CHAPTER 9

PREDICTING CROP WATER REQUIREMENTS FOR POTATOES AND ONIONS GROWN AT DIFFERENT LOCATIONS IN ETHIOPIA USING THE SOIL WATER BALANCE MODEL

9.1 Introduction

Irrigation scheduling is an activity of optimum water supply for crop productivity, by managing soil water close to the field capacity or within a limited allowable depletion level (Jones, 2004; Shock, 2004). Broner (2005) explains that irrigation scheduling is the decision of when and how much water to apply to a field. The same author further explains that the purpose of irrigation scheduling is to maximise irrigation efficiency by applying the exact amount of water needed to replenish the soil water to the desired level and save water and energy. Before irrigation scheduling is attempted, however, it is essential to determine crop water requirements, or the depth of water needed to meet the water loss through evapotranspiration (ETcrop) (Doorenbos & Pruitt, 1992). The same authors explain that the effects of climate, crop characteristics and local agricultural conditions have to be taken into consideration when calculating ETcrop. The effect of climate on crop water requirements is given by the ETo, which refers to "the rate of evapotranspiration from an extensive surface of 8-15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water" (Doorenbos & Pruitt, 1992). Hence, ETo is calculated using either the Blaney-Criddle, Radiation, Penman or Pan Evaporation method (mm day^{-1}) from mean daily climatic data (Doorenbos & Pruitt, 1992). The choice of method is primarily based on the type of climatic data available and on the accuracy required in determining water needs (Doorenbos & Pruitt, 1992). The same authors further explain that, for areas where measured data on temperature, humidity, wind and sunshine duration or radiation are available, the Penman-Monteith method provides the most satisfactory results. The effect of crop characteristics on crop water requirements is expressed by the crop coefficient (Kc) which reveals the relationship between ETo and ETcrop:

$$ETcrop = kc*ETo \qquad (9.1)$$

The value of kc varies with the crop type, its growth stage, growing season and prevailing weather conditions.

The computation of crop water requirement is significantly influenced by variations within a location and the agricultural practice specific to a given area. These include climate variations over time, altitude, field size, soil water content, advection, soil constraints, variations in cultivation and method of irrigation. Under such circumstances, however, field data specific to each location need to be compiled before crop water requirement is determined.

During early stages of irrigation scheduling, climate was solely used as a source of input data. As irrigation science continued developing, however, the soil water monitoring and plant stress sensing also became an important option of irrigation scheduling (Jones, 2004). Currently, the development of models for irrigation scheduling is one of the latest breakthroughs in irrigation science. The SWB model which combines a detailed description of the soil-plant-atmosphere continuum, making use of weather, soil and crop management data (Annandale *et al.*, 1999), is one example of such a model.

The irrigation regimes in the Ethiopian traditional schemes were not monitored for the past several years. A survey conducted to identify the amount and interval of water application on a pilot irrigation scheme, Godino, identified two irrigation regimes (Chapter 3). Due to the low crop yields obtained from these two irrigation practices, it was necessary to evaluate these practices in comparison with two other scientific scheduling methods using potato crop, one of the popular crops produced under irrigation, next to onions. The results showed that both traditional irrigation regimes were found to be significantly inferior to the scientific methods, SWB and re-filling SWD to field capacity as monitored by the neutron water meter (NP) (Chapter 4). This emphasized the need for improvement of the existing farmer practices, or replacement by one of the scientific methods that performed better during the comparison. Since the NP method requires basic data processing skills and would have unaffordably high initial costs to farmers, the SWB model, which is simple to use, was suggested to replace the traditional practice at the Godino scheme. Therefore, this chapter is dedicated to guide the extension agents and researchers on how to develop an irrigation schedule from average minimum and maximum temperatures for the two major crops produced at Godino. The work has covered about five locations where these two crops are mainly grown under traditional irrigation. Hence, the objective of this work was to develop. Irrigation calendars, using the SWB model, for five different locations for potato and onion crops. This help should extension agents to replicate the process for other crop species, planting dates and agro-ecological zones.

9.1.1 Potato water requirements

Potatoes (*Solanum tuberosum* L.) are water stress-sensitive crops with a shallow active root zone compared to other field crops (Tomasiewicz *et al*., 2003; CSIDC, 2005).

