Managing Wheel-Lines and Hand-Lines for High Profitability

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In 2008 there were nearly 3 million acres in the US irrigated by wheel-lines or hand-lines with 1.3 million of these acres being in the Pacific Northwest. However, there are very few publications providing practical management advice for wheel-lines and hand-lines. This publication is written for managers of these systems. Existing publications describe what wheel-lines are, how they work (Hill, 2000), and how to maintain them (Beard et al., 2000). The focus of this publication is to provide the background for understanding soil water management, and some best management practices for managing these systems for high profitability and improved environmental water quality.

Soil Water Basics

Water is held in the cracks and empty spaces between soil particles. When all of the empty spaces between these soil particles are completely filled the soil is said to be saturated (mud). This excess water will drain out over time to a point where the soil will hold a certain amount of water indefinitely against the downward pull of gravity. This soil water content is called *field capacity*. As the plants roots remove water from the soil, the soil will dry out to a point where the suction or pull of the soil on the water exceeds the plant's ability to absorb water. At this point the plant will wilt and die, and this soil water content is referred to as *permanent wilting point*. The difference between field capacity and permanent wilting point is the *available water holding capacity* (AWC) of the soil (Figure 1).

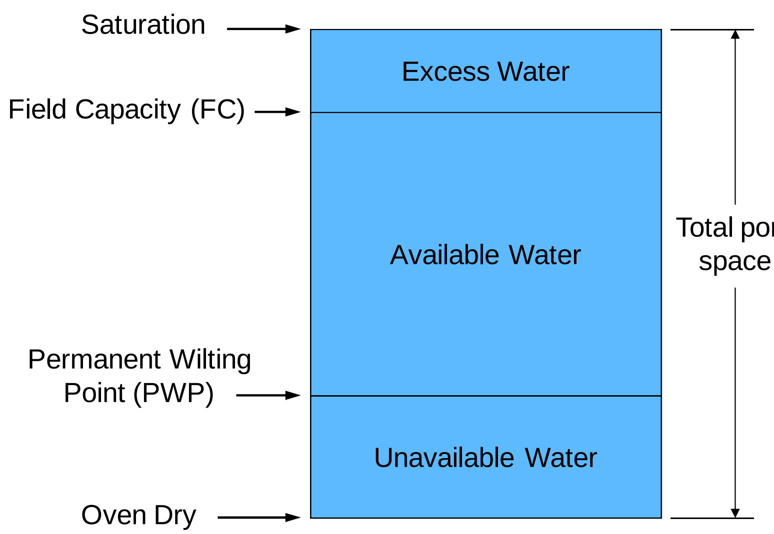

Figure 1. The various components of the soil water content.

Different soils have different available water holding capacities (Table 1). Sands can't hold very much water compared to silts and clays. The plant's rooting depth is also an important consideration. A plant with deeper roots (such as alfalfa) has access to a much larger volume of soil, and consequently to a larger reservoir of soil water to draw upon before it runs out compared to a shallow rooted plant (such as onions or potatoes).

Table 1. Typical water holding capacity ranges for various soil textures (PNW Irrigators Pocket Guide).

Soil Texture	**Available Water (AW) in/ft**
Coarse Sand	0.2 - 0.8
Fine Sand	0.7 - 1.0
Loamy Sand	0.8 - 1.3
Sandy Loam	1.1 - 1.6
Fine Sandy Loam	1.2 - 2.0
Silt Loam	1.8 - 2.5
Silty Clay Loam	1.6 - 1.9
Silty Clay	1.5 - 2.0
Clay	1.3 - 1.8
Peat Mucks	1.9 - 2.9

It is important to note that plants grown in sandy soils use the same amount of water and nutrients as those grown in heavier soils. Therefore sandy soils don't need *more* water, they just need to be irrigated *more often* but in lesser amounts since the soil can't hold as much water as a heavier soil. Applying more water than a soil can hold simply results in deep percolation (water leached past the root zone of the plant), and therefore wasted water, pumping energy, and vital plant nutrients that are held in the soil water solution.

