NITROGEN AND WATER INTERACTIONS: CROP PRODUCTION SYSTEMS CASE STUDIES

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ABSTRACT

Farmers and urban land managers have to strike a tenuous balance between achieving plant growth goals while responsibly managing natural resources. Water quality and scarcity issues are prominent concerns, along with soil quality preservation and conservation of fuel and fertilizer resources. The purpose of this presentation will be to highlight case studies where water and crop management practices were considered together to improve the efficiency of resource use. Evidences of water scarcity will be presented and the concept of crop water productivity given as a way of improving water resource use. Various plant water and nutrient need/uptake scenarios will be presented. The impacts of excess/deficit water and nutrients on each other will be briefly considered with an emphasis on management options. In one potato-grain system example, a grower achieved a 4.6% increase in net income while achieving a 22% reduction in irrigation water. In another example in a corn-bean system, the grower eliminated 4.3% of their unprofitable land and increased net income by 10.1% while minimizing environmental risks. An on-going variable rate irrigation study will be highlighted, demonstrating the spatial variability in crop water productivity and its relationship to soil type and yield. In an urban system example, desired plant canopy cover was maintained with near three-fold reduction in irrigation water. This presentation will focus on application of science in soil-plant-water systems with examples of successes, as well as some failures.

INTRODUCTION

Water is a vital resource for healthy functioning ecosystems and for municipal, industrial, and agricultural needs. The agricultural sector is the single largest user of water worldwide, using approximately 75% of freshwater resources globally. In arid and semi-arid regions of the world, water scarcity due to inadequate rainfall is one of the most pressing challenges for agricultural and food sustainability. Irrigation has been developed to enable stable, high yield agricultural production and to avoid the effects of drought. Water scarcity in many of these regions is a pressing issue due to declining groundwater levels, increasing competition for water by municipal and industrial users, increasing frequency and severity of drought, rapid population growth, and declining water quality due to pollution and salinity (Gleeson et al., 2012; Vörösmarty et al., 2000). Improved understanding of the interactions of crop management practices and crop water use is critical for sustaining agricultural production in an era of water scarcity. Nutrient management is a key crop management factor, but the interaction of nutrient management practices with crop water use are not always considered.

In this paper, we provide several case studies that illustrate the interaction of crop management and crop water productivity (CWP). Crop water productivity is an expression of the amount of "crop per drop," or the yield per unit of water consumed. While agriculturalists are accustomed to reporting crop yield per unit of land area (lbs ac^{-1}, bu ac^{-1} or Mg ha^{-1}), reporting CWP (lbs $ac\text{-}in^{-1}$, bu $ac\text{-}in^{-1}$, or Mg m^{-3}) is much less common. Assessing and reporting CWP is increasingly important, as water becomes a more limiting resource. Additional information and record keeping is required to obtain CWP. Specifically, the determination of CWP requires a measure of the crop water use (evapotranspiration, ET). ET can be calculated from an energy balance equation or obtained from a water balance. The water-balance approach is represented with the following equation,

$$ET=P+I-D-R-\Delta S$$

where ET is evapotranspiration, P is precipitation, I is irrigation, D is drainage, R is runoff, and ΔS is the change in soil water from the beginning to the end of the planting season. Where appropriate, runoff and drainage can be assumed small and ignored in the equation, requiring the user to have records of precipitation and irrigation and a reasonable understanding of the water use from the soil during the cropping season. The crop yield is then divided by the ET to give CWP as follows

$$CWP = Yield / ET$$

POTATO-WHEAT CASE STUDY

Legal issues resulted in an eventual mandated reduction in water consumption across a majority of a farm in South-Eastern Idaho. After considerable analysis, it was determined to attempt to reduce water consumption across each field rather than abandoning fields or letting them go fallow for a time. Eight of these fields (typical of the rest) are presented here as an example of the successes and problems associated with this approach.

These fields all had several cycles of a potato-wheat-wheat rotation. Potato (*Solanum tuberosum* L.) is generally a species with higher water requirement than most crops, including wheat. It has a relatively shallow, inefficient root system and higher transpiration rates, as well as being more sensitive to fluctuations in soil moisture availability (Hopkins et al, 2014).