Water is one of the most detrimental limiting factors to potato growth, yield and quality, which is why farmers frequently apply water in amounts that exceed actual ET losses (David *et al.,* 1983; Trebejo & Midmore, 1990). The complex physiological response to water stress makes this crop sensitive to even moderate plant water deficits (Epstein & Grant, 1973; Bradley & Stark, 2005). Evaporation of water from within the leaves serves to cool the leaves, resulting in a plant canopy temperature below air temperature under well-watered conditions (Trebejo & Midmore, 1990). Stomata closure under deficit water conditions reduces further water losses and is an indication of reduced transpiration to cool the leaves, which results in a reduction of carbon dioxide diffusion into the leaves. Less carbon dioxide diffusion into the leaf restricts the duction of the photosynthetic products, starch and sugar, and their translocation from the leaf to tubers (David *et al*., 1983).

Water stress during active growth of the potato also restricts the expansion of leaves, stems and tubers. This is directly related to the reduction of internal water pressure in plant cells, which is mainly responsible for the expansion of plant organs (Tourneux *et al.,* 2003). Reduced root expansion of potatoes result in limited uptake of plant nutrients, which further limits the growth and development. Once growth is restricted, other forms of physical and quality deteriorations may result, mostly the disruption of the normal tuber expansion rate, which progressively results in tuber malformation such as pointed ends, dumbbells, bottlenecks and knobs (Tourneux *et al.,* 2003;

Bradley & Stark, 2005). Growth cracks are also associated with wide fluctuations in soil water availability and corresponding changes in tuber turgidity, as well as the volume of internal tissues (Bradley & Stark, 2005).

The effect of water stress on potatoes is manifested differently at various growth stages. One of the morphological manifestations of water stress on potatoes is a reduction in leaf size, which results in a reduction in the amount of intercepted radiation and leads to a decrease in tuber dry mass accumulation (Jefferies *et al.*, 1993). Reduced leaf growth and accelerated leaf senescence are common responses to water deficit and could be an adaptation of plants to water deficit (Lahlou *et al.*, 2003). Generally, drought-stressed crops exhibit slower and less canopy expansion and earlier senescence than irrigated crops (Jefferies *et al.*, 1993).

During tuber bulking, soil water shortage affects total tuber yield more than quality. A large photosynthetically active leaf surface area is necessary for extended periods to maintain high tuber bulking rates. Maintenance of this large active leaf surface area requires continued development of new leaves to replace older ones and others that are less efficient. Hence, water stress hastens leaf senescence and interrupts new leaf formation, resulting in an unrecoverable loss of tuber bulking (Juzl & Stefl, 2002).

Not only the soil water shortage, but also excess water can significantly affect the yield and quality of potato. Bradley and Stark (2005) indicate that excess soil water, due to intensive rainfall and/or too frequent irrigation during any growth stage, leaches nitrate nitrogen below the plant root zone, potentially resulting in deficiency of nitrogen in the plant, reduced efficiency of fertiliser use and an increased hazard to groundwater. Prolonged saturation of the soil profile can cause root damage, due to the lack of the oxygen required for normal respiration. Excess soil water, especially during planting, must be avoided as it promotes seed piece decay and delays emergence because of decreased soil temperature. In general, over-irrigated potatoes during vegetative growth and tuber initiation are liable to quality deteriorations and early-die problems. Overall, excess irrigation of potatoes can lead to poor storage conditions and finally result in low dry matter percentage (Juzl & Stefl, 2002; Bradley & Stark, 2005).

9.1.2 Water requirements of onions

Onions (*Allium cepa* L.) are also a shallow rooted crop and sensitive to water stress conditions. Water stress in onions before bulbing results in stunting the plant, which causes it to form small-sized bulbs that are below market standards (Singh & Alderfer, 1966). The same authors also explain that extended water stress after bulbing induces plant re-growth and other quality deteriorations see (Chapter 7).

