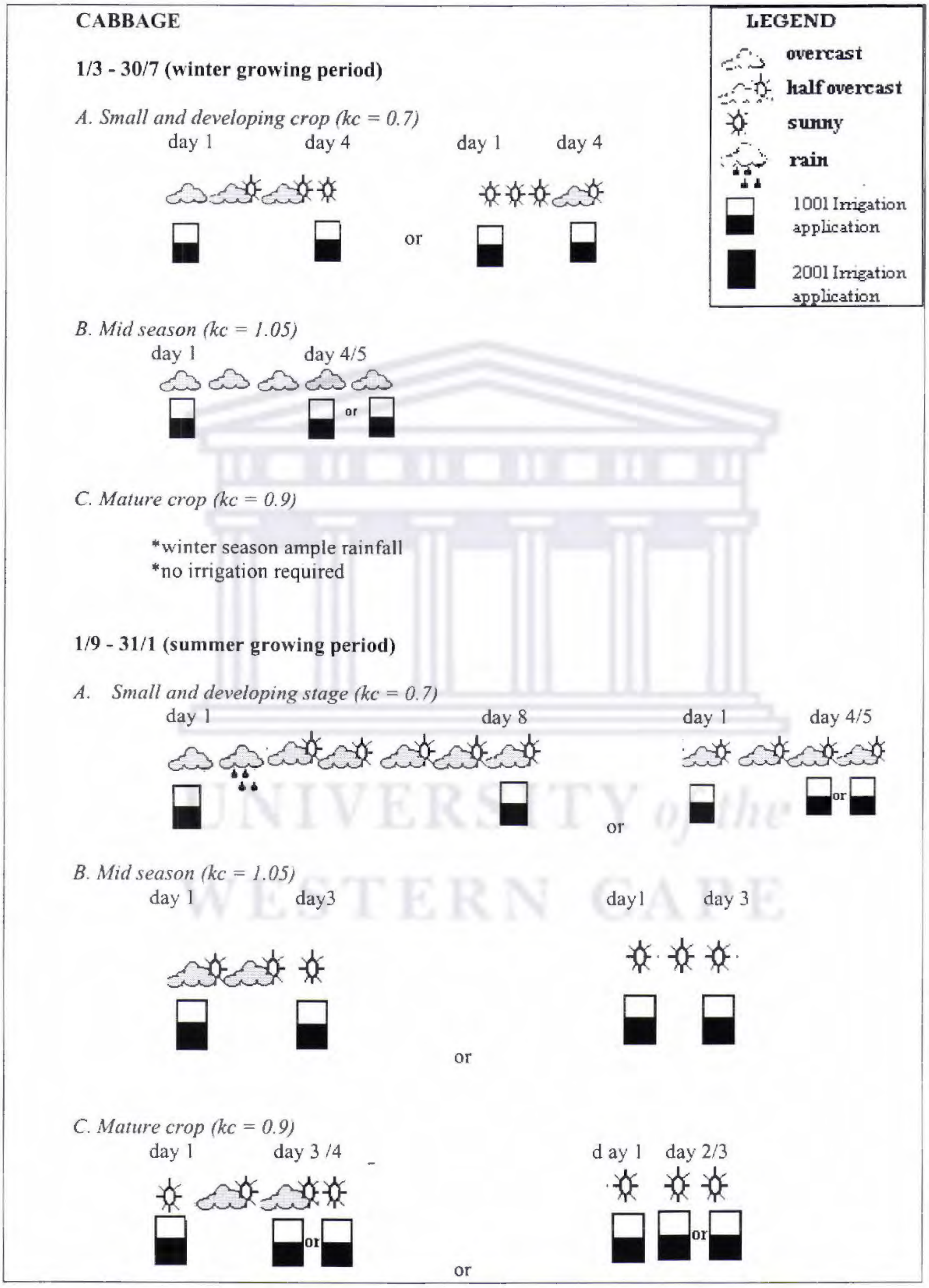
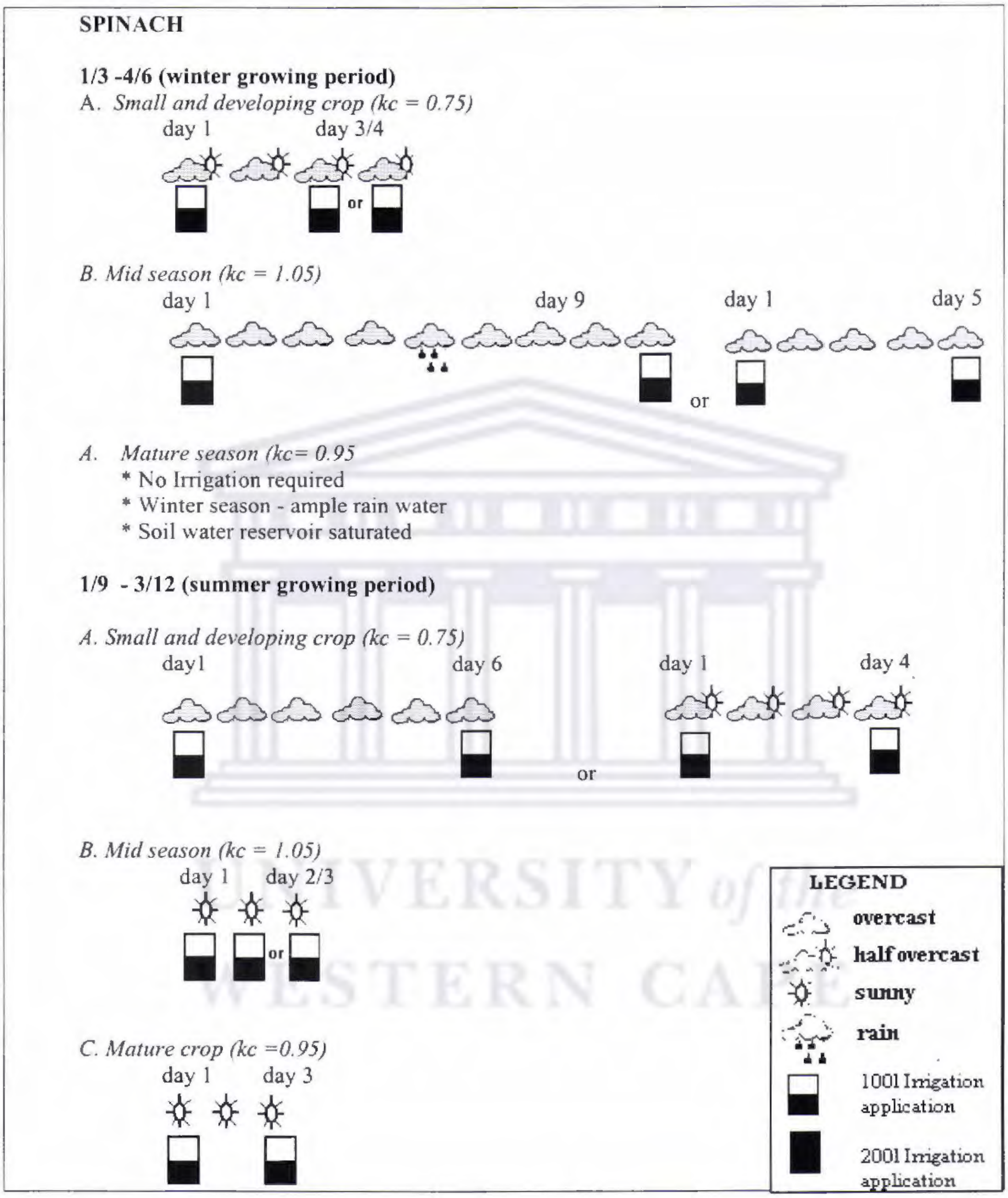


Figure 27: Illustrated irrigation schedule for spinach in SCAGA garden



The schedules presented in Figures 26 and 27 will give the gardeners an indication of when to irrigate and how much to irrigate according to the weather conditions experienced. In certain cases 2 options are provided per development stage as can be seen in Figures 26 and 27. Theses options are dependant on different weather conditions experienced. For example (Figure 26) in winter, during the developing stage the cabbage crop will require half a drum (100liters) every 4$^{th}$ day in sunny-half overcast weather. In the mid stage half a drum every 4$^{th}$/5$^{th}$ day in overcast weather and in the mature stage irrigation water does not need to be applied, as rain should exceed evapotranspiration.

In summer cabbage requires half a drum (100liters) every 8$^{th}$ day in a combination of overcast rain and half overcast weather conditions, or the 4$^{th}$/5$^{th}$ day if only overcast weather conditions prevail during the development stage. During the mid stage half a drum every 3$^{rd}$ day and during the mature phase every 2$^{nd}$ /3$^{rd}$ day in sunny weather conditions or the 3$^{rd}$ /4$^{th}$ day in slightly overcast weather conditions. As can be seen using an irrigation schedule allows for the exact amount of water to be applied, thus avoiding over-irrigation and optimising water usage. This schedule has been developed for the SCAGA gardeners to optimise water usage by means of irrigation management.

The information presented in Figures 26 and 27 are specific to weather conditions experienced in 1985. Should similar conditions prevail in the SCAGA garden these schedules can be used as a guide. If the scheduled information is not representative of the climate experienced a schedule can be developed using the methodology provided in Appendix 7.

## 5.5 CONCLUSION

The illustrated irrigation schedule developed for the gardeners would appear to be a good guide as to when and how much to irrigate their crops according to the visible weather conditions, i.e. sunny, partially cloudy, cloudy, windy and rainy condition. A daily record can be kept of weather condition experienced in the garden and used in conjunction with the schedule developed. This will give the gardeners an idea of when and how much water to irrigate.

While for extension, NGO's, institutes etc. the schedule provided in Appendix 8 and 9 will prove more valuable and meaningful as the actual calculated irrigation requirements are provided. The procedure provided in Appendix 7 can be used to determine irrigation schedules for any crop provided that all the relevant parameters are available.

In order to obtain optimal water use it is advised that an irrigation schedule be developed and applied in conjunction with the irrigation system in use.

## 6. OVERALL CONCLUSIONS

The sprinkler system presently being used in the SCAGA garden is highly ineffective in its water use. This is caused by both the specific conditions in the SCAGA garden and the design of the system. Strong winds, high path/bed ratio and an overlap of the irrigation circles reduce the efficiency of the sprinkler irrigation to an estimated 40-50%.

Replacing the sprinkler system by a drip irrigation system is the most important step to reduce water usage of the garden. Considering the various demands of a drip irrigation system for urban vegetable production on the Cape Flats, a low-tech, cheap drip irrigation system was developed. The basis of this system was the waggon wheel system as developed by the ARC- Nietvoorbij. It was adjusted to fit a rectangular garden layout. Home-made and commercial drip lines were tested. The home made dripper lines could not be constructed with uniformly low flow rates (between 2 and 4l/h). The variation in flow rates between drippers were extremely high in certain cases, resulting in unacceptable flow rates and C.V. values. The drippers were easily clogged.

Testing the home-made low-tech dripper lines in the SGAGA garden confirmed their unsuitability for the Cape Flats. Testing of the commercial drip lines yielded satisfactory results. Short (3 hr) tests showed perfect wetting profiles on virgin soil, but dry patches of manure inhibited the development of rounded wetting patterns in the non trenched vegetable beds. Overnight tests, however, showed that once the manure is saturated it allows water to seep through. Drainage was largely prevented in the trenched beds by the litter layer at the bottom of the trenched beds. Converting all vegetable beds into trenched beds will therefore reduce the likelihood of water losses through drainage.

Using simple irrigation schedules which indicate the amount of water that has to be applied to certain (groups) of crops under certain weather conditions will assist in preventing over-irrigation and reduce irrigation losses even further. The drum used in conjunction with the drip irrigation system can easily be used to measure the amount of water supplied to the vegetable beds. Replacing the sprinkler system with the developed drip irrigation system and teaching gardeners when it is necessary to apply irrigation water can significantly reduce water losses in the garden. Considering the low efficiency of the sprinkler system (40 – 50%) and the high efficiency of drip irrigation (75 – 90%), it is estimated that these changes could save between 35 - 50% of the water utilised.

In addition to optimising the irrigation system and irrigation management, reducing crop water requirements can further decrease water usage in vegetable gardening. Using FAO CROPWAT 7.0, it was shown that artificial windbreaks could reduce irrigation requirements by 7 to 13%. Optimising planting dates proved to be an even more promising option. On an annual basis, 39% of water might be saved if crops are planted in September (summer) and April/May (winter) instead of later in the summer and earlier in the winter seasons

The results obtained with CROPWAT 7.0 were verified with the irrigation model developed. Although the model was developed with the aim of providing accurate irrigation requirements, the CROPWAT model was discovered. It was then decided to use the developed model to create input data for CROPWAT 7.0.

As was shown in this study, there are various options to reduce water use in existing vegetable gardens on the Cape Flats or to teach new gardeners how to prevent the unnecessary wasting of water. Planting at the right time of the year is the easiest method of saving large amounts of water (30-40%) and can be practiced by any gardener. However, there is no option for continuous (cash) cropping systems. Installing a low-tech drip irrigation system with commercial drip lines in conjunction with an irrigation schedules could be successful in optimising water usage in any type of garden. It will not only save water but also prevent the leaching of important plant nutrients. Planting windbreaks was shown to be the least effective in reducing water use in gardening (7-13%). It should however, not be forgotten that windbreaks have other beneficial effects such as preventing sandblasting.