As the soil water content is drawn down from field capacity (100% of available water) to permanent wilting point (0% of available water) production is generally not affected until a point where production drops off (Figure 2). This point is commonly chosen as a Management Allowable Deficit (MAD). This point and the shape of this curve is different for different plants. Soil water draw-down below this point will result in significant yield losses.

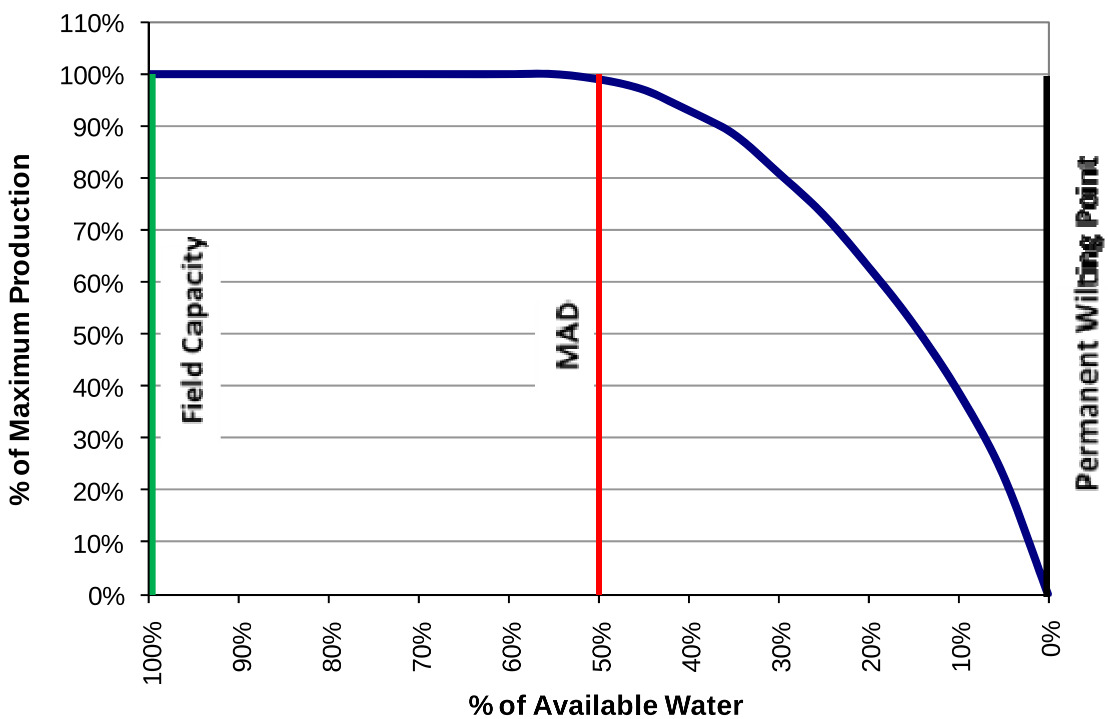

Figure 2. A generalized curve shape showing how plant production (growth) is affected by soil water stress.

Limitations of Set-Move Systems

Wheel-lines, and especially hand-lines, require a lot of time and effort to move from one set to another. Because of this, growers prefer to use longer set times because this involves the least amount of work. 24 hour sets are common. This may result in large amounts of water (typically about 3 inches in a 24 hour set) being applied with long intervals between irrigations. This is fine if the soil is capable of holding these large amounts of water. However, not all soils can hold this much water in the root zone and the water would be lost to deep percolation, or the crop will have to go into the stress zone (Figure 2) in order to use that much water.

