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Hawke's Bay
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Planning and Monitoring Irrigation Rotations

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minimum tillage , optimum water , maximum productivity

Planning and Monitoring Irrigation Rotation(s)

Introduction

Irrigation rotation(s) is synonymous with return interval, irrigation frequency, time between irrigation and a number of other "names". Simply, an irrigation rotation is the time between one irrigation and the next irrigation. Ideally the length of the irrigation rotation should not be longer than the time it takes to irrigate all the crops applying the amount of the critical deficit or the current soil moisture deficit. This will avoid moisture stress and yield loss.

In practice this simplification is complicated by;

- soil type,
- the amount of available soil water,
- the different critical deficits of the crops being grown,
- the crop's growth stage, prevailing weather, and
- rain during the irrigation season.

In addition the amount of water available for irrigation and the irrigation equipment available has a direct effect on the area that can be irrigated. Individually or in combination these factors will determine how often irrigation is required; the length of the irrigation rotation.

Why Irrigate ?

Irrigation water is applied to ENSURE crops are not subjected to moisture stress. Water held in the soil is the ONLY source of water for a plant to use in the process of growing. Most is used in transpiration, the only means for the plant to remain at ambient air temperature. Much less water is used in production of dry matter and cell development. Limiting moisture will:

- Decrease transpiration
- Decrease plant growth
- Decrease yield
- Reduce quality

These detrimental effects on plant growth are immediate and irretrievable. A useful rule of thumb is:

"When soil moisture falls below the critical soil moisture deficit there is a yield loss of 0.1-0.3%/mm" (Jamieson 1985 and Jamieson et al 1984 and 1995), and

"The rate of gain in fruit diameter is reduced by 25% when soil moisture falls below the critical deficit" (Trought, 1985).

Irrigation water is applied to replace and/or supplement soil moisture. Unless a decrease in crop yield and a reduction in crop quality are an acceptable component of a farming operation, irrigation water MUST be applied before the available soil water is depleted.

Planning (or designing) an irrigation rotation should be based on the absence of rainfall. Rainfall on the East Coast of New Zealand is inherently unreliable with no distinct wet/dry season pattern. As outlined below, rotation times for some crops are so short that more than two weeks without rainfall will result in serious crop loss. Two weeks is not an uncommon length of time between effective rainfall events and irrigation rotations must be planned on the basis of negligible rainfall. Planning and managing irrigation in the hope of rainfall is not wise and will not be profitable.

Soil Water and Available Soil Water.

The Available Water (AW) or Water Holding Capacity (WHC) is a physical characteristic of the soil and can not be changed. WHC is:

?? The amount of water that can be held in the soil that is available for plant growth.

The soil texture (type of soil) and the depth of plant roots determine the amount of AW. The AW is the moisture BANK for plant growth. Withdrawing moisture without a deposit (rainfall or irrigation) will lead to overdraft conditions where moisture limits potential plant growth. Ultimately if the moisture bank is not replenished then plant death (Bankruptcy) occurs.

Available water is;

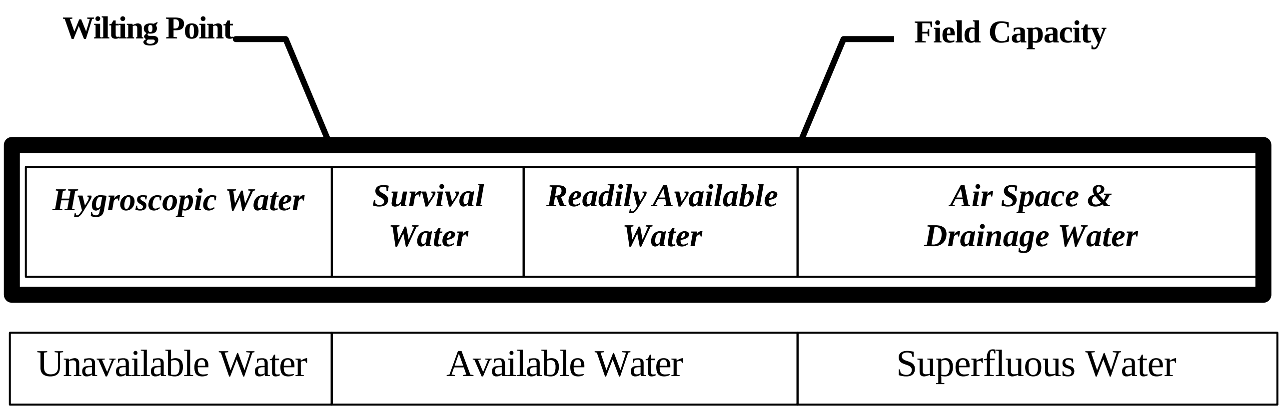
?? the amount of water in the soil between Field Capacity and Wilting Point

?? it is usually expressed as mm/depth of soil or as volumetric moisture content, V%.

