CENTER PIVOT MANAGEMENT FOR FORAGE PRODUCTION

Howard Neibling, Glenn Shewmaker, and Christi Falen[1]

ABSTRACT

Center pivots provide an energy and labor-saving, highly uniform method for irrigation of alfalfa and other forage crops. However, surface runoff and excessive wheel rutting can be a problem on some low-intake soils. By the nature of the system, water application rate must increase with distance outward from the pivot point, producing high runoff potential. On some low-intake soils, additional design factors and management practices must be considered to prevent runoff. To encourage deeper root development and reduce water stress during cutting and high ET periods, the entire root zone depth should be filled to field capacity before irrigation is stopped for first cutting. Adequate system water application capacity provides more management options and minimizes periods of water stress.

Key Words: center pivot, irrigation, alfalfa, forage, irrigation water management

INTRODUCTION

Center-pivot irrigation provides a labor-saving, highly uniform water application method for irrigating alfalfa and other forage crops. Typically, low-pressure water application packages for pivots require about half the system pressure of set systems (solid set, hand line or wheel line), and have application efficiencies of about 80-85% when compared to values of 60-70% for set systems. When considering both the reduced pump output pressure required and the higher fraction of pumped water actually delivered to the soil surface with pivots, energy consumption for pivots should be about half that for set systems. However, care must be used in system design and management to avoid surface runoff and the resulting serious rutting that can occur with pivots.

The objective of irrigation is to provide the right amount of water at the right time to maximize forage or pasture yield and quality. Irrigation water should be uniformly applied at a rate which will not produce surface runoff, and scheduled to minimize water movement below the plant root zone. In forage or pasture production, additional constraints such as system management around harvest, or integrating irrigation and grazing schedules must be considered when designing systems and selecting equipment components.

W.H. Neibling, Extension Water Management Engineer, University of Idaho, 315 Falls Ave., Evergreen Bldg., Twin Falls, ID 83301; Glenn Shewmaker, Extension Forage Specialist, 315 Falls Ave., Evergreen Bldg., Twin Falls, ID, 83301; Christi Falen, Extension Educator, Lincoln County Extension, 201 S Beverly St., Shoshone, ID, 83352; Email: hneiblin@uidaho.edu; gshew@uidaho.edu; cfalen@uidaho.edu. **In**: Proceedings, 2009 Western Alfalfa & Forage Conference, December 2-4, 2009, Reno, Nevada. Sponsored by the Cooperative Extension Services of AZ, CA, ID, NV, OR, and WA. Published by: UC Cooperative Extension, Plant Sciences Department, University of California, Davis 95616. (See http://alfalfa.ucdavis.edu for this and other alfalfa symposium proceedings.)

FACTORS THAT IMPACT CENTER PIVOT MANAGEMENT

Center pivot management decisions require consideration of soil depth, water holding capacity and infiltration rate of crop water requirements, and timing / magnitude of allowable water stress. More management options are available for a properly-designed system with an adequate application rate.

Crop Properties. Crop properties such as timing and amount of crop water use determine the required timing and rate of water addition by irrigation equipment. Rooting depth and root water extraction pattern, along with soil properties, help determine the maximum amount of any one irrigation and the time between irrigations.

Crop Water Use. Evapotranspiration (ET**)** is the sum of evaporation and transpiration. Evaporation is water loss from plant leaves or bare soil surfaces. Transpiration is water vapor loss through small openings in leaves called stomata. ET then represents the water that must be supplied on a daily, or other frequency, to support desired plant growth and yield. The seasonal crop water use pattern establishes the timing of variation in water supply required over the course of the growing season. This pattern must be considered in irrigation water management to avoid plant water stress or over-irrigation during the growing season.

Sources of crop water use data. Daily ET for a number of crops is available on-line for 83 stations in the Pacific Northwest from the U.S. Bureau of Reclamation AgriMet (http://www.usbr.gov/pn/agrimet) network, with sites located in Idaho, Montana, Oregon, Washington Nevada, and Wyoming. ET information is available in Washington through the PAWS network (http://www.weather.wsu.edu), and in California through the CIMIS network (http://www.cimis.water.ca.gov/cimis/data.jsp).