Example soil-water budget for pasture grass on a sandy soil:

If we assume that the rooting depth of pasture grass is 3 feet, and that the soil water holding capacity of the loamy sand soil is 1.2 in/ft (Table 1) then the total water holding capacity is 1.2 in/ft x 3 ft = 3.6 inches of water that can be held in the root zone. However we don't want to fully deplete the soil water because below about 50% of the available water there are significant yield losses (Figure 2). Therefore if we choose a management allowable depletion (MAD) of 50%, then 3.6 inches of water x 50% = 1.8 inches of water is the most soil water that can be depleted before irrigation in needed to refill the root zone. If we assume the typical situation described above where 3 inches of water is deposited in 24 hours then this grower should not use 24 hour sets as half of the water would be wasted, but instead use a maximum of 12 hour sets as this would apply half as much water (1.5 inches) which is less than the calculated 1.8 inch maximum soil water depletion. However, if the same grower had a field of alfalfa (with 5 ft deep root zone) on a silt loam soil (2 in/ft water holding capacity), then 24 hour sets would work fine. (5ft x 2 in/ft = 10 inches of available water. This 10 inches of available water times the 50% management allowable deficit results in 5 inches of maximum depletion. In fact, in this case the grower may actually be able to move to 36 hour sets.

Movement Patterns

There are three general patterns for moving wheel-lines or hand lines. These are commonly called TAXI, WIPE, and SKIP.

TAXI: In the TAXI pattern the farmer irrigates every riser down to the end of the field (Risers 1-14 sequentially in Figure 3) then "taxi" the system all the way back empty to the beginning (riser 1) to the original location before starting the cycle over.

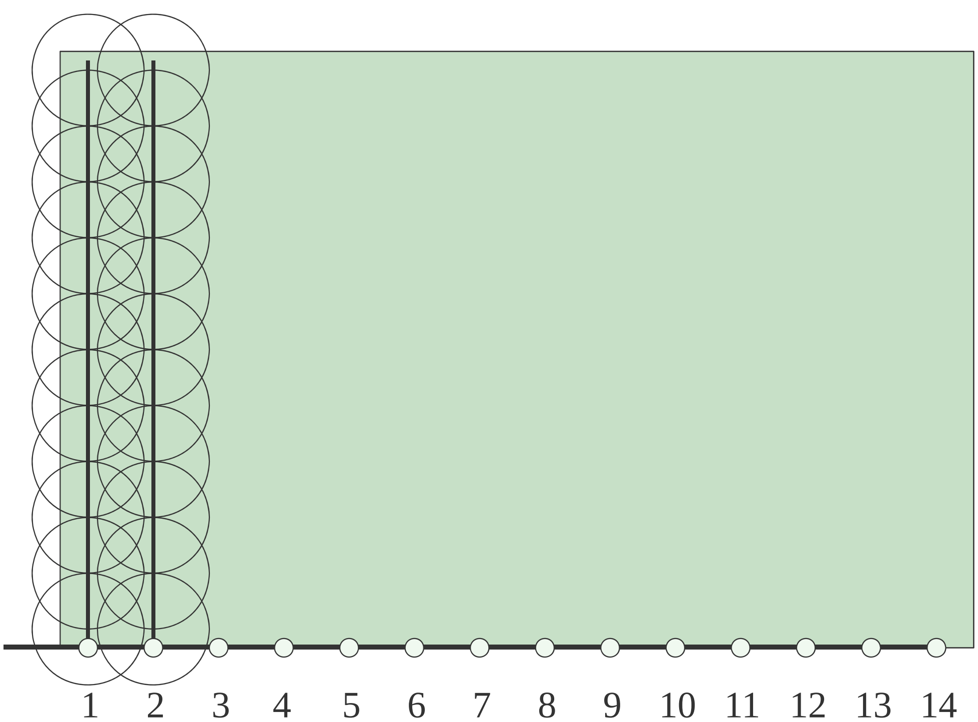

Figure 3. Typical overlap patterns and movement plan for a wheel-line or hand-line system.

TAXI is a viable option, but is often unpopular because moving the system all the way back to the beginning empty is a lot of work on the day when this must be done. Typically hand-lines are loaded onto a trailer and hauled back to the Riser 1 position before re-commencing the irrigation move cycle.

