Irrigation Effects on Nitrogen Efficiency

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Introduction

Nitrate leaching from irrigated agriculture has been an environmental concern in California for decades. However, regulatory pressure on growers to limit nitrogen losses from their field operations has recently increased with the imposition of reporting requirements regarding on-farm nitrogen (N) balance. N balance compares the amount of N applied (all sources, including fertilizer, organic amendments and N in irrigation water) with N removed in harvested products. This 'A/R ratio' will be the main metric used by Regional Water Quality Control Boards to evaluate the N use efficiency of particular crops, and growers. While it is widely recognized that N efficiency is connected with irrigation management, many people underestimate just how integrally connected N management and irrigation management are. This paper discusses this link, and suggests ways to improve irrigation management to reduce N losses.

Linking irrigation management to N leaching loss

As an anion, nitrate (NO_3^-) moves freely with water through the soil; any water moving below the effective root zone will carry nitrate-nitrogen (NO_3-N) with it. Nitrate concentration in tile drainage provides an estimate of potential N leaching, since water reaching tile drains has moved below the crop rooting zone. Studies monitoring tile drain effluent in both the Central Valley (Letey et al., 1977) and coastal production areas (Hartz et al., 2017; Los Huertos et al., 2001) found NO_3-N concentrations > 30 PPM to be common, and much higher concentrations (> 100 PPPM) periodically occurring. That leachate NO_3-N concentrations are often in the range of 30-100 PPM is not surprising. Fertilized root zones often contain 5-30 PPM NO_3-N on a soil dry weight basis. However, all soil nitrate is in the soil solution, which in a mid-textured soil weighs only about 25% as much as the dry soil. This means that the NO_3-N concentration in the soil solution is about 4 times higher than if expressed on a dry soil basis. To put this NO_3-N loss potential in context, an acre·inch of leachate at 30 PPM NO_3-N carries approximately 7 lb N, or about 23 lb N if the concentration is 100 PPM NO_3-N. Clearly, leaching losses can add up to a substantial portion of an annual N balance unless irrigation is managed carefully.

The importance of nitrogen residence time

When N fertilizer is applied, the crop does not take it up all at once. Crops take up N to support new growth; the rate of that growth drives N uptake. Table 1 compares the rate of N uptake for important California crops. These rates apply to the period of the growing season when growth rates are at the maximum (after leaf-out until pre-harvest for perennial crops, post-establishment to preharvest for annuals). When typical sidedressing (50-100 lb N $acre^{-1}$) or fertigation (30-50 lb N $acre^{-1}$) occur, it will usually take many days for the crop to utilize the applied N. In the meantime, careful irrigation is required to minimize the movement of this N downward in the soil profile. Maximizing 'residence time' in the active root zone is critical to efficient N utilization.

Table 1. Typical rate of N uptake by selected crops during the rapid growth phase.

Daily N uptake (lb N $acre^{-1}$ day^{-1})		
< 3	3-5	> 5
almond	cotton	corn
citrus	lettuce	cole crops
grape	melon	high-density leafy greens (spinach, baby lettuce)
pistachio	tomato	
walnut		

There is limited margin for error, because the efficiency of N recovery drops quickly with soil depth. Fig. 1 shows the typical distribution of roots by soil depth for almond and broccoli. While both can develop roots below a depth of three feet, the vast majority of roots are contained in the top 2 feet. This pattern is characteristic of most crops - the top half of the root zone typically contains > 75% of total roots. The deeper NO_3^- moves in the soil, the less likely it will be taken up by the crop.

