FLOOD VS. PIVOT IRRIGATION FOR FORAGE CROPS: WHAT ARE THE ADVANTAGES AND DISADVANTAGES?

Paul W. Brown[1]

INTRODUCTION

Rapid population growth in the Western US has fueled increasing demand on the part of dairies, feedlots and horse owners for quality forages such as alfalfa. Alfalfa has been successfully grown in the west for more than a century using irrigation to supplement the often meager rainfall in the region. The vast majority of western alfalfa production is irrigated using either flood or sprinkler irrigation. Both irrigation systems have strengths and weaknesses when it comes to irrigation of alfalfa and neither system can be designated as the superior in all circumstances. The purpose of this paper is to review the general advantages and disadvantages of using flood and center pivot irrigation systems to supply the water needs of western alfalfa.

IMPORTANCE OF IRRIGATION MANAGEMENT

Alfalfa requires more water than any other crop in most western production areas. Important factors that contribute to making alfalfa a high water use crop include: 1) its great tolerance of temperature extremes which allows the crop to remain productive over an extended growing season, 2) rapid recovery to full canopy conditions following harvest and 3) a canopy structure and stomatal physiology that offer minimal resistance to water use under well watered conditions. A number of studies (e.g., Grimes et al., 1992) have shown that alfalfa yield on a seasonal basis is linearly related to crop evapotranspiration (ET; Fig. 1). This relationship develops because photosynthesis, the process that produces the sugars necessary for dry matter production, requires that CO_2 enter the plant during the daytime hours via leaf pores known as stomata. Once the stomata open for photosynthesis, water contained in the internal structures of the leaves can evaporate and escape to the atmosphere in the process referred to as transpiration. Because transpiration makes up a large fraction of seasonal ET any reduction in ET generally results in a reduction in photosynthesis and yield.

ASSESSMENT OF ADVANTAGES & DISADVANTAGES

A number of publications provide general selection criteria for irrigation systems (e.g., NRCS, 1997; Neibling, 1997) and thus provide insight into the advantages and disadvantages of installing flood or center pivot systems to irrigate alfalfa and other forages. In general, the factors that impact the selection and/or utilization of an irrigation system can be divided into the general categories of: 1) site characteristics; 2) water issues; 3) economics; and 4) agronomic impacts.

---

[1]P. Brown (pbrown@ag.arizona.edu), Extension Specialist, Biometeorology, Dept. of Soil, Water & Environmental Sci., 429 Shantz, Univ. of Arizona, Tucson, AZ 85721. **In:** Proceedings, 2008 California Alfalfa & Forage Symposium and Western Seed Conference, San Diego, CA, 2-4 December, 2008. UC Cooperative Extension, Plant Sciences Department, University of California, Davis, CA 95616. (See http://alfalfa.ucdavis.edu for this and other Alfalfa Symposium Proceedings.)

Site Characteristics
One obvious factor impacting the selection of an irrigation system is topography. Flood irrigation systems are clearly more efficient on ground that is either flat or has a gentle slope that can be shaped and/or adjusted to produce the slopes or level basins required to maximize irrigation efficiency. Border irrigation systems in California and Arizona typically have slopes in the range of 0.1-0.2% (Hanson et al., 2007), and the NRCS recommends that slopes in border systems not exceed 2% (NRCS, 1997). Developing flood irrigation systems on land with steep or complex topography requires an extensive amount of expensive land preparation and can produce some undesirable soil characteristics (e.g., variable surface texture or layered soils) that are difficult to manage and thus can limit production.

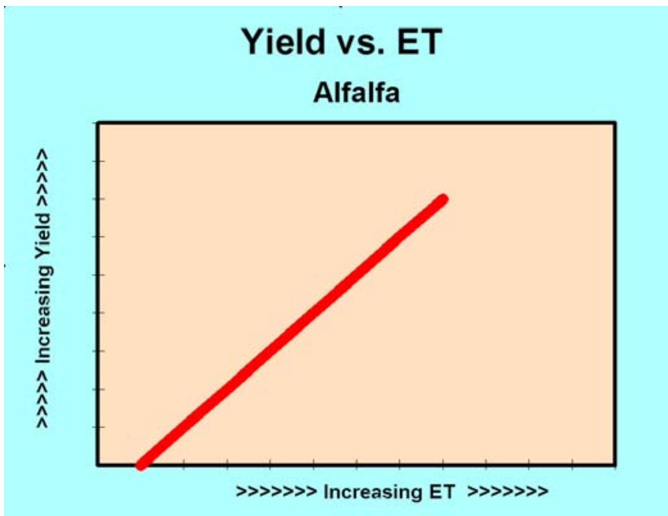

Figure 1. Yield of alfalfa is linearly related to ET. Any management activity that reduces ET usually results in loss of yield.

