HOW MUCH WATER DO I APPLY?

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Of course you know how much water you apply. Your pump puts out 900 gallons per minute to irrigate 130 acres, and you usually set the percent timer to make a revolution in 66 hours. That pencils out to almost exactly 1 inch per irrigation. How that water gets distributed across the field has a lot of bearing on how effective the irrigation is, however. Figures 1 and 2 show the depth of water distribution along the machine for two very different, but both considered acceptable, center pivots. In the first case, the depth of water varies (forget about the first 100 feet or so) from about 2.3" to 0.6" as you walk out along the machine. If you are watching a spot receiving a low application, you may conclude that you are not pumping as much as you thought. Conversely, several spots may be way overwatered. Under the pivot shown in Figure 2, on the other hand, it really doesn't matter much where you look -- the application if about the same. Thus, the question as to how much water you really apply depends on the question, Where?, and the answer can have a big impact on the real cost of irrigation. We are going to use results of field tests to estimate the impact of the question on the bottom line--your pocket book, assuming that you know how much water the crop needs and manage to apply that amount -- somewhere.

Figure 1 shows the depth of water applied along a typical center pivot evaluated by the SCS in Colorado (SCS26). We often use a number called the coefficient of uniformity (CU) to express how much the water application varies, and for many years designers have considered that 80 to 85% is sufficient. Of 60 pivots measured by the SCS in Colorado in 1983, the average CU was 81.8%. We can see that there are almost unlimited "depths" of water applied, depending on where you look. We will evaluate several ways of determining "depth" and what they mean in terms of the number of irrigations and the costs associated with irrigation. The most obvious depth, called the "mean depth" (MD) is calculated by multiplying the pump discharge by the irrigation time then dividing by the area covered. It is obvious from Figure 1 that some areas receive more that the mean depth, some less. In fact, from a mathematical viewpoint, there is not one square foot that gets exactly the mean depth. About half the field is overirrigated, half is underirrigated.

For many years, irrigation designers talked about managing systems on the "mean low-quarter depth" (MLQ). That means that we look at the one-fourth of the field that receives the least water and irrigate so that the average application on that area is adequate -- in other works, we try for top yields. This translates to about 85-90% of the field being overirrigated! When water and chemicals were cheap, and we didn't have the same environmental concerns as today, that figure worked well to assure near maximum yield. Today, however, maximum yield does not necessarily translate to maximum profits or

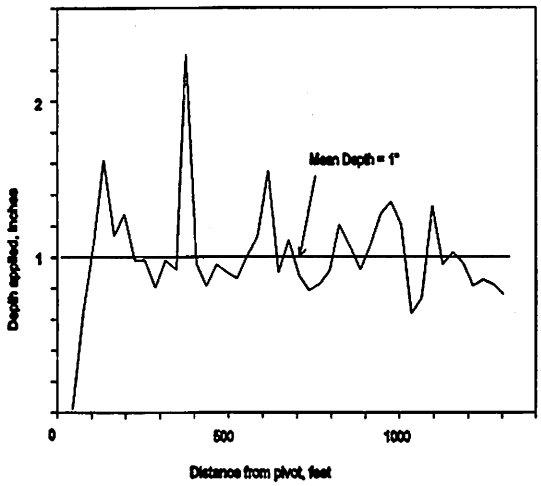

Figure 1. "Good" uniformity (CU=81.6%, 1" average application).

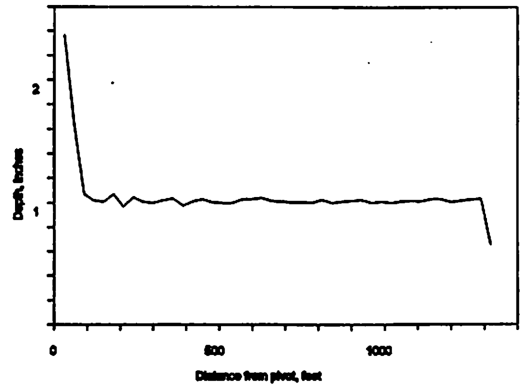

Figure 2. Excellent uniformity (CU=96.8%, 1" average application).

most responsible stewardship.