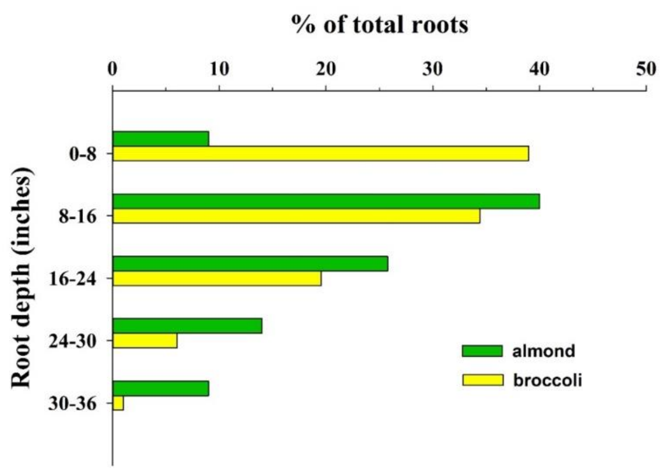

Fig. 1. Pattern of rooting in almond and broccoli; from Muhammad et al. (2016) and Smith et al. (2016).

This obviously has implications for how fertigation is applied. Nitrogen in the form of NO_3^- or urea will move with the applied water; the earlier in the irrigation cycle fertigation is done, the deeper the nitrogen will go. As a general rule it is advisable to apply N later in the irrigation cycle, as long as irrigation continues for a period of time after fertigation is terminated sufficient to clear the N from the system before shut down. It is also important that the irrigations that follow sidedressing or fertigation not contain a substantial leaching fraction.

The importance of irrigation efficiency

Irrigation efficiency, the ratio of crop evapotranspiration to applied water, is controlled by two factors. The first is the distribution uniformity (DU) of the irrigation system. DU is calculated as the ratio of water applied to the driest quarter of a field compared to the overall field average. Surveys across the state have shown that DUs in commercial fields vary widely. The majority of low volume systems (drip or microsprinklers) run between 70-90%. For nitrogen efficiency the differences between a DU of 70% and 90% are profound. If an almond orchard has seasonal irrigation requirement of 40 inches, a microsprinkler system with a DU of 90% would require approximately 44 inches of irrigation to provide adequate moisture to all areas of the orchard. Conversely, if the DU was 70%, 57 inches of water would be needed to fully irrigate the orchard; in this situation there would be no way to avoid substantial N leaching loss.

The other factor controlling irrigation efficiency is the degree of retention of applied water in the active root zone. It is possible to uniformly distribute irrigation across a field and still have low irrigation efficiency; if the volume of water applied is too great to be held in the crop root zone, leaching loss is unavoidable. Irrigation frequency is the key. To determine the appropriate frequency one needs to know the available water holding capacity of the most limiting soil type in the field, the fraction of soil volume wetted by the irrigation system, and the degree of allowable water depletion appropriate to the crop. An on-line tool (https://casoilresource.lawr.ucdavis.edu/gmap/) allows the user to quickly determine the approximate soil water holding characteristics in a given field or orchard. Available water depletion for vegetable crops should be limited to not more than 20-30% in the active root zone; for permanent crops depletion of 50% is a reasonable target.

Another on-line tool (https://agmpep.com/variability/) provides an alternative way to evaluate irrigation efficiency. This tool utilizes satellite imagery to calculate seasonal actual ET (ET_a), and displays the pattern of ET_a across a field. Several important pieces of information can be gleaned from this tool. First, the average seasonal ET_a can be compared to the seasonal amount of irrigation applied to estimate overall irrigation efficiency. Second, it provides statistics on the distribution uniformity of ET_a within the field.