Center pivot systems can tolerate a greater degree of topographical change/complexity and thus are better suited for ground that can not be shaped for flood irrigation. The maximum recommended slope for center pivot systems is approximately 15%; however, systems installed over sloping terrain must be engineered and managed properly to avoid problems associated with elevation induced pressure variations and runoff which can lower system efficiency significantly (Evans, 2001). One negative aspect of center pivot systems is their circular configuration which conflicts with the square or rectangular nature of most farm fields (Fig. 2). A center pivot with a radius of 1320' will effectively irrigate between 125 and 130 acres of a quarter section. End guns and corner systems can be added to increase the irrigated area and better utilize available field space, but such systems are expensive, require a greater water supply and add considerably to system maintenance costs.

Soil type represents a second site characteristic that impacts the selection and/or performance of an irrigation system. Flood irrigation systems are generally not recommended for very coarse textured soils because losses due to deep percolation can be very high where water enters the field. Some improvements in efficiency can be obtained in coarse textured soils using greater heads of water, steeper slopes and shorter runs; however, flood systems are better suited to finer textured soils with lower infiltration rates that allow growers to apply smaller quantities of water in a more uniform manner. Soils with extremely low infiltration rates are not well suited to border irrigation due to problems with runoff. Level basins are recommended for these low infiltration soils.

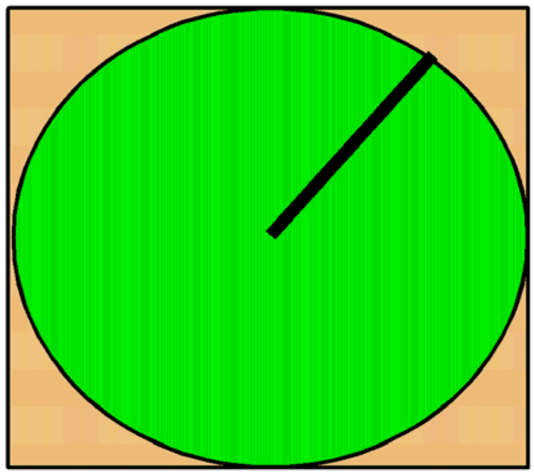

Figure 2. Center pivots irrigate circular areas and the corners of a square or rectangular field can not be irrigation without adding end guns or corner systems.

In contrast, center pivots are well suited for soils with high infiltration rates, provided the pivots are engineered to keep up with evaporative demand. The area irrigated by a center pivot increases rapidly along the radial distance of the pivot which mandates that water application rates also increase along this same distance. Application rates at the ends of the pivots can run as high as 4.0"/hr which can lead to massive amounts of runoff and/or erosion if the pivot is applying water to a low infiltration soil on sloping ground.

Water Issues

The nature of the local water supply is an important selection criterion for irrigation systems. Center pivots require a constant supply of water during much of the growing season and thus require a fixed and continuous water supply which is typically supplied by a well. Flood irrigation systems require large heads of water at infrequent intervals which allows the water supply to be located at a more remote location (well or water project). One distinct advantage of center pivots systems is the producer has water on demand and can more readily respond to short term needs for water resulting from extended periods of abnormally high ET or cultural activities (e.g., chemigation). Flood systems that draw water from projects or remote pumping stations may have to call for water several days in advance which can reduce the ability to respond to short-term water demands.