Field Capacity is often also referred to as Full Point. It is the soil moisture content of well-drained soils that is normally reached 1-3 days after a very large rainfall event that saturates the soil. At field capacity the macro pores of the soil are filled with air and moisture fills the micro pores as a film on the soil particles. Field Capacity is expressed as volumetric soil moisture V% or mm per m of soil depth.

Wilting Point. In simple terms, it is the soil moisture content when plants will die. Eventually as the soil dries out the supply of moisture to plants cannot maintain even nighttime demand and the plant will become permanently wilted. If water is not added the plant will die and the soil moisture is at Wilting Point. Technically, Wilting Point is the soil moisture content equivalent to a soil tension of 15 bar (1500 cba). The wilting point soil moisture content is expressed as V% or mm per m of soil depth.

The following diagram illustrates the above soil moisture characteristics.



The soil type determines the amount of available water and it is different for every soil type. But, is all the AW available and useful? YES, ALL the AW is available, **but** NO, NOT all the AW is useful.

?? If potential growth is to be maintained and top yields and quality are to be achieved only a portion of the AW is most useful.

When this portion of AW is used the soil moisture content has reached the Critical Deficit. At this point the readily available water is exhausted and the rest of the available water is more difficult for the plant to access. Crop water use continues but at a steadily decreasing rate. Irrigation should be applied before the Critical Deficit (CD) is reached.

Each crop has a different CD but in general the CD is about 50-70% of the AW within the root zone of the crop. Clearly the CD will be;

?? large for deep-rooted crops on deep soils, but small for shallow rooted crops on shallow soils.

CD is **always** the same proportion of AW within the crop root zone. Typical proportions of AW that can be used before CD is reached in a silt loam soil are:

- ?? Ryegrass pasture 30-35%
- ?? Spring Barley 60-65%
- ?? Peas 35-45%
- ?? Potatoes 30-45%
- ?? Lucerne 70-75%
- ?? Onions 30-60%
- ?? Pipfruit 55-65%
- ?? Grapes 70-80%

The crop water demand can then be used to estimate the return time or irrigation rotation. Table 1 below is a guide to the AW of different soil types and the likely irrigation rotation using a critical deficit of 50%AW.

Table 1. Indicative amounts of available water for soil of different texture.

Soil Texture	**AW, mm/m**	**50% AW, mm/m**	**Rotation Time (days)**	
			3 mm/day	5 mm/day
Stony, no topsoil	50-55	25-28	8-9	5-6
Stony, up to 250mm topsoil over gravel	65-80	32-40	10-13	6-8
Silt Loam, up to 600mm over gravel	110-120	55-60	18-20	11-12
Silt Loam, no stones or gravel	155-165	77-82	25-27	15-16
Clay Loam	175-190	87-95	29-32	17-19
Sand	45-55	22-28	7-9	4-6
Sandy Loam	65-110	32-55	10-18	6-11

While this is both generalised and simplified, and does not take into account crop root depth or growth stage, the table does show how short irrigation rotation MUST be on some soil types.

Crop Growth Stage and Root Depth

Crops use water at different rates until full cover (maximum leaf area) is reached. Until the maximum leaf area is reached a crop does not transpire water at potential rate; i.e. the water transpired will be a proportion of the potential evapo-transpiration. Only when the leaf area index is 1.0 can a crop intercept incoming radiation and therefore need to transpire at potential rate(s). For example;

Perennial crops such as lucerne and pasture have complete ground cover for most of the year. Consequently water use will reach potential rates early in the irrigating season and short irrigation rotations are required from early in the season to late in the season.