If SCAGA garden would incorporate all the above-mentioned options, an overall 70 % water saving could be made. It is obvious that the options presented in this study can make a huge contribution to increasing both the economic as well as the ecological sustainability of vegetable gardening on the Cape Flats. NGO's and other agricultural extension agencies are therefore advised to use this information.

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# APPENDIX 1

**EQUATON 1: VAPOUR PRESSURE DEFICIT (VPD)**

Determined according to the following relationship:

$$VPD = e_s - e_a$$

$$e_s = \frac{e^o(T_{max}) + e^o(T_{min})}{2}$$

$$e_a = \frac{e^o(T_{min})\dfrac{RH_{max}}{100} + e^o(T_{max})\dfrac{RH_{min}}{100}}{2}$$

Where:

- $e_s - e_a$ : vapour pressure deficit
- $e_s$ : saturation vapour pressure [kPa]:
- $e_a$ : actual vapour pressure [kPa]
- $e^o(T_{min})$: saturation vapour pressure at daily minimum temperature [kPa]
- $e^o(T_{max})$: saturation vapour pressure at daily maximum temperature [kPa]
- $RH_{min}$ : minimum relative humidity [%]
- $RH_{max}$ : maximum relative humidity [%]

Reference: Allen *et al* (1998)



**EQUATION 2: SLOPE VAPOUR PRESSURE CURVE (Δ)**

$$\Delta = \frac{4098\, e_a}{(T + 237.3)^2}$$

Where:

- $\Delta$ : slope vapour pressure curve
- $T$ : air temperature [°C]
- $e_a$ : saturation vapour pressure at temperature

Reference: Tetens (1930), Murray (1967).

# APPENDIX 2

**CROP INFORMATION**

*(Obtained from the FAO CROPWAT 7.0 model)*

*Crop Name*: **Green Beans**

| *Growth Stage* | | *Ini* | *Devel* | *Mid* | *Late* | *Total* |
|---|---|---|---|---|---|---|
| *Length* | [days] | 20 | 30 | 30 | 10 | 90 |
| *Crop Coefficient* | [coeff] | 0.4 | → | 1 | 0.9 | |
| *Rooting Depth* | [meter] | 0.3 | → | 1 | 1 | |
| *Depletion level* | [fract] | 0.45 | → | 0.45 | 0.6 | |

*Crop Name*: **Cabbage**

| *Growth Stage* | | *Ini* | *Devel* | *Mid* | *Late* | *Total* |
|---|---|---|---|---|---|---|
| *Length* | [days] | 25 | 40 | 45 | 15 | 125 |
| *Crop Coefficient* | [coeff] | 0.7 | → | 1.05 | 0.9 | |
| *Rooting Depth* | [meter] | 0.25 | → | 0.5 | 0.5 | |
| *Depletion level* | [fract] | 0.4 | → | 0.4 | 0.4 | |

*Crop Name*: **Maize**

| *Growth Stage* | | *Ini* | *Devel* | *Mid* | *Late* | *Total* |
|---|---|---|---|---|---|---|
| *Length* | [days] | 25 | 40 | 40 | 30 | 135 |
| *Crop Coefficient* | [coeff] | 0.3 | → | 1.15 | 0.6 | |
| *Rooting Depth* | [meter] | 0.3 | → | 1.3 | 1.3 | |
| *Depletion level* | [fract] | 0.5 | → | 0.5 | 0.8 | |

*Crop Name*: **Potatoes**

| *Growth Stage* | | *Ini* | *Devel* | *Mid* | *Late* | *Total* |
|---|---|---|---|---|---|---|
| *Length* | [days] | 25 | 30 | 45 | 30 | 130 |
| Crop Coefficient | [coeff] | 0.4 | → | 1.15 | 0.9 | |
| *Rooting Depth* | [meter] | 0.3 | → | 0.6 | 0.6 | |
| *Depletion level* | [fract] | 0.25 | → | 0.3 | 0.5 | |

*Crop Name*: **Pulses**

| *Growth Stage* | | *Ini* | *Devel* | *Mid* | *Late* | *Total* |
|---|---|---|---|---|---|---|
| *Length* | [days] | 20 | 25 | 35 | 20 | 100 |
| *Crop Coefficient* | [coeff] | 0.4 | → | 1.15 | 0.35 | |
| *Rooting Depth* | [meter] | 0.3 | → | 1 | 1 | |
| *Depletion level* | [fract] | 0.6 | → | 0.6 | 0.6 | |

*Crop Name:* **Small Vegetables**

| *Growth Stage* | | *Ini* | *Devel* | *Mid* | *Late* | *Total* |
|---|---|---|---|---|---|---|
| *Length* | [days] | 20 | 30 | 30 | 15 | 95 |
| *Crop Coefficient* | [coeff] | 0.75 | → | 1.05 | 0.95 | |
| *Rooting Depth* | [meter] | 0.25 | → | 0.6 | 0.6 | |
| *Depletion level* | [fract] | 0.3 | → | 0.45 | 0.5 | |

*Crop Name*: **Sweet Peppers**

| *Growth Stage* | | *Ini* | *Devel* | *Mid* | *Late* | *Total* |
|---|---|---|---|---|---|---|
| *Length* | [days] | 30 | 40 | 40 | 20 | 130 |
| *Crop Coefficient* | [coeff] | 0.7 | → | 1.05 | 0.9 | |
| *Rooting Depth* | [meter] | 0.25 | → | 0.8 | 0.8 | |
| *Depletion level* | [fract] | 0.2 | → | 0.30 | 0.50 | |

*Crop Name*: **Tomato**

| *Growth Stage* | | *Ini* | *Devel* | *Mid* | *Late* | *Total* |
|---|---|---|---|---|---|---|
| *Length* | [days] | 30 | 40 | 45 | 30 | 145 |
| *Crop Coefficient* | [coeff] | 0.5 | → | 1.2 | 0.65 | |
| *Rooting Depth* | [meter] | 0.25 | → | 1 | 1 | |
| *Depletion level* | [fract] | 0.30 | → | 0.40 | 0.50 | |

# APPENDIX 3

## Daily $ET_o$ values

| Month/year | day 1 | day 2 | day 3 | day 4 | day 5 | day 6 | day 7 | day 8 | day 9 | day 10 | day 11 | day 12 | day 13 | day 14 | day 15 | day 16 | day 17 | day 18 | day 19 | day 20 | day 21 | day 22 | day 23 | day 24 | day 25 | day 26 | day 27 | day 28 | day 29 | day 30 | day 31 | Average daily $ET_o$ | Monthly $ET_o$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1985/01** | 8.2 | 8.3 | 6.4 | 7.2 | 7.7 | 4.1 | 6.6 | 7.6 | 7.5 | 10.0 | 8.3 | 6.9 | 2.9 | 4.1 | 7.5 | 7.5 | 6.2 | 5.9 | 8.9 | 8.7 | 6.4 | 7.3 | 6.8 | 8.2 | 8.1 | 8.4 | 8.4 | 8.3 | 5.0 | 8.0 | 5.4 | 7.1 | 220.8 |
| **1985/02** | 4.4 | 7.1 | 7.0 | 5.6 | 7.4 | 6.1 | 5.3 | 10.7 | 10.4 | 6.3 | 6.7 | 7.8 | 7.5 | 7.5 | 6.8 | 7.0 | 6.1 | 8.1 | 10.2 | 7.5 | 8.1 | 9.6 | 6.9 | 7.4 | 7.6 | 6.3 | 6.9 | 6.3 | 2.0 | 2.0 | 2.0 | 6.8 | 210.4 |
| **1985/03** | 6.0 | 3.5 | 4.3 | 4.7 | 6.5 | 3.5 | 6.6 | 4.1 | 5.9 | 5.5 | 5.4 | 3.7 | 4.6 | 2.9 | 5.3 | 5.2 | 2.8 | 2.3 | 4.4 | 3.7 | 2.1 | 3.3 | 4.1 | 6.9 | 4.6 | 6.1 | 4.6 | 5.1 | 3.8 | 2.8 | 2.5 | 4.4 | 136.6 |
| **1985/04** | 3.6 | 2.8 | 3.9 | 3.3 | 3.4 | 3.1 | 2.9 | 3.1 | 3.4 | 3.2 | 4.4 | 4.1 | 3.3 | 2.9 | 3.1 | 2.8 | 3.8 | 2.6 | 3.3 | 3.0 | 2.2 | 2.2 | 2.3 | 3.4 | 2.9 | 3.0 | 1.7 | 3.1 | 2.7 | 2.4 | | 3.0 | 91.8 |
| **1985/05** | 2.3 | 2.2 | 2.3 | 2.2 | 1.9 | 2.1 | 1.7 | 2.8 | 3.4 | 3.7 | 2.8 | 2.3 | 2.2 | 2.2 | 2.2 | 1.8 | 2.1 | 2.6 | 2.8 | 3.7 | 1.9 | 1.6 | 1.7 | 2.7 | 1.8 | 2.7 | 1.1 | 1.5 | 1.8 | 1.9 | 2.8 | 2.3 | 71.0 |
| **1985/06** | 1.7 | 3.5 | 1.6 | 1.7 | 1.9 | 2.0 | 1.6 | 1.2 | 1.7 | 2.2 | 0.8 | 0.9 | 1.4 | 1.3 | 0.9 | 1.0 | 1.7 | 1.6 | 1.4 | 1.9 | 1.9 | 1.6 | 2.2 | 2.2 | 1.5 | 1.5 | 1.9 | 1.4 | 0.0 | 1.4 | | 1.6 | 47.7 |
| **1985/07** | 3.1 | 4.1 | 1.6 | 1.7 | 0.9 | 1.5 | 2.0 | 1.6 | 1.9 | 1.7 | 1.5 | 0.9 | 1.2 | 1.2 | 2.8 | 1.6 | 1.3 | 1.7 | 1.3 | 1.2 | 1.2 | 1.5 | 2.3 | 1.9 | 1.5 | 2.3 | 1.5 | 1.5 | 1.9 | 1.5 | 1.3 | 1.7 | 52.8 |
| **1985/08** | 2.0 | 1.9 | 2.0 | 2.5 | 2.0 | 3.1 | 1.6 | 2.1 | 2.1 | 2.4 | 2.0 | 3.2 | 2.2 | 2.5 | 2.2 | 3.4 | 4.9 | 1.8 | 2.2 | 2.4 | 2.8 | 1.8 | 2.3 | 2.6 | 3.1 | 2.4 | 2.0 | 2.9 | 3.0 | 3.1 | 2.6 | 2.5 | 77.1 |
| **1985/09** | 1.5 | 2.3 | 3.2 | 3.6 | 3.0 | 5.0 | 3.8 | 3.4 | 1.7 | 2.3 | 3.0 | 1.9 | 4.1 | 3.8 | 5.1 | 4.2 | 5.3 | 4.1 | 3.8 | 5.6 | 4.1 | 2.8 | 2.1 | 2.8 | 3.2 | 3.7 | 4.1 | 3.4 | 2.9 | 3.4 | | 3.4 | 103.1 |
| **1985/10** | 2.9 | 3.2 | 2.2 | 2.9 | 5.2 | 4.5 | 6.0 | 7.1 | 5.3 | 7.4 | 5.7 | 3.8 | 6.4 | 6.0 | 6.6 | 5.6 | 5.7 | 5.9 | 9.8 | 6.2 | 4.9 | 4.7 | 5.7 | 6.1 | 0.0 | 8.2 | 4.9 | 3.4 | 4.9 | 10.8 | 10.8 | 5.6 | 172.8 |
| **1985/11** | 4.4 | 6.1 | 6.8 | 3.7 | 4.4 | 4.2 | 7.6 | 8.3 | 8.7 | 6.9 | 7.6 | 7.3 | 6.9 | 6.4 | 6.9 | 7.1 | 5.8 | 11.0 | 8.4 | 7.4 | 6.2 | 8.7 | 7.2 | 8.3 | 9.9 | 9.7 | 6.0 | 7.0 | 9.9 | 7.4 | | 7.0 | 216.1 |
| **1985/12** | 4.4 | 5.0 | 8.6 | 8.7 | 7.7 | 7.4 | 8.0 | 7.1 | 7.3 | 7.7 | 8.8 | 7.8 | 6.1 | 10.6 | 7.9 | 9.9 | 9.4 | 8.5 | 7.5 | 5.5 | 9.8 | 9.2 | 9.6 | 7.4 | 7.4 | 8.1 | 6.9 | 7.3 | 6.8 | 5.3 | 6.5 | 7.7 | 238.0 |

## APPENDIX 4

PAMPHLET

"Growing vegetables and grapes with the waggon wheel"

By

Gerrie Albertse

## MATERIAL LIST

- 6 x 7 m x 15 mm Polyethylene class 3 pipes
- 7 x 15 mm Nylon T-pieces
- 1 x 100 mm x 15 mm Nylon running nipple with 2 backnuts
- 1 x 15 mm Ballvalve (tap)
- 5 x 15 mm x 30 cm Polyethylene class 3 pipes (Manifold)
- 1 x 210 litre oil drum - cut open at one end
- 15 mm Nylon braided string

## RUNNING THE SYSTEM

- A well planned wheel system has the potential to produce 500 kg of vegetables and 60 kg of grapes per year in the Western Cape.
- Irrigation: 200 litre water - three times per week.
- Plant vegetables next to the wetting area.
- Plant vegetables according to their growth habits e.a. mealies close to the drum, followed by tomatoes, cabbage, sweet potatoes, pumpkins and other crops which need space for their vines.
- Clean the clogged dripper by pulling the dripper string from side to side.
- Rotate the crops every season - do not plant the same crop on the same plot year after year.
- Plant grapevines or other fruit trees at the end of the dripperline.