The amount of water used by agricultural irrigation is undergoing greater public scrutiny and growers are being pressured to adopt irrigation practices that minimize water use. Flood irrigation systems usually operate at a lower overall efficiency than center pivots systems which translates to a higher level of overall water use for the growing season. Border irrigation is considered to be the most difficult irrigation system to efficiently manage because soil type, slope, surface roughness, border width and water supply impact the set time. When set times are too long, efficiencies decline due to excessive infiltration on the upper end of the field and runoff at the lower end of the field. Inadequate set times will fail to fully recharge the soil at the bottom of the field and reduce production due to water stress. Recent research provides improved guidance on managing border systems (Hanson et al., 2007), but many growers still use trial and error to establish set times. Level basin systems can operate at very high levels of efficiency provided the system has very high flow rates and soils have modest to low intake rates. The application efficiencies for a well managed flood system ranges from 60% for border irrigation on coarse texture soils to 85% for well managed level basin systems. Application efficiencies for center pivots outfitted with low pressure drop nozzles are typically rated at 85%. Because soil type impacts the efficiency of both systems, the potential for saving water varies. For coarse textured soils, the water savings associated with using center pivot irrigation with an application efficiency of 85% would approach 30% when compared to a border system with a 60% application efficiency. However, this water savings could be reduced by 50% or more in fine textured soils where the application efficiencies of flood systems improve while those of a center pivot might decrease due to runoff. In low desert production systems where the annual alfalfa ET approaches 72", the potentials annual savings associated with switching from flood to center pivot irrigation should fall in the range of 1.5-3.0 acre-feet/acre.

System capacity represents one challenge associated with using center pivot irrigation in arid and semiarid environments. There is a tendency to under engineer pivot systems to minimize installation costs which can be very high. The greatest concentration of center pivots in Arizona is located in southeast Arizona at elevations approaching 4000'. Presumably at these elevations where ET is reduced, pivot systems could be properly engineered to meet peak evaporative demand. However, we often find this is not the case as the following example shows. The gross capacity of a center pivot in gallons per minute (gpm) per acre in southeast Arizona can be computed using the following formula:

$$\text{Capacity} = (\text{Peak ET} * 453)/(\text{Hr}*\text{AE})$$

where Peak ET is set equal to 0.32"/day and is estimated by multiplying a seasonal alfalfa crop coefficient of 0.95 by the average reference ET value for the peak water use month of June; 453 is a constant that converts units from acre-inches to gallons per minute, Hr represents the number of hours per day a pivot can operate, and AE is the water application efficiency (Kranz et al., 2008). If one assumes one hour of downtime per day for maintenance (Hr = 23) and an AE = 0.85, the gross capacity of the well is computed as 7.41 gpm per acre which translates to 964 gpm for a 130 acre pivot (Fig. 3). This computation procedure is actually designed for field crops such as corn or cotton where continuous operation of the pivot is allowed. When growing alfalfa, one needs to modify the formula to address the irrigation down time during the cutting and harvest season. If one assumes a 30 day cutting cycle and 6 days of downtime for harvest and one hour of maintenance for the remaining 24 days, Hr is reduced from 23 to 20.8 for the cutting cycle which increases the required capacity to 1066 gpm (Fig. 3). The capacity of most southeast Arizona pivots is less than 900 gpm which means they struggle to meet evaporative demand during the dry late spring and early summer months – months that produce very good quality hay. Alfalfa irrigated with a pivot capacity of 800 gpm in this region (not uncommon) must extract an average of 0.08" per day from stored soil moisture for approximately 6-8 weeks each year which can push the crop into water stress before monsoon humidity and rainfall improve field water balances. This capacity problem grows more challenging as one moves to lower elevations in Arizona and California where peak ET runs ~10% higher and the monsoon offers only a slight break in ET and little in the way of supplemental rainfall. System capacities for western Arizona and the southern deserts of California would need to approach 1200 gpm for 130 acre pivot. Pivots with an inadequate water supply in western Arizona may have as many as four months (May through August) when ET exceeds the capacity of the pivot which can lead to reductions in yield and potential problems with salinity.