WIPE: In this pattern the farmer irrigates at every riser in one direction down the field, then waits a short time, like 12-24 hours before irrigating back the other way. (Irrigate risers 1-14 in order in Figure 3, then irrigation 14-1 in reverse order). This avoids having to move the system all the way back across the field empty.

Although it involves less total movement of the irrigation pipelines, the WIPE pattern will usually result in too much water being applied at the ends of the fields in a short period of time which results in water and nutrient loss to leaching. It also results in a very long interval between irrigations on the field ends during which the plants see significant water stress and yield loss. Therefore this option is not recommended.

SKIP: Irrigate every other riser down, then irrigate using the missed risers on the way back (Figure 4).

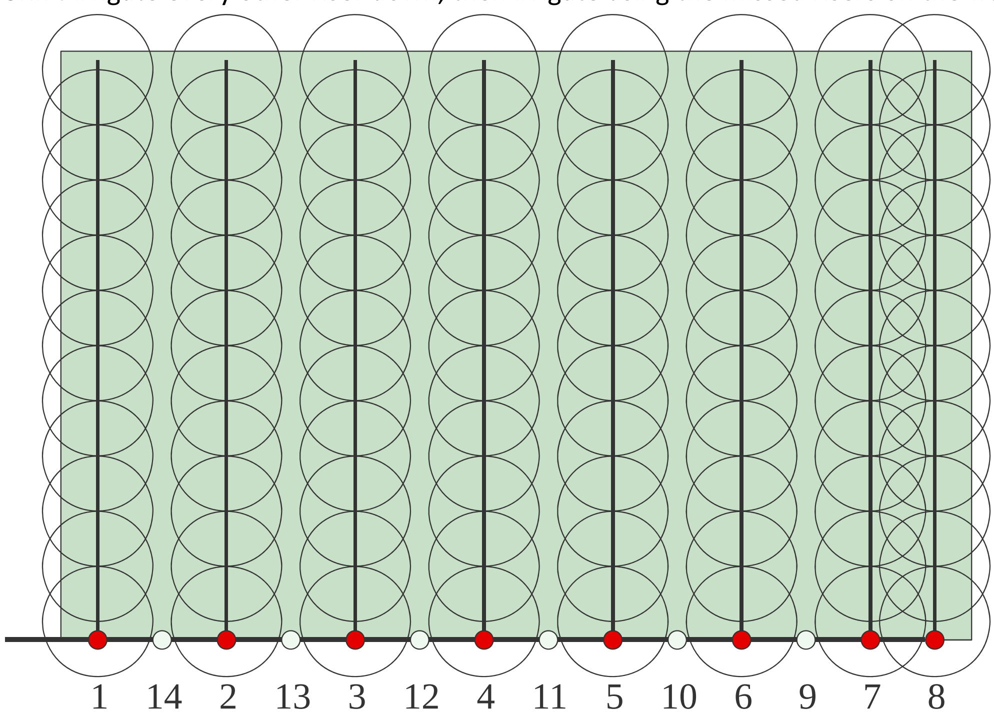

Figure 4. Showing the SKIP move pattern. Irrigate every-other riser down one side of the field (red), then catching the missed riser (white) on the way back (Riser 1 – 14 in order).

The SKIP pattern is recommended for the following reasons:

a) It avoids the problems of overwatering and long, dry intervals at the field ends of WIPE.

b) Although it involves the same total movement of lines as TAXI (move two risers each time, except on the ends of the field), this labor is spread out into regular intervals and is therefore easier to plan for and manage.

c) Because the sprinklers won't overlap on irrigated soil from the previous irrigation set (no overlap between sets 1 and 2 in figure 2), actual application depths are actually less because of a lack of overlap from the previous or subsequent sets, and it allows for soil water depletion before the soil is irrigated again. This results in the equivalent of more frequent irrigations of smaller amounts in these overlap regions. Because of this there is less likelihood of exceeding the water holding capacity of the soil and losing water and nutrients to deep percolation and runoff, and water stress between irrigations. This will result in higher yields and better crop quality than the other two options. Painting every-other riser a different color can help irrigators remember which riser they should be on.

