Managing Water And Nutrient Efficiencies

Using effective data collection and sound analysis techniques is critical.

David Lankford and Frank Lichtner, Ph.D.

The Fluid Journal • Official Journal of the Fluid Fertilizer Foundation • Summer 2014 • Vol. 22, No. 3, Issue #85

Summary: *Proper water management approaches include using smaller amounts of nutrients directly to the crop as foliar treatments, bypassing soil applications. Using fluid fertilizers allows nutrients to be immediately available to the plant. The new era in water and nutrient efficiencies will be pushed to levels once thought impossible by using effective data collection and sound analysis techniques.*

A little reflection first. We were honored when asked to give our perspective on this subject, and it caused one of us to think back to the days of his grandfather and how he was taught to grow plants. In the 1950s everything was grown using 10-10-10 fertilizer, probably because of price rather than using precise fertilizer management. Irrigation was never mentioned because there was none in the area, namely the Eastern Shore of the Delmarva Peninsula. In Maryland, it was believed that 3 to 4 inches of rain that fell each month was sufficient to grow a crop. Our forebears were good farmers, possessing the wisdom of the day. As they shared their years of knowledge, we now have been asked to share our years of knowledge. Our hope is our experiences will help motivate others to take current knowledge of managing water and fertilizer use efficiencies in growing plants to new heights tomorrow.

Times change

So let's start with the big difference between our forebears way of doing things and ours today. They were mostly self-taught via trial and error. Fate led us to a totally different path. After World War II, the electronic age was just starting and it was during this time that many ideas were developed and patented. One such patent was for the design of the capacitance probe. The dilemma was that at that time the only form of electronics available was vacuum tube technology. The size and power needed to operate the tubes prohibited any deployment of instruments to an agricultural field and so it remained a concept rather than a practical solution. By the 1960s the USA was involved in the Vietnam conflict. During this time the military began advanced electronics at a time when tubes, transistors, and chips were all being used, sometimes in combination in one machine. Much was learned from the deployment of electronics and analysis of data collected. Little did we know that this would affect the future of those involved in agriculture!

Enter probes

Almost 30 years ago the concept of using capacitance probes to measure soil water content evolved as the new world of miniaturized electronics grew. By developing this technology in Australia, Peter Buss of Sentex Technologies drove ways to benefit growers who were struggling with limited water availability. He achieved many advances in robust probe design, reliable performance, and analytical software. But like so many inventions, the use of technology was initially limited to the purpose the inventor perceived: a tool for water balance studies and water management. It is now helping growers all over the world to manage water and nutrients.

Budgeting

When we were introduced to this technology, one of our first questions was how were the budget lines determined (Figure 1)? The explanation given to us was based on the principle that the soil texture determines the limits of how much water the soil can hold and how much water is available for the plant. Most of us in agriculture with knowledge of soils and agronomy have heard the terms "field capacity," "wilt point," and "saturation." We were instructed to set the upper limit of the water balance as close to the field capacity of the soil as possible. It was pointed out that after a large water influx into the soil (rainfall or irrigation), the timeline graph would rise dramatically and then would decline quickly until the soil tension counteracted the drainage, and this point on the graph equaled "field capacity" (Figure 2). Field capacity was considered the situation where the maximum amount of water was available for the plant and is the best upper set point for water management purposes. The process to set the lower budget line was a little more contentious. There have been some who say just set the budget line at any percent of available water, and it will be OK. Others thought it should be set as a defined percent of available water

