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Combined Water-Fertilizer Management to Minimize Non-Point Water Pollution While Achieving High Crop Production



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# COMBINED WATER-FERTILIZER MANAGEMENT TO MINIMIZE NON-POINT WATER POLLUTION WHILE ACHIEVING HIGH CROP PRODUCTION

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TECHNICAL COMPLETION REPORT

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# ABSTRACT

Greenhouse and field experiments were conducted to characterize relationships between fertilizer and water management in irrigated vegetable production in California. Greenhouse trials were conducted both in hydroponic solution culture and in soil culture, with tomatoes and lettuce, to establish functional relationships between nitrogen and water uptake by single plants, and nitrogen recovery efficiency as a function of method and rate of application and placement for a simulated drip irrigation system with one fertilizer material, urea-ammonium nitrate. Over a wide range of solution culture nitrogen concentrations, the relationshp between nitrogen absorbed and water absorbed by the plant was constant. Slightly more N was taken up by plants where emitters delivered it to the soil surface than where the emitter was placed 2.5 cm below the soil surface; less than 0.1% of the supplied N was recovered in acid traps as volatilized ammonia. Field trials with drip-irrigated tomatoes and celery, furrow-irrigated broccoli, celery, and corn, and sprinkler-irrigated celery and broccoli established relationships between quantity of N applied, method of N application (soil-applied soluble or slow release fertilizers, midseason sidedressing, application through irrigation water), quantity of water applied, and crop yield and nitrogen accumulation. Application of fertilizer in the irrigation water was most efficient where no runoff occurred, and where plants grew rapidly. When plants grew slowly due to intermittent drought stress, nitrogen recovery efficiency was lower than where

adequate but not excessive quantities of water were applied. Application of fertilizer in the irrigation water must anticipate crop nutrient demand to be effective, and must be placed in the root zone.

It is impossible to separate the management of nitrogen (N) fertilizer from that of irrigation water in irrigated agriculture. Methods of application, timing, and amounts applied are key concerns both for fertilization and for irrigation water application. While many experiments have characterized crop and soil responses to one variable, relatively few have endeavored to study the interaction of fertilizer management sytems with irrigation management systems. The approach taken in this project was to examine interactions between these two centrally important components of agricultural production, with the ultimate objective of improving recommendations for the use of water and fertilizers in irrigated agriculture.

Experimental Approach:

Both greenhouse and field trials were established, at the Agricultural Field Stations at University of California, Riverside and at South Coast Field Station, Santa Ana. Greenhouse trials were undertaken to assess basic relationships between water and nitrogen supply and uptake, while field trials emphasized use of current agricultural production technology to test relationships in the fielk. Most of the research has been published, either as graduate theses or in scientific journals. These publications will be referenced throughout this report, and complete details of the research can be found within them.

## Greenhouse Experiments

Greenhouse trials were first conducted to determine the relationship between minimum $NO_3$-N concentration and N and water accumulation by tomatoes and lettuce (5, 7). Over a wide range of solution $NO_3$-N concentrations, the ratio of N uptake (mg/plant) to water uptake (L/plant) was constant, at approximately 100 mg N/L. This suggested that a constant, continuous supply of N in the irrigation water could supply the necessary nutrient without providing an excess. Experiments in soil columns with Romaine lettuce and Swiss Chard (7) demonstrated that Chard could very efficiently decrease the solution N concentrations to near zero before water passed out the bottom of the column; lettuce was much less efficient.

Tomatoes were grown in soil columns with sealed head spaces through which acid-scrubbed air was passed. Columns were irrigated frequently with water containing 0, 50, 100, or 200 mg N/L. Half of the treatments received irrigation water dripped on the surface at the base of the plant, and the other half received it 2.5 cm below the soil surface. Urea-ammonium-nitrate (32-0-0) was the source of all N. Less than 0.1% of the applied N was trapped as volatilized $NH_3$, even in the "most likely" treatment (high concentration applied at the surface). Ammonium losses does not appear to be a very significant pathway for loss. Soil pH decreased markedly a few centimeters from the emitter (Mikkelson, Jarrell, and Letey, in preparation).

Field Experiments

An experiment was conducted to evaluate celery response, N uptake and N leaching as related to form, amount, and method of N-fertilizer application under drip irrigation (2, 3, 4). Fertilizer forms included ammonium sulfate (AS) and a slow release (SR) fertilizer applied to the soil before planting and urea ammonium nitrate (UAN) applied with the irrigation water during the growing season. AS and SR were applied at 314 kg N/ha and UAN was applied at 168-, 336-, and 504 kg N/ha. Two irrigation variables were 400 and 500 mm of water application.