Improving Application Uniformity

Good irrigation water application uniformity is necessary to ensure maximum production for all areas of the field. However sprinklers don't apply water perfectly uniformly. Irrigation application uniformity can be improved over multiple irrigation cycles by using "offsets". With this practice the move position is "offset" by 20-30 ft (one roll of a seven foot wheel, 2 rolls of a 5 ft wheel), to the right or left of the riser position. This offset is held through the entire course of that irrigation cycle. The next cycle would either be offset to the other side of the riser or right at the riser. The effect of averaging application depths from the shifted position pattern can markedly improve application uniformity. This is particularly noticeable if operation pressures may be on the low side or if a constant day time – night time diurnal wind pattern is experienced. In the case of extreme diurnal wind patterns, an offset of 12 hours in set start time in successive irrigations may also be desirable. An offset can be accomplished with hand-lines using a 30 foot length of pipe, or 50% of the whatever the riser spacing is, and an elbow which are moved from riser to riser along the line.

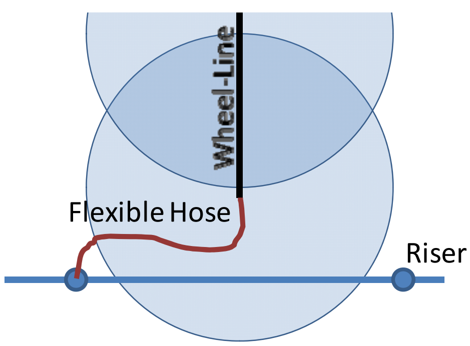

Figure 5. Using an offset on every-other irrigation cycle can significantly improve application uniformity.

Choosing a Move Frequency

Shallow soils (over bedrock), or sandier soils cannot hold very much water as discussed above. Watering on long intervals (24 hour sets) will often apply more water than the soil can hold in the root zone and this water will be lost to deep percolation taking the soil's soluble nutrients with it. In these cases the irrigation manager has two choices, (1) a shorter move interval (12 or 8 hour sets), or (2) using smaller nozzles (results in a lower application rate) and probably purchasing another wheel or hand line to run simultaneously in order to keep up with the crop water use rates.

Other Management Recommendations

Significant amounts of water can be lost to leaks. The author measured several leaks in wheel lines in grower's fields and most of these growers were surprised at the amount of water that was being lost. Even though they appeared minor, many leaks had as much water coming out as 2-5 sprinkler heads. It is a good practice to plan some time at regular intervals throughout the season to go through the system and fix leaks and replace gaskets.

Sprinkler Heads

Brass impact sprinkler heads are the most commonly used. The bases, or bearings of these are usually the first to fail and can result in sprinklers that no longer pivot even though the impact arm still functions and it looks good from a distance. A non-rotating head leads to very poor uniformity, over-watering in very localized spots, and significant water stress in other spots under the sprinkler. Take time to ensure that each head is actually rotating. Rain Bird has a very good Tech Tip on how to maintain impact sprinklers (Rain Bird a). Plastic 3/4 inch impact sprinklers tend to wear out quickly and can't stand up well to the many hours of use, and often rough treatment imposed on agricultural sprinklers. Newer 3/4 inch plastic *rotating* sprinklers have recently come out and preliminary tests are good for throw distance and uniformity. Although they looked good, at the time of publication their robustness and longevity hasn't been validated by large numbers of growers.

Figure 5. A ¾ inch brass impact, and newer ¾ inch rotating style sprinkler; both designed for agricultural use.

Sprinkler nozzles are key to metering how much water is applied. They are also subject to the highest water velocities and wear out over time. This is especially true when the irrigation water is dirty or contains sand or other abrasive materials. As they wear out the nozzle diameter gets larger and more water is applied than was originally planned for. This results in poor system uniformity. A brass nozzle diameter can be easily verified with a similarly sized drill bit. Checking this nozzle size at least seasonally is a good management practice. Replacement sprinkler nozzles are inexpensive and growers should plan to replace them every 2-5 years depending on how abrasive the water is.