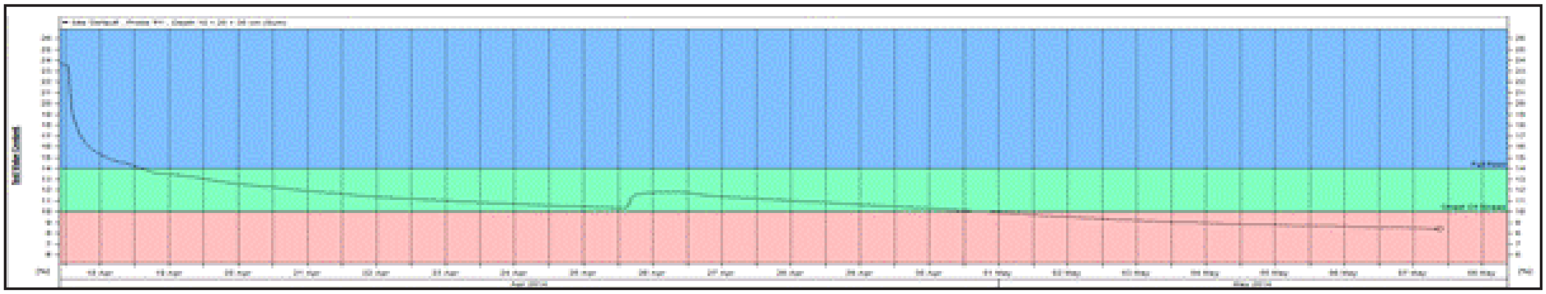

Figure 1. The green area is the desired water level.

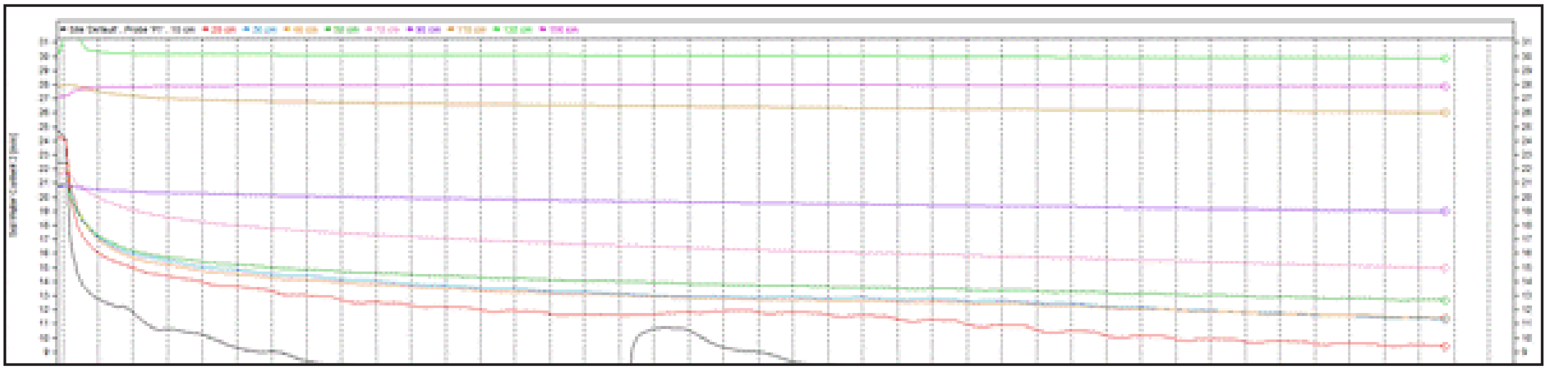

Figure 2. The decrease in lines shows water leaving the soil quickly until field capacity is achieved.

(what is now known as an "allowable deficit"). And lastly, there are those who think the lower limit should be set at the point where the first slowdown in water use by the crop occurs. The truth is, no matter which of the three was used, it always improved water use efficiency. All reduced applied water volumes and prevented waiting too long to irrigate.

Water efficiency

To debate which method is best maybe misses the real issue of water efficiency. Let's first define water efficiency. The simplest method is to add all rainfall plus the amount of irrigation the crop receives to get total applied water, then divide the total yield by that number (yield/total water applied). We would argue this is not a good method for the calculation, for reasons we will explain below. The next interaction would be to add the net change of the Starting Volumetric % Water Content and Ending Volumetric % Water Content of soil water content of the soil water [(Y/TWA) + (SWC - EWC)]. This takes into account how the water in the soil changed over the season. If EB is higher at the end, then the plant did not use all the applied water and the water efficiency of the plant should get that credit. This all makes sense but what about large rainfalls? Did the plant use all that water? When a good manager gets the large rainfall, did he really mismanage the water and cause the water efficiency to go down? Most likely not, especially if there was runoff and the soil doesn't have a high water holding capacity.

So how can we account for this in our measurement of water efficiency? Acknowledge that big rains serve more purposes than just for the growing of crops, i.e. recharging groundwater and surface flows. And how should we change the efficiency formula? How about by accounting the amount of rainfall to only the volume used by the crop?! In the past this could be at best a guess, but now, with technology, it possible to measure that consumption.