We know it is possible to achieve higher uniformity than shown in Figure 1. Figure 2 is a high pressure, impact head system that has had its nozzle package tuned to the point that CU is better than 96%, a value that can be achieved with impact heads, spray heads, or in-canopy hardware (such as LEPA). One thing obvious from Figure 2 is that it really doesn't make much difference how you measure the depth if uniformity is high. The mean depth (MD) is about the same as the MLQ, the minimum or the maximum.

Studies have been conducted in many areas to determine how many bushels of corn will be lost for each inch of water and pound of nitrogen short and how much nitrogen will be washed away by each inch of excess water. I have used these studies to calculate how much money is lost in the areas overirrigated and underirrigated <u>within the same field</u> and to minimize the sum of these costs to illustrate the importance of irrigation uniformity.

If the crop requires 27" of water to make maximum yield, the soil contains 5" of water at the beginning of the season, and we expect 6" rain during the season, then we can expect to irrigate 16". Using the "average pivot" measured by the SCS, and assuming the mean depth (MD) is 1" per irrigation, we need to apply 16 irrigations if we manage based on MD. If we use the MLQ to be sure 85%+ of the field gets enough, we will have to irrigate more times. If we estimate some costs, we can calculate the optimum depths that will result in the least costs of both under and overirrigation.

I assumed that each inch of water short reduces yield by 8bu/ac; it takes 1# of nitrogen to produce 1bu; corn will sell for $2.00/bu; nitrogen content of the fertilizer costs 16¢/lb; each extra inch of water leaches 10 pounds nitrogen/ac; the pump is 65% efficient (100% Nebraska Standard); and power costs are equivalent to electricity at 7¢/kwh. In the areas receiving too much water, we have costs for pumping the extra water and for fertilizer leached. If we applied just the right amount of fertilizer, leaching will result in reduced yield because of fertilizer shortage. Some cost, whether out-of-pocket or otherwise, should be assigned to the environmental impact of the nitrogen leached. In areas underirrigated, some fertilizer cannot be used and yields are reduced by insufficient water. All these assumptions may be different for your operation.

We will look at three economic scenarios which represent a range of physical situations and managment attitudes. The first we might call the "cheap water" operator (CW). He pumps from a ditch, is not worried about the cost of fertilizer, and probably overfertilizes enough that even with a lot of leaching he won't run short. Maybe he doesn't understand that leached nitrogen may contaminate his and his neighbors' drinking water. The second scenario may represent the average manager of today (AM). He pumps 165 feet from the Ogallala, watches his fertilizer costs, and feels he is doing a good job of controlling nitrogen leaching to the groundwater. The third scenario is a "storm cloud" scenario (REG) which might represent strict future regulations making the farmer responsible for cleanup of nitrogen, and assumes the costs to the environment of excess nitrogen is $4 per pound. Each operates the pivot at 45 psi. With these numbers, it costs each farmer $17.28 for each acre-inch of water too little, and $0.92, $24.00, and $64.00 per acre-inch excess water applied, respectively.

Using these costs, I used mathematical relationships to calculate the number of irrigations to apply for the highest net return, using a 1" average application. I used three systems: a low uniformity system (SCS35); the "average" system from the SCS tests; and a high uniformity system. From Table 1, one can see that the number of irrigations varies greatly when uniformity is low, depending on the costs associated with deficit and excess irrigation.

Table 1. Irrigations to apply 16" effective water.

System	Management Scenario				
	Mean Depth	Low Quarter	Avg. Mgr.	Cheap Water	Strict Regs
Low (SCS35) CU = 71.7%	16	24.6	14.9	38.4	12.5
Average SCS Tests CU = 81.8%	16	21.6	15.3	25.6	13.6
High CU = 96.8%	16	16.5	15.9	17.1	15.5

I also calculated the costs of nonuniformity resulting from operating the three systems at each of the depths. The mean and mean low quarter values are calculated for the same costs per acre-inch of water as used for the "average manager." These costs of the low and average uniformity systems above those of the target system are shown in Table 2.

Table 2. Net Income Lost to Nonuniformity.