## MAKING THE DRIPPERLINE

- Cut 6 x 7 metre lengths of 15 mm class 3 Polyethylene pipes, mark the position of the holes on the pipe - 30 cm apart, heat a 1,5 mm diameter nail (50 mm nail) and burn a hole through the pipe.
- Cut 10 cm pieces of string and thread the rope through the two holes. Tie a knot on each side. Close the dripperline at the end by bending the pipe and tie it with a piece of wire.

*Artwork: Anneleen Verster & Eugene de Villiers* *Layout & Design: Corliët Conradie*

NIETVOORBIJ
institute for viticulture and oenology

# GROWING VEGETABLES & GRAPES

## with the

# WAGGON WHEEL SYSTEM

by Gerrie Albertse

ARC • LNR

p/bag X5026 stellenbosch 7599

# APPENDIX 5

## QUOTATION FOR WAGON WHEEL SYSTEM

(A) Commercial dripper lines ( 4 l/h, 30 cm spacing)

| MATERIALS | COST (R) | COST (R) | COST (R) | COST (R) | COST (R) |
|---|---|---|---|---|---|
| 1. drum | 60.00 | 60.00 | 60.00 | 60.00 | 60.00 |
| 2. dripper lines | 45.73/100meters (10X 10 M dripper lines) | 36.58/80meters (8 X 10 M dripper lines) | 27.44/60meters (6 X 10 M dripper lines) | 18.29/40meters (4 X 10 M dripper lines) | 9.14/20meters (2 X 10 M dripper lines) |
| 3. seedlings | 27.00/ tray | 27.00/ tray | 27.00/ tray | 27.00/ tray | 27.00/ tray |
| 4. elbow joints x 2 | 1.44 | 1.44 | 1.44 | 1.44 | 1.44 |
| 5. T pieces x 5 | 7.10 | 7.10 | 7.10 | 7.10 | 7.10 |
| 6. 0.5 inch tap | 14.68 | 14.68 | 14.68 | 14.68 | 14.68 |
| 7. rubbers | 2.18 | 2.18 | 2.18 | 2.18 | 2.18 |
| 8. running nipple | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 |
| 9. reducing piece | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 |
| 10 backnut | 4.98 | 4.98 | 4.98 | 4.98 | 4.98 |
| **TOTAL** | **164.65** | **155.50** | **146.36** | **137.21** | **128.06** |

These materials can be purchased at Loxton : Irrigation equipment suppliers

# APPENDIX 6

## ILLUSTRATED SCHEDULE

## BEANS

**LEGEND**

overcast

half overcast

sunny

rain

half drum (100liters)

full drum (200liters)

**1 /3 - 30/5 (winter growing period)**

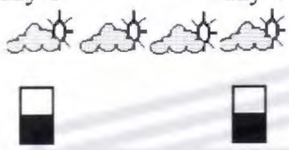
*A. Small and developing crop (kc = 0.4)*

*No irrigation required
*Crop water requirement minimal
*Soil water reservoir almost permanently saturated resulting from a change from summer to autumn
*Slightly wet weather

*B. Mid season ((kc = 1)*

Slightly overcast wet weather

day 1 day 4



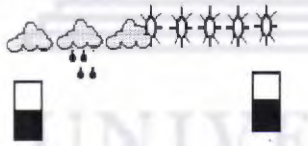
*C. Mature crop (kc = 0.9)*

* No irrigation required
* Winter season - ample rain water
* Soil water reservoir saturated

**1/9 -30/11 (summer growing period)**

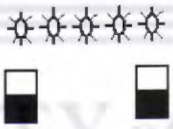
*A. Small and developing crop (kc = 0.4)*

day 1 day 7



or

day 1 day 5



*B. Mid season crop (kc = 1)*

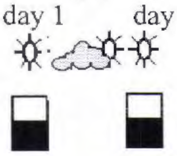
day 1 day 4

or

day 1 day 3

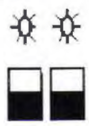
*C. Mature crop (kc = 0.9)*

day 1 day 3



or

day1 day 2



## POTATO

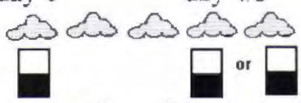
**1/3 - 9/7 (winter growing period)**

*A. Small and developing crop (kc = 0.4)*

*No irrigation required
*Crop water requirement minimal
*Soil water reservoir almost permanently saturated resulting from a change from summer to autumn
*slightly wet weather

*B. Mid season (kc =1.15)*

day 1 day 4/5



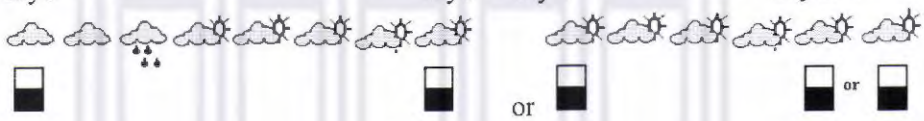

*C. Mature crop (kc = 0.9)*

* no Irrigation required
* winter season ample rain
* soil water reservoir saturated

**1/9 - 10/1 (summer growing season)**

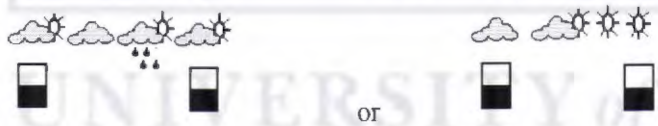
*A. Small and developing crop (kc = 0.4)*

day1 day8 day 1 day 5/6

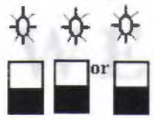



*B. Mid season (kc = 1.15)*

day 1 day 4 day 1 day 4

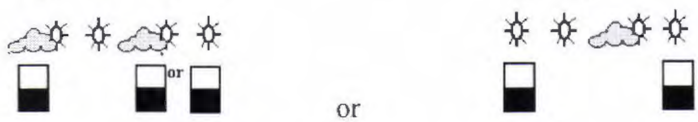



day1 day 3/4

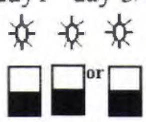



*C. Mature crop (kc = 0.9)*

day 1 day 3 /4 day1 day 4




day1 day 3/4



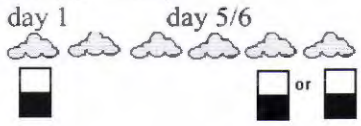
## PULSES

**1/3 - 6/6 (winter growing period)**

*A. Small and developing crop (kc = 0.4)*

*no irrigation required
*crop water requirement minimal
*soil water reservoir almost permanently saturated resulting from a change from summer to autumn
*slightly wet weather

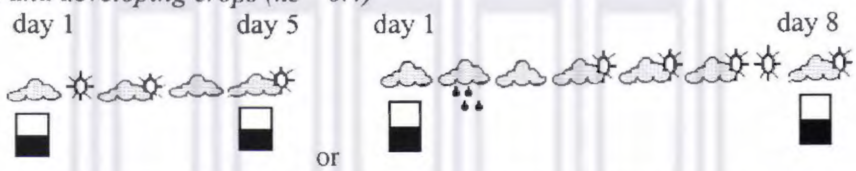
*B. Mid season (kc =1.15)*



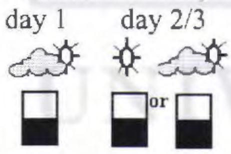

B. *Mature crop (kc = 0.35)** No Irrigation required
* Winter season - ample rain water
* Soil water reservoir saturated

**1/9- 7/12 (summer growing period)**

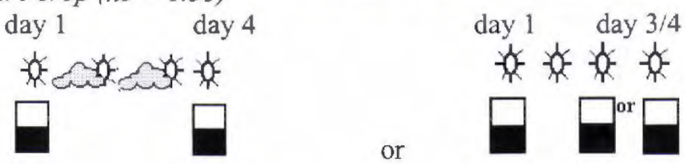
*A. Small and developing crops (kc =0.4)*




*B. Mid season (kc = 1.15)*




*C. Mature crop (kc = 0.35)*

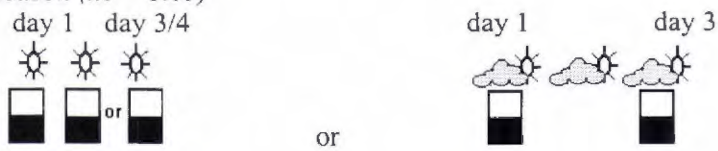


## PEPPER

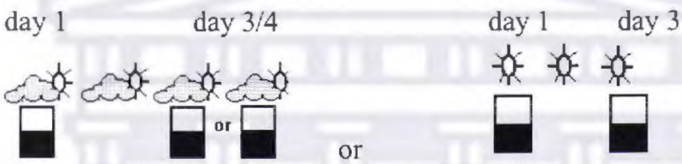
**1/9 - 8/1 (summer growing period)**

*A. Small and developing crop (kc = 0.7)*


*B. Mid Season (kc = 1.05)*



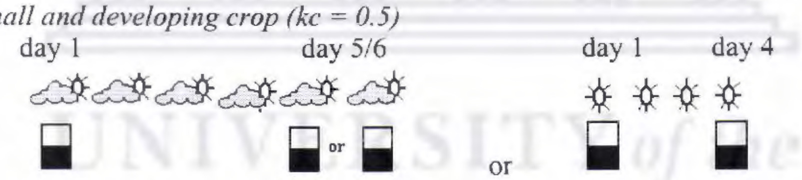

*C. Mature crop (kc = 0.9)*



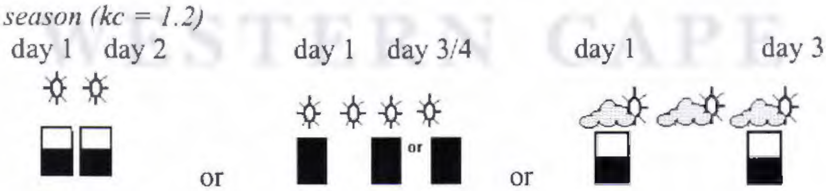

## TOMATO

**1/9 - 23/01 (summer growing period)**

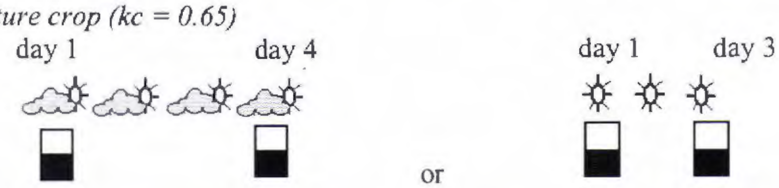
A. *Small and developing crop (kc = 0.5)*




*B. Mid season (kc = 1.2)*




*C. Mature crop (kc = 0.65)*



## VEGETABLES

**1/3 – 3/6 (winter growing period)**

*A. Small and developing crop (kc = 0.75)*

day1 day 3/4

*B. Mid season (kc = 1.05)*

day 1 day 3/4

C. *Mature crop (kc = 0.95)*

* No Irrigation required
* Winter season - ample rain water
* Soil water reservoir saturated

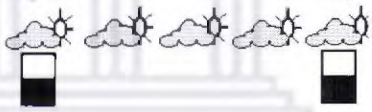
**1/9 -3/12 (summer growing period)**

*A. Small and development crop (kc = 0.75)*

day 1 day 6

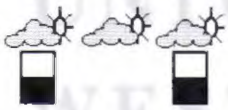
or

day 1 day 5



*B. Mid Season (kc = 1.5)*

day 1 day3

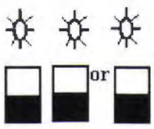


or

day1 day 2

*C. Mature crop (kc = 0.95)*

day 1 day 2/3



or

day 1 day 3

# APPENDIX 7

**PROCEDURE:** DERMINATION OF IRRIGATION WATER REQUIREMENTS

**Materials needed:** Rainfall data
Radiation data
$K_c$ values for specific crops

**Computer package:** Any spreadsheet (Such as Excel)

1. Set up a spreadsheet as was done in the example for spinach and cabbage.
2. All data is converted to the same units (rainfall, evapotranspiration irrigation, and available soil water).
3. Using the radiation data develop a key for the weather data e.g. if the radiation data ranges between 0-4 (MJ $m^{-2}$ $day^{-1}$) it is classified as overcast, 4.1-6.9 (MJ $m^{-2}$ $day^{-1}$) is classified as half overcast and 7+ (MJ $m^{-2}$ $day^{-1}$) is classified as sunny.
4. The $k_c$ values are then included into the spreadsheet according to the length of each growing phase.
5. $ET_0$ values are entered into the spreadsheet.
6. The rainfall and the evapotranspiration is then multiplied by the size of the area to be irrigated
7. $ET_c$ is then calculated by multiplying the $ET_0$ with the $k_c$ values.
8. In order to determine the available soil water after depletion (ASMAD) the first cell has to be 0 i.e. the day before the growing season starts.
9. ASMAD is calculated as follows, a formula is developed whereby the parameters irrigation requirements, ASMAD and rainfall are added, and from which crop evapotranspiration is subtracted. This is done for each day of the growing season.
10. A column for irrigation requirements will be applications will be inserted next to ASMAD, after ASMAD has been calculated, negative values will be obtained indicating that irrigation water is required. Where a negative value is obtained an application of 100/200liters (as in this study) will be added in the irrigation column to compensate for the deficit.

