Training material for extension advisors in irrigation water management

Volume 2: Technical Learner Guide
Part 3: Agro climatology

JB Stevens, PS van Heerden & MC Laker

TT 540/3/12

WATER RESEARCH COMMISSION

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Report to the

Water Research Commission

University of Pretoria

NQF

Level 5

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Volume 3: Extension learner guide

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Before we start...............

Dear Learner ....this learner Guide contains information to acquire the basic knowledge and skills leading to the unit standard:

No registered unit standards

Assessment.........

You will be assessed during the course of the study (formative assessment) through the expected activities that you are expected to do during the course of the study. At the completion of the unit standard, you will be assessed again (summative assessment).

Assessment therefore takes place at different intervals of the learning process and includes various activities - some will be done before commencement of the program, others during the delivery of the program and others after completion of the program.

How to attend to the activities.......

The activities included in the module should be handed in from time to time on request of the facilitator for the following purposes:

- The activities that are included are designed to help gain the necessary skills, knowledge and attitudes that you as the learner needs in order to become competent in this learning module.
- It is important that you complete all the activities and worksheets, as directed in the learner guide and at the time indicated by the facilitator.
- It is important that you ask questions and participate as much as possible in order to be actively involved in the learning experience.
- When you have completed the activities and worksheets, hand it in so that the assessor can mark it and guide you in areas where additional learning might be required.

- Please do not move to the next activity or step in the assessment process until you have received feedback from the assessor.

- The facilitator will identify from time to time additional information to complete. Please complete these activities.

- Important is that all activities, tasks, worksheets which were assessed must be kept as it becomes part of your Portfolio of Evidence for final assessment.

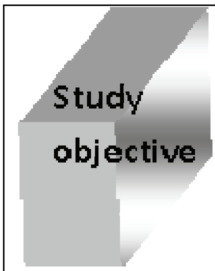
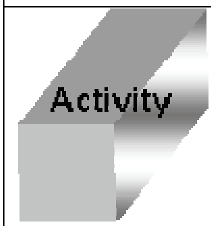
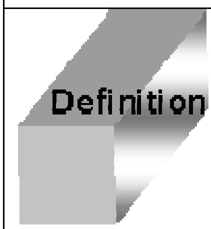
Check your progress.......

Use the following checklist to determine your competency regarding this specific learning module.

Confidence level	**I am sure**	**Still unsure**	**Do not understand and need help**	**Motivate your answer**
Can you identify problems and troubleshoot correctly?				
Are you able to work well in a team?				
Are you able to collect the correct and appropriate information required for decision making?				
Will you be able to perform the observation expected in an organised and systematic way while performing your task as an extensionist?				
Are you able to communicate the information and newly gained knowledge well to experts?				
Can you base your tasks and answers on scientific knowledge that you have learned?				
Are you able to show and perform the activities required in this learning module correctly				
Are you able to link the knowledge, skills and competencies you have learned in this module of learning to specific duties in your job?				

How to use this guide ………….

Throughout the learner Guide you will come across certain re-occurring notifications. These notifications each presents a certain aspect of the learning process, containing information, which would help you with the identification and understanding of these aspects. The following will be found in the learning material:

	What are the study objectives for a specific module? This provides an idea of the knowledge, skills and competencies that are envisaged to be
	You will be requested to complete activities, which could either be group or individual activities. Please remember that the completion of these activities is important for the facilitator to assess, as it will become part of your ***Portfolio of Evidence.***
	What does it mean? Each learning field is characterised by unique terminology and concepts. Definitions help to understand these terminology and concepts and to use it correctly. These terminology and concepts are highlighted throughout the learner guide in this manner.

My notes…………………………….

You can use this box to jot down some questions or notes you might have, concepts or words you do not understand, explanations by facilitators or any other remark that will help you to understand the work better.

What are we going to learn?

For each of the learning modules included in this learning area specific learning outcomes were set, which you need to be able to demonstrate a basic knowledge and understanding of.

Contents

Module 1: Introduction to climate and weather

Module 2: Solar radiation

Module 3: Temperature

Module 4: Heat units, chill units and day length (photoperiod)

Module 5: Frost

Module 6: Rainfall

Module 7: Evaporation, transpiration and evapotranspiration

Module 8: Vapour pressure deficit and relative humidity

Module 9: Hail, snow mist and dew

Module 10: Wind

Technical Learner Guide

Agro climatology

Level 5

Module 1

Introduction to climate and weather

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- Difference between weather and climate
- Four seasons as related to the earths' axis of rotation as it revolves around the sun
- Scale classification of climate into macro, meso and micro climate

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Climate is the key factor determining whether irrigation is required for successful production of any specific crop in a specific area. The importance of climate becomes evident when geographic precipitation (rainfall) patterns are studied. South Africa is a hot, dry country, with the average annual precipitation over 65% of its surface area being less than 500 mm, which is normally seen as the bottom boundary for successful rain fed crop production. Several crops have much higher rainfall requirements, the optimum for tea being over 1 000 mm per annum, for example. The seasonal nature of rainfall in many cases necessitates irrigation even in areas with high average annual rainfall. An example is the need for irrigation of deciduous fruit crops during the dry summers in districts in the winter rainfall area with high average annual rainfall, like Ceres, but with almost all the rain falling in winter.

Because South Africa is such a hot, dry country the average annual water loss to the atmosphere through evaporation and evapotranspiration is high. This further increases both the need for irrigation and the amounts of water required for irrigation.

Climate is also a key factor determining the suitability of any specific area for the successful production of a crop. Each crop has specific climatic requirements. Some of the most important factors in this regard include temperature, heat units, positive chill units, day length, relative humidity, frost, hail and wind.

The only way of producing higher yielding and higher value agricultural crops by means of irrigation in semi-arid and arid areas, is to increase the water supply. This can only be achieved by bringing water from more water-rich areas. Building storage dams for water and conveying the water to water scarce areas is expensive. Therefore water that has been imported into an area needs to be used as efficiently as possible. As climate is the cause and the driver of the water demand of crops, irrigators should have a thorough knowledge of the climatic factors that influence crop production.

1. Weather and climate

Weather is the day-to-day nature of local occurrences of climatic phenomena, such as temperature, precipitation, humidity, wind, frost, hail, light intensity, etc. Weather can be highly variable on a daily, weekly, monthly, or even yearly basis. This variability limits our ability to predict or forecast weather conditions more than a few days in advance. In practice detailed weather prediction is limited to about two weeks and even over this time span there is quite a degree of uncertainty.

In any location the above-mentioned phenomena assume a certain general seasonal pattern that is repeated year by year. The long-term general seasonal weather pattern is a location’s climate. The long-term averages for different climatic parameters are calculated and given in tables. Maps indicating areas with similar climate are constructed. Although the climate of a locality assumes a certain general pattern, the actual values vary from year to year. Some winters are colder than others, some summers get more rain than others, etc. Thus, climatic tables and maps should include not only the average values of the climatic parameters, but also their ranges, variability, and the frequency of various occurrences.

Perhaps the best known and clear cut example of longer-term climate predictability is El Niño, which is predictable at least six months in advance. There is some evidence that some aspects of climate are predictable on even longer time-scales. Cognisance should, for example, be taken of cyclical variations of some climatic parameters, e.g. periods of several successive years with far above average rainfall followed by periods of several successive years with far below rainfall (prolonged droughts) are common in South Africa. These have impacts on irrigation demands and especially on the assurance of water supply for irrigation. Climate records allow one to predict with some accuracy the climate of a given area for a certain time of the year, and using knowledge of crops, also predict which crops can be grown successfully where and what production practices need to be followed to reduce the risk of partial or complete crop losses.

1.1 The four seasons

The earth revolves once in 24 hours around its own axis, thus giving our 24-hour days. Another important motion of the earth is its revolution around the sun. The earth completes one revolution around the sun in 365.24 days, or one year. The decimal of the revolution time is corrected every four years when one day is added to the calendar in a leap year.

The four seasons are related to the orientation of the earth's axis of rotation as it revolves around the sun. The earth's axis is tilted at an angle of 23.5° from the perpendicular. The direction of this angle does not change as the earth revolves around the sun and this causes the spring, summer, autumn and winter seasons, as well the related two solstices and two equinoxes (Figure 1). A solstice is either of the two moments in the year when the sun's apparent path is furthest north or south from the equator. In the southern hemisphere, and thus also in South Africa, the winter solstice occurs on June 21, when the sun's apparent path is the furthest south from the equator. On this date the winter day length is in the southern hemisphere the shortest of the year and the night length the longest. During the southern hemisphere's winter period the angle between the sun and the earth surface in the southern hemisphere is such that a certain bundle of sun rays covers a relatively wide area, thus delivering less heat per unit area. The latter, combined with the shorter day lengths in winter, cause the lower temperatures in winter. In the southern hemisphere, and thus also in South Africa, the summer solstice is on December 22. On this date the summer day length is in the southern hemisphere the longest of the year and the night length the shortest. During the southern hemisphere's summer period the angle between the sun and the earth surface in the southern hemisphere is such that a certain bundle of sun rays covers a relatively narrow area, thus delivering more heat per unit area. The latter, combined with the longer day lengths in summer, cause the higher temperatures in summer. The situation is exactly the opposite in the northern hemisphere, where the seasons are reversed.

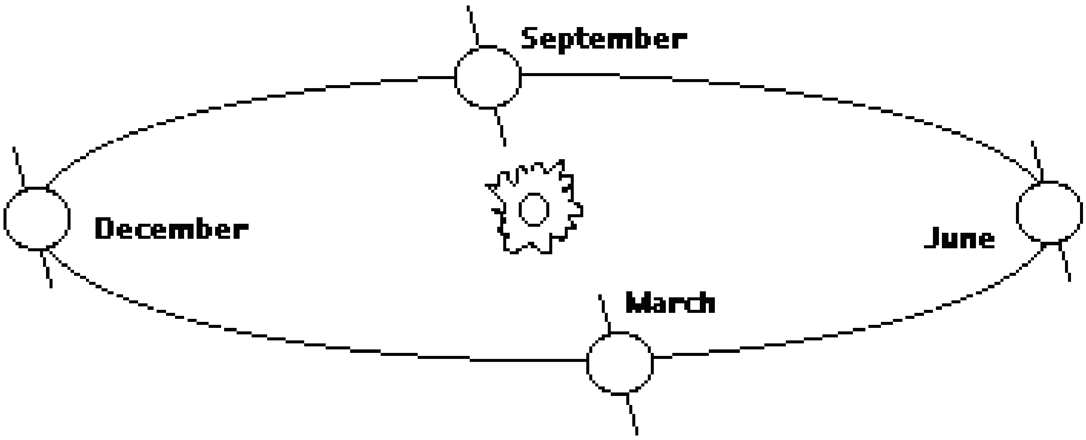

Figure 1. Schematic diagram showing earth's orbit around the sun and the 23.5° angle of the axis that causes our seasons.

The months in which the solstices or equinoxes take place, are approximately the starting points of the four seasons[10)]. Therefore, in the southern hemisphere the start of spring is the month September (vernal equinox is 21 September), the start of summer is the month December (December solstice is 22 December), the start of autumn is March (autumn equinox is 21 March) and the start of winter is June (June solstice is 21 December).

1.2 Scale classification of climate

Definition

Macro = Large. Large geographic areas are mapped together as having similar climate on small-scale maps.

Meso = Medium. Medium-sized geographic areas are mapped together as having similar climate on medium-scale maps.

Micro = Small. Micro-climate refers to a climate that is characteristic of a small to very small area on the land or even at different heights above a small to very small land area. Here one can actually refer to climate that is the same over such small area and not just similar.

1.2.1 Macro-climate

Macro-climate refers to climate mapped at a broad, e.g. national (country) scale. Large areas with similar types of climates, but with wide ranges in permissible average values are grouped together in mapping units and delineated on the map. These can be classifications based on combinations of several climatic parameters, e.g. the Köppen climate zones. It can also be classifications for individual parameters, e.g. temperature or rainfall, e.g. the maps in the "South African Atlas of Agro hydrology and – climatology" by Schulze[8)].

Classification and mapping of macro-climate zones enable general interpretation of the possibility to grow certain crops in certain broadly defined and delineated areas. This does not say that the climate over the whole of an area mapped out as falling within a specific macro-climatic zone is suitable for the growing of a specific crop in that zone. Meso-climate differences may preclude growing of the crop in some areas. Conversely, areas with a certain meso-climate or micro-climate may be suitable for the growing of a crop for which the macro-climate zone is apparently not suitable.

1.2.2 Meso-climate

Meso-climate refers to localised climate. Several types of meso-climate are usually found within any specific macro-climate zone. These are defined according to narrower permissible ranges in average values (narrower class limits) than in the case of macro-climate classification and mapped at medium scales.

The climatic characteristics of meso-climates and their geographic distribution are usually mainly determined by topography. This is most strikingly seen in areas with low mountains or steeply undulating hills, especially east-west running low mountains. Meso-climates around the Magaliesberg, running east-west from Pretoria past Rustenburg provide an excellent example: The middle slopes on the northern side of the mountain are much warmer than the middle slopes on the southern side of the mountain, as is the case in all similar scenarios. These are then two different meso-climates. There are two reasons for the higher temperatures of the northern slopes. The most important is these slopes are facing towards the sun. Thus, a certain bundle of sun rays covers a relatively narrow area, thus delivering more heat per unit area. On the southern slope a similar bundle of sun rays covers a much wider area, thus delivering less heat per unit area (Figure 2).

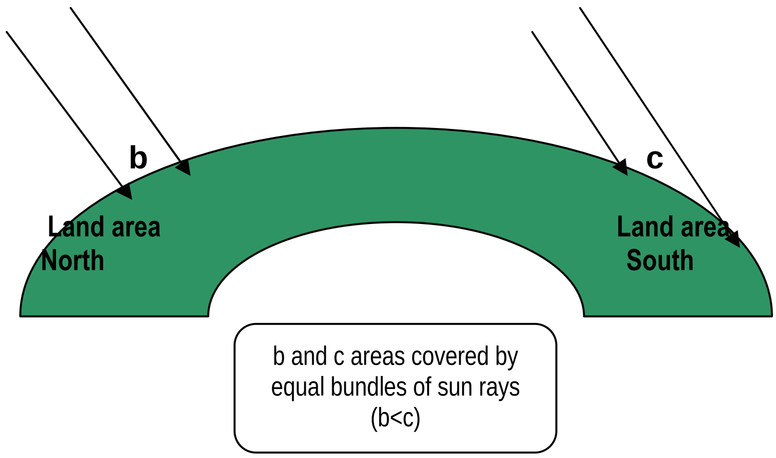

Figure 2. Illustration of mechanism whereby northern slopes are warmer than southern slopes in South Africa

Secondly, the northern slopes have longer sunshine hours, especially in winter when the angle of the sun is low. The southern slopes remain in the shadow of the mountain longer in the mornings and go into the shadow again earlier in the afternoon.

The northern slopes of the Magaliesberg are frost-free and year-round have temperatures that are high enough to enable successful production of citrus and subtropical crops successfully under irrigation. In gardens even ornamental shrubs from the KwaZulu-Natal coastal areas are grown successfully. The lower-lying foot slopes on the northern side of the Magaliesberg have a completely different climate from the middle slopes. The winters are cold and frost is prevalent, making this area unsuitable for the growing of subtropical crops. This represents a third different meso-climate associated with the Magaliesberg mountain range. The differences between the middle slopes and foot slopes on the northern side of the mountain is due to an effect called "temperature inversion" that occurs during winter. During the night the heavy cold air seeps down to the foot slopes and the lighter warmer air rises up the middle slopes. On the southern side a similar process occurs, but the effect is less striking.

It can be seen that a thorough knowledge of the meso-climate of an area is absolutely essential for successful irrigation planning and management.

1.2.3 Micro-climate

Micro-climate differences are often natural features associated with small areas. Temperature inversion causing damaging frosts near the bottom of relatively small hill slopes in some areas in winter is a well-known example. It is, for example, seen in some apple and pear orchards in the Koue-Bokkeveld, near Ceres in the Western Cape.

The microclimate of an irrigated field in a semi-arid or arid area differs vastly from the climate of the surrounding non-irrigated area, especially in desert areas. Irrigation management (systems and strategies) can be used to modify the micro-climate in an irrigated field (especially orchards and vineyards) so as to create the most favourable conditions for optimum production. Incorrect and injudicious management can, however, create very unfavourable conditions. An irrigator must be aware of both the favourable and harmful conditions that can be created. These will be discussed in detail in later modules.

Activity

ACTIVITY 1

Individual activity

1. Explain the difference between "weather" and "climate"
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   ....
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2. Explain how the monthly subdivision into the four seasons – summer, autumn, winter and spring are caused
   ……………………………………………………………………………………………………
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3. Explain the difference between macro, meso and micro climate.
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4. Why do you think are the northern slopes warmer than southern slopes?
   Why is it important for the irrigation advisor to understand these differences?
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   ……………………………………………………………………………………………………
   ……………………………………………………………………………………………………

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My notes............

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Authenticator:

- Prof S Walker

Agro climatology

Level 5

Technical Learner Guide

Module 2

Solar radiation

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- Factors affecting solar duration
- Factors affecting the solar radiation intensity
- The importance of solar radiation in agriculture
- Effects of solar radiation on plants and agriculture

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2. Factors affecting the duration of insolation 3

3. Factors affecting the intensity of solar energy (insolation) 3

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3.2 Factors that have both long- and short-term and only variable short-term effects on the intensity of solar radiation 4

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4.2 Solar radiation and photosynthesis 7

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Definition

Over 99.97% of all energy in the earth's atmosphere originates from radiation by the sun, i.e. from solar radiation. The sun radiates at a temperature higher than 6000°C. The radiation is produced through a process of nuclear fusion, in which hydrogen is converted to helium. In the process some of the mass of the sun is converted to energy. The radiation consists of electromagnetic waves travelling at the speed of light in a broad spectrum of wavelengths ranging from short (ultraviolet) through the visible light spectrum to long (infrared). Solar radiation is expressed in $MJ.m^{-2}.day^{-1}$.

The solar radiation received at the earth's surface consists of two basic components, viz. direct beam solar radiation and diffuse sky radiation:

- Direct beam solar radiation is a measure of the rate of solar energy arriving at the earth's surface from the sun's direct beam, on a plane perpendicular to the beam. Direct beam solar radiation is very intense.

- Diffuse sky radiation (sometimes also called diffuse solar radiation or radiation in the shade) is the result of the atmosphere reducing the intensity of the sun's beams. Some of the energy removed from the beam is redirected or scattered towards the ground. The rate at which this energy falls on a unit horizontal land surface is called the diffuse sky radiation (or diffuse solar radiation). Diffuse sky radiation is less intense than direct beam radiation, but does contribute as much as 30% of the total solar radiation (also termed "insolation") in parts of South Africa.

Variations in the amount of solar radiation in time and space cause all atmospheric movement and change, and are thus ultimately the generator of all weather and climate.

1. Factors affecting solar radiation

Several factors affect the amount of solar radiation received in any specific area or locality. These include factors that:

- Cause spatial differences between different areas/localities as different long term averages and/or

- Cause different long term average seasonal patterns between areas/localities and/or

- Cause short term (day/week/month) weather patterns.

The total amount of solar radiation (insolation) received at any specific locality depends on two factors, *viz.* (a) the duration of insolation on a given day, i.e. length of the daylight hours, and (b) the intensity of solar energy.

2. Factors affecting the duration of insolation

The duration of insolation on a given day at any locality is determined by a combination of latitude (distance from the equator) and the time of year (season). In summer, when the particular hemisphere is angled towards the sun, the duration of insolation per day increases with increasing latitude (increasing distance from the equator). For example, in summer the duration of insolation per day (daylight hours) is significantly longer at Cape Town than at Johannesburg, because Cape Town is at higher latitude. Because South Africa falls in mid-latitudes its average duration of insolation during summer is much shorter than its duration in Canada and Europe during their summer, because the latter are at higher latitudes. At the poles the sun never sets in the middle of summer.

In winter, when the particular hemisphere is angled away from the sun, the situation is reversed, i.e. the duration of insolation per day decreases with increasing latitude (increasing distance from the equator). For example, in winter the duration of insolation per day (daylight hours) is significantly shorter at Cape Town than at Johannesburg, because Cape Town is at higher latitude. Because South Africa falls in mid-latitudes its average duration of insolation during winter is longer than its duration in North America and Europe during their winter, because the latter are at higher latitudes. At the poles the sun never rises in the middle of winter.

3. Factors affecting the intensity of solar energy (insolation)

The factors affecting the intensity of solar radiation at any specific locality can be grouped into two groups, viz. (a) those that have permanent long-term effects and (b) those that have both long- and short-term and only variable short-term effects.

3.1 Factors that have permanent long-term effects on the intensity of solar radiation

i. Latitude:
The higher the latitude of a locality, the lower is the angle at which the rays of the sun reach it. Consequently a certain bundle of sun rays will cover a larger area at high latitude than at lower latitude. Thus, the intensity of the solar radiation will be lower at higher latitudes. It is difficult to separate this effect of latitude on duration of insulation when it comes to effects on total solar radiation (insolation). The effect of latitude is often strongly modified or over-ridden by the effects of other factors. *(See Section ii below.)* In South Africa there is in winter a very strong relationship between total solar radiation and latitude, i.e. there is a very clear decrease in solar radiation from north to south (Figure 1). The effects of latitude are seen at a macro-climate scale.

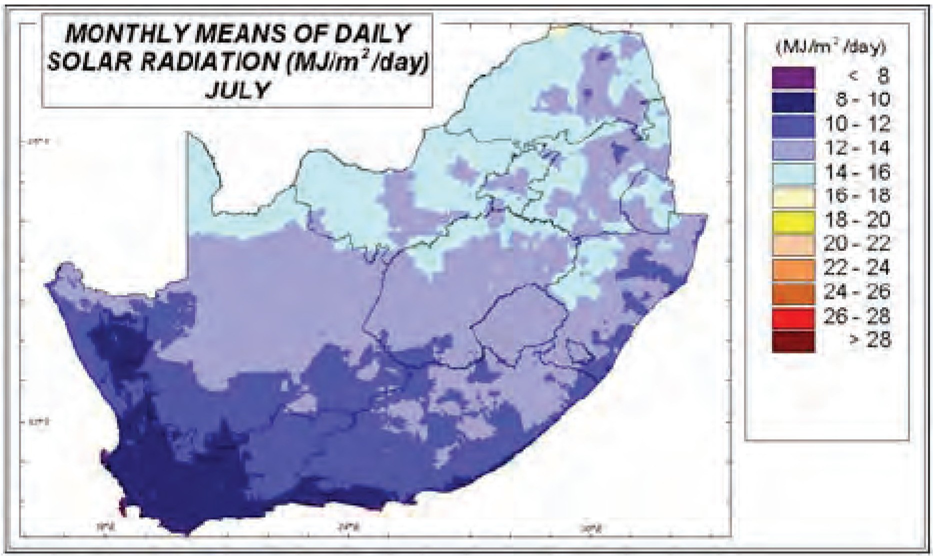

Figure 1. Total solar radiation distribution in South Africa in winter [8)]

ii. Slope aspect

With slope aspect is meant the direction in which a slope faces. In South Africa north facing slopes receive higher intensities of solar radiation than south facing slopes, as was shown in Figure 1 (Module 1). The differences become bigger as the gradients (steepness) of slopes increase. The effects of slope aspect are seen at a meso-climate scale.

3.2 Factors that have both long- and short-term and only variable short-term effects on the intensity of solar radiation

i. Clouds

The amount of cloudiness and the thickness and type of cloud affect the intensity of radiation reaching the earth. In the long term the average amounts of cloudiness and thickness and types of clouds affect the average intensity of the solar radiation reaching the earth and thus also the total amount of radiation at a specific locality. The higher the rainfall of an area or locality is, the larger is the amount of cloud cover normally and the lower is the intensity of solar radiation – and consequently also the total insolation.

The effects of cloudiness can be so strong that they over-ride the effects of latitude on total solar radiation at macro-climate scale. Such effect is clearly seen in the map showing total solar radiation distribution in South Africa in January, i.e. in mid-summer (Figure 2). In this case insolation shows a decreasing trend from west to east (especially in the north-eastern part of the country) and not from north to south, as in winter (Figure 1).