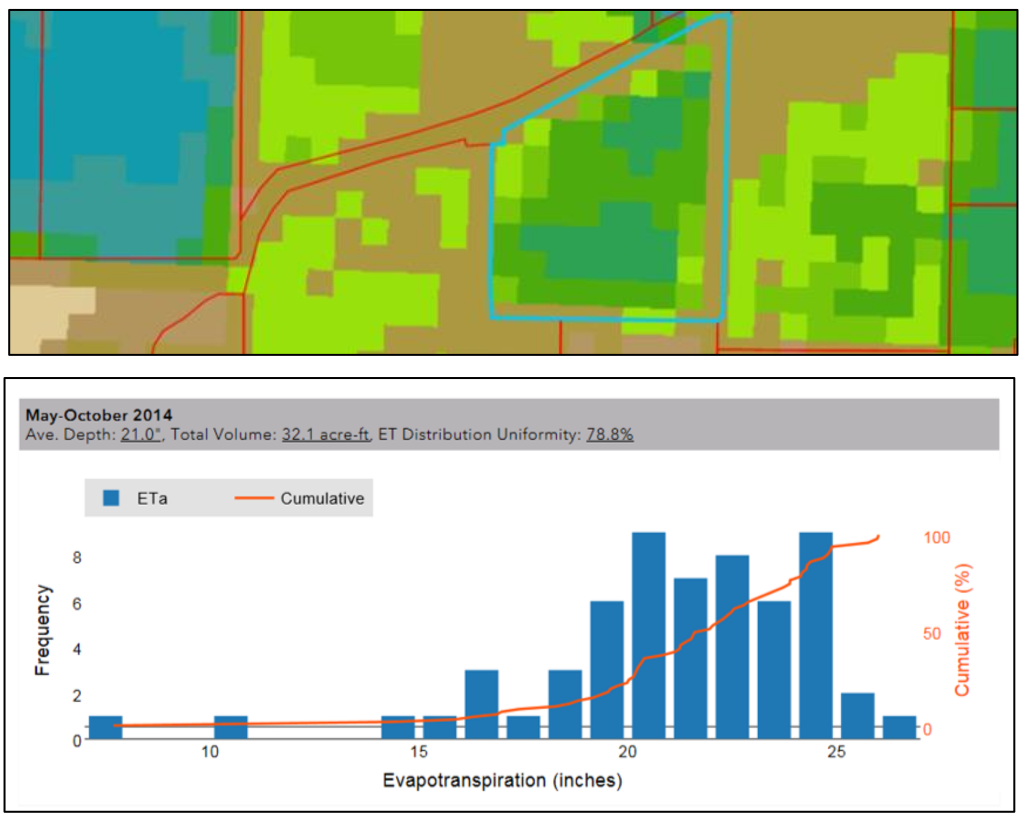

Fig. 2. Pattern of seasonal ET_a in an almond orchard (orchard highlighted in blue in the top image), and distribution uniformity of ET_a within that orchard (bottom image).

The imagery currently available in this tool is from the 2014 season, so it is most useful for mature permanent crops, for which seasonal patterns would be similar across years given consistent irrigation management. As is the case with irrigation DU, uniformity of ET_a varies widely from orchard to orchard, with a substantial percentage of orchards achieving an ET_a DU >85%, while many are <70%. Where an individual orchard shows high ET_a variability, or a mismatch between seasonal ET_a and seasonal irrigation volume, a grower should carefully evaluate current irrigation management practices.

Crediting N contained in irrigation water

The requirement to report the amount of N contained in applied irrigation water has focused attention on how one can safely adjust N fertilizer rates to account for the contribution of irrigation water NO_3-N. Unfortunately, there is no simple answer to this question, as the relative 'fertilizer credit' for irrigation water NO_3-N is situational. In a series of experiments with lettuce and broccoli, Cahn et al. (2017) showed that irrigation water NO_3-N was at least as efficiently taken up by crops as fertilizer N. However, in these trials drip irrigation was used, and only water applied after crop establishment was tracked. In these circumstances crediting 100% of irrigation water N against the N fertilizer rate may be appropriate; while some fraction of applied water may leach, the NO_3-N in that water, and fertilizer N in the soil, would be at an equal risk of leaching.

There are also situations in which the crop recovery of irrigation water N may be very poor. Pre-irrigation to fill the soil profile before planting an annual crop may place a substantial portion of the water NO_3-N deep enough to limit crop recovery; in this circumstance the most appropriate way to estimate the agronomic contribution of irrigation water N would be to conduct a post-establishment residual soil NO_3-N test. Where basin or furrow irrigation is used the practical limitations on irrigation efficiency mean that a substantial fraction of the N in the water immediately leaches beyond crop recovery. A grower should carefully consider the circumstances of individual field situations when estimating the fertilizer credit for irrigation water NO_3-N. This on-line tool (https://agmpep.com/calc-irrn/) calculates the effective N contribution in irrigation water, based on the grower-specified level of efficiency.

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