# APPENDIX 8

## IRRIGATION SCHEDULE FOR CABBAGE

### (WINTER AND SUMMER)

***CABBAGE***

**WINTER GROWING SEASON**

MARCH

| **KEY** | **overcast = 0-4** | **ASMAD = available soil moisture after depletion** |
|---|---|---|
| | **partly cloudy = 4.1-6.9** | **l = liter** |
| | **sunny = 7 -10** | |

| day | rainfall (l) | radiation (MJ $m^{-2}$ $day^{-1}$) | weather | $k_c$ | $ET_o$ (l) | $ET_o$ (l) per10$m^2$ | $ET_c$ (l) per10$m^2$ | Rain (l) | ASMAD | Irrigation (l) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 0 | |
| day1 | 13.6 | 4.92 | sunny | 0.7 | 5.96 | 59.58 | 41.71 | 136 | 94.29 | |
| day2 | 5.3 | 3.25 | half-overcast | 0.7 | 3.55 | 35.50 | 24.85 | 53 | 122.44 | |
| day3 | 0.6 | 4.84 | sunny | 0.7 | 4.31 | 43.15 | 30.20 | 6 | 98.24 | |
| day4 | 0 | 4.68 | sunny | 0.7 | 4.65 | 46.52 | 32.56 | 0 | 65.68 | |
| day5 | 0 | 4.00 | half-overcast | 0.7 | 6.48 | 64.76 | 45.33 | 0 | 20.35 | |
| day6 | 0 | 2.79 | half-overcast | 0.7 | 3.53 | 35.26 | 24.68 | 0 | 95.67 | 100 |
| day7 | 0 | 4.40 | half-overcast | 0.7 | 6.56 | 65.61 | 45.93 | 0 | 49.74 | |
| day8 | 0 | 3.74 | half-overcast | 0.7 | 4.09 | 40.95 | 28.66 | 0 | 21.08 | |
| day9 | 0 | 4.98 | sunny | 0.7 | 5.90 | 59.02 | 41.32 | 0 | 79.76 | 100 |
| day10 | 0 | 4.95 | sunny | 0.7 | 5.45 | 54.54 | 38.18 | 0 | 41.58 | |
| day11 | 0 | 4.78 | sunny | 0.7 | 5.38 | 53.77 | 37.64 | 0 | 3.94 | |
| day12 | 0 | 3.63 | half-overcast | 0.7 | 3.68 | 36.84 | 25.79 | 0 | 78.16 | 100 |
| day13 | 0 | 4.84 | sunny | 0.7 | 4.57 | 45.74 | 32.02 | 0 | 46.14 | |
| day14 | 41.6 | 2.98 | half-overcast | 0.7 | 2.93 | 29.29 | 20.50 | 416 | 441.64 | |
| day15 | 9.5 | 4.54 | sunny | 0.7 | 5.31 | 53.09 | 37.17 | 95 | 499.47 | |
| day16 | 0 | 4.50 | sunny | 0.7 | 5.16 | 51.61 | 36.12 | 0 | 463.35 | |
| day17 | 1.3 | 3.06 | half-overcast | 0.7 | 2.79 | 27.90 | 19.53 | 13 | 456.82 | |
| day18 | 0.6 | 2.33 | half-overcast | 0.7 | 2.33 | 23.28 | 16.30 | 6 | 446.52 | |
| day19 | 0 | 4.55 | sunny | 0.7 | 4.39 | 43.93 | 30.75 | 0 | 415.77 | |
| day20 | 0 | 3.81 | half-overcast | 0.7 | 3.73 | 37.31 | 26.12 | 0 | 389.65 | |
| day21 | 0 | 2.59 | half-overcast | 0.7 | 2.07 | 20.70 | 14.49 | 0 | 375.17 | |
| day22 | 0 | 3.64 | half-overcast | 0.7 | 3.27 | 32.65 | 22.86 | 0 | 352.31 | |
| day23 | 0 | 3.89 | half-overcast | 0.7 | 4.11 | 41.12 | 28.78 | 0 | 323.53 | |
| day24 | 0 | 4.58 | sunny | 0.7 | 6.93 | 69.29 | 48.50 | 0 | 275.02 | |
| day25 | 0 | 4.35 | sunny | 0.7 | 4.61 | 46.13 | 32.29 | 0 | 242.73 | |
| day26 | 0 | 4.79 | sunny | 0.7 | 6.06 | 60.57 | 42.40 | 0 | 200.34 | |
| day27 | 0 | 4.17 | sunny | 0.7 | 4.59 | 45.87 | 32.11 | 0 | 168.23 | |
| day28 | 0 | 4.45 | sunny | 0.7 | 5.07 | 50.69 | 35.48 | 0 | 132.75 | |
| day29 | 0 | 2.94 | half-overcast | 0.7 | 3.78 | 37.77 | 26.44 | 0 | 106.31 | |
| day30 | 0 | 2.82 | half-overcast | 0.7 | 2.82 | 28.15 | 19.71 | 0 | 86.60 | |
| day 31 | 0 | 2.34 | overcast | 0.4 | 3.41 | 34.1 | 13.64 | 0 | 72.96 | |

APRIL

| day | rainfall (l) | radiation (MJ $m^{-2}$ $day^{-1}$) | weather | kc | ETo (l) | ETo (l)x10$m^2$ | ETc (l)x10$m^2$ | Rain (l) | ASMAD | Irrigation (l) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 0 | 0 | 72.96 | |
| day1 | 0 | 3.60 | half-overcast | 0.7 | 3.56 | 35.55 | 24.89 | 0 | 48.08 | |
| day2 | 0 | 3.61 | half-overcast | 0.7 | 2.85 | 28.49 | 19.95 | 0 | 28.13 | |
| day3 | 0 | 3.44 | half-overcast | 0.7 | 3.89 | 38.90 | 27.23 | 0 | 0.90 | |
| day4 | 0 | 3.57 | half-overcast | 0.7 | 3.30 | 33.04 | 23.13 | 0 | 77.77 | 100 |
| day5 | 10.7 | 3.00 | half-overcast | 0.7 | 3.39 | 33.90 | 23.73 | 107 | 161.04 | |
| day6 | 12.1 | 3.09 | half-overcast | 0.7 | 3.10 | 31.05 | 21.73 | 121 | 260.31 | |
| day7 | 1.3 | 2.62 | half-overcast | 0.7 | 2.91 | 29.11 | 20.38 | 13 | 252.93 | |
| day8 | 0 | 3.22 | half-overcast | 0.7 | 3.10 | 31.01 | 21.71 | 0 | 231.22 | |
| day9 | 0 | 3.18 | half-overcast | 0.7 | 3.40 | 34.02 | 23.81 | 0 | 207.41 | |
| day10 | 0 | 3.21 | half-overcast | 0.7 | 3.17 | 31.69 | 22.19 | 0 | 185.23 | |
| day11 | 0 | 3.12 | half-overcast | 0.7 | 4.40 | 43.95 | 30.77 | 0 | 154.46 | |
| day12 | 0 | 3.23 | half-overcast | 0.7 | 4.14 | 41.37 | 28.96 | 0 | 125.50 | |
| day13 | 0 | 3.38 | half-overcast | 0.7 | 3.28 | 32.80 | 22.96 | 0 | 102.54 | |
| day14 | 0 | 3.41 | half-overcast | 0.7 | 2.88 | 28.79 | 20.15 | 0 | 82.39 | |
| day15 | 0 | 3.47 | half-overcast | 0.7 | 3.06 | 30.63 | 21.44 | 0 | 60.95 | |
| day16 | 0 | 3.06 | half-overcast | 0.7 | 2.81 | 28.14 | 19.70 | 0 | 41.25 | |
| day17 | 3.4 | 3.15 | rain | 0.7 | 3.79 | 37.92 | 26.55 | 34 | 48.71 | |
| day18 | 0.1 | 3.22 | half-overcast | 0.7 | 2.58 | 25.82 | 18.08 | 1 | 31.63 | |
| day19 | 0 | 2.94 | half-overcast | 0.7 | 3.30 | 33.02 | 23.11 | 0 | 8.52 | |
| day20 | 0 | 2.90 | half-overcast | 0.7 | 2.99 | 29.93 | 20.95 | 0 | 87.56 | 100 |
| day21 | 2.3 | 1.78 | rain | 0.7 | 2.20 | 21.95 | 15.37 | 23 | 95.20 | |
| day22 | 10.6 | 2.26 | half-overcast | 0.7 | 2.20 | 22.02 | 15.41 | 106 | 185.79 | |
| day23 | 1 | 2.56 | rain | 0.7 | 2.32 | 23.18 | 16.23 | 10 | 179.56 | |
| day24 | 0 | 2.89 | half-overcast | 0.7 | 3.39 | 33.94 | 23.76 | 0 | 155.80 | |
| day25 | 0 | 3.20 | overcast | 0.7 | 2.90 | 29.03 | 20.32 | 0 | 135.48 | |
| day26 | 0 | 3.16 | overcast | 0.7 | 2.99 | 29.88 | 20.92 | 0 | 114.56 | |
| day27 | 7 | 1.74 | rain | 0.7 | 1.69 | 16.88 | 11.82 | 70 | 172.75 | |
| day28 | 0 | 2.54 | half-overcast | 0.7 | 3.05 | 30.51 | 21.35 | 0 | 151.39 | |
| day29 | 0 | 3.18 | half-overcast | 0.7 | 2.73 | 27.33 | 19.13 | 0 | 132.26 | |
| day30 | 1.1 | 2.82 | rain | 0.7 | 2.44 | 24.41 | 17.09 | 11 | 126.17 | |

MAY

| day | rainfall (l) | radiation (MJ $m^{-2}$ $day^{-1}$) | weather | kc | ETo (l) | ETo (l)x10$m^2$ | ETc (l)x10$m^2$ | Rain (l) | ASMAD | Irrigation (l) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 126.17 | |
| day1 | 0 | 2.04 | overcast | 0.7 | 2.31 | 23.13 | 16.19 | 0 | 109.98 | |
| day2 | 0 | 2.18 | overcast | 0.7 | 2.25 | 22.47 | 15.73 | 0 | 94.25 | |
| day3 | 0 | 2.08 | overcast | 0.7 | 2.27 | 22.69 | 15.88 | 0 | 78.37 | |
| day4 | 0 | 2.18 | overcast | 0.7 | 2.20 | 22.00 | 15.40 | 0 | 62.97 | |
| day5 | 0 | 1.95 | overcast | 0.7 | 1.85 | 18.51 | 12.96 | 0 | 50.01 | |
| day6 | 0 | 2.06 | overcast | 1.05 | 2.13 | 21.30 | 22.36 | 0 | 27.64 | |
| day7 | 0 | 1.83 | overcast | 1.05 | 1.65 | 16.54 | 17.37 | 0 | 10.27 | |
| day8 | 0 | 2.03 | overcast | 1.05 | 2.76 | 27.64 | 29.02 | 0 | 81.26 | 100 |
| day9 | 0 | 1.97 | overcast | 1.05 | 3.43 | 34.29 | 36.01 | 0 | 45.25 | |
| day10 | 0 | 1.94 | overcast | 1.05 | 3.68 | 36.84 | 38.68 | 0 | 6.56 | |
| day11 | 0 | 1.80 | overcast | 1.05 | 2.85 | 28.49 | 29.91 | 0 | 76.65 | 100 |
| day12 | 0 | 1.87 | overcast | 1.05 | 2.33 | 23.30 | 24.47 | 0 | 52.18 | |
| day13 | 0 | 2.00 | overcast | 1.05 | 2.22 | 22.16 | 23.27 | 0 | 28.92 | |
| day14 | 0 | 1.92 | overcast | 1.05 | 2.17 | 21.65 | 22.74 | 0 | 6.18 | |
| day15 | 0 | 1.94 | overcast | 1.05 | 2.25 | 22.48 | 23.61 | 0 | 82.57 | 100 |
| day16 | 0 | 1.93 | overcast | 1.05 | 1.77 | 17.74 | 18.63 | 0 | 63.94 | |
| day17 | 0 | 1.97 | overcast | 1.05 | 2.11 | 21.09 | 22.15 | 0 | 41.80 | |
| day18 | 0 | 1.85 | overcast | 1.05 | 2.63 | 26.27 | 27.59 | 0 | 14.21 | |
| day19 | 0 | 1.90 | overcast | 1.05 | 2.78 | 27.75 | 29.14 | 0 | 85.07 | 100 |
| day20 | 3.8 | 1.69 | rain | 1.05 | 3.74 | 37.36 | 39.23 | 38 | 83.84 | |
| day21 | 26.6 | 1.30 | rain | 1.05 | 1.88 | 18.77 | 19.71 | 266 | 330.13 | |
| day22 | 7.3 | 1.59 | rain | 1.05 | 1.63 | 16.33 | 17.14 | 73 | 385.98 | |
| day23 | 0 | 1.65 | overcast | 1.05 | 1.70 | 16.97 | 17.82 | 0 | 368.17 | |
| day24 | 0 | 1.84 | overcast | 1.05 | 2.72 | 27.16 | 28.52 | 0 | 339.65 | |
| day25 | 0 | 1.88 | overcast | 1.05 | 1.84 | 18.40 | 19.32 | 0 | 320.32 | |
| day26 | 0.4 | 1.82 | rain | 1.05 | 2.69 | 26.95 | 28.29 | 4 | 296.03 | |
| day27 | 6.5 | 1.28 | rain | 1.05 | 1.14 | 11.35 | 11.92 | 65 | 349.11 | |
| day28 | 0 | 1.67 | overcast | 1.05 | 1.50 | 15.04 | 15.79 | 0 | 333.32 | |
| day29 | 0 | 2.04 | overcast | 1.05 | 1.79 | 17.85 | 18.74 | 0 | 314.58 | |
| day30 | 0 | 1.78 | overcast | 1.05 | 1.90 | 19.04 | 19.99 | 0 | 294.58 | |
| day31 | 0 | 2.00 | overcast | 1.05 | 2.85 | 28.46 | 29.88 | 0 | 264.70 | |