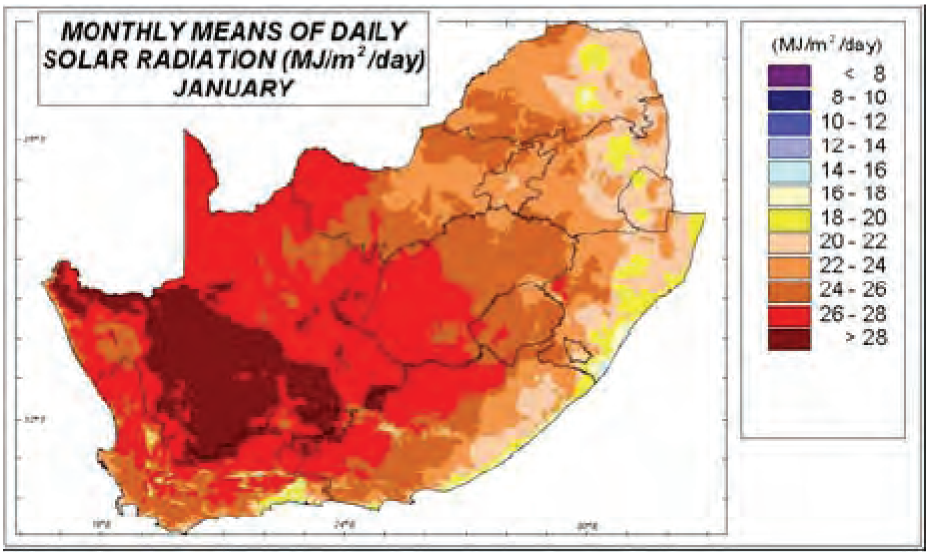

Figure 2. Total solar radiation distribution in South Africa in summer[8)]

The west-east pattern in January is strongly related to average rainfall pattern for January (Figure 3). The higher the average rainfall, the higher is the average amount of cloudiness, and thus the lower is the total solar radiation due to the lowering of the solar radiation intensity as a result of the increased amount of cloudiness. The dry south-western parts of the country are virtually cloudless.

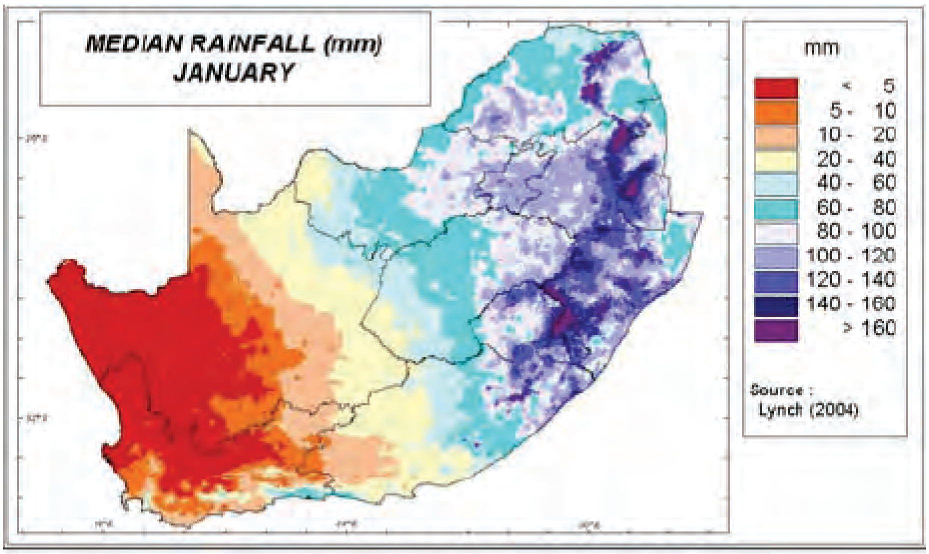

Figure 3. Rainfall distribution in South Africa in summer (January)[8)]

Cloudiness also has short-term effects (at weather scale) on solar radiation.

ii. Water vapour content of the atmosphere

The higher the water vapour content of the atmosphere is, the less solar radiation passes through. This can have long-term average effects in coastal areas. Higher water vapour content is also related to cloud cover. In some areas higher water vapour content of the atmosphere is seen in the form of mist/fog.

iii. Dust

Dense dust storms reduce the total solar radiation because less radiation is let through. In South Africa the western Free State sometimes experience very dense dust storms. It can be very severe after prolonged droughts. They usually occur towards the end of winter, when the topsoil is dry at the end of the dry (non-rain) season, the soil surface is bare (due to fallowing) and the prevailing winds are strong. Irrigation schemes like Vaalharts and Sandvet are in the dust storm zone.

iv. Smog, smoke and other particulate forms of air pollution:

Industrial pollution putting lots of smoke and other particles into the atmosphere can have perennial effects of major reduction in the intensity of solar energy reaching the earth and total solar radiation. Smog and smoke from fire (for cooking and heating) in urban areas, especially informal settlements, can have significant negative effects on the intensity of solar radiation. This is most serious in winter, when the smoke is trapped in the lower layer of the atmosphere, especially in low-lying areas, due to the effect of temperature inversion. This is fortunately not a factor on major irrigation schemes/farms.

4. Importance of solar radiation in agriculture

Solar radiation has important indirect effects on crop production through its effects on natural physical factors that are important for plant growth, such as:

- Heat factors, like temperature and heat units.
- Evaporation, which is essential for the formation of clouds and rain.

4.1 Direct effects of solar radiation on green (photosynthesizing) plants, like crop plants

The processes in green plants which are affected directly by solar radiation are divided into two groups, viz.

a. Photo-energy processes (requiring relatively high radiation intensities), such as photosynthesis.

b. Photo-stimulus processes, which are classified into:
   - Movement processes, such as movement of leaf orientation, tropism, day-night movement or stress-related movement.
   - Formative processes, such as stem elongation, leaf expansion, flowering in photoperiodical sensitive plants or the formation of chlorophyll. These

processes depend more on lengths of light and darkness, or photoperiodism, than on solar radiation intensity.

4.2 Solar radiation and photosynthesis

Photosynthesis is the fundamental growth process in which higher order green plants, like agricultural crop plants, utilize the visible range of solar radiation to produce carbohydrates (dry matter, or yield) out of water and CO_2. Photosynthesis takes place during daytime in the green (mainly leaf) parts of the plants that are exposed to light. A simplified general formula for photosynthesis is

$$CO_2 + H_2O + \text{Solar energy} \rightarrow (CH_2O) + O_2$$

The bracketed (CH_2O) indicates that a variety of carbohydrates is produced. Where adequate water and plant nutrients are provided, as is the aim in irrigated agriculture, there is usually a good daily and even hourly relationship between net photosynthesis and solar radiation. However, this is only up to a certain maximum value, called the saturation light intensity, which varies between different types of plants (different types of crops). Under hot, dry summer conditions in irrigation schemes in the central parts of South Africa, like Vaalharts, daily photosynthesis patterns have been found (e.g. with maize) that differ substantially from the normal run of the photosynthesis pattern during a day.

In South Africa solar radiation is high and is not a limiting factor to crop production, especially in the hot, almost cloudless semi-arid areas where major irrigation is practiced.

Photosynthesis is an inherently inefficient process in the utilisation of solar energy, with an efficiency of conversion of approximately 2.5%. This relates to 1.4 g of dry matter being produced per mega joule (MJ) of radiation. A major reason for this is that the low CO_2 concentration in the atmosphere (only about 0.03%) is the main limiting factor to crop production – especially in well-managed irrigated crops in semi-arid and arid areas. This also limits the level irrigation water use efficiencies that can be attained.

Under irrigation crops (e.g. maize) are planted at very high densities. This gives a very high growth density, limiting the amount of solar energy that can penetrate the canopy and reach leaves under/inside the canopy. This limits the amount of solar radiation that can be used effectively by the crop. Various experiments have been done on the modification of “canopy architecture” by means of the use of hormones. The objective is to create rows with plants of different heights, so that more solar radiation can reach more leaves in at least the top part of the canopy. So far the results on the success or not of this technique are apparently still inconclusive.

Activity

ACTIVITY 1

Individual activity

1. Describe what you understand under the concept "solar radiation".

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2. Explain the concept "insolation".

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3. Discuss the factors that influence :
   a.. The duration of insolation

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   b. The intensity of insolation

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………

4. Discuss the importance of solar radiation for irrigated agriculture.

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………

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My notes............

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Authenticator:

- Prof S Walker

Module 3

Temperature

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- Ground temperature, leaf temperature and open air temperature
- Important temperature parameters for agriculture like minimum, maximum and mean temperature
- Diurnal temperature ranges and the influence of it on thermoperiodism
- Factors affecting maximum, minimum and daily mean temperature
- Importance of air temperature for irrigation agriculture

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Solar radiation energy heats the earth, including both land and water bodies, and its atmosphere. The temperature around us is the direct result of solar radiation absorbed by the atmosphere, land and water bodies.

1. Temperature

Air temperature is inferred when referring to temperature as a climatological parameter. Air temperature is closely related to solar radiation, its main causative factor, and it is often difficult to distinguish between the effects of these two variables. Because air temperature measurement is a simple procedure and because long term temperature data are relatively abundant, temperature is a basic climatological parameter that is used frequently as an index of the energy status of the environment. Thus, it is not surprising that temperature parameters are used as input variables in the estimation of climatological parameters for which actual data are not freely available, such as solar radiation, relative humidity, potential evapotranspiration, heat units, chill units and frost incidence. Consequently, temperature parameters such as daily and seasonal means, maxima and minima, optimal and diurnal ranges of temperature are, together with rainfall, vital controls by which nature controls, for example, the distribution of different types of crops.

Temperature has a direct effect on all forms of life on earth, affecting a wide range of processes and activities – ranging from human comfort/discomfort, and consequent energy demand for heating and/or cooling, to crop and domestic animal responses, the incidence of pests and diseases as well as rates of evapotranspiration.

In both traditional and modern automatic weather stations the air temperature used as agro-climatological parameter is the air temperature measured inside shelters (Stevenson screens or ventilated radiation shields) placed 2 m above the ground, so as to imitate air temperature near the level of the crop canopy. However, this air temperature may differ substantially from

- *Ground temperature*, which at night, especially during winter, is frequently significantly lower than screen temperature. This in some areas often results in frost occurrence/damage although air temperature observations and temperature forecasts did not suggest that freezing temperatures should have been reached. Ground temperature could also be warmer than air temperature during the day depending on surface type.

- *Open air temperature in the sun*, which during day time, especially in summer, may be significantly higher than screen temperature. Thus, more heat injury may occur than screen temperatures would suggest.

- *Leaf temperature*, where the temperature of leaves exposed to the sun is usually 3-4ºC higher than the screen temperature. The difference drops to about 1ºC under shaded conditions and when temperatures exceed 33ºC. In thick non-transpiring leaves exposed to the sun the difference can be as high as 10-15ºC.

Temperature is measured in degrees Celsius (ºC) or Fahrenheit (ºF). In South Africa, as in almost the whole world, temperature is presently recorded and reported in degrees Celsius. In the USA temperature is still reported in degrees Fahrenheit, although they also tend to give it in degrees Celsius in scientific publications. Until about 50 years ago temperature was in South Africa also recorded in degrees Fahrenheit, as was done in several countries.

On the Celsius scale freezing point of water is at 0ºC and its boiling point at 100ºC. On the Fahrenheit scale the freezing point of water is at 32ºF and the boiling point at 212ºF. To convert from degrees Fahrenheit to degrees Celsius the following equation is used:

$$°C = (°F - 32) \times 5/9$$

2. Temperature parameters

Several temperature parameters are determined and these are all important for irrigated agriculture.

2.1 Minimum, maximum and mean temperatures

Air temperatures are expressed in terms of the daily minimum (T_{min}) and maximum (T_{max}), which are the maximum and minimum air temperatures observed during a 24-hour period, beginning at midnight. Minimum and maximum thermometers record the minimum and maximum air temperatures over a 24-hour period.

Because continuous recording devices, like data loggers, were not available in the past (and are still not available at all weather stations), mean daily temperature (T_{mean}) for 24-hour periods is for the sake of standardization defined as the mean of the daily maximum (T_{max}) and minimum temperatures (T_{min}) and not as the average of hourly temperature measurements.

The equation for calculating daily mean temperature is:

$$T_{mean} = \frac{T_{\max} + T_{\min}}{2}$$

Monthly mean daily maximum, minimum and mean temperatures are calculated. This is done by, for example, adding up all the daily maximum temperatures recorded during the month and dividing it by the number of days in the month. Likewise is done for the minimum and mean temperatures. Long term monthly mean daily maximum, minimum and mean temperatures are calculated for the different months of the year from the monthly means found for each month for a large number of years. The long term mean daily maximum, minimum and mean temperatures are very important for making decisions regarding which crops can be grown successfully in a specific area and about suitable planting dates for different annual crops, e.g. different kinds of vegetables.

2.2 Diurnal temperature ranges

Definition

The diurnal temperature range is the difference between the maximum and minimum temperatures on a given day. Some plants respond to the rhythmic variations caused by shifts from daytime high to night-time low temperatures. **This is called thermoperiodism**. This is important for such crops, because without an adequate diurnal temperature range flowering, seed production or even germination may be inhibited. For optimum growth some plants require a combination of a certain diurnal temperature range and a certain daytime temperature. For example, two crops may have the same diurnal temperature range requirements, but different daytime temperature requirements.

A high diurnal temperature range is ideal for high net photosynthesis, especially when high daytime temperatures are associated with low night-time temperatures. Net photosynthesis is the difference between photosynthesis, a daytime process, and respiration, which takes place during both daytime and night-time. For example, for clover a diurnal temperature range increase from 3ºC to 13ºC increases net photosynthesis by 80% at average light energy levels. This means increased production, if soil fertility and water availability are adequate.

3. Factors affecting air temperature parameters

3.1 Factors affecting maximum, minimum and daily mean temperatures

Globally geographic differences in long term annual mean daily air temperatures at macro-climate scale are largely due to latitude, altitude, distance from the sea, ocean currents, and prevailing winds. At country scale the mean air temperatures found at different places/regions are due to complex interactions between several of these factors. At different places/regions different dominant factors are mainly responsible for the mean air temperatures found there. This is well-illustrated by the general air temperature map for South Africa (Figure 1).

At global scale the effect of ***latitude*** is evident in the large north–south gradients in mean air temperature, with temperatures decreasing with increasing latitude. However, in South Africa there is no clear trend of this nature (Figure1). This is because other factors over-ride the effects of latitude in most areas. In the northern half of the country (approximately north of a line through Port Nolloth and Bloemfontein) there actually seems to be a relationship between temperature and longitude. This is a false perception, because other factors actually cause this pattern.

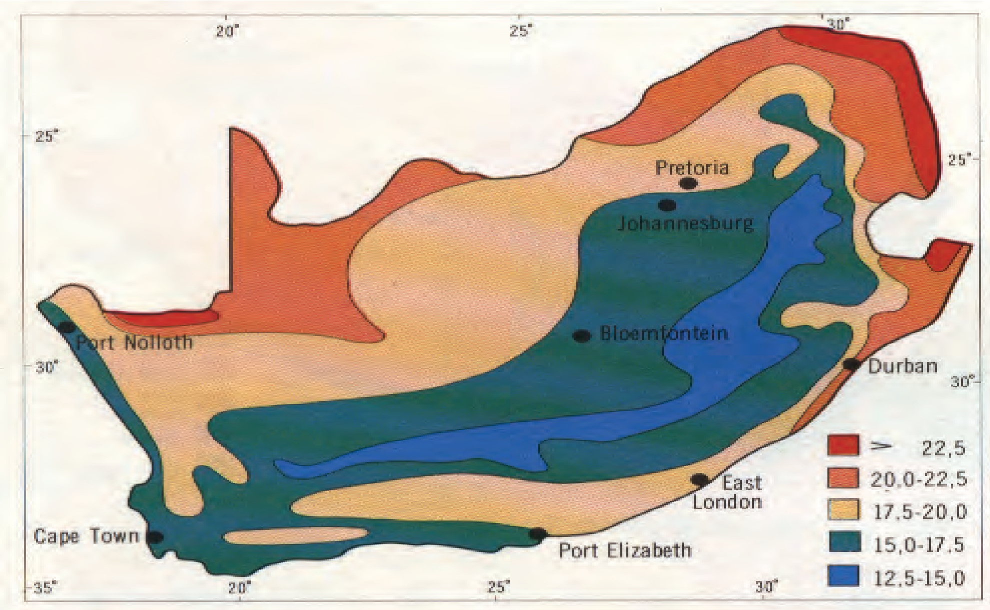

Figure 1. Broad mean air temperature regions for South Africa [8)]

If all else is equal, air temperature decreases with increasing ***altitude*** (elevation above sea level). This is called the standard adiabatic lapse rate. The adiabatic lapse rate is not a constant figure everywhere, but is influenced by a number of factors. An average lapse of -6.5ºC per 1 000 m rise in altitude is often regarded as "standard". Values ranging from as low as -4.6ºC to as high as 9ºC per 1000 m rise in altitude have been recorded at different places in the world.

Altitude is a major factor determining mean air temperatures in South Africa, over-riding the effects of other factors, such as latitude. This is well-illustrated by the following examples:

- The narrow area with the lowest mean air temperatures (the blue strip on Figure 1) is all along the highest mountains in the country (Drakensberg, Maluti, Winterberg, Sneeuberg, Nuweveld, high mountains of the Eastern Cape and Karoo). This is irrespective of latitude. Around this strip are some of the areas with the second lowest mean temperatures (green on Figure 1). These are high-lying areas, including the Mpumalanga Highveld, the Eastern Free State and the foothills of the Drakensberg in KwaZulu-Natal.

- If one draws an east-west line from Durban to the top of the Drakensberg Mountains, i.e. along the same latitude, the mean air temperature decreases progressively as the altitude increases from the coast to the mountains (Figure 1). The average temperature difference due to elevation is about 11ºC.

The relationship between daily mean temperature and altitude is clear when comparing the broad mean air temperature regions for South Africa (Figure 1) with an altitude map for the country (Figure 2).

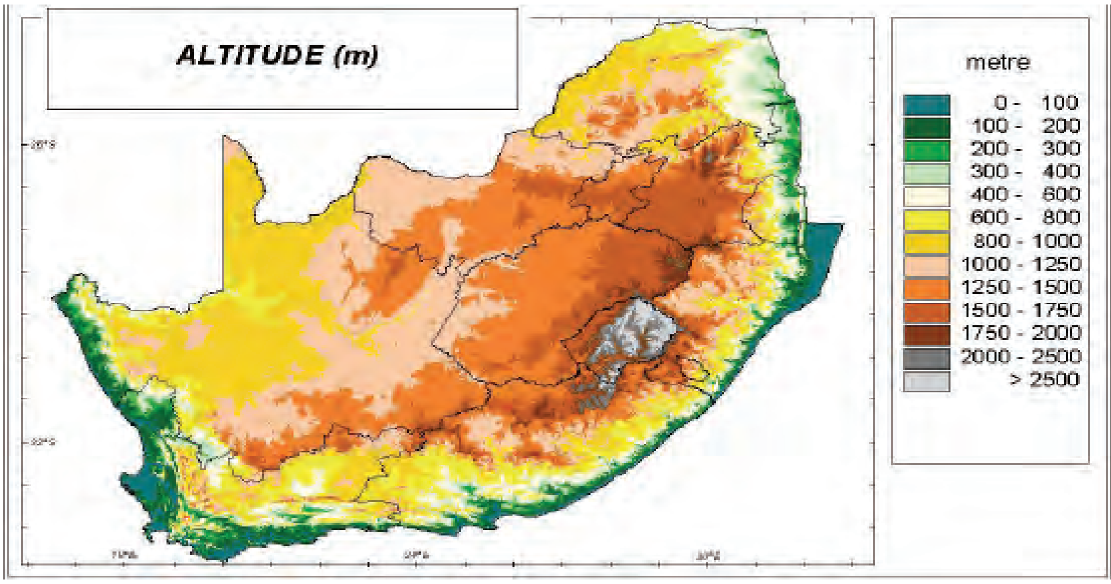

Figure 2. Altitude map of South Africa [8)]

Comparison of the mean air temperatures along the east and west coasts of South Africa illustrates the effect of ***ocean currents*** on air temperature as well (Figure 1). Temperatures along the east coast, especially along the KwaZulu-Natal coast, are significantly higher than along the west coast. The east coast is under the influence of the warm Mozambique current, which flows southwards along the coast from the equator. There is a gradual decrease in air temperature along the east coast as one move southwards, as the water of the Mozambique current becomes cooler as it moves further away from the equator. The west coast is under the influence of the cold Benguela current, which flows northwards along the coast from the polar region in the far south. Along the west coast the seemingly anomalous scenario is found that temperatures decrease as one moves northwards (towards lower latitudes). This is because the cold water of the Benguela current, which is heavy and flows deep under the ocean surface, is forced upwards as it comes into contact with the west coast of South Africa. The big magnitude of these effects is seen when comparing the mean air temperature for Durban on the east coast (21.0ºC) with that of Port Nolloth at approximately the same latitude on the west coast (14.2ºC). Such differences have major implications for irrigated agriculture in terms of:

- Crop selection according to their temperature requirements.
- Evapotranspiration rates and irrigation water demands.

At meso-climate scale ***slope aspect*** has a large impact on daily mean temperatures in especially areas with low mountains and steeply undulating hills. In South Africa north facing middle slopes have higher temperatures than south facing slopes, for the reasons explained in Module 1.

The effects of especially ***altitude, latitude and proximity to the ocean*** on differences in ***seasonal trends*** in mean daily air temperatures at different places/regions are very important for irrigated agriculture. The two most important South African examples are:

i. *The Lowveld of Mpumalanga and Limpopo Province (and the Limpopo river valley)*: The Lowveld of Mpumalanga and Limpopo province is, together with the Limpopo river valley along the western border of Limpopo province (e.g. in the Tom Burke area) and the northern part of Limpopo province, South Africa's main vegetable production area. This is especially important in winter, when the temperatures of most other areas are not suitable for vegetable production. The Lowveld and the northern part of Limpopo province are also the country's main areas for the production of sub-tropical fruits and nuts. Almost all these vegetables and sub-tropical fruits and nuts are produced under irrigation.

These areas, especially the Lowveld, are at lower elevations than the other interior areas of South Africa. The northern part of Limpopo province is north of the Tropic of Capricorn, i.e. it is in the tropics. The Tropic of Capricorn runs through a point about halfway between Polokwane and Louis Trichardt. The other two areas are just south of the Tropic of Capricorn, i.e. they are real sub-tropical areas.

These three areas are known as very hot areas. Their mean daily temperatures in summer, e.g. in January are, not higher than those in the area of the Northern Cape province area north of the Orange river and the western part of Northwest Province (Figure 3). However, from autumn (March) to early spring (September) the mean daily temperatures of the Lowveld, Limpopo valley and northern parts of Limpopo province do not drop as low as those in the Northern Cape and Northwest province areas. The most important factor is that in winter (e.g. July) the mean daily temperatures of the Lowveld and northern parts of Limpopo province, especially the Lowveld, are significantly (up to >6ºC) higher than in the Northern Cape and Northwest province areas (Figure 4). In the Limpopo valley area along the western border of Limpopo province the difference is somewhat smaller.