The experiment was conducted on San Emigdio sandy loam soil at the University of California South Coast Field Station near Santa Ana. Celery seedlings were obtained from a commercial nursery and planted in two rows per bed. The distance between centers of each bed was 1 m. Three row spacings (15-, 22.5-, and 30 cm) were used for each treatment. Bi-wall drip irrigation tubing (30 cm hole spacings) was placed on the soil surface down the center of each bed equidistant from each celery row. The soil-applied fertilizer (AS and SR) was placed approximately 5 cm below the soil surface, immediately below the drip line.

All of the AS and SR fertilizer was applied prior to transplanting. Ten per cent of the N to be applied with the drip irrigation water was applied through the drip lines prior to planting. Thereafter, UAN was applied during each irrigation to the appropriate rows until approximately one month before harvest after which fertilizer injection was stopped. Irrigation was usually done three times a week and occasionally a fourth irrigation was applied during hot, dry, windy periods.

There was no marketable yield on the plot which did not receive N fertilizer. Treatments receiving UAN with the irrigation water had higher yields with 500 as compared to 400 mm water application. On the other hand, higher yields were obtained under the 400 as compared to the 500 mm irrigation treatment for the AS and SR fertilizer treatments. Furthermore, at comparable N application rates, the soil-applied N resulted in significantly lower yields than application of N with the irrigation water. With the higher water application, more N leached below the root system than at lower irrigation rates, based on the pattern of N distribution in the profile at the end of the experiment.

Application of N with the irrigation water is superior to application of the N to the soil in a preplant operation. Split applications to the soil are mechanically impractical with drip irrigation. Celery requires continuously high soil water content which results in which leaching losses of soil-applied fertilizer. Applying the N with the irrigation water made it available to the plant continuously over the growing season and apparently much of the N was extracted by the root system as the water flowed past the roots; there was very little difference in the amount of N leached beyond the root zone for the different water application treatments. Nevertheless, there was some deep N movement with the drip system even under low N application.

The SR fertilizer produced a higher yield than AS. Nitrogen was retained within the granules and slowly released during the growing period, and was thus partially protected from leaching. In fact, observation at the end of the experiment indicated that not all of the N had been released from the capsules by harvest.

The N left in the soil after cropping is a potential source for groundwater pollution. Whether the N does in fact get carried to the groundwater depends upon a number of subsequent factors such as precipitation and/or irrigation which will carry the N downward.

A barley crop was grown on the experimental area after the celery crop was removed without further N application to measure residual N in the profile which could be removed by barley. For the plots receiving UAN, there was an increase in N uptake from plots receiving increasing amounts of UAN during the celery crop. For comparable amounts of N application, much more N was taken up in the barley on the plots receiving the SR as compared to the AS and UAN treatments. This is partially a result of the N retained in the capsules and also the N in the profile which had moved beyond the celery roots but remained accessible to the deeper rooted barley crop. For both AS and SR there was more N uptake from the 400 mm irrigation treatment as compared to the 500 mm irrigation treatment, suggesting that the higher water treatment moved some N beyond the depth of recovery by the barley plant.

Two experiments were conducted at the University of California South Coast Field Station on celery using a sprinkler irrigation system (8, 10, 12). This system was chosen to experimentally apply a continuous water amount variable across the plot to determine the interaction between fertilizer N and water application on celery growth. This was accomplished by using "line source" irrigation where water application is highest next to the sprinkler line and decreases at increasing distances from the sprinkler line. A standard sprinkler system applied water uniformly over the entire plot with fertilizer. Then irrigation was applied through a single line which provided high water application near the line which decreased with distance away from the line.

In one experiment, different fertilizer N treatments were applied to the soil in rows perpendicular to the line source. This provided an opportunity to determine the growth under the different fertilizer treatments at different rates of water application. In the second experiment, some of the N was applied with the irrigation water under the standard irrigation and again these plots were perpendicular to the line source which allowed a comparison of celery growth in response to differential water application.

In experiment 1, a comparison is made between preplant and no preplant fertilizer treatment and different amounts of N applied with the irrigation water. The preplant fertilizer was AS whereas the injected fertilizer was UAN. In experiment 2, all of the N was applied to the soil in bands with none being applied with the irrigation water.