As shown in **Figure 1**, ET rates for alfalfa are low early in the season, when temperatures are low and days are short. ET increases as temperature and day length increase. Maximum ET occurs with long days, peak solar radiation, and high temperatures—conditions seen during midseason. It decreases in the fall with decreasing day length and cooler temperatures. Seasonal ET patterns also depend on elevation and latitude. At a given latitude, peak water use is delayed as elevation increases. At a given elevation, peak water use is delayed as latitude increases.

Curves for both long-term average and low / high year of record are given for Twin Falls, Idaho in **Figure 1**. Long-term averages are useful for understanding seasonal variability and timing of peak ET. However, be careful when using averages for irrigation scheduling, since they can underestimate peak ET for many years. In **Figure 1**, note the wide range of expected water use.

Crop rooting depth. Alfalfa has a tap root type of root system with water extraction commonly occurring to depths of at least 3 feet, with significant water extraction occurring to 5 feet in deep southern Idaho soils (Falen and Neibling, unpublished data). If soil water content is sufficient, water extraction is relatively uniform with depth. It is important to note that this rooting depth information is for deep, uniform soils with no restrictive soil layers. If a restrictive soil layer (such as a hardpan, bedrock, or a previous tillage-induced layer) is near the soil surface, it will limit plant rooting depth. In some areas, a seasonally high water table may also limit the depth of root development.

SOIL PROPERTIES

The combination of water holding capacity and root zone depth defines the maximum amount of water that can be stored in the root zone for use by plants. This stored water acts as a buffer to allow continued crop growth during periods when irrigation water cannot be applied, such as around harvest or grazing, or during periods when ET is greater than daily water application.

Soil water-holding capacity. Each soil can hold only a certain amount of water. Following irrigation and drainage of free soil water, the soil is said to be at field capacity. If additional water is applied, it will run off the soil surface or move below the root zone and perhaps into the groundwater. Both scenarios waste water and may negatively impact water quality.

Water-holding capacity varies with soil texture. For example, clay soils can hold more water than sandy soils (see **Figure 2**). Water-holding capacity also increases with increasing organic matter, while compaction reduces soil pore space and therefore reduces water-holding capacity.

Information on available water for a specific soil can be obtained from the local USDA-NRCS soil survey (http://websoilsurvey.nrcs.usda.gov/app/). NRCS reports available water for each distinct soil layer (expressed as inches of water per inch of soil depth). To obtain the total water-holding capacity for a soil depth, multiply the value given times the depth in inches.

Another way to estimate water-holding capacity is to obtain a soil textural analysis. Knowing a soil's texture and organic matter content enables you to estimate water-holding capacity. **Table 1** shows average values (expressed in inches per foot of soil depth) obtained from laboratory testing of over 50 southern Idaho soils. In the absence of specific information, these numbers provide a reasonable estimate of water-holding capacity.

Matching application rate to soil intake rate. One of the most common difficulties with sprinkler systems is that water is applied at a rate higher than the soil can absorb. As a result, water intended for one spot does not move into the soil at that point, but flows to a lower area and contributes excess water at that point, resulting in dry and wet spots within the field. Yellow or wet spots indicate that nitrogen has been leached below the plant roots and is no longer available for plant use, or that excess water has reduced soil oxygen content below desired levels. Collection of surface runoff in low areas is the most important factor in causing tower drive wheel ruts to deepen and ultimately stop pivot movement. Therefore, elimination of surface runoff is the major factor in reducing pivot rut problems.

Surface runoff occurs after water application rate exceeds the intake rate for a sufficiently long period to fill surface depressions. Infiltration rate (the rate that water will move into the soil) starts out high at the beginning of irrigation and drops off to a nearly constant rate that can be sustained for a long period of time (**Figure 3a**). These steady-state design intake rates are given in **Table 2,** and are well-suited for set system design. Because center pivots apply water to areas near the outer end for a relatively short time, the application rate can be higher than steady-state (**Figure 3b)**. Given a 2.5 day rotation speed and the wetted diameter of the application packages shown in **Figures 3a** and **3b**, the time of water application was calculated and is shown on the x-axis. The area under each of the curves represents the depth of water applied and is equal for all cases (0.75 inches net irrigation). The water application curve for acceptable packages should lie near or under the infiltration curve.