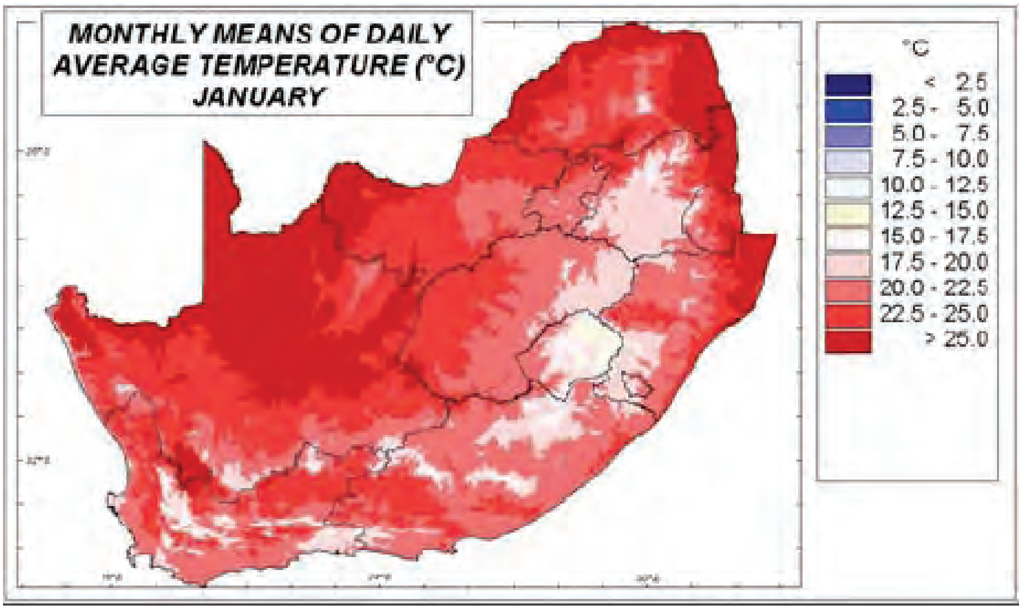

Figure 3. Daily mean temperature map for January[8)]

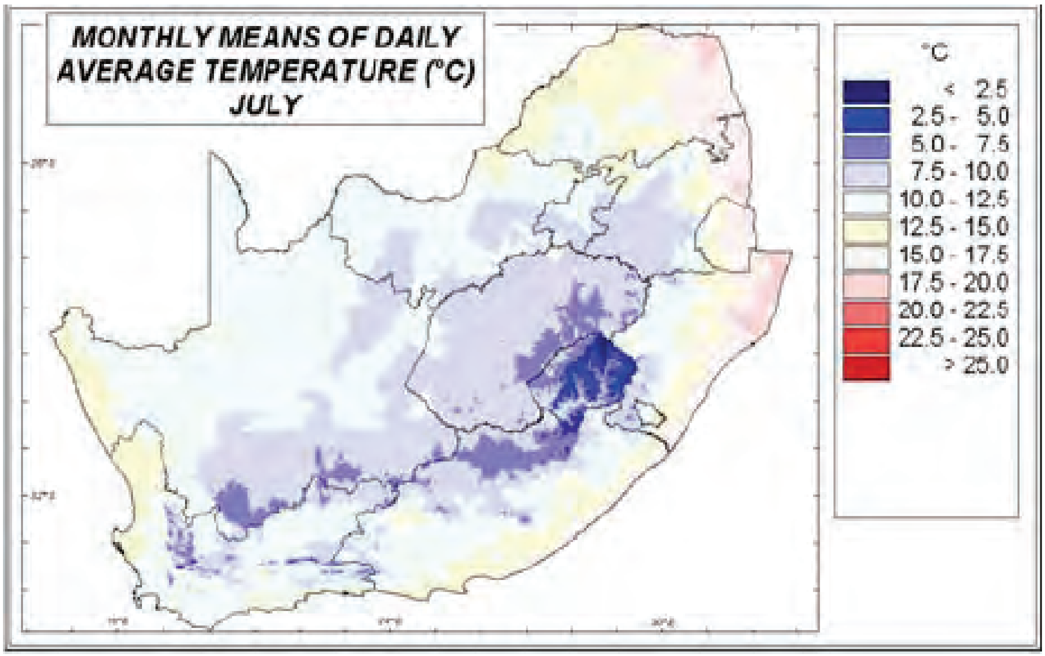

Figure 4. Daily mean temperature map for July[8)]

Of particular importance is the much higher (up to 10ºC) minimum temperatures in the Lowveld and northern parts of Limpopo province in winter (e.g. July) than in the northern parts of the Northern Cape province and western parts of Northwest province, with the minimum winter temperatures in the Limpopo valley along the western border also significantly higher than the latter (Figure 5).

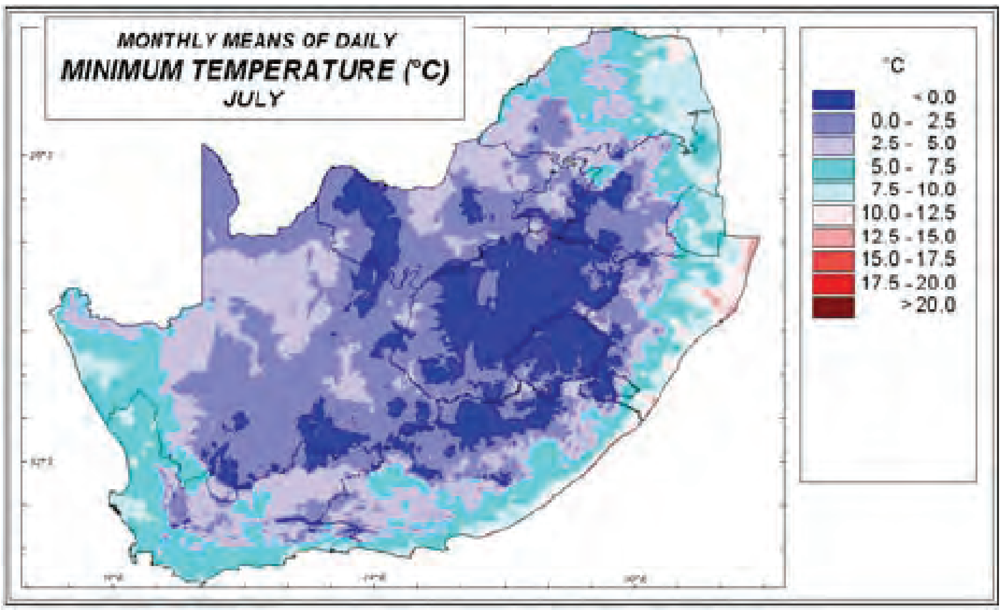

Figure 5. Daily minimum temperature map for July[8)]

ii. *Coastal areas, especially the KwaZulu-Natal north coast:* Oceans have a big moderating effect on the air temperatures of coastal areas. This is because water has a much higher heat capacity than rocks and minerals. This means that water requires more radiation energy to heat up and its temperature drops less with an equal loss of energy by irradiation or convection. Thus daily mean summer temperatures (e.g. in January) in coastal areas are lower than those in the interior of the country, except the areas at high elevations (Figure 2). In winter the daily mean winter temperatures (e.g. in July) in coastal areas are higher than those in the interior of the country, except the Lowveld, northern parts of Limpopo province, the Limpopo valley and the middleveld areas north of Pretoria (Figure 4). It is important to note that even the cool west coast areas, where lots of potatoes and other crops are grown under irrigation, have higher winter temperatures than the interior, except the areas mentioned above. The high winter temperatures of the KwaZulu-Natal north coast are important for irrigated agriculture.

The relatively high daily minimum winter temperatures (e.g. in July) are important for irrigated agriculture (Figure 4). The relatively high minimum temperatures along the east coast right down to Port Elizabeth, and especially those of the KwaZulu-Natal north coast, permit selection of a wide range of crops.

In tropical areas ***cloud cover*** affects long term mean ***seasonal temperature trends***. ***Rainfall*** acts as a co-factor. The general trend is that the highest mean temperatures occur before the summer rains start. Such areas are described as having:

- A cool dry season (winter),
- A hot dry season (spring) and
- A warm wet season.

In western Zambia September and October are the key months of the hot dry season, with October having the highest daily mean temperatures of all months and being known as the "death month". In the tropical area of the northern part of Limpopo province the temperature pattern is not as extreme, but the high temperatures and accompanying low relative humidities in September and early October, before the rainy season starts have been found to have drastic negative effects on tea grown in the area, for example. This is an important factor to take into account also for other crops grown under irrigation in the area.

In some parts of the world ***wind*** is an important factor affecting long term seasonal daily mean air temperature trends. In South Africa there is not such type of wind factor, but different winds have quite drastic effects on air temperature at short term scale (weather scale, as defined in Module 1). The most important of these are the scorching hot, extremely dry ***"berg winds"*** that afflict the coastal plateaux between the escarpment and the coast right around the coast of the country during summer. West coast areas like the Olifants River valley (Vredendal) and the Eastern Cape coastal areas are probably the worst hit by berg winds. The irrigated areas in the river valleys of the Eastern Cape are influenced strongly by berg winds. The hot, dry winds increase evapotranspiration when they occur and thus increase irrigation water requirements during such periods and affects irrigation scheduling.

Berg winds are called that because they come from the mountains (Afrikaans: "berge"). They blow from the hot, dry interior plateau down the escarpment onto the coastal plateaux. As the wind moves down the escarpment, the air gets compressed and its temperature increases. As the temperature increases the relative humidity also decreases.

During winter months areas in the central interior of the country, especially the Free State, are periodically hit by ***biting cold winds*** coming from the south to south east when it has snowed on the mountains of the Eastern Cape and Lesotho. Situations where frost does not even melt in shaded areas on bright sunny days when such winds blow is not uncommon.

Cold fronts that move through area lower temperatures at short term (weather) scale when they move through. These are more prevalent in winter and more in the southern parts of the country.

3.2 Factors affecting diurnal temperature ranges

The main factors determining solar radiation also determine diurnal temperature ranges. This is clear when comparing a summer (January) diurnal temperature range map of South Africa (Figure 6) with the solar radiation map for January (Figure 2; Module 2) and a winter (July) diurnal temperature range map (Figure 7) with the solar radiation map for July (Figure 1; Module 2).

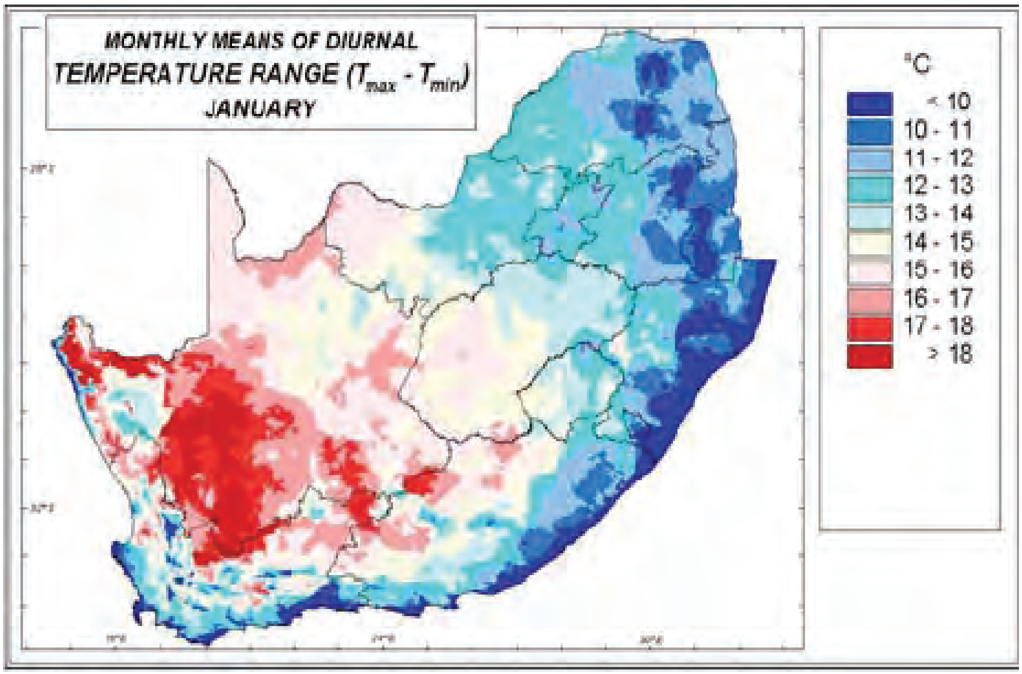

Figure 6. Diurnal temperature range map for January [8)]

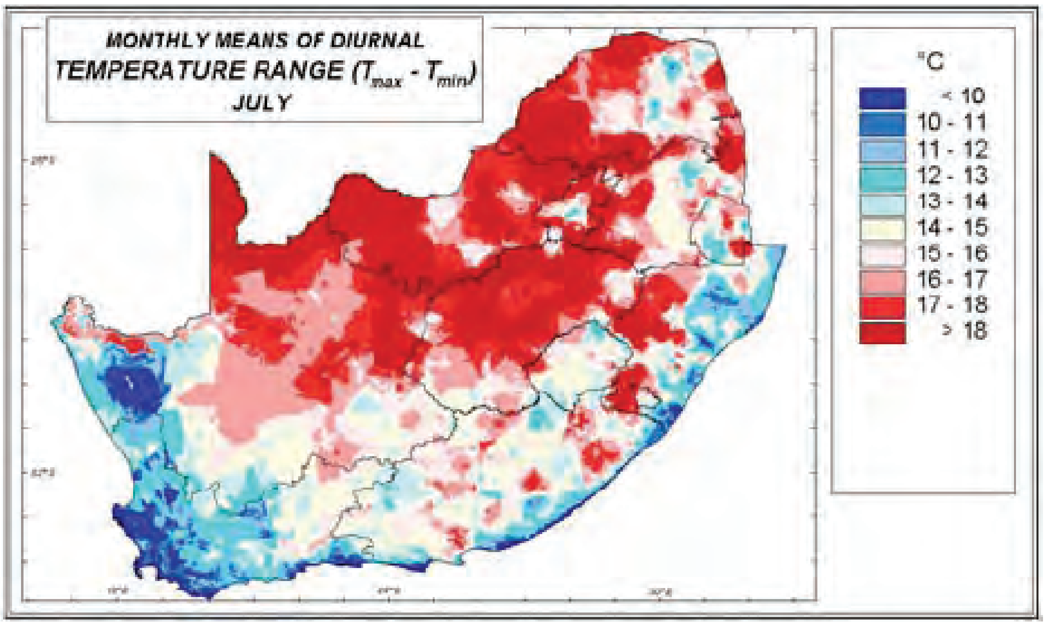

Figure 7: Diurnal temperature range map for July[8)]

Short term (weather time scale) irregular diurnal temperature conditions are often controlled by factors such as:

- Cold fronts moving through fast.
- Winds. For example, along the west coast scorching hot bergwinds usually blow only in the afternoons, followed by cool sea breezes in the evenings.
- Amount of cloud cover. Diurnal temperature differences are much smaller under a cloud cover than under clear skies.

4. Importance of air temperature to irrigated agriculture

Air temperature is very important to irrigated agriculture through two main effects, viz.

i. Its effects on the growth and production of different crops.

ii. Its effects on irrigation management, mainly through its effect on evapotranspiration – to be discussed in Module 7.

The physiological, chemical and biological processes in plants, e.g. photosynthesis, are influenced by air temperature. Most plants grow and live within a temperature range of 0°C to 50°C because biological activities are limited at the lower temperature by the freezing point of water and at the upper temperature by protein denaturation. Different plant species differ widely in regard to the optimum temperatures that they require for best growth and highest production and their tolerance to temperature extremes. For any plant species the optimum temperature range is narrow. Within this temperature range, most so-called cool weather crops (cabbages, carrots, beetroot, lettuce, spinach, peas, onion) grow best at temperatures ranging from 15ºC to 18ºC, while warm weather crops (beans, pumpkins, squashes, cucumbers, potatoes, maize, tomatoes) grow best at temperatures ranging from 18ºC to 27ºC. Since irrigated agriculture (a) is a high capital input enterprise and (b) with our limited water resources it is essential to achieve the highest possible irrigation water use efficiency, it is extremely important to first of all ascertain whether the temperature regime of an area/farm is suitable for production of any specific crop that is being considered. In the case of cool weather crops it is important to determine appropriate planting dates that will ensure that the crop is grown under optimal temperature conditions (or at least tolerable conditions). The so-called "cardinal" temperature ranges (lower tolerable, optimal, higher tolerable) differ not only between crops, but also between different phenological (growth) stages of the same crop.

Air temperature, often in combination with relative humidity, also affects the presence or prevalence of crop diseases in some cases. Such effect is not always harmful, but in some cases can be beneficial. For example: Greening disease (a virus disease) in citrus is a serious problem in the citrus growing areas of Mpumalanga and Limpopo province, but does not exist at all in the citrus growing areas of the Western and Eastern Cape provinces. The vector (an insect) carrying and distributing the greening disease virus cannot survive high temperatures. It thus appears that the scorching hot, dry berg winds hitting the citrus growing areas of the Western and Eastern Cape areas a number of times each summer is probably the reason for the absence of greening disease in these areas.

Table 1 shows crops that can be grown in the different Köppen climate regions of South Africa. Local temperature and rainy seasons would play a role in the final choice of crops, for example, grapes should be grown in a winter rainfall area, or in an area where rainfall is low. Subtropical species could only be grown successfully in an area where frost does not occur. Dates need about 180 days with daily maximum temperature higher than 18ºC and very low rainfall for successful fruit production.

Table 1. Crops adapted to Köppen climate regions

Climate: **Mild humid with hot summers.** Warmest month > 22ºC, coldest month < 18ºC and > -3ºC		
Trees & Vines	**Field & Forage crops**	**Vegetables**
Avocado	Beans	Beans
Bananas	Cotton	Cucumber
Citrus	Cowpeas	Eggplant
Coffee	Maize	Muskmelon
Figs	Peanuts	Peppers
Macadamia	Pearl Millet	Pumpkins and squashes
Mango	Rice	Tomato
Papaya	Sorghum	Watermelon
Pineapple	Soybeans	
Pistachio	Sugarcane	
	Sunflower	

Climate: **Mild humid with warm summers.** Warmest month < 22ºC, coldest month < 18ºC and > -3ºC		
Trees & Vines	**Field & Forage crops**	**Vegetables**
Almonds Apricot Apples Berries Cherry Grape Peach Pear Pecan Plum and Prune Quince Strawberry Walnut	Barley Beans Clover Italian Ryegrass Lucerne Maize Oats Rye Sorghum Soybeans Sugar beets Sunflower Tall Fescue Wheat	Beans Broccoli Cabbage Cauliflower Celery Chicory Cucumber Lettuce Muskmelon Parsley Peppers Pumpkins and squashes Spinach Tomato Watermelon
Climate: **Dry, hot.** Average annual temperature > 18ºC		
Trees & Vines	**Field & Forage crops**	**Vegetables**
Avocado Bananas Citrus Coffee Date palm Figs Macadamia Mango Papaya Pineapple Pistachio	Cotton Cowpeas Lucerne Maize Peanuts Pearl Millet Rice Sorghum Sugarcane Sunflower	Beans Cucumber Eggplant Muskmelon Peppers Pumpkins and squashes Tomato Watermelon
Climate: **Dry, cold.** Average annual temperature < 18ºC		
Trees & Vines	**Field & Forage crops**	**Vegetables**
Almonds Apricot Apples Berries Cherry Grape Peach Pear Pecan Plum and Prune Quince Strawberry Walnut	Barley Clover Italian Ryegrass Lucerne Maize Oats Rye Sorghum Sugar beets Sunflower Tall Fescue Wheat	Beans Broccoli Cabbage Cauliflower Celery Chicory Cucumber Lettuce Muskmelon Parsley Peppers Pumpkins and squashes Spinach Tomato Watermelon

In some instances, small temperature differences can affect the quality of the product or influence irrigation system design and management. The sugar content of sugar beet, for example, is reduced if temperatures during the growing season are too low or if the length of the growing season is not long enough for sugar production. Length of the growing season with high enough temperatures is also important for warm weather summer crops. Long seasons were, for example, required for optimum maize production, but high yielding shorter season cultivars have now been developed.

Temperature ranges for germination of crops show a similar pattern to that for crop growth and production: There is a minimum temperature, an optimum temperature and a maximum temperature at which germination will take place. These also differ between different plant species (Table 2). The optimum temperature is the temperature at which the highest percentage of germination takes place in the shortest time.

Table 2. Temperature ranges required germination occurs for different seeds

Crop	Temperature (ºC)		
	Minimum	Optimum	Maximum
Maize	8-10	32-35	40-44
Rice	10-12	30-37	40-42
Wheat	3-5	15-31	30-43
Barley	3-5	19-27	30-40
Tobacco	10	24	30

Activity

ACTIVITY 1

Individual activity

1. Describe what you understand under the following:

    a. Air temperature
    b. Ground temperature
    c. Leaf temperature
    d. Minimum temperature
    e. Maximum temperature
    f. Mean temperature.
    g. Thermoperiodism

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2. Discuss the major factors that influence air temperature in South Africa.

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3. Discuss the factors that influence diurnal temperature ranges in South Africa:

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4. Discuss the importance of air temperature for irrigated agriculture.

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References

1. Allen RG, Pereira L., Raes D and Smith M, 1998. *Crop Evapotranspiration. Guidelines for Computing Crop Water Requirements.* Irrigation and Drainage Paper No 56. FAO. Rome, Italy.
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My notes............

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Authenticator:

- Prof S Walker

Module 4

Heat Units, Chill Units and Day Length (Photoperiod)

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- Definition of crop heat units, chill units and daily length (photo period)
- The role of heat units, chill units and daily length (photo period) in planning of crop planting dates and orderly harvesting
- Heat and chill unit requirements for most general crops
- The weaknesses of using only heat or chill units in the planning of crop production

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2.	**Chill units (cold units)**	**3**
3.	**Day length (photoperiod)**	**5**
References		**6**

Definition

Crop Heat Units (CHU): or degree days provide a means of expressing the influence of temperature on crop growth and development. This concept holds that the growth of a plant is dependent on the total amount of heat to which it is subjected during its lifetime, accumulated as degree days.

Day length (photoperiod): With day length is meant the duration of the period from sunrise to sunset.

Chill units: It is usually called *"positive chill units"* (PCUs). PCUs are the opposite of heat units. It is calculated from the total number of hours below a given temperature, such as 4°C.

1. Heat units

The rate of development of crops from planting to maturity is dependent mainly upon temperature. Cool temperatures slow down the progress to maturity and warmer temperatures hasten maturity. Crop Heat Units (CHU) or degree days provide a means of expressing the influence of temperature on crop growth and development. This concept holds that the growth of a plant is dependent on the total amount of heat to which it is subjected during its lifetime, accumulated as degree days. Common practice is to use 10°C (valid for maize, South Africa's main staple grain crop) as a base. Thus, if the mean daily temperature for a particular day is 16°C, then 6-degree days are accumulated for that day on the Celsius scale (16-10 = 6). The total number of growing degree days required for maturity varies with plant species as well as crop cultivar.

The base line or minimum threshold temperature (the temperature below which the plant is damaged or unable to grow or does not produce a crop) is not a constant, but differs quite widely between different crops, e.g.

- 4°C for peas, a winter (cool weather) crop.
- 10°C for maize, a summer grain crop.
- 13°C for citrus and sugarcane.
- 18ºC for date palms.

Where studies have established the number of degree days required for maturity of a given crop, the planting dates can be scheduled for orderly harvest and processing. The system is helpful in selecting crop cultivars (e.g. short, medium or long season maize) appropriate to different geographical areas. It must be kept in mind that apart from temperature, there are also other environmental factors which can influence the rate of crop growth and development - such as photoperiod (daily period from sunrise to sunset), soil fertility and available water in the soil. For some crops ripening can be delayed by high soil water content during the ripening period or hastened by low soil water content during this period. In irrigated agriculture this can be manipulated by means of irrigation scheduling.

Crop pests also have minimum threshold temperatures and the heat unit/degree day concept thus also has value in scheduling spray programs and predicting insect emergence. For example, the baseline temperature for codling moth is 11ºC and for cotton bollworm 14ºC, while for oriental fruit moth it is only 7ºC.

Schulze *et al.*[8] gives degree day (heat unit) maps for South Africa for each month and accumulated for the six summer months and six winter months respectively, based on a baseline of 10ºC.

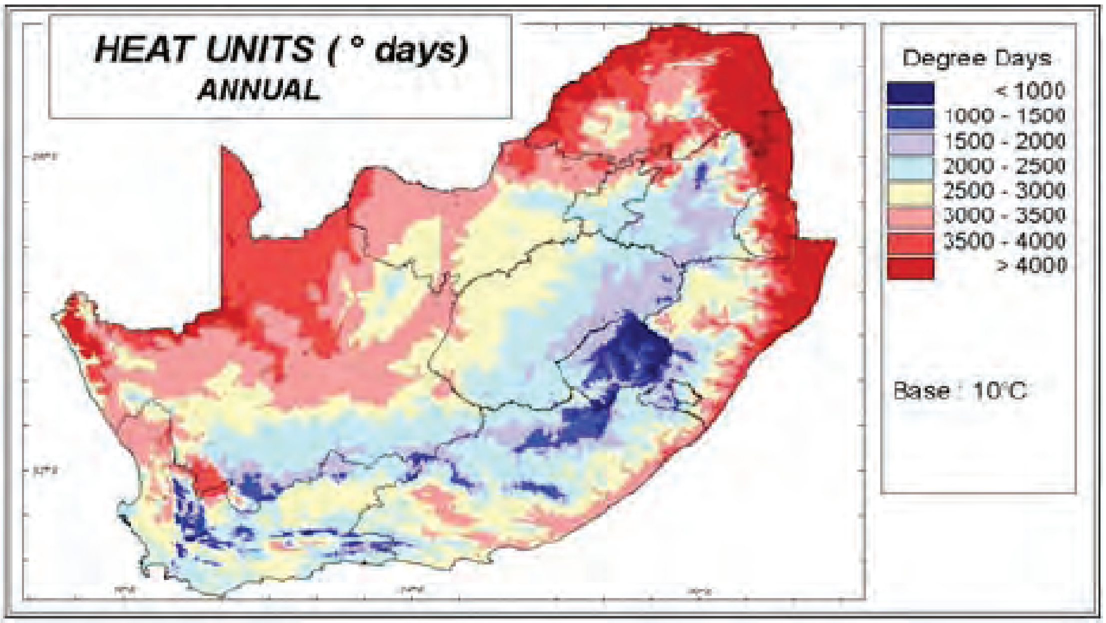

Figure 1. Annual degree day heat units for South Africa[8]

The degree day concept has weaknesses:

i. It assumes that the relationship between growth and temperature is linear, which it is not.

ii. It makes no allowance for changing threshold temperatures with advancing crop development.

iii. Too much weight is given to temperatures above 27°C, which are considered to be potentially detrimental in most cases to crop growth.

iv. Little or no account is taken of the diurnal temperature range, which is often more significant than the mean daily value.