The preplant fertilizer treatment was important for high yields. The treatment with 300 kg N/ha applied as 50% preplant and 50% with the irrigation water gave higher yield than when all of the N was applied with the irrigation water ($UAN_{300}$). High water application is necessary for rapid celery growth. Only for the $AS_{150}$ $UAN_{150}$ treatment was there a trend toward decreased production at the highest water application.

There are apparently counterbalancing factors in the effect of quantity of water application to celery. The celery prefers high soil water availability to maintain high turgor, rapid growth, and succulence. On the other hand, large applications of water could leach N from the root zone and decrease its availability to the plant. Since N was applied with the irrigation water throughout the growing season, it could partially compensate for N that might be leached. This was observed to be the case under the drip irrigation system. However, on the $AS_{150}$ $UAN_{150}$ treatment, the added leaching of preplant N under the highest water application may not have been sufficiently compensated for by the N applied in the irrigation water.

For the soil-applied fertilizer treatments the results from the control and $AS_{300}$ treatments clearly illustrate the interaction between water and N availability as dual determinants of crop yield. The highest yields under these two treatments were observed at the intermediate water application and decreased yields were found under the lower and higher water application. Presumably the reduced yields at lower water application was because of less than optimum water content and the decreased yield at high water application was due to low N availability, much of the N having leached from the root zone. Since all N in both of these treatments was in the soil at the beginning, this N was exposed to the greatest potential for leaching loss.

A small experiment was conducted on celery using furrow irrigation (9). In this experiment, four rates of N fertilizer (100, 200, 300, and 400 kg N/ha) were applied. All treatments received 100 kg N/ha preplant as ammonium phosphate. The remainder of the N was applied as sidedressed N split in two equal increments of urea applied 29 and 49 days after celery transplanting.

At harvest time, there was no significant difference in yield for the three highest N application rates but the lowest (100 kg N/ha) had significantly lower yield. Even though the final yield was not significantly different for the three higher application rates, there was increasing rate of growth with increasing N application during the early stages, with the growth rate reaching a peak and then diminishing thereafter. The lowest N treatment had not yet reached its peak growth rate at harvest time. These data illustrate that celery growth can be stimulated by high N but that with sufficient time the effects of N application rate on yield tend to diminish. Nitrogen hastened economic maturity of the celery.

Two experiments were conducted using furrow irrigation with broccoli (var. Green Comet) as the test crop (6). The first experiment was conducted on a San Emigdio sandy loam soil very low in inherent fertility. The experimental variables consisted of three fertilizer N application rates (90, 180, and 270 kg/ha), two irrigation treatments (replenishment of water lost through evapotranspiration and evapotranspiration plus 30%), and two N application procedures (application to the soil and in the irrigation water).

One-third of the fertilizer was applied to the soil in a band adjacent to the plants prior to planting on all plots including those which were to receive N with the irrigation water. Thereafter the soil-applied fertilizer was applied in two sidedressings of 16-20-0 fertilizer or injected into the irrigation water in equal proportions during each irrigation. Hereafter the treatments will be referred to "inject" where fertilizer was applied with the irrigation water and "soil-applied" when fertilizer was applied as the two sidedressings.

Irrigation frequency was the same for both irrigation treatments but 30% more water was applied at each irrigation for the ET +30 (I1) treatment than for the ET (I0) treatment. Fertilizer was injected into the irrigation water continuously by a proportioning unit except at the end of each irrigation when the lines were flushed with water. The furrows were dammed at the end to avoid runoff.

Under the lower irrigation treatment there were no differences in yield due to method of applying the N. Under the higher irrigation there was consistently higher yield when the N was applied with the irrigation water as compared to sidedressing. Furthermore, there was lower yield under each fertilizer rate for the higher irrigation treatment.

Irrigation to replenish water loss through ET provided for both high yields and higher N use efficiency as compared to excessive irrigation. Potential advantages of injecting N with the irrigation water include savings of labor and energy for the two sidedress operations and avoiding plant damage during the sidedress operations. In this experiment, efficient energy, N, and water use were consistent with high crop production.