Annual crops on the other hand have large proportions of bare soil for extended periods. Potential water use (transpiration) only occurs when there is full ground cover. Some crops (e.g. onions and corn) never have full ground cover and therefore will not transpire at potential rates. Those crops that develop full ground cover will require shorter irrigation rotations than those that never develop full ground cover.

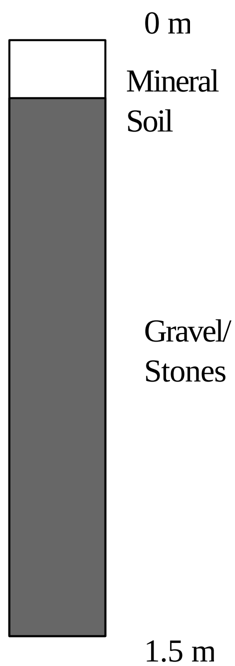
The following examples in Table 2 illustrate the effect of ground cover on transpiration and the influence on irrigation rotation.

Table 2. Proportion of potential transpiration from sowing to full ground cover.

	Effective Ground Cover, %									
Crop	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
Beans	0.2	0.23	0.3	0.4	0.5	0.65	0.75	0.9	1.0	1.07
Peas	0.2	0.25	0.3	0.4	0.5	0.65	0.75	0.85	1.0	1.05
Potatoes	0.1	0.15	0.2	0.3	0.4	0.55	0.65	0.75	0.85	0.9
Corn	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95
Lucerne	0.35	0.45	0.6	0.7	0.8	0.9	1.0	1.0	1.0	1.0
Pasture	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9

(The factors above are adapted from Jensen, 1973).

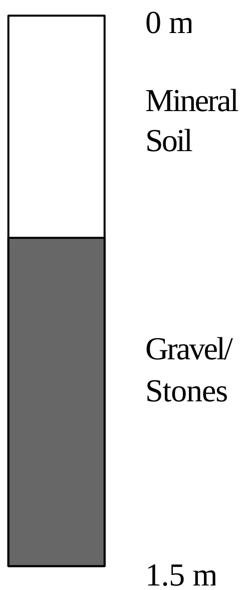
Crop root depth has a significant effect on rotation time. Some crops have naturally shallow root systems, others do not grow for sufficiently long times before harvest to develop deep root systems, and others develop deep root systems. The following diagrams illustrate the effect of root depth, readily available water and crop type on irrigation rotation time (water use 5mm/day).



Shallow Soils

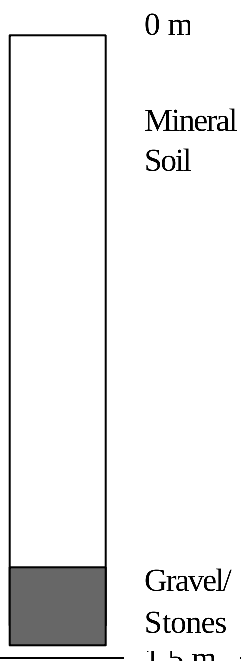
	RAW	Rotation
Ryegrass Pasture	20-25mm	4-5 days
Peas	20-25mm	4-5 days
Onions	15-30mm	3-6 days
Potatoes	20-27mm	4-6 days
Barley	40-45mm	8-9 days
Spring Wheat	45-50mm	9-10 days
Pipfruit	50-58mm	10-12 days
Lucerne	60-70mm	12-14 days
Grapes	65-85mm	13-17 days

Note: Potatoes are unlikely to be grown on soils with such shallow soil to gravel. If they are grown on these soils destoning will be required and the soil will behave the same as a medium soil (see below).



Medium Soils

	RAW	Rotation
Ryegrass Pasture	25-35mm	5-7 days
Peas	25-30mm	5-6 days
Onions	15-30mm	3-6 days
Potatoes	20-27mm	4-6 days
Barley	45-55mm	9-11 days
Spring Wheat	45-55mm	9-11 days
Pipfruit	55-65mm	11-13 days
Lucerne	65-70mm	13-14 days
Grapes	65-80mm	13-16 days



Deep Soils

	RAW	Rotation
Ryegrass Pasture	35-40mm	7-8 days
Peas	30-35mm	6-7 days
Onions	15-30mm	3-6 days
Potatoes	25-35mm	5-7 days
Barley	60-65mm	12-13 days
Spring Wheat	60-65mm	12-13 days
Pipfruit	65-70mm	13-14 days
Lucerne	135-145mm	27-29 days
Grapes	135-145mm	27-29 days