9.1.3 Irrigation management

Monitoring soil water in the crop root zone would allow better management of water application to meet crop requirements. However, direct measurement of soil water in the field is tedious on large-scale production levels. Other approaches that are most accurate require an understanding of the soil-plant-atmosphere continuum as mechanistically as possible (Annandale *et al.,* 1999). Hence, crop water use is best described by considering the supply of water from the soil root system and the demand from the canopy atmosphere (Singh *et al.*, 1990). The atmospheric demand is best estimated by the Penman-Monteith reference crop evapotranspiration equation

(Smith *et al.*, 1996), together with a mechanistic crop growth model, such as SWB, which uses soil water and grows a realistic canopy and root system.

9.1.4 The Wetting Front Detectors (WFD)

The SWB model can generate Irrigation Calendars based on the long-term average daily minimum and maximum temperatures. Under some circumstances, however, the actual environment could change and may not be represented by average long-term temperatures. Such events are quite prevalent in Ethiopia, and occur for about once in five years to up to three times in ten years. Under such unique circumstances, however, a simple tool could be used to correct the developed irrigation calendar. It is known as the Wetting Front Detector (WFD) (Stirzaker, 2003).

The WFD is a device that could be used in conjunction with SWB Irrigation Calendars for irrigation scheduling. While the SWB model develops an irrigation schedule from long-term daily mean minimum and maximum temperatures, the WFD, installed at shallow and deep layers, indicates the vertical movement of applied water for correcting the next watering depth. The detector, a funnel-shaped device, is buried open end up in the soil and works on the principle of convergence (Stirzaker, 2003). As the wetting front moves into the wide opening of the funnel, the flow lines are converged, so that the water content increases towards the base of the funnel (Stirzaker, 2003). The free water produced at the base of the funnel is collected in a chamber and raises a float through a PVC pipe leading to the ejection of the float, indicating the reach of the front. The device can be reset by extracting the water inside the chamber, using a syringe via an extraction tube and, if necessary, it can be used for nitrate or salinity appraisal (Stirzaker, 2003).

9.2 Materials and methods

Irrigation Calendars were developed using the SWB model for five different locations of Ethiopia, namely Bako, Debre-Zeit, Melkassa, Zeway and Shashemene. Long-term average daily maximum and minimum temperatures of the relevant locations were used as input data for the schedule. In addition, data on soil water characteristics, initial soil water content, bulk density, crop species and planting date, irrigation system and frequency, and management options were also used for developing the calendars. For this particular work, a furrow system was considered at a fixed interval of seven days and the planting date determined as 1 January. Prior to developing the calendars, crop growth parameters were determined for potatoes and onions (Chapter 8) – the major irrigated crops for the considered locations – so that the SWB model could soil water balance for these crops.

The irrigation interval during the scheduling period is assumed to be every seven days and any rainfall during this interval would be recorded and deducted from the recommended application depth. The efficiency of rainfall is very high compared to irrigation, especially for the furrow system. Hence, rainfall amounts of more than 60% of the predicted depth could be regarded as one irrigation, which means that the next irrigation could be skipped. Under conditions where WFDs are used to correct the irrigation amount according to the response, increasing or decreasing (response factor) of 20% of the predicted water amount would be considered.

9.3 Results and discussion

Tables 9.1 and 9.2 show the Irrigation Calendar developed by the SWB model to replace the traditional farmer practice, which was found to be significantly inferior in performance compared to the more scientific schedules. Irrigation Calendars developed for the same location of similar climate, soil characteristics and management varied with crop variation (Tables 9.1 & 9.2 and Tables A1-A8). Potato crops required less water per application compared to onion crops under the same climate and soil conditions. The number of irrigations required up to maturity is also lower for potatoes than for onions grown under similar conditions. Researchers (Scherer *et al*., 1996) agree that the water requirement of different crops planted at the same location, under identical climate and soil conditions could be attributed to the growth stage and the variation in the rooting system. Different crops reach their particular growth stage and full cover at different times after planting. As the crop coefficient (kc) varies between crops and at different growth stages, both the ETo and kc result in varying water requirements of different crops grown under the same conditions. On the other hand, plants can extract only the soil water that is in contact with their roots. Plants with a high root density per unit soil volume may be able to absorb all available soil water (Al-Kaisi & Broner, 2005). The same authors explain that other plants with a low root density may not be able to obtain much water from an equal volume of the same soil. Hence, this explains why the irrigation requirements of potatoes and onions grown at the same location of identical climate varied for each irrigation interval and across the growth stages.

