MINIMISING THE ENVIRONMENTAL IMPACTS OF IRRIGATION BY GOOD SCHEDULING

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Abstract

Irrigation constitutes a major user of water resources at a time, and in places, where resources are at their lowest. Also, by maintaining the soil in a wetter state, it increases the annual drainage, which can affect the leaching of nitrates into the groundwater. Irrigation scheduling involves, firstly, deciding the most appropriate irrigation plan (i.e. what soil water deficit to allow and how much to apply at that deficit) and secondly, deciding what is the soil water deficit on any particular day. Good scheduling will aim to meet the goals of irrigation (optimise production / quality / aesthetics) whilst minimising the water used and other adverse environmental impacts.

The main techniques for scheduling irrigation in the UK are direct measurement of soil water content and water balance modelling. 'Bad' irrigation scheduling can result from an inappropriate irrigation plan, inaccurate soil water measurement, errors in water balance modelling or uncertainty over the actual amount of water applied at each irrigation. Either will result in under- or over-watering.

A case study for potatoes grown in a medium textured soil in Silsoe (Beds) examined the impact of poor scheduling on average annual irrigation water requirement and the risk of nitrate leaching. The water requirement is very sensitive to errors in estimating evapotranspiration or the field-capacity water content of the soil, but less so to errors in the amount of water applied. Increasing the trigger soil water deficit can also minimise the water requirement.

Over-irrigation, due to a poor irrigation plan can increase the summer drainage and risk of nitrate leaching, however, over-watering due to inaccurate scheduling predominantly results in increased winter drainage which may have a positive impact on nitrate concentrations and winter recharge.

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THE ENVIRONMENTAL IMPACTS OF IRRIGATION

Impacts on water resources

Only a small proportion of abstractions, less than 1%[1] is regularly used for spray irrigation of crops. However,

- this agricultural use occurs primarily in the Anglian and Midlands Regions which are the dryer parts of the UK,

- most of the demand is concentrated over a relatively short period of 8 to 12 weeks each year, and demand is highest in dry years when water resources are at their lowest.

- most of the water abstracted for irrigation is 'consumed' rather than 'used' (i.e. it is not returned to the water resource, but returned to the atmosphere in the form of transpired water vapour). For example, comparing an irrigated potato crop in Silsoe, with an un-irrigated crop, on average about 70% of the extra water applied through irrigation is consumed as extra evapotranspiration, the remainder is returned to the system as increased drainage.

Thus abstractions for irrigation are one of the contributing factors to low flows in certain watercourses in summer is the abstraction or water for irrigation use.

Impact on nitrate leaching

Leaching occurs when the soil is wetted beyond field capacity and water drains from the root zone. This drainage water contains nitrate in solution which will eventually be carried to the drainage ditches or groundwater. The main risk periods for leaching are in spring, when nitrogen has been applied to the crop, and in winter, when nitrate remains in the soil after harvest and drainage is at its maximum.

Leaching during the growing season

By keeping the soil wetter during the growing period, there is an increased risk of drainage in the early spring, either from the irrigation itself, or from subsequent rainfall (Shepherd *et al*. 1993). This is particularly important in situations where the soil is kept close to field capacity in the spring (e.g. scab control on potatoes).

Leaching during the winter

Although irrigated crops will often receive greater applications of nitrogen fertiliser, by providing a better growing environment, nitrogen uptake by the crop is enhanced, such that the residual nitrate in the soil at harvest may be reduced. By reducing the soil water deficit at harvest, the soil will return to field capacity earlier in the autumn than under non-irrigated conditions and drainage will start earlier. Even without irrigation, in most winters on light soils, enough water drains through the soil to leach

[1] Source: Environment Agency

most of the nitrate present (Lord *et al*., 1993). Earlier autumn drainage may mean that nitrate is leached earlier, but the total mass of nitrate removed may not be very different and the greater total winter drainage may result in lower nitrate concentrations in groundwater. In this respect, irrigation may be beneficial in reducing nitrate concentrations in groundwater.

IRRIGATION SCHEDULING

Irrigation scheduling involves the day-to-day decisions about when to irrigate and how much to apply. There are two important aspects of irrigation scheduling to consider.