System	Management Scenario				
	Mean Depth	Low Quarter	Avg. Mgr.	Cheap Water	Strict Regs
Low (SCS35) CU = 71.7%	$11900	$30100	$10700	$3800	$12100
Average SCS Tests CU = 81.8%	$8200	$18500	$7600	$1800	$9300

Once you have chosen an acceptable CU for your particular operation, we can also determine how much "more water" you will have if you improve the uniformity of the system. Because higher uniformity wastes less water in spots that are overirrigated and costs less yield in dry spots, improving uniformity will increase the apparent amount of water available, or "make the water go farther." To do the same job of irrigating, it takes a smaller well when uniformity is higher. Looking at the three center pivots in the examples above, and the "low quarter" management scenario in which we attempt to keep most of the circle well irrigated, a well of 1250 gpm into the pivot of the low uniformity system (71.7% CU) can be replaced by a well of 750 gpm if uniformity is improved to 81.7% or a 575 gpm well if CU is improved to 96.8%! The improvement in uniformity is much more significant for management systems that call for more water. For example, if we manage on the mean depth rather than low quarter depth (that is, allow about half the field to be somewhat underirrigated), then there is no gain in the apparent water available from improved uniformity. What is gained by improving uniformity, however, is that water deficits are less severe and overirrigation is less extreme, resulting in better yields and less wasted energy, water, and fertilizer.

Another point I would like to make is the trade off between uniformity and operating pressure. All other things being equal, it is desirable to operate at as low pressure as possible to minimize energy costs. We have seen here that uniformity can have a huge economic impact. It must be remembered that the uniformity that is of real concern is the uniformity of water <u>entering the soil</u>. If water runs from the top of the hill to the bottom, even if it stays in the field, the uniformity suffers. The lower the pressure at which we operate, the greater the opportunity for nonuniformity. This may occur because the sprinkler heads simply cannot throw water far enough, because the pattern is so small that application rates are extreme, or because elevation differences are great compared to the operating pressure. For the pivots discussed above (pumping from 165 feet), the annual cost of electricity would be about $4992.00. Increasing the operating pressure by 10 psi to compensate for a 23 foot difference in elevation would increase the bill by $433 to $5425. For most scenarios discussed, this would be more than offset by even a small sacrifice in uniformity.

The remaining question is "How can I improve the uniformity of my system?" The first step is to determine how uniform it is now. That can be done with the "can test", but to get a good representation it should be done at several places in the field, and at different times, to average the effects of day/night, flat/sloping, andwindy/calm conditions. Another way is to use a computer program to calculate the uniformity. This method takes less field work, and may give a better indication of the uniformity over several irrigations. Then, you must determine whether the water stays where it is applied. Water running down the furrow is a sure sign of non-uniformity after application, even if no water leaves the field. If you have runoff now, you need to select a sprinkler head that will apply water in smaller drops and/or over a larger diameter. When runoff occurs, tillage practices to increase intake rates will help uniformity. Sprinkler packages may be selected to replace worn sprinklers or those that result in runoff. Pressure regulators will improve uniformity of application on systems that operate at low pressure over uneven terrain. However, it is important to note that the design of a pressure regulated system must match the well very closely. If not, the pumping pressure, thus energy use, may be very different than expected.

The bottom line boils down to this: Every situation is different, you can't compare your pivot to your neighbor's or this year to last. Effective rainfall has a large impact on the effectiveness of your irrigation system. If you pump 1500 hours/year on a 130 acre system with deep soils, then each inch of rain that is stored in the soil is worth about 40 gpm; that is, in a season it rained 5" more than normal at a time when the soil could hold it, you could have gotten by with 200 gpm lower well capacity. When soils are sandy, they can store less water for later use, thus the effect of rainfall on pumping capacity is not nearly so great. You must decide the risk you are willing to take. Because High Plains precipitation varies so much from year-to-year, it takes more water to make a good crop 19 years out of 20 than it does to make a crop 10 years of 20. It is evident that the cost of nonuniformity is very large, and you can probably afford to upgrade your system. The judgement whether to upgrade should probably be based on more than one test of your pivot's uniformity. Any type system, impact, spray or LEPA, can be designed to apply water uniformly. What is even more important is to be sure the water infiltrates as uniformly as it is applied.