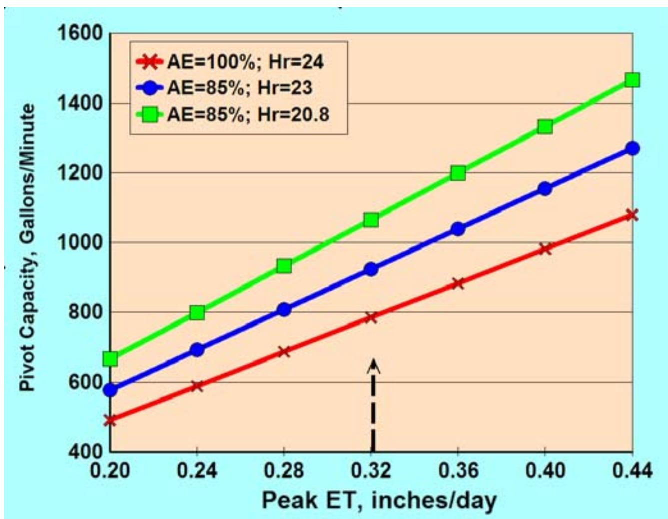

Figure 3. The water supply required to meet peak ET for center pivots assuming no downtime and 100% application efficiency (x) , one hour of downtime and 85% application efficiency (●) and a more realistic 3.2 hours of downtime to accommodate harvest operations and 85% application efficiency (■).

Another key to successfully using center pivot irrigation is to avoid runoff. A well engineered center pivot can apply water in smaller quantities and more uniformly that most flood systems. However, both the discharge rate and the ground speed of the sprinklers increase with distance from the pivot point (Evans, 2001; Kranz et al. 2005). This combination can produce application rates that exceed the infiltration capacity of the soil and produce runoff (Fig. 3). Most pivot fields are not laser leveled and this runoff collects in lower lying areas of the field or runs off the pivot completely. In both cases the runoff contributes to less uniform irrigation and a reduction in application efficiency since the outer spans may account for 10-20% of the pivot area. Water that ponds in low areas can damage or destroy plant stands and reduce yield. Runoff and ponding problems can also develop in coarse textured soils because the high application rates can destroy surface soil structure and lead to the development of thin crusts that impede flow and thus enhance runoff. Runoff problems can be minimized by changing sprinkler packages, adjusting the rotational speed of the pivot, and increasing the wetted soil area (lowering application rate) by adjusting sprinkler orientation along the lateral. Failure to address runoff problems can lead to poor application efficiency and poor crop performance due to both excessive wetness and water stress.

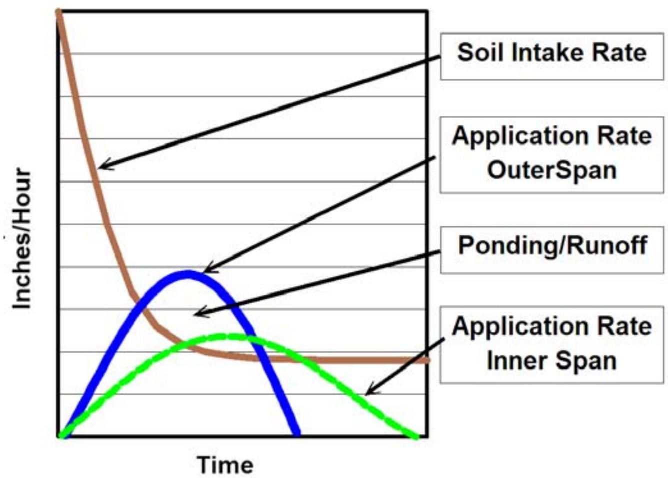

Figure 4. Water application rates are much greater near the perimeter of center pivots and can exceed the water intake rates of many soils, leading to problems with runoff and/or standing water. Application rates along the inner spans of pivots are much lower and create far less potential for runoff and ponding.

Economics

The installation and operating costs of center pivot and flood irrigation systems differ considerably and may be the most important factor that determines which system a grower implements. The purchase price for a new 130 acre center pivot systems runs between $50,000 and $60,000 while the well, pump, power unit and meter can run an additional $40,000 to $60,000 (Dumler et al., 2007a; Scherer, 2005). Recent economic assessments in North Dakota and Kansas estimates the per acre cost of installing a new pivot ranges between $700 and $1000 (Scherer, 2005; Dumler et al., 2007b). Dumler et al. (2007b) found that installing a new flood irrigation system with well and pump included would cost about $454 per acre or about 45% of the cost of a new pivot. The cost to develop new flood systems would be far less if the farming operation had access to gravity fed project water that would preclude the need for wells.

