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Irrigation water amount and salinity dictate nitrogen requirement

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ABSTRACT

Crop relative yield (RY) may be reduced by matric water potential or salinity stresses but also by nitrogen (N) deficiency. Elucidation of interactions among these factors through modeling using the ENVIRO-GRO program to compute RY and N leaching from the root zone for corn (Zea mays) was our objective. Ten-year simulations included growing seasons and fallow periods. Simulation variables were applied water divided by potential evapotranspiration (AW/PET) equal to 0.9, 1.1, 1.3, and 1.42; irrigation water salinity (ECiw, dS/m) values of 0.5, 1, 2, 3, and 4; and inorganic N applications ranging from 270 to 350 kg/ha. RY for simulations that included winter precipitation were approximately 5% greater than identical simulations without precipitation for $2 \leq \text{ECiw} \leq 4$. Except for deficit irrigation, all AW/PET values resulted in RY equal to 100% for $\text{ECiw} \leq 2$ when N was not limiting. For $\text{ECiw} > 2$ progressively greater AW/PET was required for full yield. For less saline waters, water stress was limiting for the AW/PET = 0.9 treatment and RY was unaffected by the N application rate. For a given N application rate, increasing water application caused decreasing RY and increasing leached N. When N applications were greater than required for maximum RY, a decrease in N application resulted in an equal decrease in leached N. When decreasing N applications caused decreasing RY, the reduction in leached N was less than the reduction in N application. For the very saline waters (ECiw = 4), AW/PET = 1.1 was inadequate to leach the salts and water stress was the limiting factor rather than N application. Water flow below the root zone is controlled by both water application and N deficiency which reduces plant water uptake. Regulatory attempts to restrict N leaching to groundwater that prescribe management of N applications exclusively are likely to fail because N leaching depends on water flow as well as N application.

1. Background

Writing a paper for the special issue of Agricultural Water Management honoring Dr. James Oster is a pleasure because he is a long standing colleague and friend. He made major scientific and extension contributions to matters related to soil salinity and irrigation. It is appropriate that this manuscript addresses an issue that is consistent with Jim's contributions.

Leadership in obtaining funds and directing a study that compared the transient state models that include salinity and matric stress effects on plant yield is one of Jim's major contributions to the scientific literature (Oster et al., 2012). The study included ENVIRO-GRO, SWAP, HYDRUS, UNSATCHEM, and SALTMED. SALTMED simulated lower relative yields (RY) than the other models for all irrigation water application amounts and salinity (ECiw). For other models, RY values were similar (within about 7%) for all water application amounts when ECiw was 3 dS/m or less. The relative yield (RY) was the ratio of seasonal water uptake to potential water uptake by an unstressed crop expressed in percent (Oster et al., 2012).

Of these models, ENVIRO-GRO (E-G) is the only one that includes a nitrogen (N) module to simulate the consequence of N management variables on RY and the leaching of nitrate below the root zone. The E-G model has recently been reprogrammed by the senior author to extend the capabilities and to make it more efficient. Modifications include addition of compensation for N uptake, a two-pool model for organic matter decay, mass balance calculations, comprehensive output routines and improvements to the transport calculations for salt and nitrate. Details regarding these modifications and other information are provided in the E-G user manual which is available along with the program for free at http://ciwr.ucanr.edu/Tools/ENVIRO-GRO. The simulated results reported here were from the updated E-G model.

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2. Introduction

Although the setting for this study is the Central Valley of California, the findings are relevant to all irrigated areas of the world. The semi-arid climate of California requires irrigation for achieving high crop yields. Originally irrigation water was obtained by pumping groundwater. Later federal government irrigation projects delivered large quantities of water to the area that contributed to the vast expansion of crop land. Irrigation practices that were followed generally resulted in high leaching fractions. Two factors contributed to this phenomenon. Irrigation was predominately by surface systems with very long furrows. This system is conducive to inefficient water application caused by variable opportunity times and infiltration rates that are controlled by soil properties. Even though the irrigation waters generally were relatively pure (mostly < 1 dS/m), an excessive leaching requirement based on steady-state analyses was prescribed (Letey et al., 2011).

Little consideration by growers was given to the fact that percolating water also leaches nitrate and other chemicals along with the salts that were purposely leached. As a result, the downward percolation of nitrate-laden water from agricultural fields is a major contributor to the high levels of the contaminant found in many California groundwater resources (Viers et al., 2012). Excessive application of nitrogen (N) fertilizer to crops is commonly blamed for the present groundwater degradation. The word “excessive” can have more than one connotation. Excessive application could mean that more N is applied to the soil than is removed by the crop, and there is no question that most agricultural applications could be included in this definition. Another definition is that excessive application means that more fertilizer is applied than would be required to achieve high yields and maximum profits. High yields and maximum profits almost always require the application of more N to the soil than is removed by the crop. Whether growers have historically applied more N than was necessary to obtain maximum profits is not clear.