A second experiment was conducted with broccoli and furrow irrigation on the Sorrento loam. The furrows were 90 m long. Yields were higher under the higher N application as compared to the lower application and for a given N application the average yields were always higher for the sidedressing as compared to applying the N with the irrigation water. More N was removed in the crop than applied as fertilizer for the lower application rate and a very high percentage (77 to 84) of the N applied under the higher rate was removed in the crop. Tensiometers installed indicated there was very little water movement deep into the profile, thus minimizing leaching losses. Under these conditions, N is used efficiently and growth appears to be related to the rate of application. In the second experiment, there was higher average yield when the fertilizer was applied as sidedressing rather than injected with the irrigation water whereas there was no difference in the first experiment. The more uniform application throughout the row with continuous injection in the first experiment may have been a factor as compared to injection during part of the irrigation cycle during the second experiment.

No harvestable yield resulted from unfertilized plants. There was a trend toward decreased plant growth with increased water application for the treatment which did not receive N, due to leaching of the small amount of N in the profile. The lower fertilizer treatment resulted in fairly uniform growth at different water contents except at the very dry end where there was relatively less growth, while the plots receiving the higher fertilizer treatments had a trend toward higher production with higher water content.

A smaller amount of N was taken up by the plant when irrigated with 32.3 as compared to 16.8 cm of water for each N application rate.

This is presumably because the extra water leached some of the N below the root zone. On the other hand, higher head weight was achieved under 32.3 as compared to 16.8 cm of water under the two highest N application rates. Apparently a maximum of 13.0 T/ha of broccoli could be produced with 16.8 cm of water at the experimental site regardless of the fertilizer application.

Drip-irrigated tomatoes received three N application rates and two irrigation treatments. Nitrogen was applied as $NH_4NO_3$ by continuous injection with the irrigation water at constant concentrations of 25, 50, and 75 mg N/l. The two irrigation treatments allowed the soil water suction at a 25 cm depth to drop to approximately 10 or 30 cb at time of irrigation. Pragmatically the two irrigation treatments resulted in irrigation of approximately every day (10 cb) compared to every other day (30 cb) applications.

There was no effect of the irrigation treatment on the yields. During the period of peak production, the lowest yields occurred under the lowest N application treatments. However, this yield deficit appears to have been partially offset by greater production of these low N treatments during the earlier part of the season. The total yields of the lowest N treatment were 85 to 90 per cent of the maximum and yields were not consistently improved by applying N at higher rates.

As the rate of N application increased, an increasingly greater proportion of the N taken up by the crop was partitioned into the vines and foliage. In contrast, an increase in N application rate from 120 to 585 kg/ha increased the amount of N removed in the fruit by only 40 kg/ha. Thus, the total amount of N actually removed from the field depended very little on the rate of N fertilizer application.

It is apparent from the fruit yield and N uptake data that although total N removal continued to increase with increasing N application, the additional N assimilated in the two higher treatments did little to improve fruit yield but served primarily to elaborate vegetative material and increase the storage of N in the vines. Therefore, N fertilizer efficiency expressed in terms of the per cent recovery of applied N, the amount of N used by the plant to increase yield, or the economic return for unit of N applied, decreased substantially at the higher N rates. It should be noted, however, that since almost all of the excess N taken up was partitioned into the vines, a large amount of N could be returned to the soil and should serve as an important N source for subsequent crops.

The results of the tomato experiment as well as some of the sprinkler-celery experiments illustrate that relatively high N concentration during the initial stages of growth is important. Even though the plant removal is small in total quantity, the plant has a very small root system and must, therefore, be provided with nitrogen in relatively high concentration to prevent nitrogen deficiency at the early stages of growth. On the other hand, as the plant grows larger and the root system becomes more extensive, supplying nitrogen in the amount necessary for uptake appears to be adequate. Nitrogen applied in excess of this amount may potentially be lost through denitrification or leaching depending upon water-soil interactions.

Furrow-irrigated sweet corn was grown on the UCR Experiment Station to test the effects of a nitrification inhibitor (applied both preplant and at sidedressing) and three rates of irrigation water application (based on all plants receiving the same quantity of N, 250 kg/ha as ammonium sulfate). On a sandy soil, the nitrification inhibitor significantly increased the average weight of the corn stalks. On a sandy loam soil, the nitrification inhibitor increased average N concentrations per stalk at low rates of water application but had little effect at higher application rates. Generally soil N levels were maintained higher with the nitrification inhibitor, and the effect was more pronounced at higher rates of water application (Mikkelson, Jarrell, Letey, Whaley, in preparation).

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