2. CHILL UNITS (COLD UNITS)

Low temperatures are required by various crops for different reasons. The best known examples are deciduous fruits, which develop a physiological condition, called a rest period, towards the end of summer, after which their obvious growth is arrested until they have been subject to a certain amount of chilling through the winter. If the minimum cold requirements are not met, it leads to problems like delayed bud break in a crop like peaches or lack of flower bud "break" in a crop like apples during the next spring. These cause serious reductions in yield. This phenomenon limits the culture of these crops to the temperate zones where adequate cold temperatures occur. There are significant differences between different deciduous fruit crops and between different cultivars of the same crop (e.g. peaches) regarding their cold requirements as shown in Table 1.

Wheat is another important crop that has certain cold requirements. It requires a cold treatment, called vernalization, during seed germination and during the early seedling to stool stages before the wheat goes into the reproductive phase when daylight length exceeds 12 hours. In irrigated agriculture the cold part is determined by the natural air temperature regime and basically nothing can be done about it. The moist part is provided by appropriate irrigation scheduling.

In order to provide a scientific basis for determining whether an area meets the cold requirements of crops the concept of cold units or chill units was developed. It is usually called *"positive chill units"* (PCUs). PCUs are the opposite of heat units. It is calculated from the total number of hours below a given temperature, such as 4°C. A quite complex calculation is used. In the USA 4.4°C and 7.2°C have been common baseline temperatures for determining chilling hours. With such baseline variations, apparent fine statistical differences can be deceptive because too much reliance is placed on statistical analyses based on an initial arbitrary decision. In the deciduous fruit production areas, versions of degree day or degree hours concepts, based on PCUs, are used to forecast blossom freeze risks, by predicting the time of rest completion and bud break, for varieties in a given area and date of bloom, for forecasting harvest dates, in others. Apart from using PCUs for the foregoing, it can also be used to:

- Determine the time when certain management practices intended to delay bloom should be started.
- Identify potential growing locations with sufficient chilling for various crop types and cultivars.

For some deciduous fruit crops, e.g. peaches and apples, certain chemicals can be used as sprays to induce bud break where PCUs are marginal for bud break.

Table 1. Amount of winter chilling required overcoming the rest period in buds of various deciduous fruit species

Specie	Approximate number of hours below 7ºC
Apple	800-1700
Pear	600-1400
Peaches and nectarines	500-1300
Apricots	700-1500
Almonds	200-500
Figs	none

3. Day length (Photoperiod)

With day length is meant the duration of the period from sunrise to sunset. Various vegetable crops are sensitive to photoperiod (day length), often in combination with temperature. For such crops planting dates must be chosen very carefully to achieve maximum yields. Onions are very sensitive to day length and can be used as example to explain this:

- In onions bulbing is initiated only when the day length exceeds a certain minimum, which varies between cultivars. The common popular cultivar Texas Grano is an example of a cultivar with a fairly short day length requirement and is referred to as an early or short-day cultivar. For such cultivar the daylight hours in all parts of South Africa become long enough in late spring/early summer to initiate bulbing. On the other hand a cultivar such as the well-known Australian Brown has a longer day length requirement which can be met only in areas south of latitude 28°S. Such cultivar is known as a late or intermediate day cultivar and can in South Africa be grown successfully only in the Eastern and Western Cape provinces.

- Although day length provides the stimulus for bulbing in onions, temperature plays an important role. The warmer the conditions, the earlier will bulbing of a specific cultivar start and the faster will bulbing proceed. Therefore, short day cultivars especially are more suited to areas where temperatures rise sharply in spring. Where day length is sufficient to stimulate bulbing, but if temperatures are too low, a high percentage of bolting (premature seed formation) occurs. Bolted plants do not produce marketable bulbs. Low temperatures of 8ºC to 13ºC near bulbing time retard development of the bulbs and can trigger bolting. The latter is, of course, what a farmer who produces onion seed wants to happen, so his selection of planting dates and management practices will be aimed at achieving this.

Activity

ACTIVITY 1

Individual activity

1. Describe what you understand under “Heat Units” and why is it important to have a basic knowledge as an extensionist?

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2. Explain your understanding of “Chill Units” and why is it important to understand regarding the planning of irrigated crops?

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3. What are the shortcomings of using only using degree day heat units and chill units in the planning of crops?

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4. What do you understand underneath the concept “ Photoperiodism”?
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1. Allen RG, Pereira L., Raes D and Smith M, 1998. *Crop Evapotranspiration. Guidelines for Computing Crop Water Requirements.* Irrigation and Drainage Paper No 56. FAO. Rome, Italy.
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Authenticator:

- Prof S Walker

Technical Learner Guide

Agro climatology

Level 5

Module 5
Frost

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- Frost and black frost as climatological parameters for crop production planning
- Frost parameters like entry date and exit date of frost as well the average duration of frost period
- Factors affecting the geographical patterns of frost occurrence
- The importance of the occurrence of frost in the selection of crops and crop management strategies
- Management strategies to minimise crop losses due to frost

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Definition

Frost is the term used for the white layer of frozen water seen on the ground or vegetation close to the ground on a very cold winter's morning. Frost is atmospheric moisture directly crystallized on the ground and on exposed objects, e.g. plants, when minimum temperatures at ground level are below freezing (< 0 ºC).

"**Black frost"** refers to the occurrence of subfreezing temperatures that affect plants and crops while little or no hoar (white) frost is seen.

Entry date (average first date) of heavy frost signals the end of the growing season for annual summer crops that are sensitive to frost during the ripening period.

Exit date (average last date) of heavy frost signals the start of the growing season for summer crops that are sensitive to frost during their seedling and early growth stages.

Average duration of the frost period is the number of days between the average first day of heavy frost and the average last day of heavy frost.

1. Frost and black frost

Frost is the term used for the white layer of frozen water seen on the ground or vegetation close to the ground on a very cold winter's morning. Frost is atmospheric moisture directly crystallized on the ground and on exposed objects, e.g. plants, when minimum temperatures at ground level are below freezing (< 0ºC). The term "black frost" refers to the occurrence of subfreezing temperatures that affect plants and crops while little or no hoar (white) frost is seen. Black frost is a much more severe and damaging frost than the usually seen white frost. In most areas where frost occurs, black frost occurs seldom (once in several years), but it can kill plants, like trees (or parts of them), that have survived for many years.

Since many plant species are severely damaged or killed when freezing temperatures (0ºC and lower) are reached, occurrence of frost is a very important climatic parameter. Low temperatures cause plant damage ranging from death of the entire plant to partial tissue damage.

Each crop species has a minimum temperature below which plants will be severely damaged or killed. This temperature differs widely between different crop species. Through experience and research, these temperatures are known for most crops. In decisions regarding crop selection and appropriate management practices, e.g. planting dates, it is very important to (a) ascertain the sensitivity or tolerance of each crop considered to frost, (b) determine the frost hazard of the area/farm and (c) match these to see whether they fit or not. Important frost parameters to consider:

- The expected entry date (average first date) of heavy frost.
- The expected exit date (average last date) of heavy frost.
- The average duration of the frost period (days).
- The average number of days on which heavy frost occurs within the frost period.
- The severity of frost, i.e. how low temperatures drop.
- The length of the frost free period, an important parameter for annual summer crops.

2. Frost parameters

2.1 Entry date of frost

The entry date (average first date) of heavy frost signals the end of the growing season for annual summer crops that are sensitive to frost during the ripening period. If the crop has not ripened by then, serious yield losses may occur. Working back from this date, using the growing season length required by the crop, one can then determine the last date on which the crop may be planted for successful completion of its production cycle. For example: At the irrigation schemes in the centre of South Africa (Sandvet, Vaalharts, Orange-Riet, Douglas, Lower Orange river) the entry date of frost is about 20 May (Figure 1). This means that older long season maize, with a growing season of about 150 days, would have to be planted not later than about middle December.

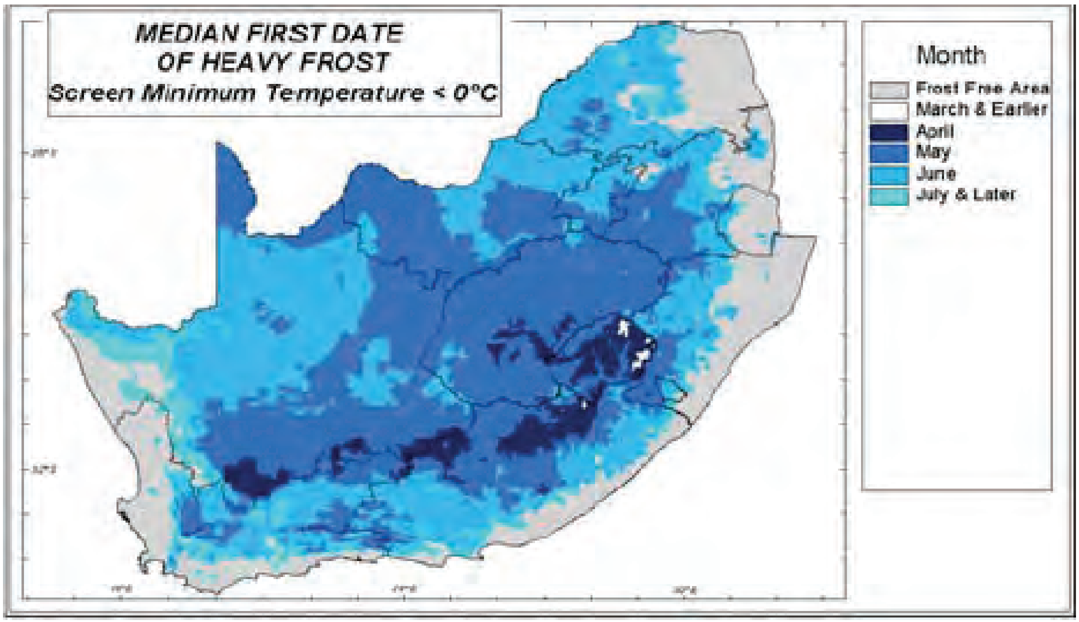

Figure 1. Average first day of heavy frost map [8)]

Some seedlings are killed by frost after they emerge from the soil. This is because they both (a) are close to the ground, where temperatures are lowest and (b) have tender succulent tissue, which is more sensitive to frosts damage. For a while after this the small plants remain sensitive to frost damage for the same reasons. So, for annual winter crops that are later in their growing cycle more resistant to frost damage the tactic would be to plant them long enough before the entry date of frost to get them past the sensitive seedling and early growth stages before frost sets in. Plants are also hardened by exposure to increasingly severe environments (e.g. progressing from light to heavy frost), following which they can better survive conditions that would otherwise cause damage. Occasional unseasonal early very heavy frost can, of course, nullify implementation of such good management strategy in such year. This happened, for example, in about 2005 in the Tom Burke area, wiping out about the whole winter vegetable crop.

2.2 Exit date of frost

The exit date (average last date) of heavy frost signals the start of the growing season for summer crops that are sensitive to frost during their seedling and early growth stages. In rain fed cropping planting can only be done after the first “planting rains” have fallen. In irrigated agriculture planting can be done as soon as the frost hazard is over and temperatures are high enough. For crops like vegetables and annual fruit crops like watermelons and sweet melons farmers who can market them early in the season, when prices are high, have an advantage. By studying the exit dates of frost in different parts of the country (Figure 2) an irrigation farmer can determine whether he/she is in an area that allows exploitation of such relative advantage or not. From Figure 2 it seems that farmers at Douglas and the Orange-Riet scheme would be at some disadvantage compared with those at Vaalharts and the Lower Orange river, but all of them would be at a disadvantage compared with farmers along the western Limpopo basin (Tom Burke area), the northern part of Limpopo province and the Lowveld of Mpumalanga and Limpopo.

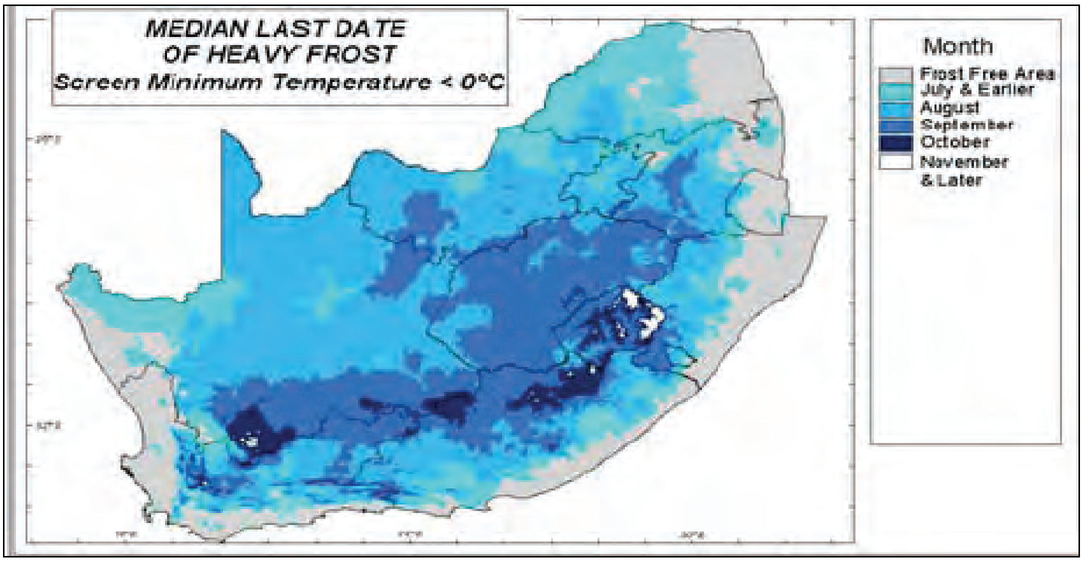

Figure 2. Average last day of heavy frost map[8)]

Some annual winter crops may be able to survive winter frosts, but be killed by spring frosts. Or their flowers or young yield components may be severely damaged, leading to major crop losses. This may happen if a crop that is sensitive to such situations is planted too late. Occasional unseasonal late frost will have the same effect.

For some deciduous fruit crops heavy frost during flowering may cause serious damage, causing serious yield losses and/or negative impacts on quality. This means that the farmer will suffer serious income losses. It often is not due to damage to the flower itself, but to the small fruit which has been initiated in the flower. For example: In apples water that freezes in the cup of the flower will not kill the flower, but will affect the tiny fruit that has been initiated in the flower. The fruit will survive and grow to become an apple of normal shape and size and with excellent taste, but with a raised brown band around its middle. Since apples are bought mainly on external appearance, such apples are, of course, not marketable as fresh fruit.

2.3 Average duration of frost period

The average duration of the frost period is the number of days between the average first day of heavy frost and the average last day of heavy frost. This does ***not*** imply that frost occurs on every day during that period. In areas with long frost periods the dangers of crop kills and/or damage by both early and late frosts are higher. In such areas the growing season for summer crops are also shorter.

The above factors mean that the selection of crops that can be grown successfully commercially in areas with long frost periods becomes more limited. In the areas of the central irrigation schemes in the Free State and Northern Cape the frost period is moderately long, i.e. between 91 and 120 days (Figure 3). This is in sharp contrast to the irrigation schemes in the Limpopo valley, northern Limpopo province, the Lowveld of Mpumalanga and Limpopo province, and the coastal plateau areas of KwaZulu-Natal and the Eastern and Western Cape provinces. These have a very short frost period of between only 1 to 30 days (Figure.3).

The occurrence of short frost period of 1 to 30 days, towards the interior in the Eastern Cape is due to the effect of the deeply incised river valleys on temperatures. Temperatures inside these valleys are a few degrees higher than on the surrounding coastal plateau areas. Thus there is also less frost in these valleys. Almost all irrigation schemes in the Eastern Cape are in these valleys. This is important to keep in mind in irrigation planning and crop selection.

Along the northern KwaZulu-Natal coast there is a wide frost free area (Figure 3). This includes the Makhatini irrigation scheme. This implies that a wide variety of sub-tropical, and even tropical, crops could be grown here. Several decades' research on a wide variety of crops has been conducted at the Makhatini experiment farm. These included exotic crops like coconut palms. Along the Eastern Cape and southern and central KwaZulu-Natal coasts there are narrow frost free areas. The narrow frost free area on the eastern border of Mpumalanga and Limpopo province is mainly in the Kruger National Park.

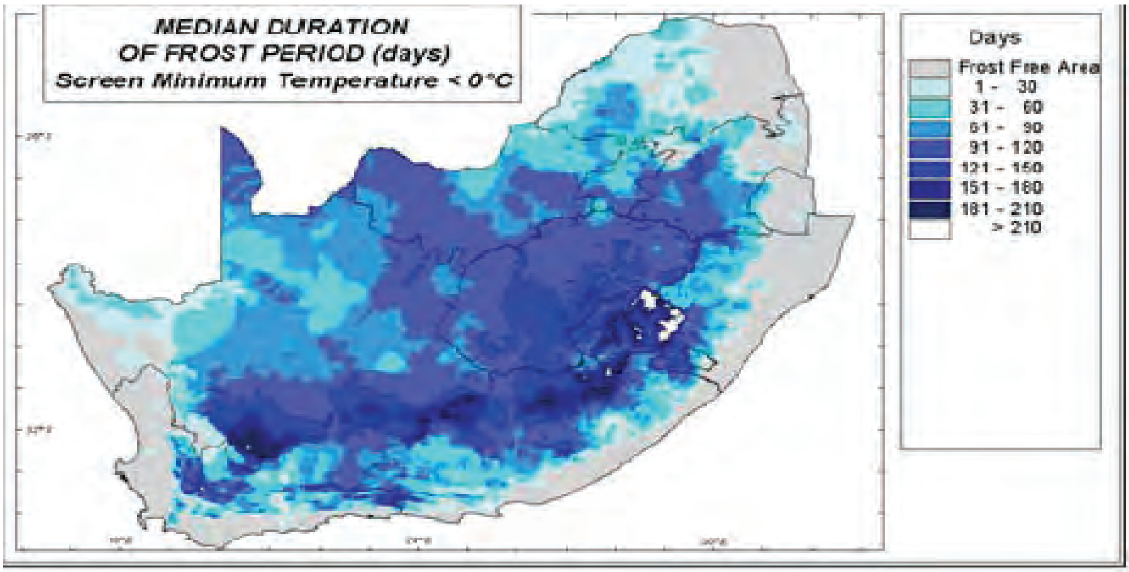

Figure 3. Average duration of frost period[8)]

2.4 Number of days with frost and severity of frost

The actual number of days on which heavy frost occurs may not affect a crop. However, the higher the number of days on which frost occurs during the frost period, the bigger may the chances be that a crop may suffer frost damage during sensitive growth stages. Greater injury to a crop is likely to occur during a period of continued freezing, where frost occurs on a number of successive days, than during a short freeze. Also, the type of situation in some irrigation areas in the Free State, where frost occasionally persists during entire sunny days under the influence of biting cold winds, could be more damaging.

No significant growth of agricultural crops takes place at temperatures of approximately 0ºC, but actual crop damage by temperatures close to 0ºC and at different levels below 0ºC varies greatly between different crops. Some crops, such as tropical and subtropical crops, may already be killed at a temperature of 5ºC. Crops that are sensitive to chilling injury are usually killed by the severe frost it experiences. Highly frost tolerant crops, on the other hand, may be frozen solid without injury. Thus, in crop selection for irrigated agriculture in any specific area it is important to know (a) the frost sensitivity or tolerance of a crop and (b) the severity of frost, i.e. minimum temperatures that can be expected in the area. Table 1 lists the tolerance levels of some common crops grown in South Africa to frost, i.e. the lowest temperatures that each can tolerate without serious damage.

Table 1. Tolerance of different crops to frost (Adapted from Schulze *et al.*)[8)]

Tolerance level and crop	Temperature (°C) harmful to plant		
	Germination	"Flowering"	Fruiting
High tolerance	-9 to -10	-1 to -2	-2 to -4
Wheat	8 to -9	1 to -2	2 to -4
Oats	7 to -8	1 to -2	2 to -4
Barley	7 to -8	2 to -3	3 to -4
Peas			
Moderate tolerance	-5 to -7	-2 to -3	-6 to -9
Cabbage	5 to -6	2 to -3	3 to -4
Beans	5 to -6	2 to -3	2 to -3
Sunflower	3 to -4	2 to -3	2 to -3
Soybeans			
Fairly low tolerance	-2 to -3	-1 to -2	-2 to -3
Maize/Sorghum	2 to -3	1 to -2	1 to -2
Potatoes	1 to -2	1 to -2	2 to -3
Cotton			
Little/No tolerance	0 to -1	0 to -1	0 to -1
Tomatoes	0 to -1		
Peanuts			

Some noteworthy observations from Table .1 are:

- Crops in the "high tolerance" group are all winter crops, as one could expect.
- The quite low tolerance of the winter grain crops (wheat/oats/barley) during their flowering stage indicates that serious crop yield losses could be caused in these crops by spring frost.
- The high tolerance of cabbages during the "fruiting" (heading) stage, far higher during this stage than any of the other crops listed.

The latter two bullets illustrate the importance of taking the greatly different tolerances of a crop to frost damage at different phenological stages into account when evaluations are made regarding the suitability of an area for a specific crop.

3. Factors determining geographic patterns of frost occurrence in South Africa and conditions conducive to frost occurrence at short term (weather) time scale

Frost is in essence a low winter temperature phenomenon. Thus, geographic patterns of frost occurrence are virtually the same as the patterns for winter daily mean temperatures, especially mean minimum temperatures (Module 3). The factors affecting occurrence of frost are also the same that affect daily mean temperatures, especially minimum temperatures in winter.

Globally ***latitude*** is considered to be a major factor determining the occurrence of frost, but, as with temperature, latitude is in South Africa totally over-ridden by ***altitude*** as factor. In addition the effects of altitude are augmented by the effect of ***continentally*** (distance from the ocean). The areas in the central parts of South Africa with the longest frost periods and highest severity of frost are both (a) at high altitudes and (b) far from the ocean. Furthermore, these areas are either summer rainfall areas or areas with low rainfall. Thus, they are dominated by long ***clear (cloudless) winter nights***, during which the loss of heat from the earth's surface by outgoing long wave radiation is rapid. Because of the lack of rain the ***air is relatively dry***, so that little of the outgoing radiation is absorbed by atmospheric water vapour and radiated back. The frost free area along the east coast is due to the influence of the warm Mozambique ***sea current***.

At meso-climate scale the effects of ***topography*** are important. In the first place ***slope aspect*** is important. Thus the north facing middle slopes of east-west orientated mountains are frost free (like in the case of the Magaliesberg) or at the worst have very seldom light frost. This allows the growing of highly frost sensitive crops on such slopes. The reason for this phenomenon was explained in Modules 1 and 2.

A second factor related to topography is ***temperature inversion***. This phenomenon is found where cold air is trapped underneath warmer air so that temperature rises with increase in altitude. This results in frost, often severe, on lower slopes, while the middle or upper slopes have only light or no frost. In areas with overall low winter temperatures, like the Koue Bokkeveld, severe frost is often also common on the lower parts of middle slopes.

Planting tree or vineyard ***rows along contours*** (across slopes – instead of down slope) can slow down seepage of cold air enough to cause damaging frosts at higher slope levels where it would otherwise not be the case. Even where tree rows are planted down slope a wind break planted across the slope can "dam up" cold air and cause damaging frost for several meters upslope from it? This has been observed very clearly in an apple orchard in the Koue Bokkeveld, for example.

At short term (weather) time scale two types of weather conditions ***prevent (or radically reduce) the occurrence of frost*** during a specific night. The first is ***cloudiness***. The clouds form a "blanket" of moist air that absorbs a lot of the heat that is radiated from the earth and radiates it back. The second is ***wind***. Wind mixes the air and thus slows down cooling of the air close to the surface of the earth.