Lower labor costs represent one significant benefit of pivot irrigation. Recent analyses indicate labor costs may be reduced by close to 90% with new pivots that incorporate modern automation equipment. It is important to note that a more skilled labor force is required when operating pivot irrigation systems. Often, however, the reduction in labor costs associated with pivot irrigation is more than offset by higher energy and maintenance costs. The recent spike in energy costs has dramatically increased the operating costs of pivots. Several years ago when diesel fuel was less than $2.00/gallon, the pumping cost for a pivot lifting water 200' was between $50 and $65 per acre foot. (Dumler et al., 2007b) With today's high energy prices, these costs have doubled for many growers. The annual maintenance costs are also higher for pivots. The NRCS estimates the annual maintenance cost of both center pivot and surface irrigation systems is ~5% of the initial installation costs. With the installation costs of flood irrigation running less than 50% that of pivots, flood systems will be less expensive to maintain.

Agronomics

A number of agronomic issues are impacted by the type of irrigation system. Perhaps the most important agronomic factor is whether there is any systematic improvement in crop yield with flood or center pivot irrigation system. Actual quantitative studies comparing yields from alfalfa irrigated with center pivots and flood systems are rare due to the difficulties associated with setting up statistically valid studies. All things being equal, one would expect yields to be slightly higher in properly designed center pivot systems since these systems can uniformly apply small amounts at frequent intervals and thus avoid the larger swings in soil moisture associated with flood systems that apply water every 10-14 days. McKnight (1983) reported that growers in the northeast and desert production areas of California had realized increased production with center pivot irrigations, but did not provide specific figures. Both McKnight (1983) and Hanson et al. (2007) indicate growers in California's Central Valley found alfalfa performance less acceptable on high clay content soils.

One potential benefit of center pivot systems is the ability to better regulate soil moisture during the harvest period. Flood systems apply large volumes of water and must be timed properly to avoid wet soils which can make harvest operations difficult and reduce stands due to compaction damage. Alfalfa subjected to 30-day cutting cycle in summer will usually benefit from two irrigations per cycle – one following bale removal and another 10-14 days later. Often soil moisture at harvest dictates the timing of this second irrigation rather than soil water deficits. If water is applied too early, excessive amounts of deep percolation may result, lowering overall irrigation efficiency. Other times, there may be insufficient time between the optimal irrigation time and harvest forcing the grower to skip this irrigation. This can lead to yield reductions in both the current crop due to water stress and the subsequent one due to slow regrowth. Irrigations may continue up to within a few days of harvest with center pivots which can improve the soil water status for both the current and subsequent crops.

Water management in the period prior to harvest may also impact hay quality. Late spring and early summer cuttings produce large yields of high quality hay. However, dry conditions at this time of year reduce hay moisture contents to levels that produce unacceptable levels of leaf shatter/loss during hay making operations. Growers often delay haying operation until the early morning hours hoping for a moisture increase caused by dew fall. It is important to understand that dew in semi-arid and arid production areas does not originate from the atmosphere, but rather from the soil. Water vapor escapes from the soil during the evening hours and may condense on downed hay if the moisture flux is sufficiently high and wind speeds are low. Higher levels of soil moisture increase this moisture flux and may produce and/or extend the period of time when hay moisture is optimal for baling. Because center pivots can be operated to within a few days of harvest, they may produce better baling conditions during periods with very low humidity than flood irrigation systems.

Salinity management is an ongoing concern in western production areas and must be addressed by applying excess water referred to as the leaching fraction. While studies have shown that slow, continuous leaching is a more efficient means of salt removal than a sudden flooding events, flood irrigation systems are still better suited for salinity management in most circumstances. Center pivot systems struggle to apply sufficient water to meet ET during the summer months, let alone leaching fractions. The frequent light water applications associated with center pivots can produce high levels of surface salinity which must be leached during the fall and winter months when system capacity exceeds ET. Unfortunately, such leaching activities are not always accomplished in an effort to reduce costs and/or avoid excessive wetness during the winter months. Flood systems with their higher applications rates and slightly lower efficiencies represent a more effective means of controlling soil salinity.