Main forces

There are four main forces moving water in the soil.

Drainage (or percolation) is the water loss from the soil macropores and as gravity pulls that water deeper into the soil profile, it is replaced by air. Drainage is a downward movement.

Evaporation is the soil water loss due to sunlight and wind, and the water is lost off the surface of the soil into the air above the soil surface. This is upward movement of water.

Transpiration is the water that enters the roots, moved upward through the plant, and evaporates from the leaves through the stomata (leaf pores). This is water leaving the soil (generally, below the soil surface) and going out to the atmosphere. This is the water that is used by the crop.

Normalization is the movement of water from areas of high concentration (wet areas) to areas of low concentration (dry areas) by diffusion. This can be in any direction: up, down, sideways, or any combination. Depending on the soil texture and the current water balance, each of these forces moves water at different velocities, with drainage (powered by gravity) as the most rapid, and transpiration as slower than gravity, but faster than evaporation and normalization, which are the laggards in the pack.

Due to the difficulty to distinguish between evaporation and transpiration, we mostly talk about ETo (the combined effect of the two forces of evaporation and transpiration). But Etc (plant coefficient of water uptake by the crop) is what we really need to know in order to talk about plant water efficiencies. There have been several ways the crop consumptive use has been measured (or calculated). The most straightforward method is to grow plants in a container (that can be weighed periodically or with lysimetry, which involves large soil cores and sophisticated weighting methods). The basic premise is that the weight of water added can be measured, and then, as the water leaves the plant, the total weight of the container or soil core will go down; the difference is the water transpired (used by the plant). The complications in using these methods are that the soil in these cases is not like the soil in field production.

First, there is not an impervious wall around the roots restricting water movement to only up in that field.

Second, the soil around the crop plant might have been disturbed using these methods and so it doesn't mimic the distinct layers of soil stratification that occur after years of rainfall and cultural practices (tillage) in the field.

Third, the water lost due to evaporation can only be stopped by some cover, which again may not reflect field conditions (without a cover, the weighing of the container or soil core computes ETo and not Etc).

Options

So what are the options? The best scenario is to minimize the impact of the plant and cultural practices and yet still measure all the forces acting on soil water.

Probe. Using the capacitance probe can come closest to this optimal method, but only when the following criteria are followed:

- Installing probe so as not to disturb the native soil structure
- Using the correct sampling time appropriate for a soil and crop matrix
- Determining the soil texture correctly
- Using algorithms to determine which force moved the water from (or into) the location in the soil where the probe is located.

Stacked probe. Using a stacked capacitance probe can be configured to measure the soil moisture in 10 cm (4 inch) "slices" in the soil. This is more helpful for water management than just a bulk measurement of the complete soil profile that lysimetry offers. This second new feature that the capacitance probe now offers allows measurement of ion content as well as water content, so that we can now look at basic water and ion content and compare where in the soil profile that consumption is taking place. Is the consumption occurring where the resources needed by the crop are located (i.e., in alignment)? If not, will any benefit be realized if water and nutrient management changes are made to move the locations of the resources? This now defines a new and exciting frontier.

Probe ion measurements in the soil contain very broad information, meaning that all ions are measured, not specific ionic species; agriculturally-useful ions (such as calcium and nitrate) as well as non-useful ions (such as chloride or sodium) are measured. We can use complementary methods to extract soil water from different depths in the profile and measure specific ions of interest to get a complete picture of what is available to the crop. Using these complementary techniques, a lot of useful information can be obtained. When fertilizer is applied, the top sensors will show the increase in ions. Over time, the total will decrease through plant consumption and movement into lower layers in the soil. In almost all cases, the ions will increase at lower levels over the crop season. What is moving down? It can be the chlorine from the fertilizer or salty irrigation water, or it can be nitrates. This is where the complementary techniques can determine the element(s) that are moving.