4. Management strategies to minimise crop losses due to frost

Frost damage causes considerable crop losses, leading to large financial losses for the farmer. Damage from frost is most likely from unexpected cold periods in the spring, after young crop seedlings have emerged or flower buds have opened. The risk is greatest during the hours just before sunrise on still, clear nights.

Various management strategies, technologies and types of equipment can be used to avoid or minimize crop losses due to frost. These include, *inter alias*:

i. ***Effective land suitability evaluation and land use planning***
Avoiding planting of a frost sensitive crop in an area or at a site with a high frost hazard is the most effective and most sensible way to avoid crop losses due to frost, especially for perennial fruit tree crops, grapes, etc. that requires high capital inputs at establishment. This does not necessarily mean that the area or site cannot be used for crop production. There may be an alternative crop that is more frost tolerant that can be produced successfully profitable in the area or at the site on the farm.

In areas that are rated "marginal" or even "presently unsuitable" for a certain crop, it may sometimes be possible to grow the crop successfully, provided that certain special measures are taken. Such measures have cost implications that reduce the profitability of the crop. Also in this case one must way up the profitability of a frost tolerant crop that does not require such special technology or equipment with that of the crop requiring it.

ii. ***Adjusting planting dates***
Average entry and exit dates of frost have been determined from meteorological data or many years' experience of farmers in an area. Crop losses due to late frost can be reduced by planting sensitive crops when the danger of frost has passed. However, this is not always possible or even desirable. For example, early harvest can bring such a big price advantage that it is worth risking damage by frost or bearing the added cost of frost protection.

Where it is worthwhile, harvest can be brought forward somewhat by propagating seedlings under protection, e.g. in small tunnels, towards the end of the frost period and transplanting them out in the field as soon as the frost hazard is over. This can even be done with crops that are normally not considered to be grown from seedlings. It was, for example, found that traditional small-scale farmers in East Pondoland (in the former Transkei) grow maize from seedlings, so as to have green mealies earlier. This has since also been implemented at Zanyokwe irrigation scheme near Keiskammahoek in the former Ciskei, planting maize seedlings obtained from the East London area.

Crop losses due to early frost can be avoided by ensuring that crops planted during the middle or second half of summer is planted early enough to complete their production cycles and be harvested before the onset of frost.

iii. **In-*field polythene tunnels, row covers, mulches:***
Small "tunnels" and row covers can be constructed of thin plastic sheeting supported over the plant rows, resembling miniature greenhouses. The covering is held down by soil to prevent it blowing away. Temperatures under the sheets may become very high and ventilation through openings in the sheeting may be necessary, or partial uncovering or removal during daytime may be done.

iv. ***Greenhouses and tunnels***

Intensive cultivation of high value vegetable crops during winter can be done during winter in greenhouses or tunnels in areas with high frost hazards. The both the capital and production costs are very high, but exceptionally high yields can be obtained under very good management. The biggest advantages of these are obtained when done near a city with big markets and near an international airport, if production is aimed at the export market. This is why much greenhouse/tunnel farming is seen near Krugersdorp – very close to both Johannesburg and O.R. Tambo international airport.

v. ***Special measures applied especially in fruit orchards and vineyards***

Several types of special measures have been applied in the past or are being applied presently to avoid or minimize frost damage in fruit orchards and vineyards. These *include, inter alias*, the following:

- In about the 1950s old motor oil was burned in drums in apple and pear orchards in the Koue Bokkeveld on nights when frost damage was expected. This gave both heat and a smoke cover. It is, of course, a very environmentally unfriendly method.

- The advent of overhead sprinkler irrigation in about the 1960s provided a better and easier alternative. Sprinkler applied water can reduce frost damage to some crops because water releases its latent heat of fusion upon freezing. Additional heat is available for frost prevention if the applied water is warmer than 0ºC. The heat thus produced, warms the developing buds and other tissues on the trees, vines or other plants protected in a similar manner. Moreover, the ice that forms insulates the buds against air temperatures below freezing. This practice often provides sufficient heat and insulation to reduce frost damage, but it is not effective if the air temperature drops too far below 0ºC. Thermocouple-activated switches can be used to set off an alarm when the air temperature during specific nights drops below a set warning temperature. The farmer will then start the pumps so that the sprinklers can spray enough water so that applied water can freeze around the flowers and protect them when the temperature reaches 0ºC. The sprinklers will be kept running until the frost danger disappears the next morning. Otherwise the thermocouple-activated switches can directly trigger the pumps to start sprinkler irrigation. Excess water application should be avoided to prevent a heavy ice build-up that can cause branches to break off. During recent decades overhead sprinkler irrigation has been replaced by drip and ground level micro-sprinkler irrigation in most orchards and vineyards and the use of overhead sprinklers to curb frost damage is no longer an option in such orchards or vineyards.

- In some vineyards in the well-known Napa valley in California, USA, electric heaters with big fans that blow the hot air over the vineyard are presently used.

Activity

ACTIVITY 1

Small group activity

1. Describe the difference between "Frost" and "Black frost".

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2. Which important frost parameters are required for appropriate decision making regarding crop selection and crop management practices?
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3. Discuss the most important geographical parameters that determine patterns of frost occurrence in South Africa.
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   ....

4. Frost damage causes considerable crop losses each year in South Africa. Discuss in your small group possible frost management strategies a crop farmer can consider.
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- **Authenticator:** Prof S Walker

Technical Learner Guide

Agro climatology

Level 5

Module 6

Rainfall

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- Difference between precipitation and condensation
- The formation of clouds and the different classes of clouds (e.g. stratiform and cumuliform)
- Classification of rain according to the mode of formation (e.g. convention vs. orographic)
- Geographic distribution of rain and the nature of rainfall in South Africa
- Seasonable distribution of rainfall in South Africa
- South Africa's rainfall variability and reliability

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Definition

- **Rain:** Rain is the precipitation of liquid water drops with diameters greater than 0.5 mm. When the drops are smaller, the precipitation is usually called drizzle
- **Precipitation:** Precipitation is the fall of liquid water (rain) or solid water (hail or snow) from the atmosphere to reach the earth's land or ocean surface
- **Condensation:** Condensation is the process of changing matter from a gas (in this case water vapour) to a liquid (in this case water).
- **Convection rain:** Convection occurs in an unstable moist atmosphere when the earth's surface becomes heated, leading to upward movement of the moist air. Thus, convection requires a combination of adequate moisture in the atmosphere and heat. If conditions are favourable this leads to convection (convective, convectional) rain from convective clouds, e.g. cumulonimbus or cumulus clouds, in the form of thunderstorms.
- **Frontal or cyclonic rain:** Frontal or cyclonic rain is caused by frontal systems surrounding cyclones (low pressure systems) outside the tropics when a warm air mass (warm front) meets a cold air mass (cold front). A cyclone develops, i.e. a system with low pressure in the centre and higher pressure around it.
- **Orographic rain:** Orographic rain is produced when winds carrying moist air are forced up the side of a mountain. The lifting of the air up the side of the mountain results in adiabatic cooling, and eventually condensation and precipitation

1. Forming of rain

*Precipitatio*n is the fall of liquid water (rain) or solid water (hail or snow) from the atmosphere to reach the earth's land or ocean surface. Rain is the main form of precipitation that takes place. Condensation is required before precipitation can take place. *Condensation* is the process of changing matter from a gas (in this case water vapour) to a liquid (in this case water). Thus, clouds are formed when the air temperature is low enough to allow the condensation of water vapour into visible water

Clouds are formed by the lifting of moist air, which cools by expansion as it encounters the lower pressures existing at higher levels in the atmosphere. The relative humidity increases until the air becomes saturated with water vapour, then condensation occurs. In the process of condensation water droplets are formed on a cold surface or around a particle. Continuous condensation, as found in rain-forming clouds, results in water droplets that are big enough to overcome the upward draught of the air and fall to earth as rain.

Clouds form under different conditions which cause lifting of moist air to levels in the atmosphere where the temperature and pressure are low enough to cause condensation.

Such conditions include:

- Up-draughts, as found during the formation of thunder-clouds, carry water vapour to great heights.
- Up-draughts, as also found along mountain ranges and escarpments, where the flow of moist wind is forced upwards by the mountain slopes.
- Cold air of a cold front that moves in at ground level forces warm, moist air upwards. Clouds associated with cold fronts are usually recognisable as a bank of clouds that have a straight boundary on one side.

The continuous condensation that leads to the formation of cloud droplets requires air that must be slightly supersaturated (over-saturated) with water vapour. Condensation onto nuclei in the clouds continues as rapidly as water vapour is made available through cooling. Droplets about 10 micrometers in diameter are produced in this manner. These droplets constitute a non-precipitating cloud. The essential difference between a precipitation (rain) particle and a cloud particle is one of size. An average raindrop has a mass equivalent to about one million cloud droplets. Because of their large size, precipitation particles have significant falling speeds and are able to survive the fall from the cloud to the ground, without being dissipated before they reach the ground.

Regardless of whether the initial precipitation particle is an ice crystal or a droplet formed on a condensation nucleus, the bulk of the growth of the precipitation particle is through the mechanisms of collision and coalescence (clinging together). Because of their larger size, the incipient precipitation droplets fall faster than cloud droplets. As a result, they collide with droplets lying in their fall path. The rate of the growth in size of a precipitation particle through collision and coalescence is governed by the relative sizes of the particle and the cloud droplets in the fall path that are actually hit by the precipitation particle and the fraction of these droplets that actually coalesce with the particle after collision.

Rain is the precipitation of liquid water drops with diameters greater than 0.5 mm. When the drops are smaller, the precipitation is usually called drizzle. Meteorologists classify rain according to its rate of fall. The hourly precipitation rates described as light, moderate, and heavy rain are, respectively, less than 2.5 mm, 2.8 to 7.6 mm, and more than 7.6 mm.

Clouds are grouped in two major classes on the basis of their form, viz. (i) *stratiform* clouds which are blanket-like and cover large areas, and (ii) cumuliform clouds which are globular in appearance and usually develop vertically (Figure 1). Stratiform clouds are formed when air layers are forced to rise gradually over large regions, often forming layers. If the top layer is moist and rising continues, dense, thick stratiform clouds result that can bring abundant rain or snow. *Cumuliform* clouds are globular masses of clouds that are associated with small to large pockets of rising air. The air parcels rise because they are warmer than the surrounding air, like bubbles in fluid. As they rise, they are cooled, condensation occurs and clouds are formed. The most common cloud of this type is the cumulus cloud. Sometimes the upward movement yields dense, tall, cumulonimbus clouds that produce thunderstorms.

Apart from the trifling contributions made by dew, frost and by desalination of sea water, the sole source of fresh water for sustaining rivers, lakes, underground water sources and all life on earth is provided by precipitation from clouds. Precipitation is therefore indispensable for the survival and welfare of humankind. Water is often not provided by rain falling on site, but by runoff from areas elsewhere with high rainfall. This is particularly true for irrigated agriculture.

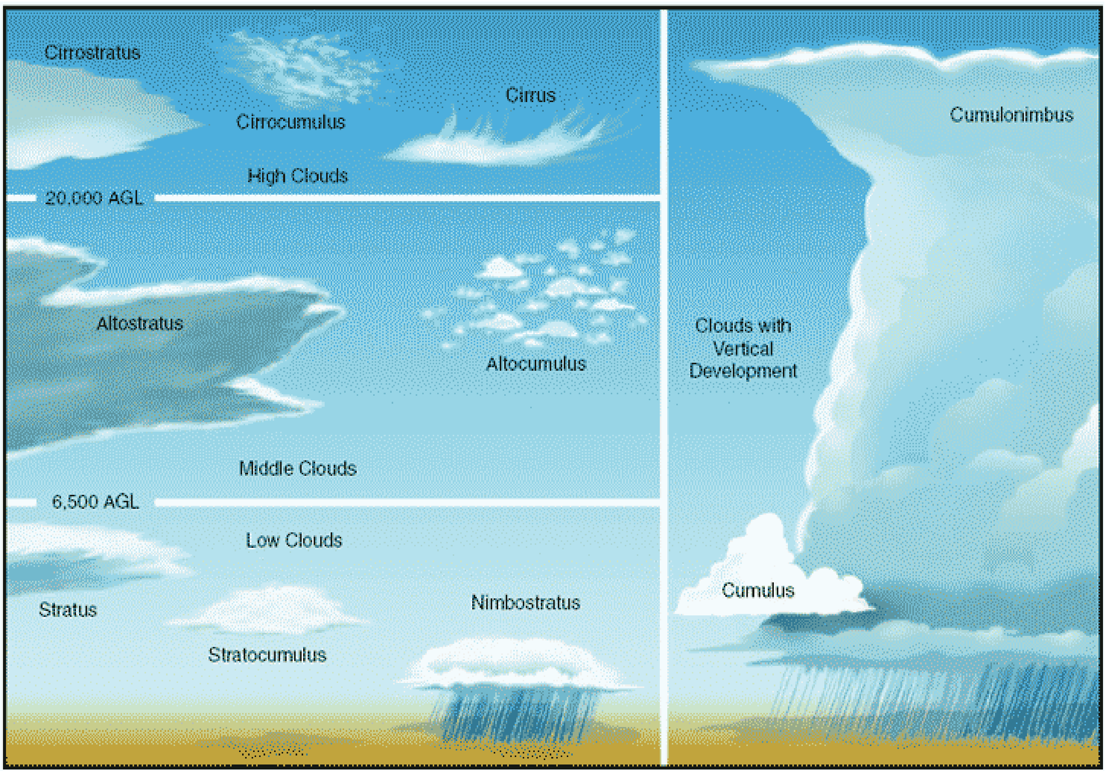


Figure 1. Different cloud types[10)]

2. Classification of rain according to mode of formation

In order to understand the nature and geographic and seasonal distribution of rainfall better, rain is classified according to its mode of formation.

2.1 Convection rain

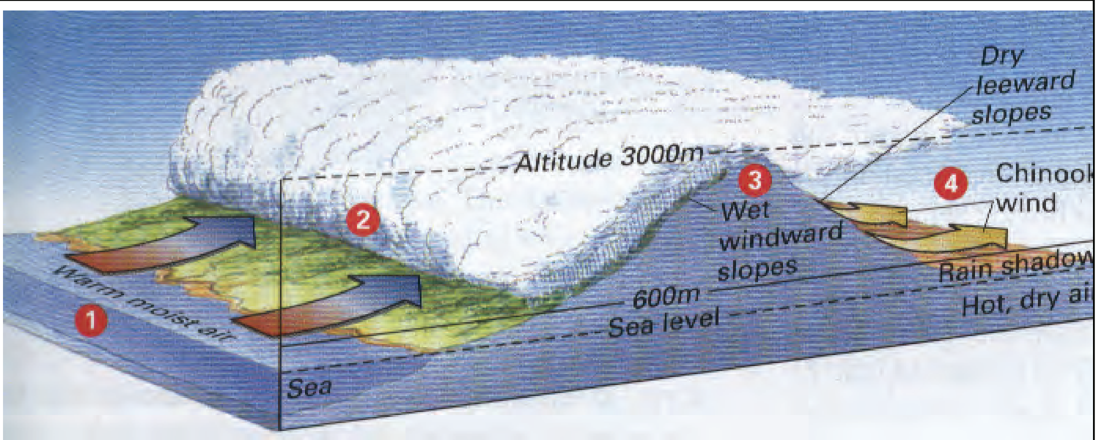
Convection occurs in an unstable moist atmosphere when the earth's surface becomes heated, leading to upward movement of the moist air. Thus, convection requires a combination of adequate moisture in the atmosphere and heat. If conditions are favourable this leads to convection (convective, convectional) rain from convective clouds, e.g. cumulonimbus or cumulus clouds, in the form of thunderstorms.

Thunderstorms are short-lived storms that are always accompanied by lightning and thunder. A thunderstorm has limited horizontal extent, i.e. it falls over a relatively small area. In an advanced stage, the summits of cumulonimbus clouds, the main type of cloud associated with thunderstorms, have a smooth, fibrous appearance and occasionally resemble a huge anvil. The base of a cumulonimbus cloud is usually dark because it has great depth. A thunderstorm frequently produces strong, gusty winds, heavy rain, and occasionally hail. Sometimes, particularly in desert areas, water drops from a thunderstorm are small, and they evaporate before reaching the ground as precipitation.

Convective rains are most strongly found in humid equatorial and tropical areas, because of the high moisture contents of the atmosphere and the intense heat. Such rains also occur during summer in those sub-tropical areas where a combination of adequate atmospheric moisture and heat is conducive for it to occur. In such areas the amount of convective rain is much lower than in the humid tropics.

2.2 Orographic rain

Orographic rain is produced when winds carrying moist air are forced up the side of a mountain. The lifting of the air up the side of the mountain results in adiabatic cooling, and eventually condensation and precipitation (Figure 2). Nimbostratus clouds form and serve as the source of the precipitation, most of which falls on the windward side (upwind) of the mountain. Some also falls a short distance downwind of the ridge and is sometimes called spill over. On the leeward (downwind) side of the mountain, rainfall is usually low, and the area is said to be in a rain shadow. There two reasons for this, viz. (i) moist moisture has been removed from the wind by the rain on the windward side and (ii) the dry wind on the windward side becomes warmer as it descends down the mountain and consequently the relative humidity of the air decreases. Heavy precipitation typically occurs upwind of a prominent mountain range that is oriented across a prevailing wind from a warm ocean.



Temperatures: 1 = 20°C; 2 = 14°C; 3 = 2°C; 4 = 25°C

Figure 2. Orographic rain [10)]

2.3 Frontal or cyclonic rain

Frontal or cyclonic rain is caused by frontal systems surrounding cyclones (low pressure systems) outside the tropics when a warm air mass (warm front) meets a cold air mass (cold front). A cyclone develops, i.e. a system with low pressure in the centre and higher pressure around it. In the southern hemisphere the rotation of the earth causes the air to circulate clockwise around a low-pressure centre, with the warm air moving inward towards the low-pressure centre (Figure 3). The warm, less dense air is forced to rise above the colder dense air, which undercuts it, at two locations: the leading edge of the warm front and the leading edge of the cold front. The air that rises in the middle of this system and cools down, leading to condensation, formation of nimbostratus clouds and precipitation. Occasionally (perhaps once in several years) an occluded (cut-off) low develops in an area. This sometimes leads to very heavy rain in that area.

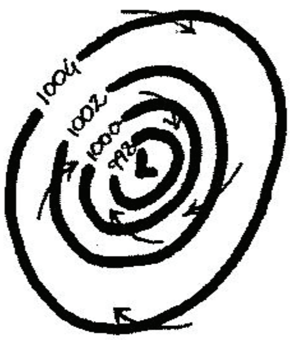


Figure 3. Cyclonic air flow in the southern hemisphere

3. Geographic distribution and nature of South Africa's rainfall

Over most of South Africa there is a definite strong pattern of mean annual rainfall increasing from west to east (Figure 4). The magnitude of the extremes is illustrated by the difference between Port Nolloth on the west coast, receiving only 50 mm rain per annum, and Richards Bay, at the same latitude on the east coast, receiving over 1 000 mm per annum. The exceptions to this west-east pattern are the far northern parts of the country (the whole of Limpopo province) and the far southern parts of the country (the southern Cape coastal areas and the south-western Cape).

The largest part of the country is a summer rainfall area (Figure 5). The interior plateau, including the relatively high (for South Africa) rainfall areas of the eastern Free State and Mpumalanga, receives almost all its rain as ***convective rains***, i.e. as thunderstorms. Also KwaZulu-Natal and the Eastern Cape receive a lot of their rain as thunderstorms. The convective rains develop because all these areas have enough heat in summer. The higher rainfall in the eastern Free State and the Highveld is because these areas also have enough moisture in the atmosphere, due to spill over from the humid eastern seaboard areas. It must be kept in mind that even in these areas the mean annual rainfall is much lower than in the humid equatorial and tropical areas which receive convective rains. Towards the west the rainfall is low, because there is not enough moisture in the atmosphere for effective development of convective rains.

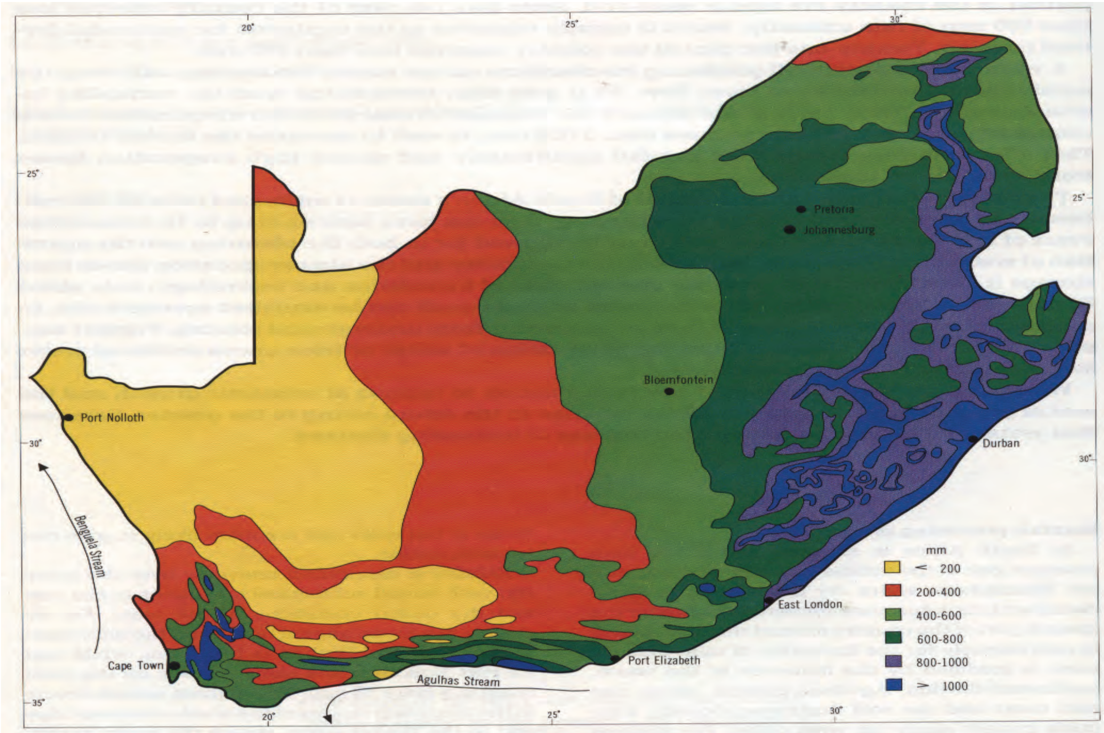


Figure 4. Mean annual rainfall map of South Africa [2)]

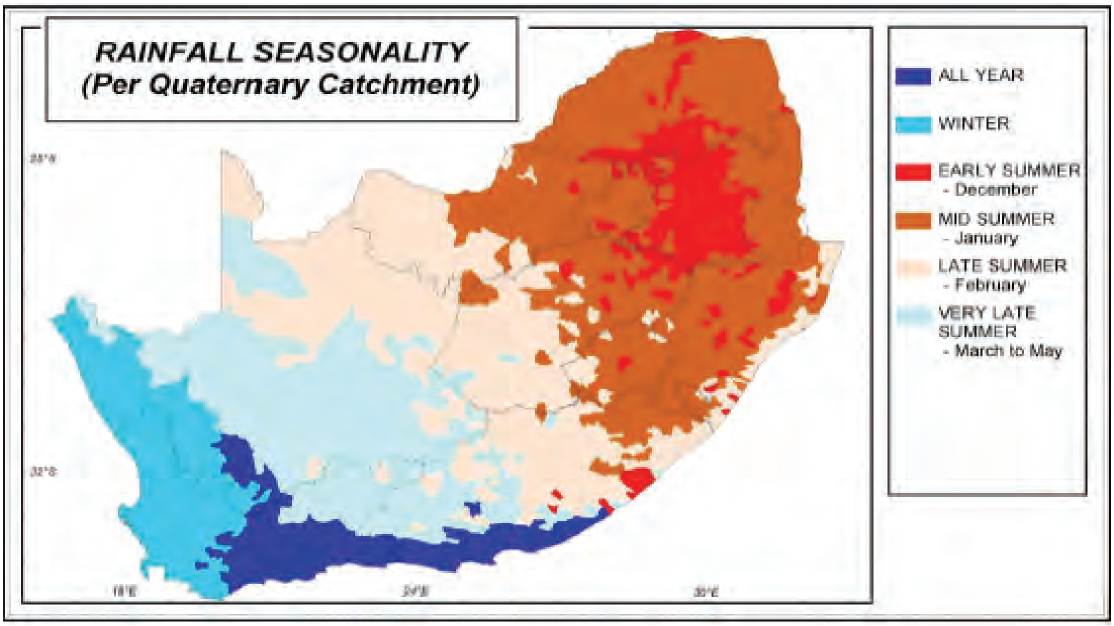


Figure 5. Rainfall seasonality map of South Africa [8)]

South Africa's highest rainfall occurs in the eastern and southern mountains (Figure 4), viz.