Four of these fields were farmed with the grower's standard practices (GSP) and the other four were managed in a paired experimental design with enhanced Best Management Practices (BMP). An example of one of these fields is shown in Fig. 1. The BMPs were:

- Severe center-pivot irrigation system uniformity problems, which are common, were identified with aerial imagery and corrected (Fig. 1).
- An irrigation specialist (consultant) was hired to manage rate and timing of water applications.
- A high quality non-ionic polymer surfactant was applied to enhance water infiltration.
- Switched variety from Russet Burbank potato to Alturas and Ranger Russet (increased yield potential, water use efficiency, rooting depth, rooting efficiency, and overall pathogen resistance).
- Variable rate fertilization (VRF) with zones determined via aerial bare-soil imagery and yield map (wheat only) history and grower input. In general, nitrogen (N) was increased in areas with relatively higher yield potential. The other nutrients were fertilized based on zonal soil sampling with the primary difference being that eroded ridges were more

highly calcareous and lower in residual soil phosphorus, zinc, and manganese. Consequently, higher rates of these nutrients were applied in these areas.

- Pre-plant N was generally reduced to only that applied in conjunction with the phosphate fertilizers (typically 10-20 lb N/ac).
- Polymer coated urea (PCU) applied variable rate at 75% of anticipated N needs just prior to hilling/cultivation.
- Limited in-season N (tissue samples often showed no need for additional N) applied based on zonal petiole and, in some cases, soil sampling.

There were positive and negative outcomes observed for each approach. Over three years, yields were 3.2% greater in fields with application of BMPs, with a 15.2% increase in US No. 1 tubers (grower contract is most sensitive to this quality parameter). Most significantly, water use dropped dramatically by 22%—with associated reductions in pumping costs and expected reductions in leaching of fertilizers and pesticides. Because yields increased and water use decreased, there is a significant improvement in crop water productivity and the case study clearly illustrates the interactions of management practices on crop water use.

While the overall outcome of BMP implementation was positive, it should be noted that seed potato costs were 7% higher for BMPs and, fertilizer (PCU) and spreading costs were 33% higher. Further, management time/costs increased by an estimated 5%. Another downside to the varieties used for the BMP fields was that they do not store as long as Russet Burbank and, thus, were sold sooner (which did not impact the economics in this case, but could in others). The net income was a significant 4.6% greater for BMP than GSP. The wheat data was similar, but not generally statistically significant or as great in magnitude (data not shown). In all cases, water was used more efficienty.

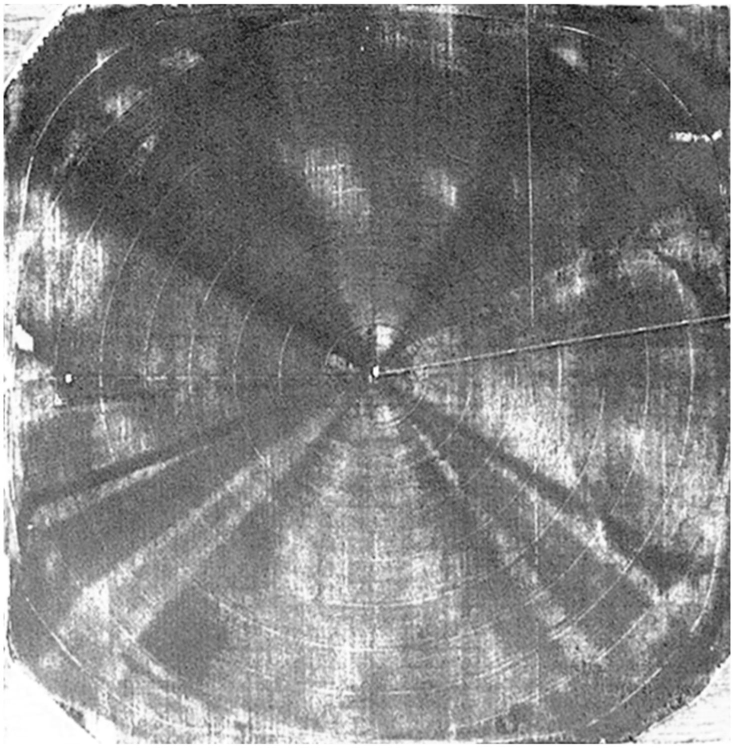

Fig. 1. Potato field with serious irrigation system installation/maintenance issues with resultant problems with soil moisture deficits in some areas and leaching of nutrients and pesticides in other areas with excessive irrigation. BMPs were implemented in this field, resulting in increased net income and improved water use efficiency.

CORN-BEAN CASE STUDY

In contrast to the potato-wheat case study, an evaluation of a corn-bean rotation field in western Nebraska shows that some land is just simply not profitable for farming and, as such, reduces overall efficiency of water and other resource use. This particular grower had experienced net losses in most years and was in danger of losing the farm. They hired a consultant and began evaluating net profits on a per field basis. After a few years, profitability was improving over the farm, but one field lost money each year. Reliable calibrated yield maps were evaluated over a six year period (Fig. 2). Site-specific yields ranged from 62 to 145% of the field average. The poor areas of the field were eroded ridges with rocks and shallow, calcareous soils with low water holding capacity.