The irrigation calendar developed for the same crop grown at different locations also varied due to the major change in climatic conditions (Tables 9.1 & A1). Even though the minimum and maximum temperatures were used as an input for the climate data, the SWB model estimates the remaining factors for different altitude and latitude changes (Annandale *et al*., 1999). Scherer *et al.* (1996) further explain that the same crop's water requirement variation for different locations is very much dependent on climatic variables, that is, air temperature, amount of sunlight, humidity and wind speed. Hence, the variation observed among locations is mainly due to the variation in ET of the same crop, caused by the climate changes. This, once again, confirms that the irrigation schedule predicted for potatoes and onions, which differ from one location to another, was due to the climatic differences detected by the SWB scheduler. Therefore, the varied irrigation requirements observed between potatoes and onions across locations are mainly attributed to the variation in crop characteristics and the prevailing climatic conditions.

Table 9.1 Irrigation calendar output as recommended by SWB scheduler, using potato crop for Debre-Zeit climate and soil conditions

IRRIGATION CALENDAR

Farmer:
Field: Debre-Zeit
Soil type: Sandy clay loam
Irrigation system: Furrow
Management options: Fixed, every seven days
Irrigation frequency option: Interval (Days)

Crop: Potato (Awash)
Planting date: 01/01/2006
Wetting Front Detectors:
Shallow: 4
Deep: 4
Response factor (%): 20

Date and Day	* Irrigation requirement (IR), depending on number of shallow and deep Wetting Front Detector (WFD) responses			Rain since previous irrigation (mm)	Recommended irrigation amount = IR-Rain
	0-2 Shallow and 0-2 Deep	3-4 Shallow and 0-2 Deep	3-4 Shallow and 3-4 Deep		
	Irrigation requirement (mm)				
5 Jan 2006		119			
12 Jan 2006	33	26	18		
19 Jan 2006	33	26	18		
26 Jan 2006	33	26	18		
2 Feb 2006	37	29	20		
9 Feb 2006	40	31	21		
16 Feb 2006	48	37	25		
23 Feb 2006	57	44	30		
1 Mar 2006	64	50	35		
8 Mar 2006	68	53	37		
15 Mar 2006	70	54	37		
22 Mar 2006	70	54	37		
29 Mar 2006	70	54	37		
5 Apr 2006	70	54	37		
12 Apr 2006	66	51	35		
19 Apr 2006	57	44	30		
25 Apr 2006	40	31	21		

*** Notes**

- Just before irrigation, check Wetting Front Detector response (to the previous irrigation) and use to correct the irrigation requirement.
- Encircle the applicable irrigation requirement, based on WFD response.
- If 0-2 shallow 3-4 deep WFDs have responded, check your shallow WFDs for problems.
- Record rain and empty gauge just before irrigation.
- Subtract rainfall from irrigation requirement to obtain the irrigation amount.
- If IR-rain<0, then skip the irrigation, i.e. irrigation amount = 0.

Table 9.2 Irrigation calendar output as recommended by SWB scheduler, using onion crop for Debre-Zeit climate and soil conditions

IRRIGATION CALENDAR

Farmer: Crop: Onion (Texas Grano)
Field: Debre-Zeit Planting date: 01/01/2006
Soil type: Sandy clay loam Wetting Front Detectors:
Irrigation system: Furrow Shallow: 4
Management options: Fixed, every seven days Deep: 4
Irrigation frequency option: Interval (Days) Response factor (%): 20