- Firstly there is a need to identify the most appropriate *irrigation plan* for the site being irrigated. This will involve setting the target soil water conditions (critical SMD[2]) and amounts to be applied at each irrigation. The plan will depend upon the plant, the soil and irrigation system being used and may vary through the season reflecting critical water sensitive growth stages. Suggested plans for a range of crops may be found in the literature (e.g. MAFF, 1981). For example, a typical irrigation plan for potatoes grown on a medium textured soil, irrigated with a rain-gun is shown in Table 1.

Table 1 Typical irrigation plan for maincrop potatoes grown on a medium textured soil and irrigated with a rain-gun.

Period	Application amount (mm)	Critical SMD (mm)
Before planting	No irrigation	
Planting to tuber initiation	30	55
After tuber initiation for 6 weeks	12	15
Until mid-August	30	55
After mid-August	No irrigation	

- Secondly, the irrigator needs some system for deciding when the critical SMD has been reached (and preferably forecasting ahead). Several techniques are commonly used in the UK largely based on water balance methods, soil water measurements or a combination of the two (see Groves & Stansfield, 1996). A recent survey (I Matthieson, *Pers. Com.*) suggested that only about 25% of irrigated farms in England and Wales use a commercial irrigation scheduling service, of which about 46% use soil moisture measurements (neutron probe or capacitance probe) and 54% use a water balance bureau service. Many more may be doing their own scheduling using water balance computer programs, spreadsheets or tensiometers.

There is no such thing as ‘un-scheduled’ irrigation as nobody would irrigate completely at random. However, there is ‘good’ and ‘bad’ scheduling.

[2] Soil Moisture Deficit

- There are ‘better’ and ‘worse’ irrigation plans. A good plan will provide optimal soil water conditions for the plant and minimise adverse environmental impacts.

- There are ‘accurate’ and ‘inaccurate’ methods for deciding when to irrigate. An accurate method will mean that irrigation is scheduled at the correct time. An inaccurate method may result in early or late application.

- There is ‘accurate’ and ‘inaccurate’ water application. The irrigator may not actually be applying the depth of water that was scheduled due to poor calibration of the system, pressure fluctuations, wind drift, etc.

Good scheduling will apply water at the right time and in the right quantity in order to optimise production (quantity, quality, aesthetics) and minimise adverse environmental impacts. Bad scheduling will mean that either too little water is applied or it is applied too late resulting in *under-watering*, or too much is applied or it is applied too soon resulting in *over-watering*. Under- or over-watering will lead to reduced yields, lower quality and inefficient use of nutrients. This itself should be good enough reason to want to schedule accurately. However, poor scheduling also leads to adverse environmental impacts.

ENVIRONMENTAL IMPACTS OF OVER-WATERING

Causes of over-watering

Over-watering could result from;

1. An ineffective scheduling method. For example

    a) An over-estimation of ET_o. There are several different ways of estimating the evapotranspiration on a particular day which give different answers (Hess, 1996). Some may give random errors which may cancel out, others may give systematic errors which will compound.

    b) An incorrect setting (too high) of the full-point with neutron probe methods. As irrigation is usually scheduled according to soil water deficits, the correct definition of field capacity is crucial, yet difficult to measure under field conditions.

2. Uncertainty over the amount of water applied by a given system set-up. The actual application may be more that than the irrigator thinks. This could result from pressure changes as parts of the system start or stop or simply inaccurate calibration of the application rates.

3. An irrigation plan that does not make best use of rainfall. Rainfall is free irrigation and therefore it makes sense to maximise the contribution of rainfall to the plant’s water demand. Irrigating on a fixed cycle, irrespective of the weather or, more commonly, failure to allow adequate storage capacity in the soil for unforeseen rainfall will result in under-utilisation of rainfall.

The impact of inaccurate scheduling or an inappropriate irrigation plan was evaluated using an irrigation scheduling simulation model (Hess, 1997) over a 35 year period between October 1962 and September 1997, The basic scenario considered was; maincrop potatoes, grown on a medium textured soil in Silsoe, (Beds) and irrigated with the irrigation plan shown in Table 1 above. The impacts were considered in terms of water resources (i.e. water abstracted) and summer drainage loss.

Impact on water resources

The effect of over-watering on abstraction is linear - 20% over-watering at each irrigation means 20% more water than necessary is abstracted. Therefore over application means over abstraction.