JUNE

| day | rainfall (l) | radiation (MJ $m^{-2}$ $day^{-1}$) | weather | kc | ETo (l) | ETo (l)x10$m^2$ | ETc (l)x10$m^2$ | Rain (l) | ASMAD | Irrigation (l) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 0.00 | | 264.70 | |
| day1 | 0 | 1.27 | overcast | 1.05 | 1.69 | 16.91 | 17.76 | 0 | 246.94 | |
| day2 | 0 | 1.02 | overcast | 1.05 | 3.55 | 35.48 | 37.25 | 0 | 209.69 | |
| day3 | 0 | 1.34 | overcast | 1.05 | 1.61 | 16.12 | 16.93 | 0 | 192.77 | |
| day4 | 0 | 1.34 | overcast | 1.05 | 1.68 | 16.76 | 17.59 | 0 | 175.17 | |
| day5 | 0 | 1.47 | overcast | 1.05 | 1.94 | 19.37 | 20.34 | 0 | 154.83 | |
| day6 | 0 | 1.35 | overcast | 1.05 | 2.04 | 20.43 | 21.46 | 0 | 133.37 | |
| day7 | 0 | 1.30 | overcast | 1.05 | 1.60 | 16.02 | 16.82 | 0 | 116.55 | |
| day8 | 0 | 1.31 | overcast | 1.05 | 1.19 | 11.90 | 12.49 | 0 | 104.06 | |
| day9 | 0.1 | 1.06 | rain | 1.05 | 1.69 | 16.93 | 17.78 | 1 | 87.29 | |
| day10 | 2.7 | 1.08 | rain | 1.05 | 2.25 | 22.50 | 23.62 | 27 | 90.66 | |
| day11 | 35.8 | 1.05 | rain | 1.05 | 0.84 | 8.42 | 8.84 | 358 | 439.82 | |
| day12 | 27.6 | 1.06 | rain | 1.05 | 0.94 | 9.42 | 9.89 | 276 | 705.93 | |
| day13 | 2.1 | 1.29 | rain | 1.05 | 1.44 | 14.36 | 15.08 | 21 | 711.85 | |
| day14 | 0 | 1.36 | overcast | 1.05 | 1.34 | 13.43 | 14.11 | 0 | 697.75 | |
| day15 | 20.6 | 1.04 | rain | 1.05 | 0.85 | 8.53 | 8.96 | 206 | 894.79 | |
| day16 | 0 | 1.29 | overcast | 1.05 | 1.01 | 10.10 | 10.60 | 0 | 884.19 | |
| day17 | 0 | 1.31 | overcast | 1.05 | 1.67 | 16.69 | 17.52 | 0 | 866.66 | |
| day18 | 14.8 | 1.07 | rain | 1.05 | 1.58 | 15.80 | 16.59 | 148 | 998.07 | |
| day19 | 0 | 1.34 | overcast | 1.05 | 1.39 | 13.89 | 14.59 | 0 | 983.48 | |
| day20 | 0 | 1.36 | overcast | 0.9 | 1.89 | 18.91 | 17.02 | 0 | 966.46 | |
| day21 | 4.5 | 1.10 | rain | 0.9 | 1.85 | 18.52 | 16.67 | 45 | 994.79 | |
| day22 | 0.5 | 1.19 | rain | 0.9 | 1.60 | 16.00 | 14.40 | 5 | 985.39 | |
| day23 | 0 | 1.20 | overcast | 0.9 | 2.17 | 21.71 | 19.54 | 0 | 965.86 | |
| day24 | 0 | 1.15 | overcast | 0.9 | 2.19 | 21.93 | 19.73 | 0 | 946.12 | |
| day25 | 0.2 | 1.04 | rain | 0.9 | 1.45 | 14.55 | 13.09 | 2 | 935.03 | |
| day26 | 0 | 1.22 | overcast | 0.9 | 1.45 | 14.52 | 13.06 | 0 | 921.97 | |
| day27 | 1.2 | 1.24 | overcast | 0.9 | 1.94 | 19.44 | 17.49 | 12 | 916.48 | |
| day28 | 0.2 | 1.33 | rain | 0.9 | 1.44 | 14.39 | 12.95 | 2 | 905.52 | |
| day29 | 0 | 1.28 | overcast | 0.9 | 0.00 | 0.00 | 0.00 | 0 | 905.52 | |
| day30 | 0 | 1.39 | overcast | 0.9 | 1.42 | 14.23 | 12.80 | 0 | 892.72 | |

JULY

| day | rainfall (l) | radiation (MJ $m^{-2}$ $day^{-1}$) | weather | kc | ETo (l) | ETo (l)x10$m^2$ | ETc (l)x10$m^2$ | Rain (l) | ASMAD | Irrigation (l) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 0.00 | | 892.72 | |
| day1 | 0.1 | 1.37 | overcast | 0.9 | 3.05 | 30.51 | 27.46 | 1 | 866.26 | |
| day2 | 0 | 1.09 | overcast | 0.9 | 4.13 | 41.26 | 37.13 | 0 | 829.13 | |
| day3 | 17.8 | 1.27 | rain | 0.9 | 1.61 | 16.07 | 14.46 | 178 | 992.67 | |
| day4 | 61.2 | 1.27 | rain | 0.9 | 1.71 | 17.14 | 15.43 | 612 | 1589.24 | |
| | | | | | | | | | | **HARVEST** |

**SUMMER GROWING SEASON**

SEPTEMBER

| day | rainfall (l) | radiation | weather | kc | ETo (l) | ETo (l) | ETc (l) | Rain (l) | ASMAD | Irrigation (l) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 0 | |
| day1 | 0 | 2.02 | overcast | 0.7 | 1.52 | 15.18 | 10.62 | 0 | 89.38 | 100 |
| day2 | 5.7 | 2.06 | rain | 0.7 | 2.25 | 22.53 | 15.77 | 57 | 130.60 | |
| day3 | 0 | 3.79 | half-overcast | 0.7 | 3.22 | 32.25 | 22.57 | 0 | 108.03 | |
| day4 | 0 | 3.96 | half-overcast | 0.7 | 3.61 | 36.06 | 25.24 | 0 | 82.79 | |
| day5 | 0.6 | 3.42 | half-overcast | 0.7 | 3.05 | 30.48 | 21.34 | 6 | 67.45 | |
| day6 | 0 | 3.84 | half-overcast | 0.7 | 5.00 | 49.95 | 34.97 | 0 | 32.49 | |
| day7 | 0 | 3.71 | half-overcast | 0.7 | 3.80 | 38.04 | 26.63 | 0 | 5.86 | |
| day8 | 0 | 3.99 | half-overcast | 0.7 | 3.37 | 33.71 | 23.60 | 0 | 82.26 | 100 |
| day9 | 1.1 | 2.06 | rain | 0.7 | 1.72 | 17.18 | 12.03 | 11 | 81.23 | |
| day10 | 4.2 | 2.36 | rain | 0.7 | 2.28 | 22.76 | 15.93 | 42 | 107.30 | |
| day11 | 5.1 | 2.62 | rain | 0.7 | 3.03 | 30.28 | 21.19 | 51 | 137.11 | |
| day12 | 1.4 | 2.43 | rain | 0.7 | 1.86 | 18.61 | 13.03 | 14 | 138.08 | |
| day13 | 0 | 3.69 | half-overcast | 0.7 | 4.08 | 40.82 | 28.57 | 0 | 109.51 | |
| day14 | 0 | 3.98 | half-overcast | 0.7 | 3.76 | 37.57 | 26.30 | 0 | 83.21 | |
| day15 | 0 | 4.01 | half-overcast | 0.7 | 5.05 | 50.51 | 35.36 | 0 | 47.85 | |
| day16 | 0 | 3.98 | half-overcast | 0.7 | 4.22 | 42.20 | 29.54 | 0 | 18.31 | |
| day17 | 0 | 4.07 | half-overcast | 0.7 | 5.27 | 52.74 | 36.92 | 0 | 81.39 | 100 |
| day18 | 7.9 | 3.57 | rain | 0.7 | 4.06 | 40.57 | 28.40 | 79 | 131.99 | |
| day19 | 0 | 2.87 | half-overcast | 0.7 | 3.78 | 37.83 | 26.48 | 0 | 105.51 | |
| day20 | 0 | 3.78 | half-overcast | 0.7 | 5.65 | 56.48 | 39.53 | 0 | 65.98 | |
| day21 | 0 | 3.68 | overcast | 0.7 | 4.09 | 40.92 | 28.64 | 0 | 37.33 | |
| day22 | 0 | 2.14 | overcast | 0.7 | 2.76 | 27.60 | 19.32 | 0 | 18.02 | |
| day23 | 3.5 | 2.26 | rain | 0.7 | 2.14 | 21.43 | 15.00 | 35 | 38.02 | |
| day24 | 2.3 | 2.75 | rain | 0.7 | 2.84 | 28.39 | 19.88 | 23 | 41.14 | |
| day25 | 0 | 3.57 | overcast | 0.7 | 3.20 | 31.99 | 22.40 | 0 | 18.75 | |
| day26 | 0 | 3.92 | overcast | 0.7 | 3.67 | 36.74 | 25.72 | 0 | 93.03 | 100 |
| day27 | 0 | 3.80 | overcast | 0.7 | 4.13 | 41.33 | 28.93 | 0 | 64.10 | |
| day28 | 0 | 3.96 | overcast | 0.7 | 3.43 | 34.29 | 24.00 | 0 | 40.10 | |
| day29 | 1.3 | 2.86 | rain | 0.7 | 2.88 | 28.82 | 20.17 | 13 | 32.93 | |
| day30 | 0 | 3.80 | overcast | 0.7 | 3.41 | 34.05 | 23.84 | 0 | 9.09 | |

OCTOBER

| day | rainfall (l) | radiation | weather | kc | ETo (l) | ETo (l) | ETc (l) | Rain (l) | ASMAD | Irrigation (l) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 6.06 | |
| day1 | 0 | 3.89 | half-overcast | 0.7 | 2.91 | 29.08 | 20.36 | 0 | 85.70 | 100 |
| day2 | 0 | 3.26 | half-overcast | 0.7 | 3.17 | 31.74 | 22.22 | 0 | 63.49 | |
| day3 | 1 | 2.56 | rain | 0.7 | 2.16 | 21.58 | 15.10 | 10 | 58.38 | |
| day4 | 1.4 | 3.30 | rain | 0.7 | 2.93 | 29.31 | 20.52 | 14 | 51.87 | |
| day5 | 0 | 5.32 | sunny | 0.7 | 5.23 | 52.28 | 36.59 | 0 | 15.27 | |
| day6 | 0 | 4.98 | sunny | 0.7 | 4.49 | 44.90 | 31.43 | 0 | 83.84 | 100 |
| day7 | 0 | 5.41 | sunny | 0.7 | 5.99 | 59.91 | 41.93 | 0 | 41.91 | |
| day8 | 0 | 5.38 | sunny | 0.7 | 7.06 | 70.56 | 49.39 | 0 | 92.52 | 100 |
| day9 | 0 | 5.51 | sunny | 0.7 | 5.30 | 53.02 | 37.11 | 0 | 55.40 | |
| day10 | 0 | 5.10 | sunny | 0.7 | 7.43 | 74.27 | 51.99 | 0 | 3.41 | |
| day11 | 0 | 5.04 | sunny | 0.7 | 5.68 | 56.80 | 39.76 | 0 | 63.65 | 100 |
| day12 | 0.2 | 3.58 | half-overcast | 0.7 | 3.78 | 37.76 | 26.43 | 2 | 39.22 | |
| day13 | 0 | 5.38 | sunny | 0.7 | 6.35 | 63.51 | 44.45 | 0 | 94.76 | 100 |
| day14 | 1.7 | 4.88 | sunny | 0.7 | 6.04 | 60.40 | 42.28 | 17 | 69.48 | |
| day15 | 0 | 5.41 | sunny | 0.7 | 6.60 | 66.01 | 46.21 | 0 | 23.27 | |
| day16 | 0 | 5.61 | sunny | 0.7 | 5.64 | 56.36 | 39.45 | 0 | 83.82 | 100 |
| day17 | 0 | 5.81 | sunny | 0.7 | 5.72 | 57.23 | 40.06 | 0 | 43.76 | |
| day18 | 0 | 5.66 | sunny | 0.7 | 5.90 | 59.03 | 41.32 | 0 | 2.44 | |
| day19 | 0 | 5.50 | sunny | 0.7 | 9.83 | 98.26 | 68.78 | 0 | 33.66 | 100 |
| day20 | 0 | 5.93 | sunny | 0.7 | 6.25 | 62.50 | 43.75 | 0 | 89.91 | 100 |
| day21 | 0 | 5.37 | sunny | 0.7 | 4.90 | 49.02 | 34.31 | 0 | 55.60 | |
| day22 | 0.2 | 4.57 | sunny | 0.7 | 4.73 | 47.33 | 33.13 | 2 | 24.47 | |
| day23 | 0 | 5.02 | sunny | 0.7 | 5.72 | 57.16 | 40.01 | 0 | 84.45 | 100 |
| day24 | 0.2 | 5.72 | sunny | 0.7 | 6.09 | 60.91 | 42.63 | 2 | 43.82 | |
| day25 | 0 | 4.00 | half-overcast | 0.7 | 0.00 | 0.00 | 0.00 | 0 | 43.82 | |
| day26 | 0 | 5.52 | sunny | 0.7 | 8.16 | 81.55 | 57.09 | 0 | 86.73 | 100 |
| day27 | 0 | 4.25 | overcast | 0.7 | 4.95 | 49.47 | 34.63 | 0 | 52.10 | |
| day28 | 0.3 | 3.40 | half-overcast | 0.7 | 3.39 | 33.93 | 23.75 | 3 | 31.35 | |
| day29 | 0.7 | 3.81 | half-overcast | 0.7 | 4.89 | 48.87 | 34.21 | 7 | 4.14 | |
| day30 | 0 | 5.02 | sunny | 0.7 | 10.76 | 107.64 | 75.35 | 0 | 28.80 | 100 |
| day31 | 0 | 5.52 | sunny | 0.7 | 10.80 | 107.99 | 75.59 | 0 | 53.20 | 100 |