As shown in **Figures 3a** and **3b**, the maximum acceptable application rate at specific points along the pivot depends on the shape of the infiltration curve. This information is difficult to obtain for sprinkler-applied water, so in most cases, the maximum water application rate (or slowest rotation time) must be determined by trial and error. As a general guide, experience in southern Idaho indicates that applications in excess of about 0.75 inch per revolution tend to produce runoff on silt loam soils. Runoff potential can be further reduced by creating surface storage with pitting devices. Water is held in these depressions until it can infiltrate.

Water application rate is low near the pivot point since little area is covered by a sprinkler during one revolution. Application rate increases with distance from the pivot point as shown in **Figure 4**. Center pivot application rates for three types of application packages are shown in **Figure 4**. As the wetted diameter of the application package increases, water applied is spread over a larger area, resulting in lower application rate per unit area and reduced potential for surface sealing or runoff. Additional benefits in runoff reduction can be achieved by using booms on the outer spans to further enlarge the water application pattern and further reduce peak water application rate.

Current USDA-ARS research (Dr. Bradley King, personal communication) indicates that the area over which water is applied has more of an effect on initiation and continued surface runoff than does drop size. Therefore, sprinkler application packages and use of offset booms appear to be more important in reducing runoff than drop size considerations. Applying this information to a "typical" sandy loam situation, **Figure 4** would suggest that spray heads (20 ft diameter) are acceptable out to about 200 feet. Then low-pressure sprinklers such as Wobblers or Rotators are acceptable out to 500 feet. Beyond that point, offset booms should be used. On very tight or other runoff-prone soils, another possibility to eliminate runoff is to use shorter lateral length on multiple machines (e.g. two 40-acre pivots vs. one 80-acre windshield wiper). In most cases, this will reduce the application rate at the outer end to an acceptable level.

SYSTEM DESIGN CAPACITY IMPACT ON MANAGEMENT

The combination of soil water storage and irrigation system application must be able to supply the peak water requirements or production will be reduced. Given the variability in peak use shown in **Figure 1**, judgment must be exercised in selecting the design capacity. Selection of appropriate design capacity is beyond the scope of this paper. However, some management implications resulting from a range of design capacities will be discussed.

Gross and net irrigation. Irrigation industry personnel typically refer to system capacity in terms of gallons per minute per acre of irrigated area (e.g. gpm/ac), which may be obtained by dividing the system hydraulic capacity (in gpm), by irrigated area in acres. This form of system capacity is useful for hydraulic calculations such as pipe and pump sizing. However, irrigation scheduling calculations require system capacity in terms of depth of water applied per unit time, usually inches per day. To convert gpm/ac to inches/day, multiply by 0.05303. For example, 7 gpm/ac*0.05303 = 0.37 inch/day. This is the gross application rate, the water pumped per day spread uniformly over the area to be irrigated.

However, only a portion of the water applied by irrigation is used by plants. The rest is lost to evaporation, wind drift, runoff, or deep percolation. Application efficiency (AE) refers to the fraction of applied water that is stored in the root zone and is usually expressed as a percentage. Net irrigation, the quantity used in irrigation scheduling calculations, may be obtained by multiplying gross irrigation by AE/100. This represents the water that actually reaches the ground for use as ET. Typical AE values are 0.7 for high-pressure pivots and 0.8 to 0.85 for low-pressure systems. A value of 0.8 would be used for systems with nozzle height at 6 feet or higher, while 0.85 would be used for nozzles placed closer to the ground. For example, net irrigation for the above example and an AE of 80% is 0.37 inches/day * 0.80 = 0.30 inches/day.