Prevailing Weather

Obviously it is not possible to predict the weather so that long term rotation time can be planned. But historical weather conditions can be used to determine the extreme conditions that can be expected and that are considered to be an acceptable risk. For East Coast regions in New Zealand the of northwesterly conditions have the greatest effect on water demand. Warm N-W conditions can increase potential water use by a factor of more than 1.5. For example;

?? Corn water use at tassling is about 4.5mm/day. Hot N-W will increase this water use to 6.5-8 mm/day. If the irrigation rotation had been 12-14 days the N-W will shorten the rotation to 6-9 days.

?? Russet Burbank potato water use from 60-90 days after planting is normally about 5-5.5mm/day. Hot N-W will increase this water use to 7.5-8 mm/day reducing irrigation rotation by 2-3 days.

When designing irrigation the highest practical water demand should be used. In practice the rotation can only be modified according to weather conditions through careful soil moisture and crop monitoring.

Water Available for Irrigation

Groundwater and surface water can limit rotation time when restrictions are imposed. If water supply is restricted then to fully irrigate crops will require a proportionate decrease in the rotation time. This will restrict the area and number of crops that can be irrigated.

The Effect of an Inadequate Irrigation Rotation

The key to determining the effect of an irrigation rotation that is too short is estimating the potential soil moisture deficit. This deficit accumulates at the crop water use rate until the Critical Deficit is reached. The effect on yield is based on the time before irrigation and/or rainfall replenish the deficit accumulated (at the potential rate) during this time. For example, in December and January crop water use may be as high as 6mm/day, so if irrigation is four days late the <u>potential deficit</u> would be 24mm below CD.

The effect on yield is immediate and is irretrievable. Using the above example of being just four days late with irrigation, Table 3 estimates the expected yield losses. It must be noted that:

?? The yield loss is greater for a crop with a high yield potential than for one with a low yield potential (an example for wheat is used to illustrate this effect).
?? The critical deficit will be reached sooner on shallow and coarse textured soils than heavier and deeper soils. BUT, the yield response relationship(s) is the same.
?? The yield response relationship(s) are taken from Jamieson *et al.*

Table 3. Expected yield loss resulting from a short irrigation rotation.

Crop	Expected Yield, t/ha	4 day deficit	Yield response, %/mm	Yield Loss, t/ha
Wheat	7	24	0.22	0.37
Wheat	14	24	0.22	0.75
Barley	12	24	0.25	0.72
Field Peas	5	24	0.22	0.26
Maize	12	24	0.08	0.26
Russet Burbank	70	24	0.10	1.68
Sweetcorn	25	24	35kg/ha/mm	0.84

Determining and Managing Irrigation Rotation

(a) For Ryegrass Pasture

?? Consider the Critical Deficit for pasture (30-35% of AW) for the soil type. Divide the %AW by the expected crop water use to obtain the return interval.
?? On shallow stony soils (20cm topsoil to stones) with a critical deficit of 25mm during December when crop water use is about 5mm/day, the return interval should be 5 days.
?? On deep soils the critical deficit is 40mm, crop water use is likely to be lower at 4.5mm/day and the return interval is 9 days. (Water use is likely to be less because on deeper soils capillary rise from deeper layers will provide some of the soil water depleted from the critical root zone).
?? Irrigation MUST begin or the rotation speed increased so as to have the last paddock irrigated before the critical deficit is reached.

(b) For Crops

?? Determining the return interval for crops is more complex than for pasture.

?? The mix of crops, the different critical deficits, the growth stage of the crop(s) and the distance between crops on the farm must be considered.
?? The pressure time for irrigating crops will be in November and December when all crops could require irrigation.
?? Each crop should be considered in the same way as the pasture example above.
?? When the rotation time for all crops in the mix has been determined, plan when and where each irrigator must be and on which day.
?? Do not use some "rule of thumb". The consequence of a wrong decision is much too severe - there is no room for error.

Key Requirements to Determine Irrigation Rotation

To determine how long the irrigation rotation can be, knowledge of the following parameters is essential:
?? Water Holding Capacity
?? Crop Root Depth
?? Expected Crop Water Use
?? Allow for crop growth stages (particularly annual crops).