NOVEMBER

| day | rainfall (l) | radiation | weather | kc | ETo (l) | ETo (l) | ETc (l) | Rain (l) | ASMAD | Irrigation (l) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 53.2 | |
| day1 | 0 | 4.08 | half-overcast | 0.7 | 4.36 | 43.60 | 0.00 | 0 | 53.20 | |
| day2 | 0 | 5.23 | sunny | 0.7 | 6.10 | 61.00 | 42.70 | 0 | 10.50 | |
| day3 | 0 | 6.77 | sunny | 0.7 | 6.79 | 67.86 | 47.50 | 0 | 63.00 | 100 |
| day4 | 0 | 3.66 | half-overcast | 0.7 | 3.65 | 36.52 | 25.57 | 0 | 37.43 | |
| day5 | 2.9 | 4.32 | half-overcast | 1.05 | 4.38 | 43.79 | 30.65 | 29 | 35.78 | |
| day6 | 0 | 4.17 | half-overcast | 1.05 | 4.15 | 41.53 | 43.61 | 0 | 92.17 | 100 |
| day7 | 0 | 6.02 | sunny | 1.05 | 7.63 | 76.34 | 80.16 | 0 | 12.01 | |
| day8 | 0 | 6.55 | sunny | 1.05 | 8.30 | 83.04 | 87.19 | 0 | 24.82 | 100 |
| day9 | 0 | 6.72 | sunny | 1.05 | 8.70 | 87.04 | 91.40 | 0 | 33.42 | 100 |
| day10 | 0 | 6.76 | sunny | 1.05 | 6.94 | 69.37 | 72.84 | 0 | 60.58 | 100 |
| day11 | 0 | 6.90 | sunny | 1.05 | 7.61 | 76.08 | 79.88 | 0 | 80.69 | 100 |
| day12 | 0 | 6.92 | sunny | 1.05 | 7.28 | 72.83 | 76.47 | 0 | 4.22 | |
| day13 | 0 | 6.10 | sunny | 1.05 | 6.95 | 69.46 | 72.93 | 0 | 31.29 | 100 |
| day14 | 0 | 6.83 | sunny | 1.05 | 6.41 | 64.08 | 67.29 | 0 | 64.01 | 100 |
| day15 | 0 | 6.06 | sunny | 1.05 | 6.89 | 68.85 | 72.30 | 0 | 91.71 | 100 |
| day16 | 0 | 6.25 | sunny | 1.05 | 7.08 | 70.79 | 74.33 | 0 | 17.38 | |
| day17 | 0 | 4.95 | sunny | 1.05 | 5.75 | 57.51 | 60.38 | 0 | 57.00 | 100 |
| day18 | 0 | 6.48 | sunny | 1.05 | 10.96 | 109.61 | 115.09 | 0 | 41.91 | 100 |
| day19 | 0 | 7.50 | sunny | 1.05 | 8.43 | 84.35 | 88.57 | 0 | 53.35 | 100 |
| day20 | 0 | 7.09 | sunny | 1.05 | 7.41 | 74.11 | 77.82 | 0 | 75.53 | 100 |
| day21 | 0 | 5.79 | sunny | 1.05 | 6.19 | 61.91 | 65.00 | 0 | 10.52 | |
| day22 | 0 | 7.19 | sunny | 1.05 | 8.72 | 87.24 | 91.60 | 0 | 18.93 | 100 |
| day23 | 0 | 7.06 | sunny | 1.05 | 7.23 | 72.29 | 75.90 | 0 | 43.03 | 100 |
| day24 | 0 | 7.01 | sunny | 1.05 | 8.27 | 82.75 | 86.88 | 0 | 56.14 | 100 |
| day25 | 0 | 6.96 | sunny | 1.05 | 9.87 | 98.71 | 103.65 | 0 | 52.49 | 100 |
| day26 | 0 | 7.06 | sunny | 1.05 | 9.66 | 96.63 | 101.46 | 0 | 51.03 | 100 |
| day27 | 0 | 5.96 | sunny | 1.05 | 6.05 | 60.47 | 63.49 | 0 | 87.54 | 100 |
| day28 | 0 | 6.20 | sunny | 1.05 | 7.03 | 70.28 | 73.80 | 0 | 13.74 | |
| day29 | 0 | 6.94 | sunny | 1.05 | 9.94 | 99.43 | 104.41 | 0 | 9.33 | 100 |
| day30 | 0 | 6.11 | sunny | 1.05 | 7.36 | 73.60 | 77.28 | 0 | 32.05 | 100 |

DECEMBER

| day | rainfall (l) | radiation | weather | kc | ETo (l) | ETo (l) | ETc (l) | Rain (l) | ASMAD | Irrigation (l) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 32.05 | |
| day1 | 0 | 4.08 | half-overcast | 1.05 | 4.36 | 43.56 | 0.00 | 0 | 32.05 | |
| day2 | 0 | 4.51 | sunny | 1.05 | 5.01 | 50.14 | 52.64 | 0 | 79.41 | 100 |
| day3 | 0 | 5.49 | sunny | 1.05 | 8.60 | 86.00 | 90.30 | 0 | 89.11 | 100 |
| day4 | 0 | 7.19 | sunny | 1.05 | 8.67 | 86.67 | 91.00 | 0 | 98.11 | 100 |
| day5 | 0 | 6.83 | sunny | 1.05 | 7.67 | 76.72 | 80.55 | 0 | 17.55 | |
| day6 | 0 | 6.88 | sunny | 1.05 | 7.39 | 73.86 | 77.55 | 0 | 40.00 | 100 |
| day7 | 0 | 7.24 | sunny | 1.05 | 8.02 | 80.22 | 84.23 | 0 | 55.77 | 100 |
| day8 | 0 | 6.54 | sunny | 1.05 | 7.06 | 70.60 | 74.13 | 0 | 81.64 | 100 |
| day9 | 0.2 | 6.94 | sunny | 1.05 | 7.29 | 72.87 | 76.51 | 2 | 7.13 | |
| day10 | 0 | 6.72 | sunny | 1.05 | 7.73 | 77.26 | 81.12 | 0 | 26.01 | 100 |
| day11 | 0 | 7.24 | sunny | 1.05 | 8.77 | 87.66 | 92.04 | 0 | 33.96 | 100 |
| day12 | 0 | 7.51 | sunny | 1.05 | 7.84 | 78.36 | 82.28 | 0 | 51.69 | 100 |
| day13 | 0 | 5.78 | sunny | 1.05 | 6.10 | 61.05 | 64.10 | 0 | 87.59 | 100 |
| day14 | 0 | 7.23 | sunny | 1.05 | 10.61 | 106.11 | 111.42 | 0 | 76.17 | 100 |
| day15 | 0 | 7.41 | sunny | 1.05 | 7.89 | 78.92 | 82.86 | 0 | 93.31 | 100 |
| day16 | 0 | 7.41 | sunny | 1.05 | 9.92 | 99.23 | 104.19 | 0 | 89.12 | 100 |
| day17 | 0 | 7.41 | sunny | 1.05 | 9.38 | 93.83 | 98.53 | 0 | 90.59 | 100 |
| day18 | 0 | 6.57 | sunny | 1.05 | 8.46 | 84.55 | 88.78 | 0 | 1.82 | |
| day19 | 0 | 6.57 | sunny | 1.05 | 7.51 | 75.07 | 78.82 | 0 | 22.99 | 100 |
| day20 | 4.2 | 5.25 | half-overcast | 0.9 | 5.46 | 54.65 | 57.38 | 42 | 7.61 | |
| day21 | 0 | 7.11 | sunny | 0.9 | 9.77 | 97.68 | 87.91 | 0 | 19.70 | 100 |
| day22 | 0 | 6.59 | sunny | 0.9 | 9.21 | 92.14 | 82.92 | 0 | 36.77 | 100 |
| day23 | 0 | 7.10 | sunny | 0.9 | 9.56 | 95.61 | 86.05 | 0 | 50.72 | 100 |
| day24 | 0 | 6.91 | sunny | 0.9 | 7.42 | 74.21 | 66.79 | 0 | 83.93 | 100 |
| day25 | 0 | 7.29 | sunny | 0.9 | 7.36 | 73.61 | 66.25 | 0 | 17.69 | |
| day26 | 0 | 7.41 | sunny | 0.9 | 8.13 | 81.27 | 73.14 | 0 | 44.54 | 100 |
| day27 | 0.3 | 6.92 | sunny | 0.9 | 6.89 | 68.88 | 61.99 | 3 | 85.56 | 100 |
| day28 | 0 | 6.63 | sunny | 0.9 | 7.27 | 72.70 | 65.43 | 0 | 20.12 | |
| day29 | 4.2 | 5.63 | sunny | 0.9 | 6.78 | 67.85 | 61.06 | 42 | 1.06 | |
| day30 | 0.5 | 5.10 | sunny | 0.9 | 5.34 | 53.43 | 48.08 | 5 | 57.98 | 100 |
| day31 | 0 | 6.04 | sunny | 0.9 | 6.53 | 65.27 | 58.75 | 0 | 99.23 | 100 |

JANUARY

| day | rainfall (l) | radiation | weather | kc | ETo (l) | ETo (l) | ETc (l) | Rain (l) | ASMAD | Irrigation (l) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 99.23 | |
| day1 | 0 | 7.52 | sunny | 0.9 | 8.20 | 82.03 | 73.82 | 0 | 17.20 | |
| day2 | 0.2 | 6.76 | sunny | 0.9 | 8.29 | 82.94 | 74.65 | 2 | 36.26 | 100 |
| day3 | 0.2 | 5.55 | sunny | 0.9 | 6.39 | 63.87 | 57.48 | 2 | 74.39 | 100 |
| | | | | | | | | | | **HARVEST** |

# APPENDIX 9

## IRRIGATION SCHEDULE FOR SPINACH

**(WINTER AND SUMMER)**

***SPINACH***

**WINTER GROWING SEASON**

MARCH

**KEY**

**overcast = 0-4**

**partly cloudy = 4.1-6.9**

**sunny = 7 -10**

**ASMAD = available soil moisture after depletion**

**l = liter**

| day | rainfall (l) | radiation (MJ $m^{-2}$ $day^{-1}$) | weather | $k_c$ | $ET_o$ (l) | $ET_o$ (l) per10$m^2$ | $ET_c$ (l) per10$m^2$ | Rain (l) | ASMAD | Irrigation (l) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 0 | |
| day1 | 13.6 | 4.92 | sunny | 0.75 | 5.96 | 59.58 | 44.69 | 136 | 91.31 | |
| day2 | 5.3 | 3.25 | half-overcast | 0.75 | 3.55 | 35.50 | 26.62 | 53 | 117.69 | |
| day3 | 0.6 | 4.84 | sunny | 0.75 | 4.31 | 43.15 | 32.36 | 6 | 91.33 | |
| day4 | 0 | 4.68 | sunny | 0.75 | 4.65 | 46.52 | 34.89 | 0 | 56.44 | |
| day5 | 0 | 4.00 | half-overcast | 0.75 | 6.48 | 64.76 | 48.57 | 0 | 7.88 | |
| day6 | 0 | 2.79 | half-overcast | 0.75 | 3.53 | 35.26 | 26.45 | 0 | 81.43 | 100 |
| day7 | 0 | 4.40 | half-overcast | 0.75 | 6.56 | 65.61 | 49.21 | 0 | 32.22 | |
| day8 | 0 | 3.74 | half-overcast | 0.75 | 4.09 | 40.95 | 30.71 | 0 | 1.51 | |
| day9 | 0 | 4.98 | sunny | 0.75 | 5.90 | 59.02 | 44.27 | 0 | 57.24 | 100 |
| day10 | 0 | 4.95 | sunny | 0.75 | 5.45 | 54.54 | 40.90 | 0 | 16.34 | |
| day11 | 0 | 4.78 | sunny | 0.75 | 5.38 | 53.77 | 40.32 | 0 | 76.01 | 100 |
| day12 | 0 | 3.63 | half-overcast | 0.75 | 3.68 | 36.84 | 27.63 | 0 | 48.38 | |
| day13 | 0 | 4.84 | sunny | 0.75 | 4.57 | 45.74 | 34.30 | 0 | 14.08 | |
| day14 | 41.6 | 2.98 | half-overcast | 0.75 | 2.93 | 29.29 | 21.97 | 416 | 408.11 | |
| day15 | 9.5 | 4.54 | sunny | 0.75 | 5.31 | 53.09 | 39.82 | 95 | 463.29 | |
| day16 | 0 | 4.50 | sunny | 0.75 | 5.16 | 51.61 | 38.70 | 0 | 424.59 | |
| day17 | 1.3 | 3.06 | half-overcast | 0.75 | 2.79 | 27.90 | 20.93 | 13 | 416.66 | |
| day18 | 0.6 | 2.33 | half-overcast | 0.75 | 2.33 | 23.28 | 17.46 | 6 | 405.20 | |
| day19 | 0 | 4.55 | sunny | 0.75 | 4.39 | 43.93 | 32.94 | 0 | 372.25 | |
| day20 | 0 | 3.81 | half-overcast | 0.75 | 3.73 | 37.31 | 27.98 | 0 | 344.27 | |
| day21 | 0 | 2.59 | half-overcast | 0.75 | 2.07 | 20.70 | 15.52 | 0 | 328.75 | |
| day22 | 0 | 3.64 | half-overcast | 0.75 | 3.27 | 32.65 | 24.49 | 0 | 304.26 | |
| day23 | 0 | 3.89 | half-overcast | 0.75 | 4.11 | 41.12 | 30.84 | 0 | 273.42 | |
| day24 | 0 | 4.58 | sunny | 0.75 | 6.93 | 69.29 | 51.97 | 0 | 221.45 | |
| day25 | 0 | 4.35 | sunny | 0.75 | 4.61 | 46.13 | 34.59 | 0 | 186.86 | |
| day26 | 0 | 4.79 | sunny | 0.75 | 6.06 | 60.57 | 45.42 | 0 | 141.43 | |
| day27 | 0 | 4.17 | sunny | 0.75 | 4.59 | 45.87 | 34.40 | 0 | 107.03 | |
| day28 | 0 | 4.45 | sunny | 0.75 | 5.07 | 50.69 | 38.02 | 0 | 69.02 | |
| day29 | 0 | 2.94 | half-overcast | 0.75 | 3.78 | 37.77 | 28.33 | 0 | 40.69 | |
| day30 | 0 | 2.82 | half-overcast | 0.75 | 2.82 | 28.15 | 21.11 | 0 | 19.57 | |
| day 31 | 0 | 2.34 | overcast | 0.4 | 3.41 | 34.1 | 13.64 | 0 | 5.93 | |