It was determined that the poorest areas of the field in the southeast corner would be abandoned and sold for housing. Another area on the east-center had similarly poor yield potential, but could not be abandoned easily due to the nature of the set-move irrigation system (other parts of the field wouldn't be able to be irrigated). While those areas were still kept in production, the nitrogen and seed inputs were reduced. The CWP in this area would be poor, but the net income improved as a result of input reductions. The CWP of the entire field increased modestly due to the elimination of part of the poor producing area. If variable rate irrigation (VRI) were an option in this field, further improvements in CWP could be achieved, together with increases in net profits, by reducing water inputs in the low yielding areas.

The net returns on this field increased an average of 10.1% compared to previous years (adjusted for inflation). This resulted in shifting from consistent losses to mostly profits for this field each year. Additionally, water savings were approximately 5%, with associated expected reductions in leaching losses from these shallow, low water holding capacity soils.

Fig. 2. Yield extremes for averaged corn-bean yield map history over six years showing relatively high yields in the upper left quadrant and poor yields on the right.

VARIABLE RATE IRRIGATION CASE STUDY

It was not very many years ago that VRF seemed to be an out of reach technology and appeared unlikely to be widely adopted. At present, this technology has become commonplace. Variable rate irrigation is at the stage of very early adoption with less than 1% of irrigation systems using VRI. However, the potential for water savings and crop yield/quality gains is very high as adopted by growers is likely to increase in coming years.

A VRI system was installed as described elsewhere in this conference proceedings (Svedin et al., 2017). The system allowed for a detailed evaluation of the variation of CWP within a single field. CWP ranged from 1.5 – 9.4 bu $acre^{-1}$ $inch^{-1}$ (0.40 – 2.5 kg m^{-3}) with an average of 6.3 bu $acre^{-1}$ $inch^{-1}$ (1.7 kg m^{-3}). The producer reports that in the first year after installation, water savings were in excess of 30% with no compromise in grain yield. Additional work is underway as added layers of information (yield history, aerial bare soil and in-season imagery, topography, soil depth, CWP, and zonal soil sampling) are being used to fine tune the VRI zones.

URBAN TURFGRASS SYSTEM CASE STUDY

Turfgrass is the irrigated crop of greatest acreage in the USA. Unlike farmers who necessarily have to manage inputs very carefully to be profitable, the average urban landscape manager is typically driven by social issues (aesthetics, functionality) rather than economics or environmental issues. Various studies show that the average home owner or urban landscape manager applies nearly two to four times more irrigation water than is necessary.

A case study in Provo, UT was conducted comparing a "typical" situation where an automatic sprinkler applied irrigation water three times daily at the same rate throughout the entire growing season (~340% more water applied than ET losses over that time frame). The fertilization and pest management were handled with a commercial "one-size-fits-all" landscape company that applied 6, 2, and 3 lb of N, P_2O_5, and K_2O per 1000 ft^2, respectively (260, 90, 130 lb/ac) annually, along with various herbicides, insecticides, and fungicides without regard to soil test or pest pressure. This wasteful scenario was transitioned to a conserving landscape via adoption of BMPs, including:

- Irrigation system uniformity was improved from 33% to 71% by fixing leaks, adjusting sprinkler heads, and installing correct nozzles.
- The grass roots were encouraged to grow deeper through the following:
    - Adopting the practice of "deep and infrequent" irrigation by monitoring seasonally fluctuating root depths (becomes more shallow in summer as compared to spring/fall) and irrigating to the root depth. This resulted in irrigation frequency ranging from about every 10 days in spring to every 2-4 days in summer.
    - Intentionally water stressing it two times in spring (to the point of visual stress symptoms),
    - Cutting the N rate by 50% with 2/3 applied as a controlled release fertilizer (PCU) and the rest as ammonium sulfate with two applications (early spring and early fall)—ensuring ample N in Fall when root growth is most prolific. (No other nutrients were needed according to soil test.)
    - Increasing mowing height to 2.5 inches with frequency such that never more than 1/3 of the shoots were cut off in any one mowing.
- Pest management was reduced to spot spraying weeds and pathogens as needed based on scouting. Insecticide applications were continued due to consistent pressure grub pressure.

The net result was significant increase in plant health, as determined by visual ratings and Normalized Difference Vegetative Index (NDVI). This was especially true in early spring green-up, fewer dormancy issues (browning) in summer, and late fall/winter color. All of this was done with a near 300% reduction in water (and fertilizer and pesticide use as well). We would suggest that this situation is common and that there isn't a need in most areas to completely abandoning the irrigation of landscapes (which provide many benefits to society), but rather the promotion of these concepts will allow society to "have our cake and eat it too" (which have no additional costs, although do require more management).

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