Date and Day	* Irrigation requirement (IR), depending on number of shallow and deep Wetting Front Detector (WFD) responses			Rain since previous irrigation (mm)	Recommended irrigation amount = IR-Rain
	0-2 Shallow and 0-2 Deep	3-4 Shallow and 0-2 Deep	3-4 Shallow and 3-4 Deep		
	Irrigation requirement (mm)				
1 Jan 2006		60			
8 Jan 2006	45	35	24		
15 Jan 2006	45	35	24		
22 Jan 2006	48	37	25		
29 Jan 2006	48	37	25		
5 Feb 2006	51	40	28		
12 Feb 2006	55	43	30		
19 Feb 2006	61	47	32		
26 Feb 2006	68	53	37		
4 Mar 2006	75	58	40		
11 Mar 2006	77	60	42		
18 Mar 2006	77	60	42		
25 Mar 2006	77	60	42		
1 Apr 2006	77	60	42		
8 Apr 2006	77	60	42		
15 Apr 2006	77	60	42		
22 Apr 2006	77	60	42		
29 Apr 2006	77	60	42		
6 May 2006	77	60	42		
13 May 2006	77	60	42		
20 May 2006	77	60	42		
27 May 2006	77	60	42		
3 Jun 2006	75	58	40		
5 Jun 2006	23	18	12		

*** Notes**

- Just before irrigation, check Wetting Front Detector response (to the previous irrigation) and use to correct the irrigation requirement.
- Encircle the applicable irrigation requirement, based on WFD response.
- If 0-2 shallow 3-4 deep WFDs have responded, check your shallow WFDs for problems.
- Record rain and empty gauge just before irrigation.
- Subtract rainfall from irrigation requirement to obtain the irrigation amount.
- If IR-rain<0, then skip the irrigation, i.e. irrigation amount = 0.

The Wetting Front Detectors could be used in conjunction with the Irrigation Calendar developed by SWB (Tables 9.1 & 9.2 and Tables A1-A8). The WFDs installed in the representative area of the field indicate the physical movement of water in the profile, revealing a shortage of water and the adequacy or excess water applied during the previous application. The SWB model sometimes predicts less or an excess water amount where the supplied long term climate, soil and plant data are not accurate enough. The data on soil characteristics always remain less accurate, due to the high heterogeneity of soils within the small unit area in the farm. Hence, the use of WFDs avoids crop water stress induced due to under-prediction. It also prevents excess water application under conditions of over-prediction, which further avoids leaching of nutrients below the crop root zone that could pollute the groundwater.

The SWB scheduling output is very flexible and could be varied according to the preference of the individual user. A fixed irrigation interval of seven days was used in developing these irrigation calendars. However, users can also accept the intervals predicted by the model, when fixed amount or depletion % are selected.

Generally, the SWB model predicts an appropriate irrigation depth and interval once the farmer has determined the allowable depletion level for each growth development stage. Similarly, different planting dates, irrigation systems, soil types, management options, crop species and cultivars could be accommodated successfully. The SWB model can be applied under full-irrigation conditions, as well as for supplementary irrigation. It also indicates the critical crop growth stage and level of yield reduction, so that the farmer could select the growth stage at which irrigation is most important under limited irrigation conditions.

9.4 Conclusions

The experiment conducted on the comparison of four irrigation-scheduling methods revealed that the two traditional irrigation scheduling practised by the community irrigation schemes were significantly inferior to the two scientific methods (Chapter 4). From this result, it was suggested that the poor scheduling methods be improved or replaced by more efficient and affordable irrigation water management techniques. Hence, the SWB scheduler, that delivered a good performance and was affordable for farmers, was recommended to replace the traditional practice.

Therefore, the SWB model was used to generate irrigation calendars for five agro-ecological areas of Ethiopia for potatoes and onions. The SWB model predicted the irrigation calendar for five locations, namely Debre-Zeit, Melkassa, Bako, Zeway and Shashemene. The results revealed that the predicted irrigation amount and intervals varied between the two crops planted under the same conditions, because of different rooting systems for water uptake and length of growing conditions. On the other hand, the developed irrigation calendar also differed from one location to another, because of varying climate conditions: air temperature, amount of solar radiation, humidity and wind speed. The irrigation prediction, using the SWB model, should be performed separately for various climate conditions, planting dates, plant species, cultivars and soil types.