APRIL

| day | rainfall (l) | radiation (MJ m$^{-2}$ day$^{-1}$) | weather | $k_c$ | $ET_o$ (l) | $ET_o$ (l) per10m$^2$ | $ET_c$ (l) per10m$^2$ | Rain (l) | ASMAD | Irrigation (l) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 0 | 0 | 5.93 | |
| day1 | 0 | 3.60 | half-overcast | 0.75 | 3.56 | 35.55 | 26.66 | 0 | 79.27 | 100 |
| day2 | 0 | 3.61 | half-overcast | 0.75 | 2.85 | 28.49 | 21.37 | 0 | 57.90 | |
| day3 | 0 | 3.44 | half-overcast | 0.75 | 3.89 | 38.90 | 29.18 | 0 | 28.72 | |
| day4 | 0 | 3.57 | half-overcast | 0.75 | 3.30 | 33.04 | 24.78 | 0 | 3.94 | |
| day5 | 10.7 | 3.00 | half-overcast | 0.75 | 3.39 | 33.90 | 25.42 | 107 | 85.51 | |
| day6 | 12.1 | 3.09 | half-overcast | 0.75 | 3.10 | 31.05 | 23.28 | 121 | 183.23 | |
| day7 | 1.3 | 2.62 | half-overcast | 0.75 | 2.91 | 29.11 | 21.83 | 13 | 174.40 | |
| day8 | 0 | 3.22 | half-overcast | 0.75 | 3.10 | 31.01 | 23.26 | 0 | 151.14 | |
| day9 | 0 | 3.18 | half-overcast | 0.75 | 3.40 | 34.02 | 25.51 | 0 | 125.63 | |
| day10 | 0 | 3.21 | half-overcast | 0.75 | 3.17 | 31.69 | 23.77 | 0 | 101.86 | |
| day11 | 0 | 3.12 | half-overcast | 1.05 | 4.40 | 43.95 | 46.15 | 0 | 55.71 | |
| day12 | 0 | 3.23 | half-overcast | 1.05 | 4.14 | 41.37 | 43.44 | 0 | 12.27 | |
| day13 | 0 | 3.38 | half-overcast | 1.05 | 3.28 | 32.80 | 34.44 | 0 | 77.83 | 100 |
| day14 | 0 | 3.41 | half-overcast | 1.05 | 2.88 | 28.79 | 30.23 | 0 | 47.60 | |
| day15 | 0 | 3.47 | half-overcast | 1.05 | 3.06 | 30.63 | 32.16 | 0 | 15.44 | |
| day16 | 0 | 3.06 | half-overcast | 1.05 | 2.81 | 28.14 | 29.55 | 0 | 85.89 | 100 |
| day17 | 3.4 | 3.15 | rain | 1.05 | 3.79 | 37.92 | 39.82 | 34 | 80.07 | |
| day18 | 0.1 | 3.22 | half-overcast | 1.05 | 2.58 | 25.82 | 27.12 | 1 | 53.96 | |
| day19 | 0 | 2.94 | half-overcast | 1.05 | 3.30 | 33.02 | 34.67 | 0 | 19.29 | |
| day20 | 0 | 2.90 | half-overcast | 1.05 | 2.99 | 29.93 | 31.43 | 0 | 87.86 | 100 |
| day21 | 2.3 | 1.78 | rain | 1.05 | 2.20 | 21.95 | 23.05 | 23 | 87.81 | |
| day22 | 10.6 | 2.26 | half-overcast | 1.05 | 2.20 | 22.02 | 23.12 | 106 | 170.70 | |
| day23 | 1 | 2.56 | rain | 1.05 | 2.32 | 23.18 | 24.34 | 10 | 156.35 | |
| day24 | 0 | 2.89 | half-overcast | 1.05 | 3.39 | 33.94 | 35.63 | 0 | 120.72 | |
| day25 | 0 | 3.20 | overcast | 1.05 | 2.90 | 29.03 | 30.48 | 0 | 90.24 | |
| day26 | 0 | 3.16 | overcast | 1.05 | 2.99 | 29.88 | 31.38 | 0 | 58.86 | |
| day27 | 7 | 1.74 | rain | 1.05 | 1.69 | 16.88 | 17.72 | 70 | 111.14 | |
| day28 | 0 | 2.54 | half-overcast | 1.05 | 3.05 | 30.51 | 32.03 | 0 | 79.10 | |
| day29 | 0 | 3.18 | half-overcast | 1.05 | 2.73 | 27.33 | 28.70 | 0 | 50.41 | |
| day30 | 1.1 | 2.82 | rain | 1.05 | 2.44 | 24.41 | 25.64 | 11 | 35.77 | |

MAY

| day | rainfall (l) | radiation (MJ $m^{-2}$ $day^{-1}$) | weather | $k_c$ | $ET_o$ (l) | $ET_o$ (l) per10$m^2$ | $ET_c$ (l) per10$m^2$ | Rain (l) | ASMAD | Irrigation (l) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 35.77 | |
| day1 | 0 | 2.04 | overcast | 1.05 | 2.31 | 23.13 | 24.28 | 0 | 11.49 | |
| day2 | 0 | 2.18 | overcast | 1.05 | 2.25 | 22.47 | 23.60 | 0 | 87.89 | 100 |
| day3 | 0 | 2.08 | overcast | 1.05 | 2.27 | 22.69 | 23.82 | 0 | 64.07 | |
| day4 | 0 | 2.18 | overcast | 1.05 | 2.20 | 22.00 | 23.10 | 0 | 40.96 | |
| day5 | 0 | 1.95 | overcast | 1.05 | 1.85 | 18.51 | 19.44 | 0 | 21.53 | |
| day6 | 0 | 2.06 | overcast | 1.05 | 2.13 | 21.30 | 22.36 | 0 | 99.16 | 100 |
| day7 | 0 | 1.83 | overcast | 1.05 | 1.65 | 16.54 | 17.37 | 0 | 81.79 | |
| day8 | 0 | 2.03 | overcast | 1.05 | 2.76 | 27.64 | 29.02 | 0 | 52.78 | |
| day9 | 0 | 1.97 | overcast | 1.05 | 3.43 | 34.29 | 36.01 | 0 | 16.77 | |
| day10 | 0 | 1.94 | overcast | 1.05 | 3.68 | 36.84 | 38.68 | 0 | 78.08 | 100 |
| day11 | 0 | 1.80 | overcast | 1.05 | 2.85 | 28.49 | 29.91 | 0 | 48.17 | |
| day12 | 0 | 1.87 | overcast | 1.05 | 2.33 | 23.30 | 24.47 | 0 | 23.70 | |
| day13 | 0 | 2.00 | overcast | 1.05 | 2.22 | 22.16 | 23.27 | 0 | 0.44 | |
| day14 | 0 | 1.92 | overcast | 1.05 | 2.17 | 21.65 | 22.74 | 0 | 77.70 | 100 |
| day15 | 0 | 1.94 | overcast | 1.05 | 2.25 | 22.48 | 23.61 | 0 | 54.09 | |
| day16 | 0 | 1.93 | overcast | 0.95 | 1.77 | 17.74 | 16.86 | 0 | 37.24 | |
| day17 | 0 | 1.97 | overcast | 0.95 | 2.11 | 21.09 | 20.04 | 0 | 17.20 | |
| day18 | 0 | 1.85 | overcast | 0.95 | 2.63 | 26.27 | 24.96 | 0 | 92.24 | 100 |
| day19 | 0 | 1.90 | overcast | 0.95 | 2.78 | 27.75 | 26.36 | 0 | 65.87 | |
| day20 | 3.8 | 1.69 | rain | 0.95 | 3.74 | 37.36 | 35.50 | 38 | 68.38 | |
| day21 | 26.6 | 1.30 | rain | 0.95 | 1.88 | 18.77 | 17.83 | 266 | 316.55 | |
| day22 | 7.3 | 1.59 | rain | 0.95 | 1.63 | 16.33 | 15.51 | 73 | 374.04 | |
| day23 | 0 | 1.65 | overcast | 0.95 | 1.70 | 16.97 | 16.12 | 0 | 357.92 | |
| day24 | 0 | 1.84 | overcast | 0.95 | 2.72 | 27.16 | 25.81 | 0 | 332.11 | |
| day25 | 0 | 1.88 | overcast | 0.95 | 1.84 | 18.40 | 17.48 | 0 | 314.63 | |
| day26 | 0.4 | 1.82 | rain | 0.95 | 2.69 | 26.95 | 25.60 | 4 | 293.03 | |
| day27 | 6.5 | 1.28 | rain | 0.95 | 1.14 | 11.35 | 10.78 | 65 | 347.25 | |
| day28 | 0 | 1.67 | overcast | 0.95 | 1.50 | 15.04 | 14.29 | 0 | 332.96 | |
| day29 | 0 | 2.04 | overcast | 0.95 | 1.79 | 17.85 | 16.96 | 0 | 316.00 | |
| day30 | 0 | 1.78 | overcast | 0.95 | 1.90 | 19.04 | 18.09 | 0 | 297.91 | |
| day31 | 0 | 2.00 | overcast | 0.95 | 2.85 | 28.46 | 27.03 | 0 | 270.88 | |

JUNE

| day | rainfall (l) | radiation (MJ $m^{-2}$ $day^{-1}$) | weather | $k_c$ | $ET_o$ (l) | $ET_o$ (l) per10$m^2$ | $ET_c$ (l) per10$m^2$ | Rain (l) | ASMAD | Irrigation (l) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 0.00 | | 270.88 | |
| day1 | 0 | 1.27 | overcast | 0.95 | 1.69 | 16.91 | 16.06 | 0 | 254.82 | |
| day2 | 0 | 1.02 | overcast | 0.95 | 3.55 | 35.48 | 33.70 | 0 | 221.11 | |
| day3 | 0 | 1.34 | overcast | 0.95 | 1.61 | 16.12 | 15.31 | 0 | 205.80 | |
| day4 | 0 | 1.34 | overcast | 0.95 | 1.68 | 16.76 | 15.92 | 0 | 189.88 | |
| | | | | | | | | | | **HARVEST** |