In order to function properly most wheel line and hand line sprinklers must be operated between 40 and 60 psi. It is best to operate at the pressure the sprinklers were designed for. At higher pressures the nozzle will "mist" and will be highly affected by the wind, and less efficient.. At very low pressures the water isn't broken up enough as it leaves the nozzle (very large droplets) and the sprinkler applies water in a doughnut pattern with not enough water applied in between the sprinkler riser and the radius at which the majority of the water hits the ground (Figure 7). In general, as the nozzle size increases, so must the pressure for good performance. Improper pressure will result in poor irrigation application uniformity. To compensate for poor irrigation uniformity the irrigation manager must either apply more water to adequately irrigate the field, or the crop will suffer water stress in many areas of the field. Using offsets as described above also helps.

Higher pressures also result in higher nozzle flow rates. On a sloped field, the downhill sprinklers will be at a higher pressure than those at higher elevations. This will result in inadequate water application to the higher parts of the field. Pressure compensating nozzles are available that help nozzles flow at nearly the same rate regardless of the operating pressures. These are recommended for fields with elevation difference greater than 15-25 ft.

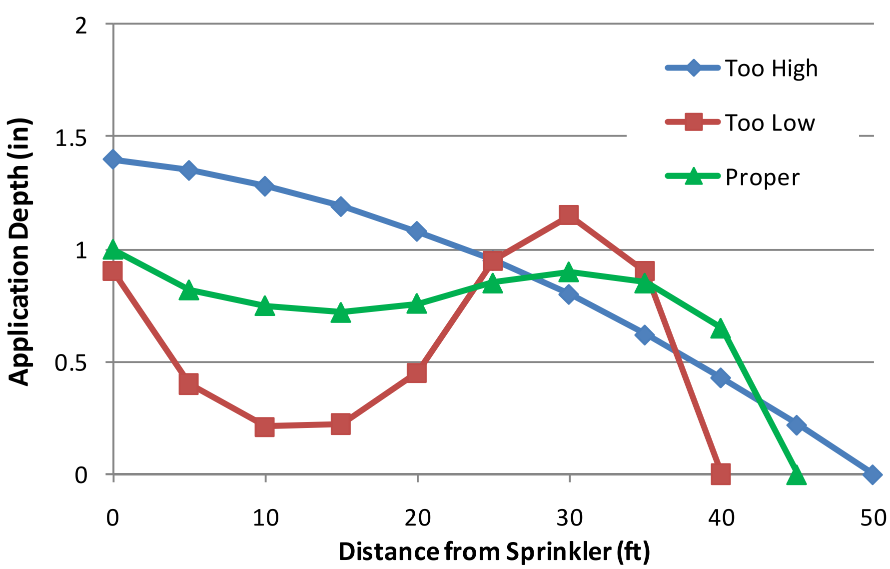

Figure 6. Application depths (patterns) with respect to distance from sprinkler head for pressure settings that are too high, too low, and properly adjusted.

Determine Application Rate or Depth

How much water is being applied? The best way to determine application rate or depth during an irrigation event is to measure it directly. This can be easily done by setting a straight sided can or bucket (coffee, or soup can) under the sprinkler during an irrigation cycle and measuring the depth of water caught during an irrigation cycle. Be aware that sprinklers apply different amounts of water at different points (this is why sprinkler overlap is important). Picking a point about 1/3 to 2/3 of the throw distance from the pipeline should give you a good average. Setting more cans or buckets out at different points such as in a square grid-like pattern 10 ft on a side will give a better idea of the average.

If a direct measurement can't be done, an alternate method is to calculate it from the sprinkler nozzle diameter and pressure, and the sprinkler spacing. A publication by Thomas Ley (1992; WSU EB1305) or one done by Rain Bird (b) helps step through how this is done. Also live calculators are available at online at http://irrigation.wsu.edu that can help with these calculations. Many of these calculators are optimized for use with smart phones (Peters, 2011).

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