Based on extensive field research during the 1970s, it was concluded that the optimal (i.e., profit-maximizing) amount for N application is dictated by the amount of precipitation and irrigation. That research focused on a total of 55 farmer fields drained by tile systems and 31 naturally drained fields that did not have a shallow water table (Letey et al., 1977, 1979). By measuring the rate of water discharged and the nitrate concentration of the water samples collected from the tile systems, the total nitrate discharged into the tile systems was calculated. For the natural drainage studies, soil samples were collected and analyzed from various depths, usually reaching to a depth of 17 m. Procedures were then developed to calculate the rate of water flow through the soil profile. This water flow rate, multiplied by the nitrate concentration, provided an estimate of the nitrate leached below the root zone. Information on fertilizer application was obtained from the growers.

Results were similar for both systems: the correlation coefficient between the amount of N leached and the drainage volume was greater than the correlation coefficient for amount of N leached and amount of N applied. As expected, the highest correlation coefficient was between the amount of nitrate leached and a combination of drainage volume and fertilizer application, indicating that both factors are important. Importantly, no significant correlation was found between the nitrate concentration of the drainage water and either the amount of fertilizer applied or the drainage volume. By itself, the numerical value of the concentration is of little value, and it may even lead to erroneous conclusions.

The researchers hypothesized that growers would be likely to apply more N to fields that had higher drainage volumes even though they had no information on the drainage volumes. Indeed, the experimental data supported this hypothesis. A linear regression analysis resulted in a significant relationship between the fertilizer N applied and the amount of drainage water. Greater drainage flows, therefore, induced growers to increase their N applications.

Letey and Vaughan (2013) did simulations using the E-G model and demonstrated that soil type, crop, and irrigation technique, in addition to the amount of N applied, all affect the amount of leached N. Major focus of that study was on organic N with a smaller section concerned with inorganic N applications. The temperature effect on the rate of N mineralization was included in the analyses and revealed that the temperature impacts the consequences of applying the organic material at various times of year. The findings of the simulation study were completely consistent with measurements made on 86 farm fields (Letey et al., 1977, 1979). First, the amount of N leached was more closely related to the amount of water percolating beyond the root zone than on the amount of N applied. Second, no correlation was found between the amount of N leached and the concentration of N in the soil-water. The scientific evidence overwhelmingly indicates that the irrigation management decisions dictate what nitrogen management options are available for achieving high yield with low groundwater degradation.

The results of the study were discussed in context of regulatory action being taken or proposed in California. The California State Water Resources Control Board (SWRCB) submitted a report to the California Legislature with recommendations that address nitrate problems in groundwater (SWRCB, 2013). None of the recommendations identifies water management as a potential controlling factor; nor are the soil and crop types recognized as significant factors. The Board’s recommendations emphasize development and implementation of an N mass balance tracking and reporting system to manage application of N fertilizer materials. The authors proposed the development of Best Management Practices (BMPs) that considers all of the factors affecting potential groundwater degradation by nitrate to be a more effective approach (Letey and Vaughan, 2013).

3. Objective

The objective of this paper is to expand the analyses of Letey and Vaughan (2013) by incorporating the effects of irrigation water salinity and amounts as factors in N application decisions for the dual purpose of low groundwater degradation and high crop yields.

4. Methods and simulated conditions

The simulated conditions were the same as those used by Oster et al. (2012) in comparing the various models. The only difference was in programming winter precipitation during the fallow season. Whereas, Oster et al. had a pseudo-continuous cropping system where the soil-water status at the end of the growing season represented the initial condition in the following year, winter precipitation was included in the present study. For the fallow period potential soil evaporation was calculated assuming that the reference ET_0 was equal to soil evaporation from a wetted surface ($Kc = 1$). The computed soil evaporation was reduced as the soil dried due to reduction of soil hydraulic conductivity near the surface.

Corn (*Zea mays* L.) was simulated to be growing on a clay loam soil. The crop was seeded on June 1 and harvested on Oct. 15. Irrigation was applied weekly. The last two irrigation events for each cropping season were deferred until the start of the next season when the combined depth of water was applied as a preplant irrigation on May 31. The time and amount of rainfall were those recorded at CIMIS (California Irrigation Management and Information System) station no. 145, Madera, California, during the calendar year 2006, a relatively wet year that recorded 29 cm