Another production related problem related to irrigation is summer scald. Scald develops during the hot summer months when alfalfa remains flooded (anaerobic) for periods approaching 36 hours just after cutting. Scald can reduce stands by as much as 44% and is most prevalent on fine texture soils that are irrigated with flood irrigation (Haldeman, 1972).

Pest management is another issue that can be impacted by irrigation management. Center pivot systems wet crop canopies on a regular basis and may produce micro-climates that are more conducive for the development of pests and diseases. Evans (2001) indicates the interior of pivots are more prone to disease because pivot rotation is much slower and crop canopies remain wet for more extended periods. The ability to implement chemigation regimes represents another potential benefit of center pivot irrigation and can assist with certain pest and crop management activities.

CONCLUSIONS

Both flood and center pivot irrigation systems have strengths and weaknesses when it comes to irrigation of alfalfa. Clearly, center pivots offer advantages over flood irrigation systems in areas with complex terrain and coarse textured soils. They may also prove advantageous in areas where surface water is unavailable or limited, and where labor is in short supply. However, the high costs of installation and the higher operating costs will likely overwhelm these benefits unless: 1) new laws greatly restrict access to labor required to manage flood systems; 2) a grower is chronically short on water which limits production; 3) the water saved can be leased or sold to other growers or other users (e.g., municipalities) for a very high price; or 4) regulatory agencies impose fees/fines for excess water use or drainage. Economic analyses conducted in the plains states indicate shifting from flood to center pivot is a viable option. However, in the western US where many growers are served by inexpensive gravity fed project water, and finer textured soils lessen the advantages of center pivots, flood systems will likely remain the option of choice for irrigation of alfalfa.

REFERENCES

Dumler, T.J., D.M. O'Brien, C.R. Thompson and B.L.S. Olson. 2007a. Center-pivot-irrigated alfalfa cost-return budget in western Kansas. Farm Management Guide MF-584. Kansas St. Univ. Agric. Exp. Stn. & Coop. Ext. Serv.

Dumler, T.J., D.M. O'Brien, and D.H. Rogers. 2007b. Irrigation capital requirements and energy costs. Farm Management Guide MF-836. Kansas St. Univ. Agric. Exp. Stn. & Coop. Ext. Serv.

Evans, R.G. 2001. Center pivot irrigation. Published on line at: www.ars.usda.gov/Site_Publisher_Site/pdfs/personnel/center%20pivot%20design%202.pdf. USDA ARS.

Grimes, D.W., P.L. Wiley and W.R. Sheesley. 1992. Alfalfa yield and plant water relations with variable irrigation. Crop Sci. 32: 1381-1387.

Haldeman, A. D. 1972. Summer "scald" damage of alfalfa. Q-170. Arizona AGRI-FILE. Coop. Ext. Serv. University of Arizona.

Hanson, B.L., K.M. Bali and B.L. Sanden. 2007. Irrigating alfalfa in arid regions. In: C.G. Summers and D.H. Putnam, eds., Irrigated alfalfa management in Mediterranean and Desert zones. Chpt 16, Oakland: Univ. of California Agric & Nat. Resources Pub. 8293.

Kranz, W. L., S. Irmak, S. J. van Donk and C.D. Yonts. 2008. Minimum center pivot design capacities in Nebraska. NebGuide G1851. Univ. of Nebraska-Lincoln Ext., Inst. Of Agric & Nat. Resources.

Kranz, B., D. Yonts and D. Martin. 2005. Operating characteristics of center pivot sprinklers. NebGuide G1532 Univ. Of Nebraska-Lincoln Ext., Inst. Of Agric & Nat. Resources.

McKnight, T.L. 1983. Center pivot irrigation in California. Geographical Review. 73(1): 1-14.

Natural Resource Conservation Service. 1997. Irrigation Guide. Part 652. In: National Engineering Handbook. USDA, NRCS. Washington DC.

Neibling, H. 1997. Irrigation systems for Idaho agriculture. CIS 1055. College of Agriculture, Extension Service, Agricultural Experiment Station, Univ. of Idaho.

Scherer, T. 2005. Selecting a sprinkler irrigation system. AE-91 North Dakota St. Univ. Ext. Serv.