Inaccurate scheduling

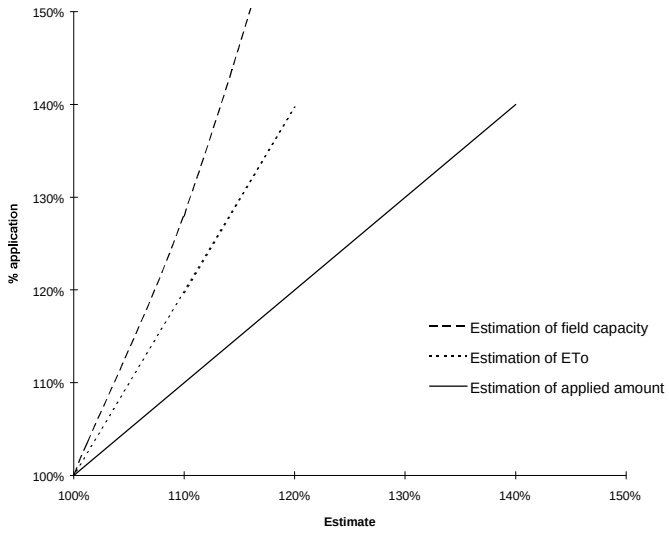


Figure 1 The impact of inaccurate scheduling on water applied

The effect of inaccurate application on water used is 1:1. That is, if at each irrigation you are putting on 10% more than you think you put on, then you end up using 10% more water than you needed. However, Figure 1 shows that the effect of over-estimation of ET is 1:2. - a 10% over-estimation of ETo results in a 20% increase in the volume of water applied. The schedule is even more sensitive to an error in estimating the full-point is soil moisture measurements are used. A 10% over estimate in field capacity (e.g. a volume water content 23.4% instead of 21.3%) would result in 28% over watering. The soil would be wetted beyond field capacity and the excess would be lost as drainage. This is a particular problem during periods when the soil is kept close to field capacity (e.g. scab control). Note that a good advisor should notice apparently high estimates of water use and should question the definition of the full - point.

To irrigate costs money and over-watering is a waste of money and energy. However, the cost of applying extra water is only about 0.16 £/m^3 (Weatherhead *et al.*, 1997) thus 20% over-watering on the above scenario would only cost an additional £44/ha/year (on average). This is unlikely to be large enough to stimulate an improved approach to scheduling.

Inappropriate irrigation plan

The choice of the correct irrigation plan will not only have agronomic impacts, but will also affect the total amount of water needed. The UK summer is characterised by unpredictable rainfall and there is always a chance of rain falling soon after an irrigation. Rainfall on a soil which is at, or close to field capacity, is less likely to be useful to meeting the plants water requirements and will increase drainage losses. To reduce the chances of rainfall exceeding the soil water deficit, the irrigation plan should allow as great a deficit as agronomically desirable before irrigation and apply as small a quantity as practical. Figure 2 shows the effect of varying the application amount and trigger deficit on the average seasonal irrigation requirement. For simplicity, the scab control period in the irrigation plan used above has been removed and a single plan followed for the season. The benefits of allowing storage capacity by not irrigating back to field capacity are clearly demonstrated. It also shows that the saving in water due to increasing the trigger deficit is much greater than that due to reducing the application depth.