Efficiency

Plants only take up nutrients in solution (i.e., dissolved salts). As we work toward more production with current resources (or even fewer) this fact must not be overlooked. Preplant and traditional in-season soil tests reflect what could be available for the plant if moisture is sufficient, while the soil water test (using soil samplers) is what is available in the water at that moment for the plant. So the first step in any management plan to increase water use efficiency demands that we must supply the water based on needs of the crop, rather than ETo measurements or general guidance (one inch per week, for example). In order to get nutrients into a crop, the plants need to be taking up water. The first step then, to increased efficiency, is to replace only the water the crop used, and replace it from where the plants got it. This may sound easy, but since we apply water (as irrigation or rain) at a one-source or -depth (mostly close to or at the soil surface), we subsequently can only hope the water distributes the way that gives the greatest benefit to the crop. Without monitoring, it is almost impossible to put back the exact amount that was removed and make sure that it gets to where we want it to go. This leads to the first aspect of inefficiency, since either over- or under-watering causes stress to the crop and stress causes lost production. Lost yield directly reduces input efficiencies, eliminating the opportunity to improve.

Measuring

The first step is measuring where and how much water is to be replaced, then confirming you achieved that goal. But another problem can be calibrating the scale to know where optimum water levels are and how dry the soil profile can become before replacing water. To achieve the correct volume, we must go back to the crop and measure water consumption. We have learned that as the soil gets drier the effort needed to extract that water gets greater for the crop. This means that as the soil water content goes down, the water uptake rate by the plant is reduced. Getting the most water into the plant will give the greatest potential for yield (and we have determined in crop variety comparisons that the plant that consumes the most water has the best yield). Allowable deficits (the level to which the soil profile can be depleted before yield losses set in) have been measured by universities for a variety of crops, and can be obtained online; these measurements offer the best way to set the lower limit of the water budget. The USDA in Beltsville showed that corn lost 60 bushels as a result of too little (below an allowable deficit) or too much water (above field capacity) for a period of 10 days. This means that waiting too long to irrigate reduces yield and then over-watering reduces more yield--double trouble! This underscores the importance of setting proper budget lines and also scanning the water content of each individual level in the soil, rather than only using the sum of all levels.

"Measure all forces acting on soil water."

FUE

Now, if all the plant needed was water, we could stop here. It is early in the fertilizer efficiency work we've begun, but some data collected so far are hard to ignore and inspires us to continue our work. Small changes in fertilizer use (not what is applied) can have large yield increases. This means that improving fertilizer use efficiency (FUE) will have a bigger impact on total yield than water management alone. However, nutrient efficiency increases are not possible without observing and reacting to crop-driven water management data. A recent study at the irrigation Research Foundation (Yuma, CO) gave some very interesting insights to nutrient management. Many projects there involved measuring soil water content at several depths, often up to 1.5 meters deep to be sure we are measuring all the resources available to the crop. Some of the best yields (corn, sugar beets) have been with low amounts of applied water. How is this possible? Tests showed that plots of corn with high yield had higher concentration of total N than in plots with lower N levels. Since research has found that water uptake by the crop brings dissolved nutrients close to the roots so that they can then take up the nutrient ions, it makes sense that if the water contains 60 ppm of total N, the crop in a plot with lower concentrations of total N would need to take up more water to bring the same level of nutrients close to the roots. This is a simplified way to explain these results. Other data have shown that over-watering soil (above field capacity) reduces air (oxygen) in the soil water, and, in turn, reduces water and nutrient uptake by plant roots. Coupled to this is that over-watering also reduced the N concentration. So, is the critical dominant factor for better yield "more water uptake" or "higher nutrient concentration"? Certainly more tests are needed; the good news is that we have new tools in the tool box to help unravel this dilemma.

Summing up

There are many fertilizer products developed to help resolve problems of plant uptake and NUE. Some contain additives to increase nutrient availability. Others reduce nutrient migration. Management approaches include using smaller amounts of nutrients directly to the crop as foliar treatments, bypassing soil application. Using fluid fertilizers allows nutrients to be immediately available to the plant. All of these approaches have merit and, when applied to problems correctly, can be very successful. The new era in water and nutrient efficiencies will be pushed to levels once thought impossible by using effective data collection and sound analysis techniques. The future is bright for keeping the American farmer profitable by higher yields and using fewer resources. We are grateful to have been involved in seeing a true Precision Ag revolution--in water and nutrient management possibilities!

Mr. Lankford is an agricultural consultant at AgriMeasures, working with fertilizer manufacturers, and Dr. Lichtner is a product development consultant for several companies involved in irrigation, as well as an agronomy consultant for agricultural commodities risk management firms.