- The Drakensberg of the eastern escarpment, from Limpopo, through Mpumalanga and KwaZulu-Natal to the northern parts of the Eastern Cape.
- The southern Cape mountains, especially the Outeniqua Mountains.
- The mountains of the south-western Cape.
- Other smaller areas, like the Winterberg and Amatola mountains in the central parts of the Eastern Cape.

The high rainfall in the mountains is due to ***orographic rains***. In the Drakensberg convective rains also make some contribution. The orographic effect is most strongly expressed in the central Eastern Cape and the south-western Cape. In the central Eastern Cape the mean annual rainfall at Alice and Middledrift, just outside the foothills of the Amatola mountains is about 500 to 550 mm, while at Wolfridge, in the mountains, it is about 1 700 mm. In the south-western Cape the mean annual rainfall throughout the Swartland and Rûens is only about 420 mm. In the Berg and Breede river valleys the rainfall is also low, but in the surrounding mountains it is over 1 000 mm per annum. The most extreme is at Wemmershoek, in the mountains above Franschhoek, where the mean annual rainfall is far above 3 000 mm.

There is no significant orographic rain effect in the mountains along the western escarpment. This is because (i) the prevailing coastal winds do not blow perpendicular to the mountains, but parallel to them and (ii) very little moisture is released into the atmosphere through evaporation over the ocean, because of the cold sea current. *(See Module 7.)*

The Little Karoo (with Oudtshoorn as main town) is the most extreme example of a rain shadow in South Africa. Rainfall on the windward (coastal) side of the Outeniqua Mountains is up to over 1 000 mm per annum, but in most of the Little Karoo it is less than 200 mm, and some areas less than 100 mm, per annum.

The orographic rains of the mountain areas are extremely important for irrigated agriculture in South Africa. Although the cover only a small fraction of the country's land area, they generate most of the country's runoff. This runoff is then used for irrigation (and other uses) in semi-arid and arid areas. The areas where the runoff is used is often far (even many hundreds of kilometres) from the mountains where the runoff is generated. For example: Runoff from the Drakensberg/Maluti mountains of Lesotho and the northern escarpment mountains of the Eastern Cape provides water for irrigation in the central and lower Orange river areas and through inter-basin transfers (tunnels) also for irrigation in the Fish, Sundays and Gamtoos river valleys in the central and southern parts of the Eastern Cape.

The winter rains of the south-western and southern Cape are brought by ***cyclones/cold fronts*** passing through the area from west to east. These are soft rains of long duration. As indicated earlier, the mean annual rainfall in these areas is low – except where there is orographic influence. A major reason for the low rainfall is that the moist air comes from a cold ocean, giving low evaporation levels.

The high rainfall in KwaZulu-Natal and the north-eastern parts of the Eastern Cape Province is due to moisture-laden air brought in from the warm Mozambique Sea current. Because of the warm water of the ocean, evaporation is high, bringing high levels of water vapour into the atmosphere.

In KwaZulu-Natal heavy rains are also caused by tropical cyclones that develop in the Mozambique Channel. Occasionally these cyclones develop into tropical storms that bring devastating rains and floods, such as Domoina in January 1984. Occasionally these storms develop further north, bringing heavy rains that lead to devastating in Limpopo province, such as those in January 2000. Such floods are disastrous for irrigated agriculture, but one cannot plan for such abnormal events.

A very important special geographic rainfall distribution pattern is found in the Eastern Cape and KwaZulu-Natal. The deeply incised river valleys that are characteristic of these provinces ***all*** have much lower mean annual rainfall than the plateau areas between them. The valleys are too narrow to indicate on a small scale map, like Figures 4 or 5. On the Acocks veld type maps they are clearly seen as the strips of “Valley Bushveld”. Together with higher evapotranspiration in the valleys (due to higher temperatures) irrigated agriculture in these river valleys has very high irrigation water demands. For example:

- The mean annual rainfall at Addo in the Sundays river valley is only about 390 mm and the highest official air temperature recorded in South Africa (55ºC) was recorded at Kirkwood, close to Addo in this important irrigation area.
- The mean annual rainfall at Dank den Goewerneur in the deep Keiskamma river valley is only 390 mm, compared with about 500 mm at Middledrift, not far from it outside the deep valley.

4. Seasonal distribution of rainfall in South Africa

As shown earlier (Figure 5) most of South Africa is a summer rainfall area. Only the south-western Cape is a winter rainfall area, while the southern Cape receives rain all year round.

The summer rainfall areas are subdivided as having early, middle, late or very late summer rainfall (Figure 5). This does ***not*** indicate the time when the summer rain starts in an area. It indicates the time when the summer rain peaks in an area, i.e. the month with the highest mean monthly rainfall.

Studies of monthly rainfall data for the central Eastern Cape (former Ciskei) revealed an important special summer rain pattern, viz. a small rainfall peak in spring and a fairly large peak in late summer/early autumn. In-between there is a low rainfall period, i.e. a major mid-summer drought. Furthermore the low rainfall mid-summer period coincides with very high potential evapotranspiration, a combination that causes a very big mid-summer water deficit. It is also the growth period of summer crops when they have the highest daily water requirements. It all means that decisions regarding irrigation strategies and irrigation system design for these areas must make special provision for the high mid-summer irrigation water demands.

The dual peak rainfall pattern of the central Eastern Cape is not unique. Such pattern is found all along East Africa, right up to Eritrea in the north. It is particularly well-known in Kenya. A similar pattern is probably also found in other parts of the Eastern Cape and in KwaZulu-Natal.

Long-term weekly or 10-day period (decadal) rainfall data enables one to see whether this phenomenon is present in an area. Monthly rain data could also be used, but is usually not such a good indicator as weekly. This phenomenon is best illustrated in areas that have a spring and autumn monsoon rainfall, such as found in India and other southern Asian countries. During the monsoon seasons these countries receive an excess of rain, interspersed with dry periods in between. A good example is Colombo the capital city of Sri Lanka, which have very high rainfall, seasons in spring and autumn, with relatively dry summer seasons in between. Table 1 and Figure 6 show that the rainfall during spring (Apr, May) and autumn (Oct, Nov) is up to three times as much as during mid-summer (July - August). However, crop growth and development does not slow down, so a water stress situation could occur during summer which would reduce yields (Figure 6).

Table 1. Monthly rainfall (mm) and monthly reference evapotranspiration (mm) showing a typical midsummer drought situation in a monsoon area at Colombo, Sri Lanka.

Month	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Rain	256	336	195	129	97	155	362	309
Reference evapotranspiration	135	124	114	118	127	123	121	111

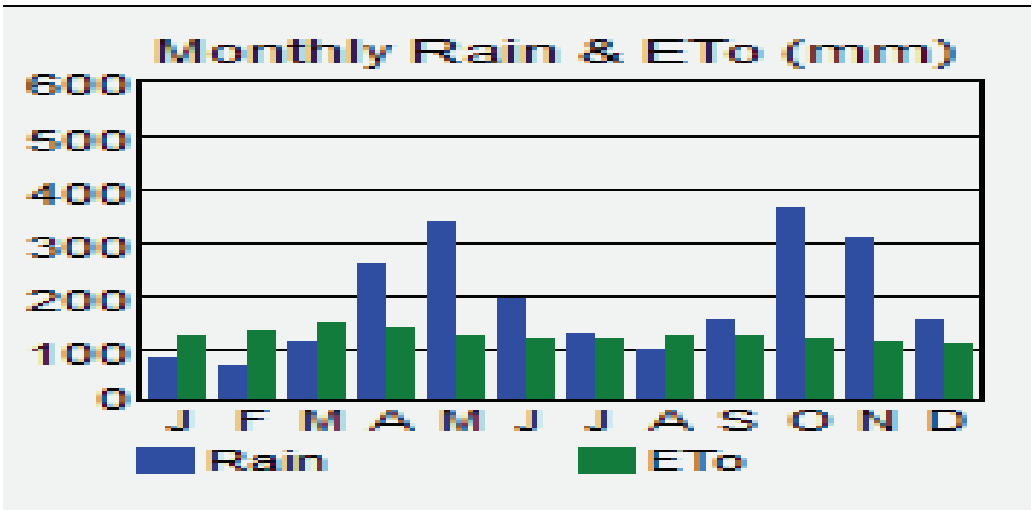


Figure 6. Monthly rainfall and monthly reference evapotranspiration found at Colombo, Sri Lanka, showing a typical mid-summer drought phenomenon

As mentioned earlier, a mid-summer drought situation is found in most of the summer rainfall, crop production areas of South Africa, although the severity is not necessarily the same for all areas. As an example, the crop production area in the vicinity of Bronkhorstspruit can be investigated for a pattern representing a midsummer drought. Both Table 2 and Figure 7 show lower rainfall for December than for November and January, while crop growth and development, represented by the level of reference evapotranspiration are high as a response to the high levels of solar energy reaching that area during December.

Table 2. Monthly rainfall (mm) and monthly reference evapotranspiration (mm) showing a typical midsummer drought situation in the vicinity of Bronkhorstspruit east of Pretoria

Month	Nov	Dec	Jan	Feb
Rain	111	99	120	121
Reference evapotranspiration	135	146	146	126

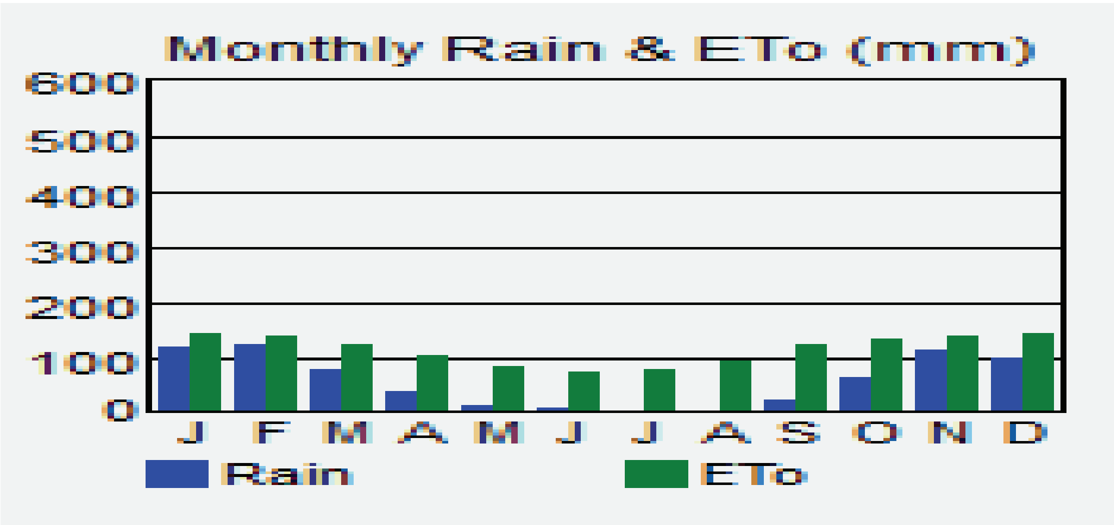
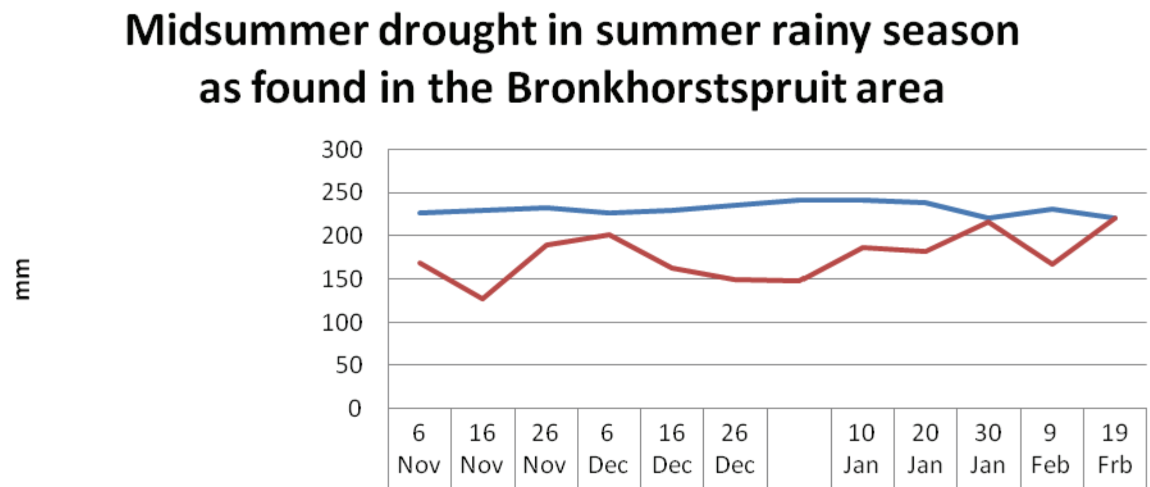


Figure 7. Average monthly rainfall and monthly refernce evapotranspiration in the vicity of Bronkhorstspruit showing a tendency of a midsummer drought.

Analysing the situation in this area for shorter periods, say 10-day (decadal) intervals in stead of monthly intervals, shows a clearer picture of the midsummer drought situation (Figure 8).



	6 Nov	16 Nov	26 Nov	6 Dec	16 Dec	26 Dec		10 Jan	20 Jan	30 Jan	9 Feb	19 Frb
Decadel evapotranspiration	226	229	233	227	230	235	242	242	239	220	231	220
Decadel rainfall	169	127	189	202	163	149	148	186	182	216	168	221

Figure 8. Midsummer drought in the Bronkhorstspruit area based on 10 day periods and averaged for 50 years.

The situation shown in Figure 8 is found in the summer rainfall, highveld cropping areas of South africa. If analysed on 10 day intervals the rainfall shows a typical drop during the hot December months when crop evapotranspiration can be as high as about 8 mm per day. In Figure 8 it can be seen that the shortage of rainfall reaches in excess of 70 mm for the period starting on 16 December and ending on 9 Januarie. The total shortage of soil water during the period 6 Novenber to 29 February because of the drought situation is 384 mm, which is more than the total soil water holding capacity of the soils enerally found in that area. The result is that crops undergo water stress, with a resultant loss in production.

This situation can be managed by irrigating the crop and by planting crops so that their peak water requirement period either falls before or after the midsummer drought period. In semi-arid and sub humid areas there is also substantial variation between years, not only regarding total rainfall, but also in regard to the distribution of rain within the rain season. The objective of irrigated agriculture is to eliminate, or at least greatly minimize, the impacts of drought stress in crops caused by the unreliable rainfall.

5. Variability and reliability of South Africa's rainfall

South Africa's rainfall is highly variable and extremely unreliable. The lower the mean annual rainfall is, the higher is the variability (differences in rainfall between years), especially in the summer rainfall areas. In the arid areas (<200 mm mean annual rainfall) mean rainfall figures are meaningless, because they are inflated by occasional abnormally heavy rains. For example, about 50% of the runoff water that reached the Orange River over a 50 year period from a specific catchment in Bushmanland came in one flood. Thus, in areas like the Lower Orange river (Upington) irrigation should be planned as if the area receives no rainfall.

In semi-arid and sub humid areas there is also substantial variation between years, not only regarding total rainfall, but also in regard to the distribution of rain within the rain season. The objective of irrigated agriculture is to eliminate, or at least greatly minimize, the impacts of drought stress in crops caused by the unreliable rainfall.

Another phenomenon of major importance for irrigated agriculture is the cyclical pattern of several successive years of abnormally low rainfall being followed by several successive seasons with abnormally high rainfall. The latter is again followed by several successive years of abnormally low rainfall, etc. The change from high to low rainfall is not gradual, as shown by the following:

Ottosdal in Northwest Province, with a long term (72 year) mean annual rainfall of 553 mm/.a, had a nine year high rainfall period, averaging 688 mm/.a, from 1973 to 1981. This was followed by a five year drought, having a mean rainfall of only 376 mm/.a and every individual year receiving less than 450 mm. The results of an experiment by the Fertiliser Society of South Africa at Ottosdal during the last three seasons of the wet period and the first four seasons of the drought illustrate the effects of these on rain fed maize yields (Table 3). This shows the importance of irrigation to stabilize yields.

Table 3. Maize yields in an on-farm experiment in Ottosdal district, Northwest province of South Africa from FSSA research conducted in 1985

Season	Maize yield ($t.ha^{-1}$)
1978/79	7.1
1979/80	5.4
1980/81	7.4
1981/82	1.1
1982/83	1.3
1983/84	NY*
1984/85	NY

*Note: *NY = No yield, i.e. total crop failure due to drought.*

A succession of several below normal rainfall years potentially has serious implications for irrigated agriculture. Because of a succession lower than normal runoff years the levels of storage dams drop until they become too low to meet irrigation water requirements. During the prolonged drought of the 1960s a stage was reached when severe water restrictions had to be imposed at the Vaalharts irrigation scheme, for example. Farmers received only 20% of their normal irrigation water quotas.

Farmers must have contingency plans and strategies in place to limit losses and damage to crops during periods of limited water supply, especially in the case of high capital input crops like fruits, nuts and grapes. Possibilities include, *inter alias*:

- Use of anti-transpirant sprays to limit water losses by transpiration. These may, however, perhaps be expensive and have negative side effects, e.g. by also reducing CO_2 exchange (photosynthesis). More than 5 000 Google sites give information on the use of anti-transpirants on various crops.

- In extreme situations trees can be cut back drastically to reduce the leaf area and thus limit transpiration. This is less expensive and gives much quicker recovery to full production when there is enough water again than if mature trees would die and new ones would have to be planted. This strategy was used in citrus orchards in the Letsitele area during the big drought of the 1980s.

Activity

ACTIVITY 1

Small group activity

1. Define your understanding of how rain is formed.

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2. What is the difference between convection rain and orographic rain?

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3. Discuss briefly the general geographic distribution and nature of rainfall in South Africa.

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Authenticator: Prof S Walker

WATER RESEARCH COMMISSION

agriculture, forestry & fisheries
Department: Agriculture, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA

Technical Learner Guide

Agro climatology

Level 5

Module 7

Evaporation, transpiration and evapotranspiration

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- Definitions of evaporation, transpiration, evapotranspiration, potential evapotranspiration and reference evapotranspiration
- Implications of annual potential evaporation of South Africa on crop production
- Factors that affect transpiration
- Methods to estimate potential evaporation (e.g. evaporation pan)

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Definition

Evaporation: Evaporation is the process whereby liquid water is converted to water vapour and removed from the evaporating surface. Water evaporates from a variety of surfaces, such as oceans, lakes, rivers, soils and wet vegetation

Transpiration: The evaporation of water from the plant through the stomata into the atmosphere (mainly a leaf function)

Evapotranspiration: Evaporation and transpiration occur at the same time and there is no easy way to distinguish between the two processes

Reference evapotranspiration: The evaporative demand of the atmosphere independently of crop type, crop development and management practices

1. Evaporation

Evaporation is the process whereby liquid water is converted to water vapour and removed from the evaporating surface. Water evaporates from a variety of surfaces, such as oceans, lakes, rivers, soils and wet vegetation. Evaporation from big water bodies, such as oceans or lakes is essential to produce the water vapour that will lead to rain. Evaporation from storage dams that are built to provide water for irrigation and other uses is a negative factor. Dams that have big surface areas and/or are shallow are relatively inefficient, especially if they are in hot, dry areas.

Energy is required to change the state of the molecules of water from liquid to vapour. Direct solar radiation and the temperature of the air provide this energy. The driving force to remove water vapour from the evaporating surface is the difference between the water vapour pressure at the evaporating surface and that of its immediate surrounding atmosphere. As evaporation proceeds, the immediate surrounding air gradually becomes saturated and the evaporation process will slow down and may stop if the moist air is not transferred further away into the atmosphere. The replacement of the saturated air with drier air depends greatly on wind factors. In addition to solar radiation, which is usually not measured, the following climatologically factors determine evaporation rates:

- Temperature: Higher temperatures increase evaporation. This is an important factor in almost all South African irrigation schemes.

- Humidity: Drier surrounding air increases evaporation.

- Wind: Winds have different effects on evaporation. These include:
    - A hot, dry wind entering an irrigated area will replace moist air with dry air and remove the moist air. This results in faster evaporation. This is an

important factor in the central irrigation schemes (Lower Orange river, Vaalharts, Riet River, Sandvet, etc.) and schemes that are subject to berg winds.

- Wind causes turbulence which mixes dry atmospheric air with the saturated air in the immediate vicinity of the evaporation surface. This results in faster evaporation.

- Cool, moist winds from a cold ocean or big delta increase humidities and reduce evaporation rates. These are, for example, important determinants of wine grape quality in parts of the south-western Cape and in central California.

South Africa is in the mid-latitudes, with high temperatures and low humidities. Consequently it has very high evaporation. For example: Potential evaporation in the areas receiving 500 mm rain per annum is between about 2 000 and 2 600 mm per annum. In an area in central Europe with the same mean annual rainfall potential evaporation is only 300 mm per annum, giving much higher rainfall efficiency in the latter.

The mean annual potential evaporation map of South Africa shows that long term evaporation varies from less than 1400 mm per year in the Drakensberg/Maluti areas of Lesotho, KwaZulu-Natal and the Eastern Cape to more than 2 800 mm per year in parts of the Kalahari (Figure 1). There is more-or-less an inverse relationship between mean annual rainfall and mean annual evapotranspiration. (Compare Figures 4, Module 6 and Figure.1, Module 7.) The areas of low evaporation are the result of a combination of lower than average temperatures and higher humidity than the averages of the country. The opposite is true for the areas with high evaporation. It is important to note the very high potential evaporation figures of the areas where major irrigation schemes, like the Lower Orange river, Vaalharts, Douglas, Rama, Barkley West, etc. are.

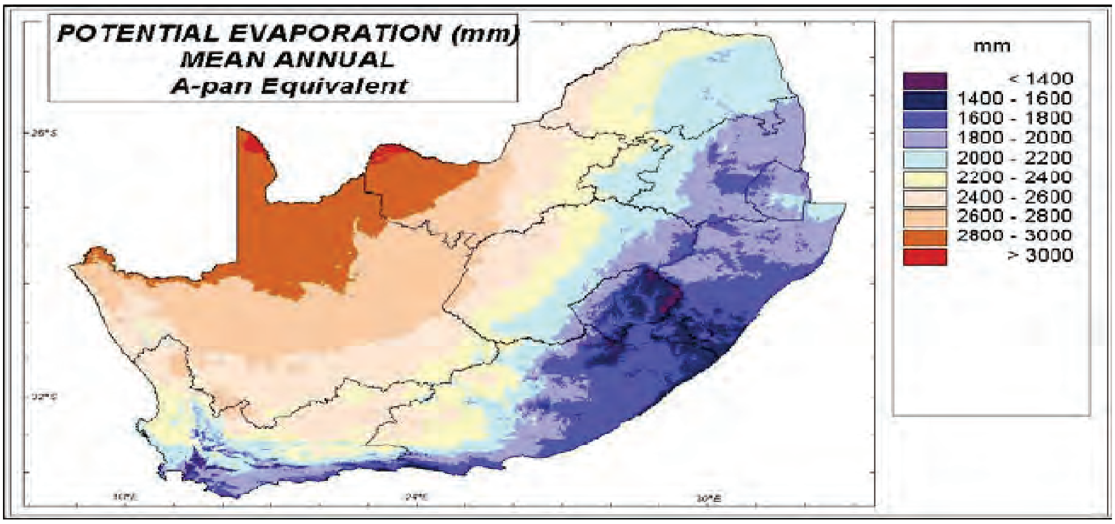

Figure 1. Mean annual potential evaporation map [8)]

The water content of the soil has an important impact on evaporation losses of water. Evaporation takes place much faster from the soil surface in a soil with water content close to field capacity. Evaporation is also mainly from the top 15 to 20 cm soil layer. Evaporation from soil surface in irrigated fields can thus be reduced by applying as much water per irrigation at as long intervals between irrigations as is practically possible within crop requirement limitations. This increases the relative period during which the exposed soil surface is not at or very near field capacity, which in turn reduces evaporation loss from the soil surface. Keeping the soil surface wet, as is found when frequent light irrigations are applied, results in a relatively high evaporation loss. Reducing evaporation loss is a way of increasing irrigation water use efficiency. Mulches and similar soil covers can be used to reduce evaporation from surface soil.