CHAPTER 10

GENERAL CONCLUSIONS AND RECOMMENDATIONS

10.1 General conclusions

Traditional irrigation has been practised since time immemorial in Ethiopia. The country is known to have adequate land and water resources for irrigation, but only a small area of land is being used at present. The current irrigation practice in the country are still not advanced and no one even knows how much water to apply and how often farmers are applying it. A survey on one of the traditional irrigation schemes, Godino, was conducted with the objective of monitoring the amount and interval of water application on traditional irrigation schemes, and identifying major constraints on the irrigated agriculture. The results revealed that irrigation depth varied from less than 30 mm to more than 60 mm, regardless of crop species and growth stage. Similarly, the watering interval on the scheme varied from 7-14 days without considering the crop species and maturity group. Furthermore, the crop productivity level under traditional water management was found to be very low for irrigated agriculture. This has led to the conclusion that most crops under this practice could be water-stressed due to low water depth per application and too long irrigation intervals, resulting from limited irrigation water supplied by the scheme.

The lack of strong commitment in the social structures responsible for water distribution was evident, as water was allocated on the basis of friendship or priority given to committee members. Even though the social aspect of this study is recommended to be dealt with by the appropriate professionals, was deemed necessary to evaluate the performance of traditional water management practices in comparison with more scientific irrigation management techniques.

Most farmers rated irrigation intervals, application depth and when to stop water application as their major constraints under the traditional irrigation practice. These constraints observed under traditional irrigation management need to be improved through research or replaced by effective and efficient water management techniques for better crop productivity.

Two average irrigation regimes observed under traditional farmer water management were evaluated in comparison with two other scientific irrigation water management techniques. The farmers' average irrigation regime included an application of 50 mm of water every 10 days (FTP) or an application of 60 mm of water every 6 days (RCP), which were evaluated in comparison with the SWB model scheduling and the soil water replenishment to field capacity depending on neutron water meter (NP) measurements. The overall result from the experiment deduced that both farmers' traditional irrigation regimes were significantly inferior to the scientific irrigation water management methods. Both the SWB and NP irrigation schedules were found to maintain good crop growth and final yield as compared to FTP and RCP under the furrow water management method, using a potato crop. The various growth components that contributed to yield and the fresh potato tuber yield confirmed that both traditional irrigation regimes proved to be inadequate in meeting crop water requirements as compared to the SWB and NP methods. The total water application revealed that the SWB scheduling resulted in the highest water use as compared to FTP, which was the lowest and resulted in relatively high water use efficiency.

Climate influences the growth and yield potential of crops across and within species. Potatoes are one of the crops that are affected by micro-climate and management conditions. Potato cultivars vary in the efficient use of climatic resources, such as solar radiation and temperature, as well as water, where some researchers agree that the growth of a potato crop is about proportional to its solar radiation absorption (Spitters, 1987; Van Delden, 2001). The total biomass production and accumulation of potato cultivars are dependent on the absorbed PAR, which is to a large extent related to the plant canopy cover (Vos & Groenwold, 1989). Not only the growth and yield, but also the processing quality of potatoes is greatly influenced by the genetic makeup of cultivars, the climate and biological property of soils (Brown, 1993). In view of this, four potato cultivars, namely Frodo, Pentland Dell, Darius and Shepody, were evaluated for their growth performance and processing quality under the same climate and management system. In addition, crop parameters were developed for these cultivars to model with SWB and generate irrigation calendars. The results revealed that potato cultivars differed in their growth performance and processing quality, even though they were grown under the same climate and management system. The dry matter partitioning into various plant parts (leaf, stem and tuber) strictly followed the growth rate of cultivars. The early maturing cultivar, Shepody, partitioned dry matter to different plant parts much earlier than the slow-maturing Frodo cultivar. The overall experiment revealed that high yield is not governed by the rate of crop growth and replacement of new leaves, but the LAD. Cultivars with a relatively longer growth period would have adequate time to collect a high proportion of solar radiation that is proportional to dry matter accumulation. Hence, Frodo, which is a slow-growing cultivar, produced a significantly higher dry matter and final tuber yield as opposed to the early cultivar, Shepody, which was the lowest yielder.

As far as tuber-processing quality is concerned, most cultivars were within the acceptable range of the USDA quality standards (USDA, 1997). However, for some particular qualities such as SG, Shepody was found to be unacceptably low. Generally, cultivars with better growth performance and yield also possessed superior tuber-processing quality, according to the USDA quality evaluation standard. Hence, the newly developed potato cultivar in South Africa, Frodo, was significantly superior in terms of growth performance, yield and tuber-processing quality.