The template in Appendix 1 provides a step by step guide to repeatedly assessing irrigation dates in various paddocks. It requires use of the information in this booklet and details of;
?? Crop area
?? Irrigation capacity (how much area can be covered in one day and how much water can be applied in the day). Always allow less than 24hours for irrigation unless the run length can not be covered in 24 hours.
?? Soil moisture parameters such as field capacity, wilting point and available water.
?? Root zone of the crop and its sensitivity to moisture stress.
?? An estimate of the soil moisture content in the root zone on the day(s) the rotation is assessed.

The template requires an assessment of the likely crop water demand over the next few days or week. The prevailing weather and the crop stage will determine this demand. The highest water demand will be when hot (usually northwesterly) weather is expected and the crop has maximum leaf area.

References

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Appendix 1. Irrigation Rotation Template.

A step by step guide to determine irrigation of a single or multiple paddocks and different crops.

Irrigation Rotation Plan

Date: 1/11/01

Paddock/Crop	**A.** PA	**B.** RAW	**C.** IA/D	**D.** CD	**E.** Bal.	**F.** EDWU,	**G.** DTI	**H.** DIP	**I.** DS	**J.** SD	**K.** FD	**K.** IV
				FP - CSMC	B-D		E?F	A?C	G-H	Date + I	J+ H	(D + (F G)) ? C 10
A, Squash	8	35	8	20	15	3	5	1	4	5/11	6/11	2800
B1, Sweetcorn	8	50	4	10	40	3	13	2	11	12/11	14/11	1960
B2, Sweetcorn	12	50	4	25	25	5	5	3	2	3/11	6/11	1960

PA = Paddock Area, ha

RAW = Readily Available Water (Full Point-refill point), mm

IA/D = Area (ha) that can be irrigated/day applying the RAW amount

CD = Current Deficit (Full point less current moisture content), mm

Bal. = Balance (Readily Available Water less the Current deficit),mm

EDWU = Estimated Daily Water Use, mm/day

DTI = Days until irrigation required (or finished)

DIP = Days to irrigate the paddock

DS = Days until irrigation must be started

SD = Date Irrigation **MUST** started

IV = Irrigation volume, m^3/day

Explanation and definition of terms.

PA = paddock area or the area of crop in hectares that will need to be irrigated.

RAW = Readily Available Water in mm in the critical root zone of the crop. Refer to the section "Soil water and available soil water".

IA/D = the area the irrigation system can cover in one day (23 hours) applying the amount of the RAW. Remember the RAW is the depth of water to be replaced in the soil and the efficiency of the irrigator must be considered. If a gun is to be used with an efficiency of say 70%, the gross application needs to be 350.7 = 50mm.

CD = current soil moisture deficit and is easily calculated. It is the difference between Full Point and the current soil moisture content.

Bal. = the balance of RAW; i.e. how much moisture can still be used before irrigation is required. The calculation is simple being the difference between RAW and the Current Deficit (CD).

EDWU = the expected daily water use of the crop (evapotranspiration) for the next few days or week.

DTI = the number of days before irrigation needs to be completed in the paddock and is simply the Balance (Bal.) ? EDWU.

DIP = the number of days it will take to irrigate the paddock, or PA ? IA/D

DS = the number of days before the irrigation event must be started, or the number of days before irrigation must be completed (DTI) less the number of days it will take to irrigate the paddock (DIP). This calculation will ensure irrigation commences on time and allows sufficient time for the entire paddock to be irrigated before moisture stress occurs.

SD = the date irrigation must be start or have started. This date is simply the current date (when the template is completed) plus DS.

FD = the date on which irrigation is likely to finish. This date is simply the start date (SD) plus the number of days it takes to irrigate the paddock.

IV = the volume of water that must be pumped per day to irrigate the paddock. If this volume exceeds the consented take of water an adjustment must be made to the schedule and application depth to stay within the conditions of the consent.

If two paddocks have start and finish dates that overlap or are the same the irrigation rotation plan must be adjusted. Change a start date so that both (or were applicable) all the paddocks with conflicting dates can be accommodated. In the example given the squash and B2 sweetcorn overlap and finish on the same day. In this case the sweetcorn could be started a day early, completed on the 5/11. This allows the squash to be irrigated on time. Once a rotation plan has been developed recalculation may be required to eliminate (if possible) conflicting dates.