2. Transpiration

Transpiration consists of the vaporisation of liquid water contained in plant tissue and removal of the vapour to the atmosphere. Crops predominantly lose their water through stomata. These are small openings on the plant leaf through which gasses and water vapour pass (Figure 2). The water together with some nutrients is taken up by the roots and transported through the plant. Vaporisation occurs within the leaf, namely in the intercellular spaces, and the vapour exchange with the atmosphere is controlled by the stomatal aperture (size). Nearly all water taken up is lost through transpiration and only a tiny fraction is used within the plant.

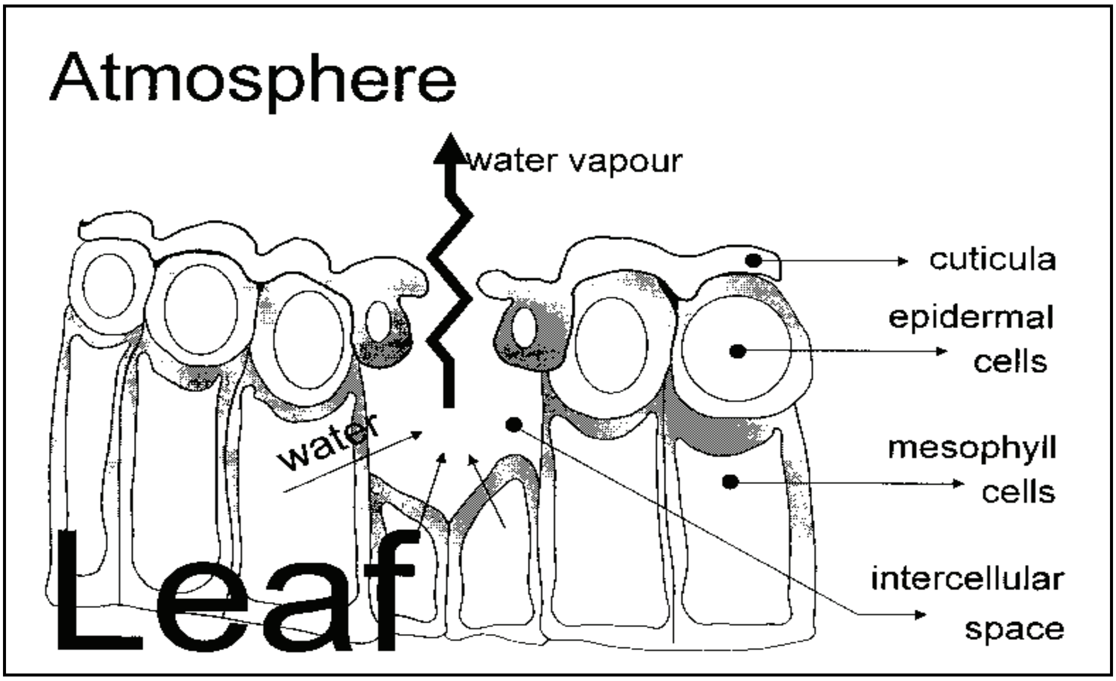

Figure 2. Water vapour escapes from the plant leaf through stomata to the atmosphere [1)]

Transpiration, like direct evaporation, depends on the energy supply, water vapour pressure gradient and wind. Thus, there is a direct relationship between the total evaporation experienced in an area and the total transpiration than can be expected in the same area. The following factors affect transpiration rate:

a. Climatological factors: Air temperature, air humidity and wind affects transpiration in the same ways as discussed for evaporation.

b. Soil factors: Soil factors that affect transpiration rate include:

Soil water content: The lower the soil water content, the slower is water supply to the plant roots until a point is reached where it becomes too slow to maintain a high transpiration rate.

Pore characteristics of the soil: In some clayey soils micro-pores have such small diameters that they limit the rate at which water can be supplied to plant roots and thus limit the transpiration rate, even in a soil that is close to field capacity.

Water logging: Water uptake by plant roots is an active process which means that root respiration is required for efficient water uptake. Under waterlogged conditions this is not possible and transpiration is restricted.

Salinity: In saline soils, e.g. soils with high salt contents, a high osmotic tension develop which hampers water uptake by plants and reduces the transpiration rate.

c. Crop factors: Transpiration rate is also influenced by crop characteristics and the responses of crops to environmental conditions. Different types of crops have different transpiration rates. Not only the type of crop, but also the phenological (development) stage of the crop makes a difference. There are often also large differences between different cultivars or clones of the same crop. Some crop factors include:

- Type of crop: For example, xerophytic (drought tolerant) plants have mechanisms that reduce transpiration rates, such as stomata that only open during the night and/or layers of hair on leaf surfaces that shade the leaves and reduce the effect of sunlight and wind at the leaf surface and/or or stomata only on the underside of the leaf.

- Stomatal control: Some crops have the ability to exercise stomatal control, i.e. to close stomata, under extreme water stress conditions. This may include very high atmospherically induced transpiration demand conditions, caused by very hot, dry atmospheric conditions. Actual transpiration rates will then be much lower than the potential rates calculated. In some crops there are large differences between different cultivars or clones regarding their ability to exercise stomatal control.

- Radial and axial resistances to water flow: Radial (sideways) resistances in roots and axial resistances in the vascular systems of roots, stems and shoots limit water transport rates in plants. Thus, actual transpiration rates may be much lower than potential rates as a result of this factor. Again, it will be more pronounced where the transpiration demand is very high.

- Crop diseases: Corp diseases cause stress in the plant which has a tendency to reduce the transpiration rate. Root rot diseases reduce the ability of roots to absorb water and thus decrease the transpiration rate.

- Plants in net houses transpire less than plants outside because of the different micro-climate caused by the protection against wind and direct sunlight as well as the higher humidity caused by the net cover.

Transpiration rate is measured in a number of ways. The traditional method is to measure differences in soil water content at the plant roots by instruments such as tensiometers, resistance blocks and neutron probes, or by keeping track of weight changes in lysimeters with the soil surface covered in mulch to eliminate soil evaporation. These have developed into probes placed permanently in the ground with radio or cell phone linkages to computers as well as distance methodologies such as infra-red measurement and satellite imagery. A methodology also applied in tree crops is to measure sap flow in the trunk by noting differences in trunk diameter or by placing micro-measuring devices in or on the tree trunk.

3. Evapotranspiration

Evaporation and transpiration occur at the same time and there is no easy way to distinguish between the two processes. Apart from the water availability in the topsoil the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing season as the crop develops and the crop canopy shades more and more of the ground surface. When the crop is small, water is predominantly lost by evaporation from the soil, but as the crop develops, transpiration becomes the main process because more and more of the soil surface is shaded by foliage and total leaf area increases. At sowing nearly all of evapotranspiration is evaporation from the soil surface, but at full foliage cover more than 90% of evapotranspiration comes from transpiration (Figure 3).

Potential evapotranspiration is the evapotranspiration rate from a hypothetical grass reference surface with specific characteristics and never short of water. It is used as a standard against which the water requirement of all other crops is measured.

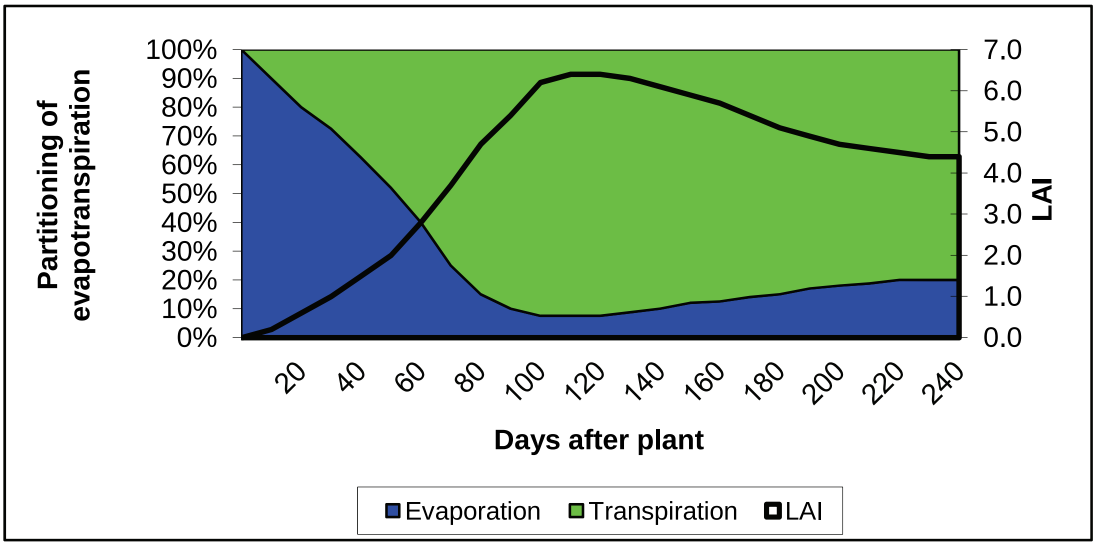

Figure 3. Partitioning of evapotranspiration between evaporation and transpiration[1)]

The concept of reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices (Figure 4).

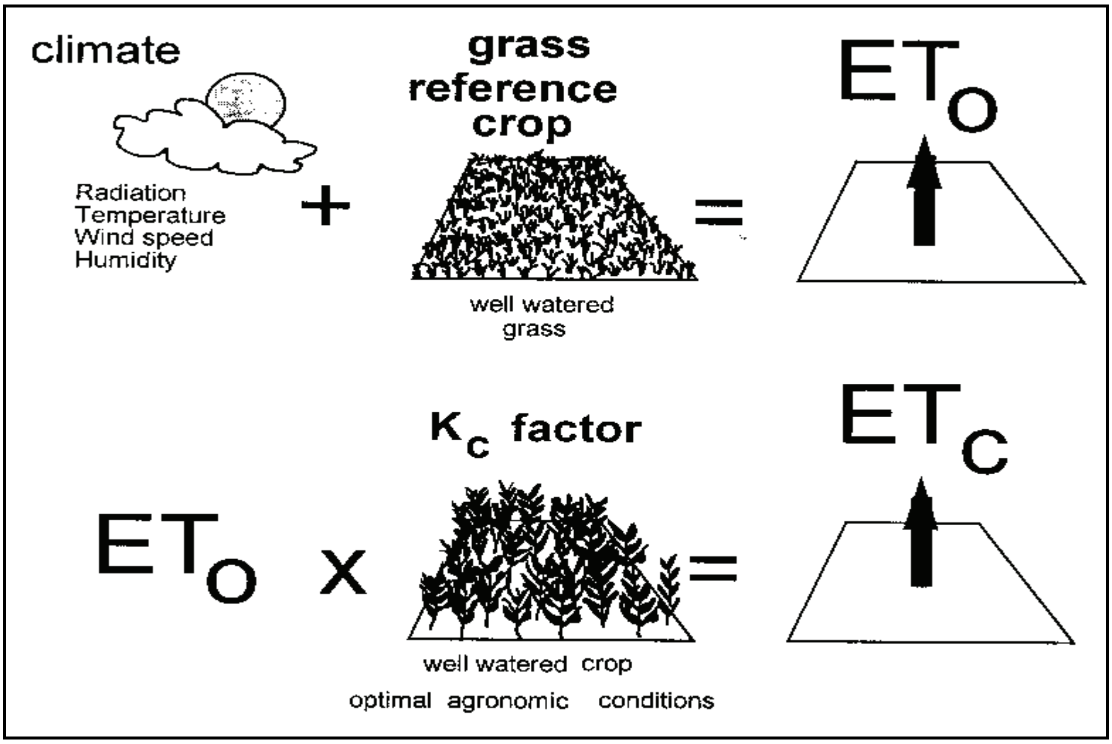

Figure 4. Reference evapotranspiration and crop coefficient which gives crop evapotranspiration[1)]

As water is abundantly available at the reference evapotranspiration surface, soil factors do not affect evapotranspiration. Relating evapotranspiration to a specific surface provides a reference to which evapotranspiration from the surface can be related. It obviates the need to define separate evapotranspiration levels for crop and stage of growth. Reference evapotranspiration values measured or calculated at different locations or in different seasons are comparable as they refer to the evapotranspiration of the same reference surface.

The only factors affecting reference evapotranspiration are climatic parameters. Consequently, reference evapotranspiration is a climatic parameter and can be computed from weather data. Reference evapotranspiration expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and the soil factors. The Penman-Monteith method is recommended as the sole method for determining reference evapotranspiration. This method has been selected because it closely approximates grass reference evapotranspiration at the location evaluated, is physically based, and explicitly incorporates both physiological and aerodynamic parameters. Moreover, procedures have been developed for estimating missing climatic parameters.

Linking a crop through its crop coefficient to potential evapotranspiration is used to calculate the net crop evapotranspiration.

The following equation is used:

$$ETc = f * ETo$$

where: ET_c = crop evapotranspiration; f = crop coefficient and ET_o = reference evaporation.

4. Estimating crop evapotranspiration

4.1 The evaporation pan approach

The evaporation rate from pans filled with water is easily obtained. In the absence of rain, the amount of water evaporated during a period (mm/day) corresponds with the decrease in water depth in that period. Pans provide a measurement of the integrated effect of radiation, wind, temperature and humidity on the evaporation from an open water surface. Although the pan responds in a similar fashion to the same climatic factors affecting crop transpiration, several factors produce significant differences in loss of water from a water surface and from a cropped surface. Reflection of solar radiation from water in a shallow might be different from the assumed 23% for the grass reference surface. Storage of heat within the pan can be appreciable and may cause significant evaporation during the night while most crops transpire only during the daytime. There are also differences in turbulence, temperature and humidity of the air immediately above the respective surfaces. Heat transfer through the sides of the pan occurs and affects the energy balance.

Notwithstanding the differences between pan-evaporation and the evaporation of cropped surfaces, the use of pans to predict ET_o for periods of 10 days of longer may be warranted. The pan evaporation is related to the reference evapotranspiration by an empirically derived pan coefficient:

$$ET_0 = K_p E_{pan}$$

Where

ET_0 Reference evapotranspiration (mm/day)

K_p Pan coefficient

E_{pan} Pan evaporation (mm/day)

4.2. Pan coefficient (K_p)

Pan coefficients are pan-specific. In selecting the appropriate pan coefficient, its surrounding ground cover, general wind and humidity conditions should be checked. The placing of the pan and the pan environment also influence the results. This is particularly so where the pan is placed in fallow rather than in cropped fields.

Depending on the type of pan and the size and state of the upwind buffer zone (fetch), pan coefficients will differ. The larger the upwind buffer zone, the more the air moving across the pan will be in equilibrium with the buffer zone. At equilibrium with a large fetch, the air contains more water vapour and less heat if the fetch is over a green, actively growing grass surface, than if it is over a dry, bare area.

Figure 5. The American Class A Pan commonly used in South Africa [8)]

The American Class A pan is one of the most commonly used evaporation pans in South Africa, and was adopted as the standard evaporation pan since the International Geophysical Year (1957/58). The tool is providing reasonably reliable information, particularly for times longer than one day.

Activity

ACTIVITY

1. Explain what you understand under the following concepts:

a. Evaporation

b. Transpiration

c. Evapotranspiration

d. Potential evapotranspiration.

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2. Farmer Moses who is currently farming in the Burgersfort area, Limpopo, wants to expand his crop farming by introducing vegetables. Use Figure 1 to determine what the potential evaporation figures for his specific area will be, and explain how this information will help with the planning of the expansion of farming.

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3. Explain the pan method of measuring evapotranspiration.

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Authenticator: Prof S Walker

Technical Learner Guide

Agro climatology

Level 5

Module 8

Vapour pressure deficit and relative humidity

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- Definition of vapour pressure deficit (VPD)
- Definition of relative humidity (RH)
- Implications of RH and VPD on the planning and management of irrigation crops

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1. Vapour deficit (VPD) 2

2. Relative humidity (RH) 3

3. Importance of vapour pressure deficit and relative humidity in irrigated agriculture 4

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Definition

Vapour pressure deficit (VPD): Vapour pressure deficit (VPD) is the difference between the actual water vapour pressure at a specific site at a specific point in time and the saturation water vapour pressure at the prevailing air temperature at that time.

Relative humidity: Relative humidity is the ratio between the amount of water vapour that the ambient air actually holds and the maximum amount that it could hold, i.e. its water vapour storage capacity, at the same temperature. Relative humidity (RH) is dimensionless and is commonly given as a percentage.

1. Vapour pressure deficit (VPD)

Vapour pressure deficit (VPD) is the difference between the actual water vapour pressure at a specific site at a specific point in time and the saturation water vapour pressure at the prevailing air temperature at that time. When the air is not saturated, the actual vapour pressure is lower than the saturation vapour pressure.

VPD indicates the difference between the amount of moisture in the air and the amount of moisture that the air can hold when it is saturated. The vapour pressure deficit is an accurate indicator of the actual evaporative capacity of the air, i.e. of the amount of water vapour that the air can take up before it becomes saturated. The higher the VPD, the higher is the evaporative demand. Under normal conditions there is a simple linear relationship between VPD and evapotranspiration rate. However, under extreme conditions, this relationship and/or other VPD relationships become confused and can even be reversed. Vapour pressure deficits in the summer months December to February are lowest at < 0.5 kPa in the higher lying areas in the east of South Africa, notably over Lesotho, the eastern Free State, much of Mpumalanga and parts of KwaZulu-Natal. Highest *VPD*s, in excess of 2.5 kPa, are experienced in summer over the Northern Cape. *VPD*s decrease towards the winter months and from May to August a central belt of *VPD* < 0.5 kPa stretches from the Western Cape to Mpumalanga. This belt is surrounded by an arc around the boundaries of South Africa in which *VPD* is 0.5-1.0 kPa.

WRC sponsored research at Vaalharts and Cradock has shown that maize, for example, acts “abnormally” in terms of evapotranspiration, phosynthesis rate, leaf water potentials, etc. under very hot, dry (high VPD) conditions. It was also found under extreme conditions with sultana grapes at Upington that midday leaf water potentials were higher at the higher the VPD was, which is exactly the opposite of the normal pattern. It indicates increased stomatal closure, and thus also lower transpiration and photosynthesis rates, the higher the VPD was. The latter two relationships are exactly opposite to the normal patterns.

The maximum number of water molecules that can be stored in the air depends on the temperature. Thus, the higher the air temperature, the higher is the saturation vapour pressure and the higher is VPD at any actual vapour pressure.

Correct knowledge of VPD relationships and application of the knowledge in irrigation planning and management is vitally important, especially where extreme climatic conditions prevail. The importance of this is illustrated by the amount of VPD-related research that has been conducted at the US Water Conservation Laboratory at Phoenix in the hot, dry desert of Arizona. Because so many of South Africa’s irrigation areas have extremely hot, dry climates, notice should especially be taken of the abnormal patterns that can occur under such circumstances.

The actual vapour pressure (AVP) cannot be measured. It is calculated using the air temperature, relative humidity and (where possible) canopy air temperature (or leaf temperature). Saturation vapour pressure (SVP) is read off from psychrometric charts relating saturation pressure to air temperature. VPD is calculated by simply subtracting AVP from SVP. Vapour pressure is expressed in kilopascal (kPa).

2. Relative humidity (RH)

Relative humidity is the ratio between the amount of water vapour that the ambient air actually holds and the maximum amount that it could hold, i.e. its water vapour storage capacity, at the same temperature. Relative humidity (RH) is dimensionless and is commonly given as a percentage. Relative humidity fluctuates diurnally, usually between a maximum near sunrise and a minimum around early afternoon. The variation of the relative humidity is the result of the fact that the saturation vapour pressure is determined by the air temperature. As the temperature changes during the day, the relative humidity also changes substantially (Figure 1). For example over a 29 year period in the Lower Orange River (Upington) irrigation area mean minimum and maximum RH values for mid-winter (June and July) were 28 and 79% respectively. Diurnal RH patterns can be disturbed by afternoon cloudiness and rain, cold fronts moving through, etc.

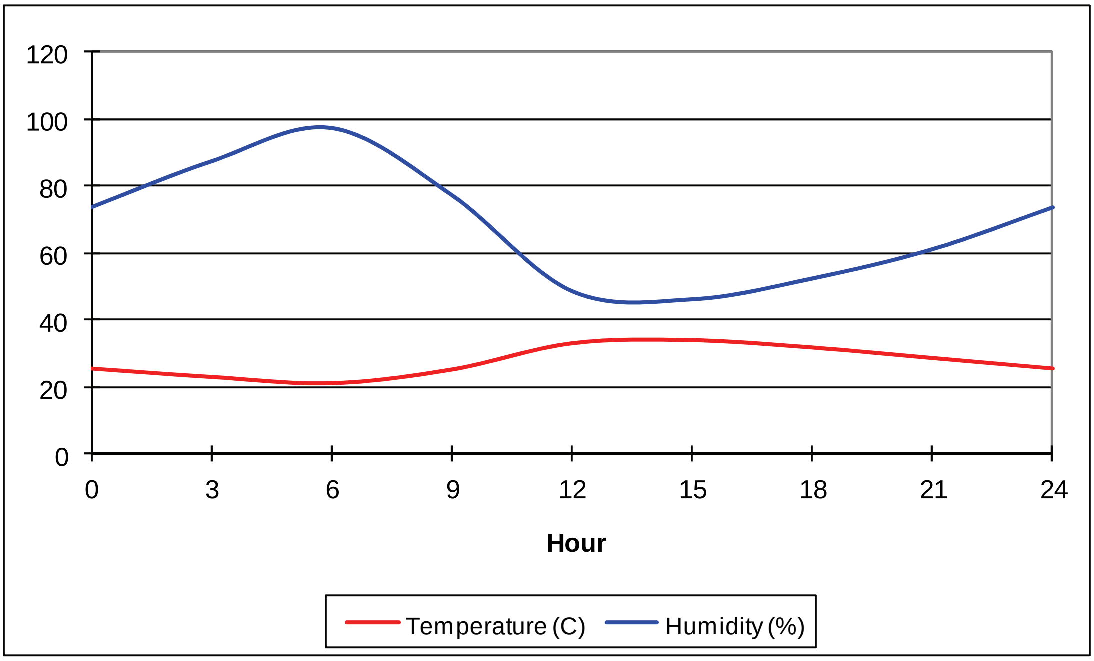

Figure 1. Normal diurnal relationship between air temperature and relative humidity [1)]

At relatively higher air temperatures the water vapour storage capacity of the atmosphere increases at an increasingly faster rate, with the result that the relationship between air temperature and the water vapour storage capacity of the atmosphere is curvilinear (Figure 2).

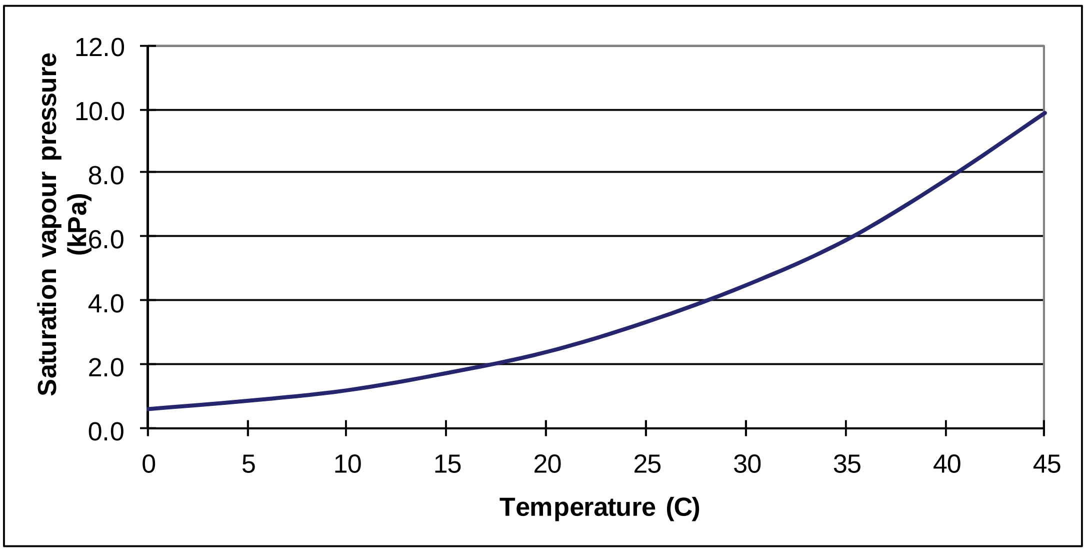

Figure 2. Relationship between air temperature and saturation vapour pressure[1)]

3. Importance of vapour pressure deficit and relative humidity in irrigated agriculture

It is important to take the effects of vapour pressure deficit and relative humidity into consideration in the planning and management of irrigated agriculture. Almost all crops, especially those that originated in humid tropical or subtropical areas, require a relatively low vapour pressure deficit/ high relative humidity. As a general rule the optimum VPDs for most plants are between 0.8 and 0.95 kPa, but VPDs between about 0.45 and 1.25 kPa are quite well tolerated. It was, for example, found that tea (leaf) yields are adversely affected if midday VPD exceeds 2.0 kPa. Most crops seem to prefer a relative humidity of more than 60%, but some crops or cultivars/clones of a specific crop can tolerate values as low as 40% quite well.