**SUMMER GROWING SEASON**

SEPTEMBER

| day | rainfall (l) | radiation (MJ $m^{-2}$ $day^{-1}$) | weather | $k_c$ | $ET_o$ (l) | $ET_o$ (l) per10$m^2$ | $ET_c$ (l) per10$m^2$ | Rain (l) | ASMAD | Irrigation (l) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 0 | |
| day1 | 0 | 2.02 | overcast | 0.75 | 1.52 | 15.18 | 11.38 | 0 | 88.62 | 100 |
| day2 | 5.7 | 2.06 | rain | 0.75 | 2.25 | 22.53 | 16.90 | 57 | 128.72 | |
| day3 | 0 | 3.79 | half-overcast | 0.75 | 3.22 | 32.25 | 24.19 | 0 | 104.53 | |
| day4 | 0 | 3.96 | half-overcast | 0.75 | 3.61 | 36.06 | 27.04 | 0 | 77.49 | |
| day5 | 0.6 | 3.42 | half-overcast | 0.75 | 3.05 | 30.48 | 22.86 | 6 | 60.63 | |
| day6 | 0 | 3.84 | half-overcast | 0.75 | 5.00 | 49.95 | 37.46 | 0 | 23.16 | |
| day7 | 0 | 3.71 | half-overcast | 0.75 | 3.80 | 38.04 | 28.53 | 0 | 94.64 | 100 |
| day8 | 0 | 3.99 | half-overcast | 0.75 | 3.37 | 33.71 | 25.28 | 0 | 69.35 | |
| day9 | 1.1 | 2.06 | rain | 0.75 | 1.72 | 17.18 | 12.89 | 11 | 67.46 | |
| day10 | 4.2 | 2.36 | rain | 0.75 | 2.28 | 22.76 | 17.07 | 42 | 92.40 | |
| day11 | 5.1 | 2.62 | rain | 0.75 | 3.03 | 30.28 | 22.71 | 51 | 120.69 | |
| day12 | 1.4 | 2.43 | rain | 0.75 | 1.86 | 18.61 | 13.96 | 14 | 120.73 | |
| day13 | 0 | 3.69 | half-overcast | 0.75 | 4.08 | 40.82 | 30.62 | 0 | 90.12 | |
| day14 | 0 | 3.98 | half-overcast | 0.75 | 3.76 | 37.57 | 28.18 | 0 | 61.94 | |
| day15 | 0 | 4.01 | half-overcast | 0.75 | 5.05 | 50.51 | 37.89 | 0 | 24.05 | |
| day16 | 0 | 3.98 | half-overcast | 0.75 | 4.22 | 42.20 | 31.65 | 0 | 92.40 | 100 |
| day17 | 0 | 4.07 | half-overcast | 0.75 | 5.27 | 52.74 | 39.56 | 0 | 52.85 | |
| day18 | 7.9 | 3.57 | rain | 0.75 | 4.06 | 40.57 | 30.43 | 79 | 101.42 | |
| day19 | 0 | 2.87 | half-overcast | 0.75 | 3.78 | 37.83 | 28.37 | 0 | 73.05 | |
| day20 | 0 | 3.78 | half-overcast | 0.75 | 5.65 | 56.48 | 42.36 | 0 | 30.69 | |
| day21 | 0 | 3.68 | overcast | 0.75 | 4.09 | 40.92 | 30.69 | 0 | 0.00 | |
| day22 | 0 | 2.14 | overcast | 0.75 | 2.76 | 27.60 | 20.70 | 0 | 79.30 | 100 |
| day23 | 3.5 | 2.26 | rain | 0.75 | 2.14 | 21.43 | 16.07 | 35 | 98.23 | |
| day24 | 2.3 | 2.75 | rain | 0.75 | 2.84 | 28.39 | 21.30 | 23 | 99.94 | |
| day25 | 0 | 3.57 | overcast | 0.75 | 3.20 | 31.99 | 23.99 | 0 | 75.94 | |
| day26 | 0 | 3.92 | overcast | 0.75 | 3.67 | 36.74 | 27.56 | 0 | 48.39 | |
| day27 | 0 | 3.80 | overcast | 0.75 | 4.13 | 41.33 | 30.99 | 0 | 17.39 | |
| day28 | 0 | 3.96 | overcast | 0.75 | 3.43 | 34.29 | 25.72 | 0 | 91.68 | 100 |
| day29 | 1.3 | 2.86 | rain | 0.75 | 2.88 | 28.82 | 21.61 | 13 | 83.07 | |
| day30 | 0 | 3.80 | overcast | 0.75 | 3.41 | 34.05 | 25.54 | 0 | 57.53 | |

OCTOBER

| day | rainfall (l) | radiation (MJ $m^{-2}$ $day^{-1}$) | weather | $k_c$ | $ET_o$ (l) | $ET_o$ (l) per10$m^2$ | $ET_c$ (l) per10$m^2$ | Rain (l) | ASMAD | Irrigation (l) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 57.73 | |
| day1 | 0 | 3.89 | half-overcast | 0.75 | 2.91 | 29.08 | 21.81 | 0 | 35.92 | |
| day2 | 0 | 3.26 | half-overcast | 0.75 | 3.17 | 31.74 | 23.80 | 0 | 12.12 | |
| day3 | 1 | 2.56 | rain | 0.75 | 2.16 | 21.58 | 16.18 | 10 | 5.93 | |
| day4 | 1.4 | 3.30 | rain | 0.75 | 2.93 | 29.31 | 21.98 | 14 | 97.95 | 100 |
| day5 | 0 | 5.32 | sunny | 0.75 | 5.23 | 52.28 | 39.21 | 0 | 58.74 | |
| day6 | 0 | 4.98 | sunny | 0.75 | 4.49 | 44.90 | 33.67 | 0 | 25.07 | |
| day7 | 0 | 5.41 | sunny | 0.75 | 5.99 | 59.91 | 44.93 | 0 | 80.14 | 100 |
| day8 | 0 | 5.38 | sunny | 0.75 | 7.06 | 70.56 | 52.92 | 0 | 27.22 | |
| day9 | 0 | 5.51 | sunny | 0.75 | 5.30 | 53.02 | 39.76 | 0 | 87.46 | 100 |
| day10 | 0 | 5.10 | sunny | 0.75 | 7.43 | 74.27 | 55.70 | 0 | 31.75 | |
| day11 | 0 | 5.04 | sunny | 1.05 | 5.68 | 56.80 | 59.64 | 0 | 72.11 | 100 |
| day12 | 0.2 | 3.58 | half-overcast | 1.05 | 3.78 | 37.76 | 39.65 | 2 | 34.46 | |
| day13 | 0 | 5.38 | sunny | 1.05 | 6.35 | 63.51 | 66.68 | 0 | 67.78 | 100 |
| day14 | 1.7 | 4.88 | sunny | 1.05 | 6.04 | 60.40 | 63.42 | 17 | 21.35 | |
| day15 | 0 | 5.41 | sunny | 1.05 | 6.60 | 66.01 | 69.31 | 0 | 52.04 | 100 |
| day16 | 0 | 5.61 | sunny | 1.05 | 5.64 | 56.36 | 59.17 | 0 | 92.87 | 100 |
| day17 | 0 | 5.81 | sunny | 1.05 | 5.72 | 57.23 | 60.09 | 0 | 32.78 | |
| day18 | 0 | 5.66 | sunny | 1.05 | 5.90 | 59.03 | 61.98 | 0 | 70.79 | 100 |
| day19 | 0 | 5.50 | sunny | 1.05 | 9.83 | 98.26 | 103.17 | 0 | 67.62 | 100 |
| day20 | 0 | 5.93 | sunny | 1.05 | 6.25 | 62.50 | 65.62 | 0 | 2.00 | |
| day21 | 0 | 5.37 | sunny | 1.05 | 4.90 | 49.02 | 51.47 | 0 | 50.53 | 100 |
| day22 | 0.2 | 4.57 | sunny | 1.05 | 4.73 | 47.33 | 49.70 | 2 | 2.83 | |
| day23 | 0 | 5.02 | sunny | 1.05 | 5.72 | 57.16 | 60.02 | 0 | 42.81 | 100 |
| day24 | 0.2 | 5.72 | sunny | 1.05 | 6.09 | 60.91 | 63.95 | 2 | 80.86 | 100 |
| day25 | 0 | 4.00 | half-overcast | 1.05 | 0.00 | 0.00 | 0.00 | 0 | 80.86 | |
| day26 | 0 | 5.52 | sunny | 1.05 | 8.16 | 81.55 | 85.63 | 0 | 95.23 | 100 |
| day27 | 0 | 4.25 | overcast | 1.05 | 4.95 | 49.47 | 51.94 | 0 | 43.28 | |
| day28 | 0.3 | 3.40 | half-overcast | 1.05 | 3.39 | 33.93 | 35.62 | 3 | 10.66 | |
| day29 | 0.7 | 3.81 | half-overcast | 1.05 | 4.89 | 48.87 | 51.32 | 7 | 66.35 | 100 |
| day30 | 0 | 5.02 | sunny | 1.05 | 10.76 | 107.64 | 113.02 | 0 | 53.32 | 100 |
| day31 | 0 | 5.52 | sunny | 1.05 | 10.80 | 107.99 | 113.39 | 0 | 39.94 | 100 |

NOVEMBER

| day | rainfall (l) | radiation (MJ $m^{-2}$ $day^{-1}$) | weather | $k_c$ | $ET_o$ (l) | $ET_o$ (l) per10$m^2$ | $ET_c$ (l) per10$m^2$ | Rain (l) | ASMAD | Irrigation (l) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 39.94 | |
| day1 | 0 | 4.08 | half-overcast | 1.05 | 4.36 | 43.60 | 45.78 | 0 | 94.16 | 100 |
| day2 | 0 | 5.23 | sunny | 1.05 | 6.10 | 61.00 | 64.05 | 0 | 30.11 | |
| day3 | 0 | 6.77 | sunny | 1.05 | 6.79 | 67.86 | 71.25 | 0 | 58.85 | 100 |
| day4 | 0 | 3.66 | half-overcast | 1.05 | 3.65 | 36.52 | 38.35 | 0 | 20.50 | |
| day5 | 2.9 | 4.32 | half-overcast | 1.05 | 4.38 | 43.79 | 45.98 | 29 | 3.53 | |
| day6 | 0 | 4.17 | half-overcast | 1.05 | 4.15 | 41.53 | 43.61 | 0 | 59.92 | 100 |
| day7 | 0 | 6.02 | sunny | 1.05 | 7.63 | 76.34 | 80.16 | 0 | 79.76 | 100 |
| day8 | 0 | 6.55 | sunny | 1.05 | 8.30 | 83.04 | 87.19 | 0 | 92.57 | 100 |
| day9 | 0 | 6.72 | sunny | 1.05 | 8.70 | 87.04 | 91.40 | 0 | 1.17 | |
| day10 | 0 | 6.76 | sunny | 1.05 | 6.94 | 69.37 | 72.84 | 0 | 28.33 | 100 |
| day11 | 0 | 6.90 | sunny | 1.05 | 7.61 | 76.08 | 79.88 | 0 | 48.44 | 100 |
| day12 | 0 | 6.92 | sunny | 1.05 | 7.28 | 72.83 | 76.47 | 0 | 71.97 | 100 |
| day13 | 0 | 6.10 | sunny | 1.05 | 6.95 | 69.46 | 72.93 | 0 | 99.04 | 100 |
| day14 | 0 | 6.83 | sunny | 1.05 | 6.41 | 64.08 | 67.29 | 0 | 31.76 | |
| day15 | 0 | 6.06 | sunny | 0.95 | 6.89 | 68.85 | 65.41 | 0 | 66.35 | 100 |
| day16 | 0 | 6.25 | sunny | 0.95 | 7.08 | 70.79 | 67.25 | 0 | 99.10 | 100 |
| day17 | 0 | 4.95 | sunny | 0.95 | 5.75 | 57.51 | 54.63 | 0 | 44.46 | |
| day18 | 0 | 6.48 | sunny | 0.95 | 10.96 | 109.61 | 104.13 | 0 | 40.34 | 100 |
| day19 | 0 | 7.50 | sunny | 0.95 | 8.43 | 84.35 | 80.13 | 0 | 60.21 | 100 |
| day20 | 0 | 7.09 | sunny | 0.95 | 7.41 | 74.11 | 70.41 | 0 | 89.80 | 100 |
| day21 | 0 | 5.79 | sunny | 0.95 | 6.19 | 61.91 | 58.81 | 0 | 30.98 | |
| day22 | 0 | 7.19 | sunny | 0.95 | 8.72 | 87.24 | 82.87 | 0 | 48.11 | 100 |
| day23 | 0 | 7.06 | sunny | 0.95 | 7.23 | 72.29 | 68.67 | 0 | 79.44 | 100 |
| day24 | 0 | 7.01 | sunny | 0.95 | 8.27 | 82.75 | 78.61 | 0 | 0.83 | |
| day25 | 0 | 6.96 | sunny | 0.95 | 9.87 | 98.71 | 93.78 | 0 | 7.05 | 100 |
| day26 | 0 | 7.06 | sunny | 0.95 | 9.66 | 96.63 | 91.80 | 0 | 15.25 | 100 |
| day27 | 0 | 5.96 | sunny | 0.95 | 6.05 | 60.47 | 57.45 | 0 | 57.81 | 100 |
| day28 | 0 | 6.20 | sunny | 0.95 | 7.03 | 70.28 | 66.77 | 0 | 91.04 | 100 |
| day29 | 0 | 6.94 | sunny | 0.95 | 9.94 | 99.43 | 94.46 | 0 | 96.58 | 100 |
| day30 | 0 | 6.11 | sunny | 0.95 | 7.36 | 73.60 | 69.92 | 0 | 26.65 | |

DECEMBER

| day | rainfall (l) | radiation (MJ $m^{-2}$ $day^{-1}$) | weather | $k_c$ | $ET_o$ (l) | $ET_o$ (l) per10$m^2$ | $ET_c$ (l) per10$m^2$ | Rain (l) | ASMAD | Irrigation (l) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 26.45 | |
| day1 | 0 | 4.08 | half-overcast | 0.95 | 4.36 | 43.56 | 41.39 | 0 | 85.06 | 100 |
| day2 | 0 | 4.51 | sunny | 0.95 | 5.01 | 50.14 | 47.63 | 0 | 37.44 | |
| day3 | 0 | 5.49 | sunny | 0.95 | 8.60 | 86.00 | 81.70 | 0 | 55.74 | 100 |
| day4 | 0 | 7.19 | sunny | 0.95 | 8.67 | 86.67 | 82.33 | 0 | 73.40 | 100 |
| | | | | | | | | | | **HARVEST** |