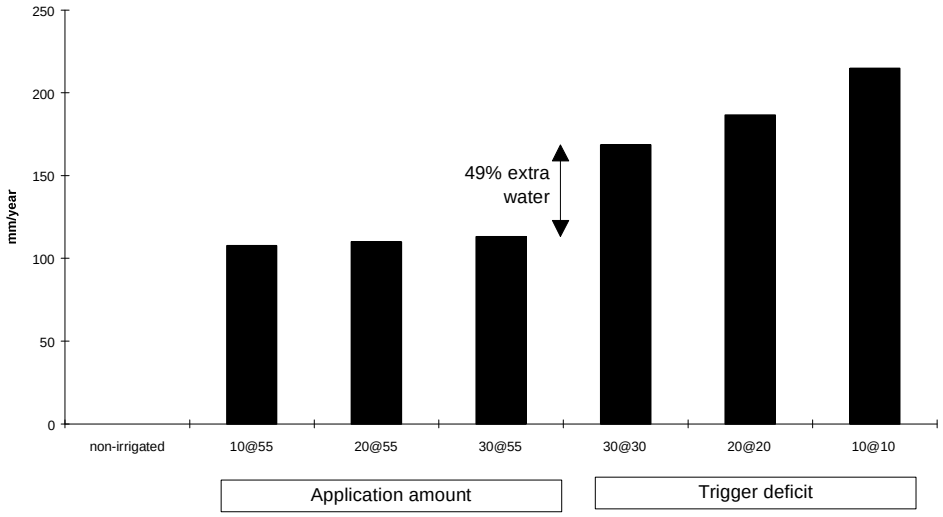


Figure 2 The impact of varying the irrigation plan on average water used for irrigation

Return flows

Almost all of the excess water applied, over and above the plant's requirements, is returned to the water resource through drainage (generally less than 5% is lost through extra evapotranspiration), however this may not occur at the appropriate time, or in an acceptable quality. The return flows from irrigated land may have positive environmental benefits - such as lower concentrations of nitrates in winter recharge water and increased aquifer recharge that may augment low flows at other times of the year (see Allen *et al*. 1997 for examples from the USA).

Impact on summer nitrate leaching

Any irrigation will result in an increase in total drainage, however, Figure 3 shows that with optimum scheduling, most of this increased drainage occurs in the winter months (October - March). Inaccurate scheduling or an inappropriate irrigation plan will lead to significantly increased summer drainage. This may increase nitrate leaching and pollution of groundwater.

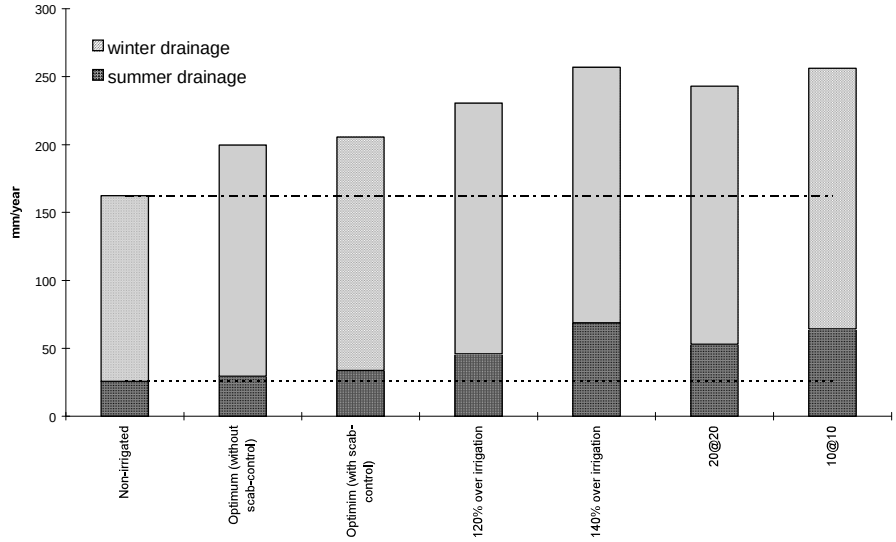


Figure 3 The impact of irrigation schedule of summer and winter drainage

ENVIRONMENTAL IMPACTS OF UNDER-WATERING

Under-watering will have no adverse effect on water resources, but may lead to increased nitrate leaching in the autumn. For example, Groves & Bailey (1997) found that in a dry year the residual soil N under a fully irrigated sugarbeet crop was less than half of that of a non-irrigated treatment (and proportionally less in sub-optimally irrigated crops). Similar effects have been observed under potatoes (Bailey and Groves, 1992). Thus the potential for winter leaching was significantly reduced by optimal irrigation scheduling.

CONCLUSIONS

Poor irrigation scheduling will result in under- or over-watering. Over-watering has a direct impact on water resources at a time when they are at their lowest. Over-watering will also result in increased drainage during the growing season, which increase nitrate leaching to groundwater. Under-irrigation may conserve water resources, but by reducing nitrogen uptake by the growing plant, may increase the risk of winter nitrate leaching. A good irrigation plan will set trigger deficits as high as possible and irrigation applications should leave sufficient storage capacity in the soil to allow for rainfall.

The example demonstrates the need for accuracy in irrigation scheduling, whether by water balance methods or direct measurement of soil water content.

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