At fairly low VPDs/high relative humidities evapotranspiration demands and rates are relatively low and the crop can cope with the required water supply rate – if the soil contains enough plant-available water. At too high VPDs/too low relative humidities the evapotranspiration demand may be too high for the crop to cope with, even in a soil at field water capacity. This is aggravated by high temperatures. The consequence is atmospherically induced water stress in the plant, which cannot be overcome by applying additional irrigation water to the soil. Plants which cannot exercise stomatal control will become desiccated and wilt or leaves may become scorched and drop. This was the case with several tea clones grown in the now defunct tea estates in Limpopo province. Plants which can exercise stomatal control will close their stomata and save themselves, but in the process photosynthesis may also slow down, with resultant yield decreases. The effects of hot, dry conditions found on maize at Vaalharts have for similar findings in the USA been described as "corn (i.e. maize) takes a photosynthesis siesta in the afternoon". The implication is that in areas where high VPDs/low RHs exist the yield potential will be lower than where VPDs/Rhs are favourable.

Studies of annual sultana grape yields over a 29 year period in the Lower Orange river irrigation area showed that the major yield differences between years were related to the mean minimum relative humidities for the different years. The lower the minimum RH, the lower was the yield. It was unexpectedly found that the minimum RH during June and July, the middle of the dormant period of the vines was the most important factor determining yield, explaining 75% of the yield differences. It was found that this effect of low minimum RH was aggravated by low soil water content. In this case irrigation during winter could to some extent alleviate the negative effect of low minimum RH. The lesson from this example is that one should not generalise but approach each situation with an open mind.

High VPDs/low RHs can in some cases be advantageous, e.g. during the ripening period of some fruit crops and grapes - to give high quality products. Such conditions during and immediately after harvesting are also advantageous for the production of high quality dried fruits and raisins.

Very low VPDs/high RHs, i.e. where the atmosphere is close to or at its saturation with water vapour, are also harmful to crop production, especially if it is maintained for a lengthy period. Some possible effects are:

- Favourable conditions are created for the proliferation and growth of micro-organisms causing crop diseases, especially fungal diseases. Insect pests may also proliferate.
- Weeds and parasites proliferate under such conditions.
- Low VPD/high RH during the ripening period of fruits like deciduous fruits may cause watery fruit with poor taste and poor storage and transportation qualities.

Activity

ACTIVITY

Small group activity

1. Explain in your own words what you understand with the following:
   a. Relative Humidity
   b. Vapour Pressure Deficit

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2. Discuss why it is important to take the effects of Relative Humidity and Vapour Pressure Deficit into account with the planning and management of irrigation crops.
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Authenticator: Prof S Walker

Technical Learner Guide

Agro climatology

Level 5

Module 9

Hail, snow, mist and dew

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- Definition of hail and the process involved in hail formation
- The occurrence of hail in South Africa and importance of identifying the “hail season” and “hail belts” for a specific area
- Defining snow and the occurrence of snow in South Africa
- Defining mist and the occurrence of mist/fog in South Africa
- Defining dew and implications for irrigation crop management

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Definition

Hail is the precipitation of balls or pieces of ice with a diameter of less than 3 mm to more than 50 mm. Because the formation of hail usually requires cumulonimbus or other convective clouds with strong updrafts, it often accompanies thunderstorms.

Mist (or fog) is a dense layer of tiny water droplets, creating a very humid layer in the lower atmosphere – often down to ground level.

Dew is water that is seen in the form of droplets on exposed objects in the evening or morning, mainly the latter. Condensation of water into droplets depends on the temperature. The temperature at which droplets form, is called the *dew point*.

1. Hail

Hail, snow, mist and dew are also forms of precipitation. Hail is the precipitation of balls or pieces of ice with a diameter of less than 3 mm to more than 50 mm. Because the formation of hail usually requires cumulonimbus or other convective clouds with strong updrafts, it often accompanies thunderstorms.

Hailstorms are amongst the most devastating weather conditions in the mid-latitudes of the world. South Africa is prone to severe hailstorms, being situated in the mid-latitudes. Hailstorms usually last about 15 minutes. They ordinarily occur in middle to late afternoon. At a very general scale the frequency of hail occurrences is higher in the interior of KwaZulu-Natal, the northern and western parts of the Eastern Cape, central Orange Free State and on the Highveld areas of the Gauteng, eastern Free State and Mpumalanga than in other areas of the country (Figure 1). Hail can cause substantial damage to crops in these areas.

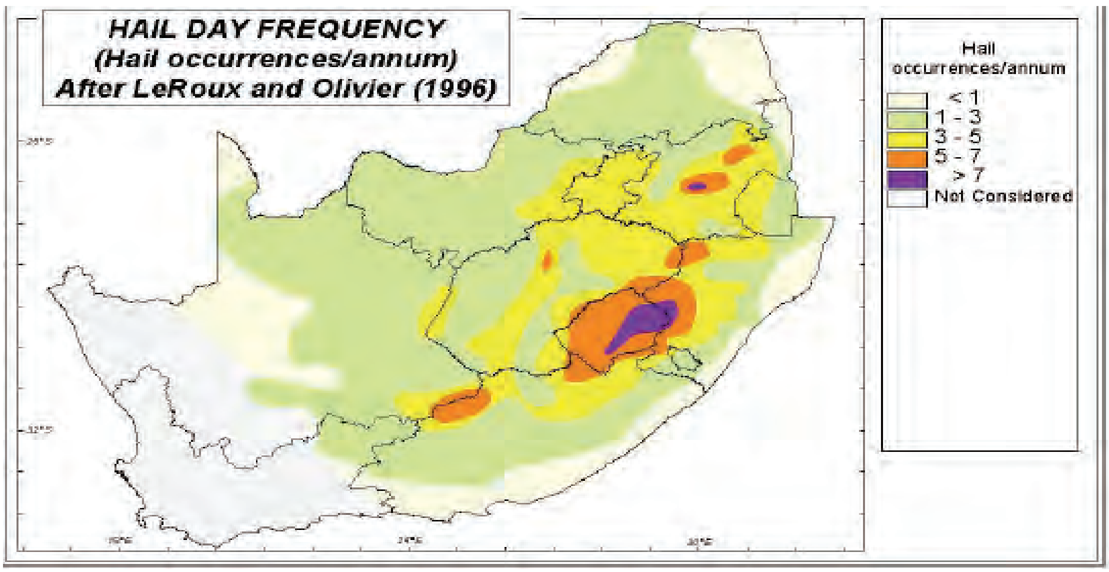

Figure 1. Hail day frequency map of SA [8)]

1.1 Hail formation

Hailstones generally begin forming on seeds of small frozen raindrops or soft ice particles known as *graupel*, (hardened conglomerates of snowflakes). Hail can be found in the middle and upper portions of almost all thunderstorms. However, most hail either melts before hitting the ground or, when very soft, disintegrates in the violent thunderstorm interior. The size of hailstones usually increases with the intensity of the storm cell from which they spawn. To form hailstones the size of golf balls requires over 10 billion supercooled droplets be accumulated, and thus they must remain in the storm cloud for at least 5 to 10 minutes (This should be compared to the one million or so droplets needed to form a typical raindrop). Therefore, large hail (> 50 mm) forms mostly in *super cell* thunderstorms which have strong updraft winds. In order for the frozen raindrops or graupel to grow into true hailstones, they must accumulate additional ice, a process called *accretion*. To do so, the hail embryo must spend time in cloud regions rich in supercooled water, a layer where temperatures are below the 0°C level [5)].

Hailstorms require strong updrafts, cold levels, sufficient ice nuclei and super cooled water to form (Figure 2). Thus, squall line and super cell thunderstorms are the most frequent hail producers. Super cells have the greatest potential to produce damaging hail since they are physically taller clouds and have access to the colder levels of the atmosphere. They are also longer lived and thus have a better chance of acquiring nuclei in sufficient quantities to form hail. For the smallest hail to form, an updraft of around 35-55 km/h is required. Larger stones, the size of golf balls (40 mm diameter), require updrafts of around 90 km/h to form. Hailstones fall as a result of an increase to a size unable to be countered by storm cell's updrafts, or they may be caught in a downdraft and hurled earthward. Large hailstones fall at speeds faster than 160 km/h.

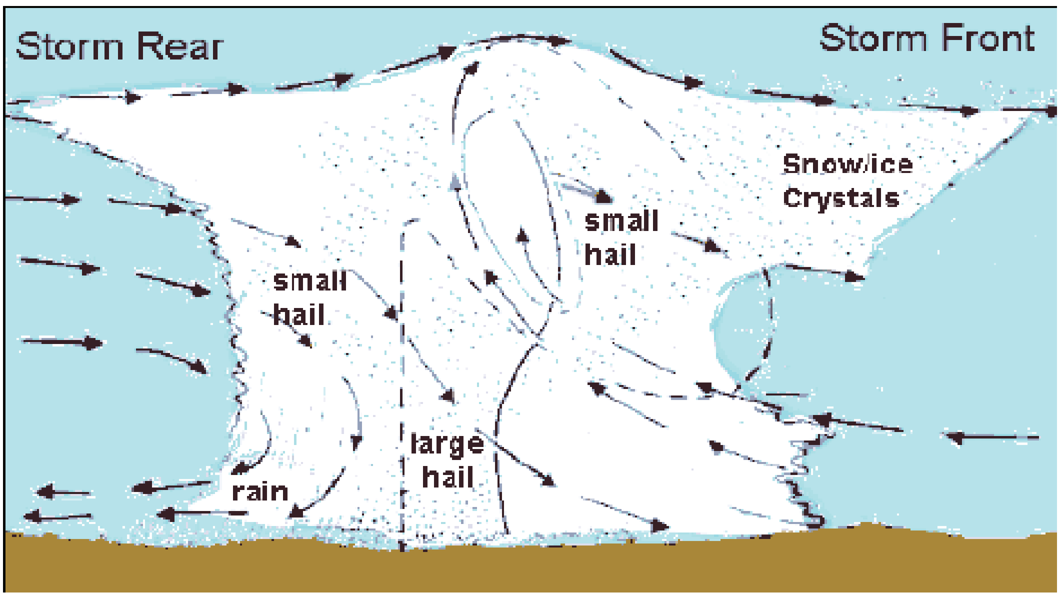

Figure 2. Process of hail formation [5)]

1.2 Hail belts and hail season

Hail damage from convective storms in South Africa's summer rainfall regions is estimated at several millions of rand per year. One should not be complacent about areas indicated as having low frequencies of hailstorm occurrence. A devastating hailstorm once a year or even once every two or three years, can impact very seriously on the economic viability of capital intensive crops grown under irrigation. For example, table grape producers in the Waterberg area of Limpopo province, indicated as experiencing "only" 1-3 hailstorms per year, have to install expensive hail nets over the vineyards. In addition, there are hailstorm "hotspots" or "hail belts" in most areas. These have much higher hailstorm frequencies than the surrounding areas. An example of each from the Eastern Cape is:

- The Misgund area in the Langkloof valley, one of South Africa's main deciduous fruit production areas (under irrigation) is a hailstorm hotspot, suffering regular losses from severe hailstorms e.g. 1985 (millions of Rand), 1987 (millions of Rand), 1992 (R750 000), 1996 (R30 million).

- A big hail belt stretches along the southern slopes of the Winterberg mountains from north of Somerset East in the west to north of Fort Beaufort in the east. Commercial citrus farmers in the Kat River Valley near Fort Beaufort have suffered great losses due to regular severe hailstorms e.g. 2000 (R5 million), 2004 (R13 million), 2005 (R4 million).

In both these examples hailstorm frequency is statistically less than one per year, but in financial terms to the irrigation farmers it is devastating.

It is also important to know when the "hail season" for a specific area is, because the crop stage at which a hailstorm strikes, makes a big difference to the damage caused. In the Eastern Cape the hail season is from November to January, with a peak in December. December and January storms in the Eastern Cape are devastating because most are characterised by very large (larger than hen's egg) hail stones. For example: A single hailstorm, lasting only ten minutes, which hit Elliot and its surrounding farms in the Eastern Cape on 25 January 2006 caused damage amounting to R12.1 million. Hailstones were the size of a man's fist.

Unfortunately information regarding hailstorm frequency, hailstorm hotspots, and hail belts, the nature of hailstorms or hail stone sizes cannot be obtained from meteorological records. The only meaningful way to obtain information would be by means of unstructured interviews with local farmers.

2. Snow

Snow falls at low elevations only at high latitudes, pole-ward of latitude 35°N and 35°S. At higher latitudes, e.g. in Canada and the northern parts of the USA, late spring melting of snow and thawing of frozen soil delay growing of crops and reduce growing season length.

South Africa is in the warmer mid-latitudes; less than 35°S, and thus most of the country does not receive any snow. Only the higher mountains regularly receive a few snowfalls every winter. Snowfalls are light and the snow melts quickly after each fall. Melting snow leads to runoff, contributing to the filling up of water storage dams and assisting in maintaining winter flows of rivers in summer rainfall areas. Compared with rainfall this contribution is very small, however.

The Koue Bokkeveld near Ceres is the only major irrigation farming area (growing crops like deciduous fruits and potatoes) where snow falls a few times each winter in orchards and croplands themselves.

3. Mist/fog

Mist (or fog) is a dense layer of tiny water droplets, creating a very humid layer in the lower atmosphere – often down to ground level. It is mostly seen in summer and usually from late afternoon until early morning. It evaporates when temperatures rise during daytime. In undulating hilly areas it often occupies just the lower-lying areas.

Mist is common along the cool west coast areas of South Africa, especially during summer. It is also common in the mid-altitude areas below the eastern escarpment of the country. The KwaZulu-Natal Midlands mist belt area is the best known of these, forming a special ecological zone in the province. Mist also occurs less commonly in many other parts of South Africa.

Early summer mist has been described as a “crop production hazard” in the mist belt of the KwaZulu-Natal mist belt. Mist belt areas are, for example, described as unsuitable for production of forage sorghum, because of the hazard of diseases like rust and ergot, which thrive under such conditions. On the other hand mist belt conditions are described as ideal for avocado production, a crop which requires high relative humidities. Thus, mist must be considered when doing land suitability evaluations for irrigated agriculture.

4. Dew

Dew is water that is seen in the form of droplets on exposed objects in the evening or morning, mainly the latter. Condensation of water into droplets depends on the temperature. The temperature at which droplets form, is called the dew point. When the temperature of a surface drops to the dew point through irradiation of its heat, dew forms. Dew formation requires a clear (cloudless), calm (windless) night.

Dew occurs periodically in most areas of South Africa, and is even in arid areas important. Dew formation occurs especially along the arid cool west coast and adjoining interior areas of South Africa.

Frequent occurrence of dew leads to increased disease hazards in many crops, e.g. potatoes, soybeans, Swiss chard, etc. This is because plant leaves comprise an important surface on which dew forms and this dew creates favourable conditions for the development of diseases. Dew is thus a factor to consider in land suitability evaluation for irrigated agriculture.

Activity

ACTIVITY

Small group/Individual activity

1. Explain in your own words what you understand underneath:
   a. Hail
   b. Dew
   c. Snow
   d. Mist

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   ……………………………………………………………………………………………………
   ……………………………………………………………………………………………………
2. Explain how hail is formed.
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   ……………………………………………………………………………………………………
3. What do understand with the following concepts:
   a. “Hail belt”

   b. “Hail season”

   ……………………………………………………………………………………………………
   ……………………………………………………………………………………………………

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Authenticator: Prof S Walker

Module 10

Wind

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- Trade wind belts and the influence of it on weather and climate patterns in South Africa
- Effect of wind on crop and irrigation management
- The use of various types of wind breaks
- Advantages and disadvantages of planting wind breaks

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1. Trade winds

Global wind belts are found at certain latitudes north and south of the equator. Of interest to South Africa are the so-called trade wind belts of the mid-latitudes south and north of the equator. The trade winds develop as follows: Due to intense heating at the equator air rises. At great height this air moves away from the equator in the troposphere. At about 30^o latitude in both hemispheres this air starts subsiding towards the surface in subtropical high-pressure belts called subtropical ridges. As the air descends, its temperature increases, but its absolute humidity remains the same. Consequently its relative humidity decreases. Thus around 30^o a high pressure zone of stable dry air prevails. The result is a region with high temperatures and low rainfall. The 30^{o}S latitude runs across the centre of South Africa, explaining why South Africa is predominantly a hot, dry country.

The rising of the air at the equator causes low pressure at low levels in that zone. Air from high pressure trade wind zones moves towards the lower pressure zones. This air movement is not directly northwards (in the southern hemisphere) or southwards (in the northern hemisphere). It is deflected due to the rotation of the earth around its axis. The deflection is such that the winds blow predominantly from the southeast in the southern hemisphere (known as the south-easterly trade winds) and from the northeast in the northern hemisphere.

In South Africa the south-easterly trade winds are important for bringing rain to the eastern coastal areas of the country. During summer months the south-western Cape is tormented by very strong south-easterly winds, but they do not bring rain, because they do pass over a wide enough stretch of ocean to pick up enough moisture.

2. Other important winds in South Africa

As discussed in earlier modules, there are several other winds that have important implications for irrigated agriculture in South Africa. These and other important, winds include:

- The hot, dry berg winds, affecting areas below the escarpment.
- Cool sea breezes.
- The cyclones bringing winter rains to the south-western Cape.
- Tropical cyclones on the northern areas of the east coast and the immediate interior.
- Cold south-easterly winds in the Free State.
- Strong westerly winds blowing during late winter and spring in the western Free State and Northwest province (the “August” winds).
- Westerlies affect the southern parts, especially during winter: North-westerlies ahead of cold fronts and south-westerlies behind cold fronts.

3. Wind effects important for irrigated agriculture in South Africa

Winds have important effects on various climatic parameters, crops themselves and efficiencies of some irrigation systems.

3.1 Wind effects on other climatic parameters

Wind effects on other climatic parameters include, *inter alia*:

- Effects on temperature.
- Effects on evapotranspiration.
- Effects regarding orographic rain.
- Effects on frost occurrence.
- Effects on dew formation.

These in turn have effects on crop growth and yield, crop disease incidence, etc.

3.2 Wind effects on crops

Wind effects on crops include:

- Gentle winds may benefit crops by replenishing CO_2 to leaves in densely planted crops.
- Crop yields can be impaired by strong winds at critical times in the crop's production cycle, such as inhibiting bee activity during blooming period when it is essential for pollination.
- Some fruits are tender during certain development stages and whipping winds can cause skin blemishes, making the fruit unacceptable for marketing.
- Deciduous tree branches, heavily laden with ripening fruit can be broken by strong winds.
- "Tree throw" (i.e. blowing over) of mature fruit trees can happen.
- Trees with weak bud unions between the rootstock and scion can be snapped at the bud union by wind. Some rootstock/scion combinations have inherently weak bud unions. It sometimes means that a good cultivar on an excellent rootstock cannot be planted in a specific area due to wind hazard.

- Continuous winds accompanied by high temperatures during the growing season markedly increases water losses through transpiration and evaporation, to such an extent that the plant may not be able to cope with it.
- Increased air flow through the canopy of densely planted crops can reduce disease incidence and improve photosynthetic efficiency by refreshing CO_2 at the surface of the leaves.
- Crops can be "sandblasted" or even buried under sand where wind erosion is a problem, e.g. at the Vaalharts and Sandvet irrigation schemes in the "August wind" zone or on the Cape and Joostenberg Flats areas, tormented by strong south easterlies during summer.
- Vineyards receiving cool sea breezes may produce better quality wines.

It is important to take wind into consideration when doing land suitability evaluation for different crops for irrigated agriculture. Factors like exposure of a specific site/hill slope to damaging winds or, in contrast, its seclusion from it is important to consider. Care should be taken for localities where strong winds coming over mountains "slam" down.

3.3 Wind effects on overhead irrigation systems

Strong winds can disturb the water distribution patterns of overhead irrigation systems and reduce their efficiencies. In relatively moderate cases system design can be adapted to compensate for this. In extreme cases an area can be unsuitable for the use of such systems. An example of the latter was found in the panhandle of Texas: Farmers traditionally used furrow irrigation. In the 1970s they switched to overhead sprinkler irrigation. The effects of the high winds prevailing in the area on the systems were so severe that by the early 1980s the farmers were forced to switched back to furrow irrigation. Hot, dry winds can also cause very high evaporation losses during water application by such systems.

4. Windbreaks

Where soil and all other climatic conditions are suitable for irrigated crop production, but a serious wind hazard prevails, windbreaks are used to overcome the problem. Normally tall growing trees are planted as windbreaks, but other types of windbreaks can also be effective for certain situations.

4.1 Trees as windbreaks

The following publication by the KwaZulu-Natal Department of Agriculture gives an excellent outline of the design, planning, establishment and maintenance of tree windbreaks. It also gives information on the selection of suitable trees for different ecological regions in summer rainfall areas, as well as a comprehensive list of tree species that can be used. It also outlines how windbreaks work and the advantages and disadvantages of windbreaks, some of which are listed below.

Haigh, H. 1997. Windbreaks for farms in KwaZulu-Natal. Internet reference

http://agriculture.kzntl.gov.za/publications/production_guidelines/conservation_farmland/cons_farm_2.9.htm

a. *Some of the main **advantages** of trees as windbreaks are*:

- Wind speed is greatly reduced, thus
  - Preventing/limiting wind throws of trees, breaking of fruit-laden branches, etc.
  - Preventing physical damage to flowers, fruit and plants by dust, hail, snow and abrasion. Both the quantity and the quality of the crop is improved.
  - Facilitating pollination by bees, which is especially important for fruit production.
- Windbreaks can supply products such as timber, poles and firewood, as well as nectar and pollen for honey production.
- Windbreaks can provide shelter for desirable birds and animals.

b. *Some of the main **disadvantages** of trees as windbreaks are:*

- Windbreaks can have negative impacts on the micro-climate in an orchard or field. For example: Windbreaks on the contour can trap cold air (resulting in frost pockets) or hot air (resulting in heat scorch), both of which can cause crop damage. Normally evergreen trees are used as windbreaks. However, where protection is required against summer winds and there is a danger of frost pockets in winter, it may be preferable to plant deciduous windbreaks. A reduction in windbreak density in deciduous windbreaks during winter, due to being leafless during that period, will allow some air drainage through the windbreak and reduce the formation of frost pockets in orchards.
- A too dense windbreak barrier can cause winds to become turbulent of the leeward side (i.e. in the orchard or field), causing physical damage to crops.
- Undesirable birds may find shelter in windbreaks.
- If a wrong tree species is chosen it may invade adjoining areas.
- Some windbreak tree species may be hosts for the survival of insect pests and/or disease organisms affecting the crop.

4.2 Other types of windbreaks

a. *Grain crop strips:* In overseas research in the 1970s/1980s it was found that for crops like vegetables narrow grain crop strips are the most effective windbreaks. This technique was applied very successfully already in the 1940s by watermelon and vegetable farmers on the Joostenberg Flats near Cape Town. They used to grow something like oats during the winter rain season. Fairly narrow strips of oats were ploughed in as green manure in spring, leaving strips of it as windbreaks to protect summer crops like watermelons and vegetables, planted in the "beds", against the southeaster. During summer the strips of oats are dead and dry and do not compete with the crop for water and nutrients.

b. *Nets:* Nets can be used as windbreaks for some purposes. Some advantages of nets over natural windbreaks (trees) include:

- Nets are quickly erected.
- They do not take up productive land and do not compete with the crop for water and plant nutrients.
- They do not host harmful insect pests or disease organisms.

Activity

ACTIVITY

Small group/Individual activity

1. Explain the meaning of "trade wind belts "and how it is formed.
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2. What are the effects of wind that irrigation farmers should try and take care of?
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3. Discuss how windbreaks can be used to combat where serious wind hazard prevails.
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