The critical growth stage of crops to water stress is one of the important factors in irrigation management, especially under conditions of irrigation water constraint. Similarly, onions are one of the crops that responds differently to water stress at different growth stages. The result from the onion experiment exposed to water stress at different growth stages revealed that stress at any growth stage affected the growth and yield of onion bulbs to a different extent. Withholding water early after transplanting imposed little effect on onion growth and yield, but rather promoted deep root growth that probably helped capture maximum water, along with nutrients, from wider areas. On the other hand, water stress at bulb development and maturity stage was found to be critical for onion growth, with a significant reduction in growth performance and yield. Hence, under conditions of scarce irrigation water, onion producers have to avoid stressing onion crops at bulb development and maturity stage, that is, from 70-145 DAT for cultivar Texas Grano.

The SWB model simulations for potato and onion growth, development and yield were evaluated in comparison with the crop measurements collected in the experimental field for five potato cultivars and one water-stressed onion cultivar at different growth stages. The results revealed that model simulations fitted excellent by the measured data collected from the experiment for LAI and FI. For treatments grown under water-stress conditions, however, the simulated LAI and FI, had irregular (stepped) graphs. In addition, the model simulation for TDM and HDM also fitted very well the measurements, with a high accuracy of agreement, according to De Jager (1994). The SWD simulations for some experiments were either slightly underestimated or overestimated, resulting in less accuracy, according to the statistical parameters recommended by De Jager (1994). The SWB was successfully calibrated for potatoes and onions and could, therefore, be used to develop Irrigation Calendars for different areas of Ethiopia.

The irrigation schedules practised by the traditional farmers were found to be significantly inferior to the two scientific methods tested. It led to the suggestion that it needed to be replaced by a more efficient and productive schedule. The best performing schedule, the NP, involves high initial cost and also requires skilled personnel for data processing and interpretation, therefore the SWB model Irrigation Calendar was suggested to replace the traditional practice. Hence, Irrigation Calendars were developed for potato and onion crops grown in five different agro-ecologies of Ethiopia, using the SWB model. Results of the predicted calendars varied between the two crops grown under the same climate, soil and management options. The predicted calendar showed less water per application and a smaller number of irrigations for potatoes as compared to onions grown under the same conditions. Similarly, the water requirements of potatoes and onions were found to vary between locations because of the difference in climate and altitude. This suggested that the model was capable of producing different calendars for different crops at the same location, indicating the variation between crops in their water requirements under the same soil and climatic conditions. In addition, the model has also demonstrated that the water requirement of a crop varied from place to place accounting to the climate, soil and planting date. Therefore, it is envisaged that the SWB model prediction could successfully replace the poor performing traditional farmers' irrigation practice at irrigation schemes in Ethiopia. These can now be used as basis for development of irrigation calendars for different crops and locations by extension staff.

10.2 Recommendations

The traditional irrigation practised at the Godino scheme was found to be inefficient with poor water distribution, poor on-farm water application and overall low irrigation efficiency. During the survey conducted at the Godino scheme, results indicated that an improvement of the irrigation practise through research, or replacement by a system that is more efficient, would be desirable. In view of this, the following points were recommended for further improvement:

- The development of efficient water management technologies: when to irrigate, how much water to apply and how to irrigate are priorities to water users of the scheme;
- The development of high-yielding crop cultivars that would improve the economic feasibility of irrigation enterprises;
- The formation of a linkage with micro-processing units for agricultural productions to make irrigated agriculture sustainable;
- The training of farmers in general farm management, efficient water use and the use of appropriate inputs, mainly plant nutrients and market-oriented farming;

- The improvement of water users' organisational structures, their participation in water management and the strengthening of their bylaws, mainly for equitable water sharing.

The WFDs used in this experiment did not provide adequate information. It could be due to the fact that not much work has been done on its performance under the furrow irrigation method or on finer textured soils, for example, placement of WFDs, depths under furrow/flood conditions and particle sizes of filter materials. Hence, detail assessment on the performance of WFDs would be important in the future.