Application depth / return time. A properly designed irrigation system applies water to take advantage of the deep rooting characteristics of alfalfa. Assuring that soil is filled to the full rooting depth reduces plant water stress during the period when irrigation is off for harvest, or during periods of reduced water supply. However, some physical constraints such as soil intake (infiltration) rate limit water application rates, and therefore, depth of wetting. For example, center pivots often apply 1 inch of water or less per revolution to minimize surface runoff and excessive pivot track deepening. On a silt loam or other medium- to heavy-textured soil, 1 inch of water usually wets the soil to a depth of only 15 to 18 inches. Deeper soil is not refilled. Because roots do not grow in dry soil, the irrigation system effectively limits root depth. In a sandy soil, 1 inch of water usually is adequate to re-wet soil depths of 2 to 3 feet. **Table 1** also shows the relationship between amount of water applied and depth of wetting for the most common soil textures.

Return time (or rotation speed) for pivots and linear-move systems is not usually based on root zone water holding capacity but on how much water can be applied per pass without excess runoff occurring. For example, on many soils, net application (considering AE = 85%) of about 0.9 inches or more per pass results in excess runoff and rutting. For average ET of 0.3 in/d and net irrigation of 0.9 inches, return time is 0.9/0.3 or 3 days. With this return time, average root zone soil water content (assuming a 2-foot root zone) is still relatively moist (about 75% available for sandy loam and 81% available for silt loams), but the top portion will be drier than deeper soil layers (70% for sandy loam and 78% for silt loam, assuming 60% from top foot and 40% from second foot).

Estimated seasonal variation in soil water content with varying design capacity. A water balance analysis was performed using daily estimated ET and partitioning root water extraction throughout an 18-inch root zone. Irrigation water was partitioned within the root zone by using a cascading approach: filling the top 6-inch layer to field capacity and continuing downward until all irrigation water was placed in soil water storage. Results are shown in **Figures 5** through **7** for Kimberly, Idaho conditions. Water contents of less than 50 % available (the horizontal line in the figures) will result in less than optimal growth and forage production. Note that a pivot with a design capacity of 6.5 gpm/ac that is operated to just add back the water used by ET before first cutting (June 1) will not be able to fill the 12-18 inch depth above 50% available, in essence, limiting the active root zone to 12 inches during this period (**Figure 5**). Also note the period of water stress following the third cutting.

Increasing the system capacity to 7 gpm/ac, made little difference before first cutting when the pivot was operated only to replace ET (**Figure 6**). However, the stress period after third cutting was reduced in length and severity. In **Figure 7**, the same pivot capacity was used, except the pivot was operated as required to fill the entire root zone to field capacity and keep it full until first cutting. As a result, stress periods were minimized and the 12-18 inch depth was sufficiently moist for active water uptake most of the season. In summary, assuring that the root zone is filled to field capacity before first cutting provides a soil water reserve to support crop growth through hot periods and re-growth after cutting. **Figure 9** shows actual re-fill data for a silt loam soil starting with a very dry profile. Significant rain in early June helped re-fill the profile to a depth of about 40 inches.

IRRIGATION SCHEDULING AROUND HARVEST – WATER STRESS AND COMPACTION ISSUES

In crops like alfalfa or grass hay, a window of non-irrigation for each cutting must be considered. To minimize soil compaction, irrigation should be stopped several days before cutting so that soil moisture is reduced to below field capacity in the top foot of soil by the time of cutting. This not only reduces potential for soil compaction but also allows the crop to be dropped on drier soil which should reduce drying time. The ET pattern considering reduction due to cutting and re-growth is shown in **Figure 9**. Assuming a 7-day period for drying and harvest, the minimum time without irrigation will be about 10-11 days for silt loam soils, 10 for sandy loam and 9 for sandy soils (**Table 5**). Estimated ET for the time without irrigation ranges from about 1.4 to 1.7 inches. Even though ET is reduced following cutting, the ET deficit during drying is still about 1 inch. Adequate system capacity will allow this deficit to be re-filled before the next cutting. Another method of evaluating the cumulative effect of system capacity is shown in **Figure 10**. The cumulative water added was limited to meeting ET before first cutting. The ET shown by the solid line is the 30-year average for Kimberly, Idaho. A system capacity of 7.5 gpm/ac will be able to re-fill the root zone after each cutting and have minimal water stress. If the system is managed to enter the first cutting with a full root zone, an additional 1-3 inches of water can be stored in the soil for future use. This would allow the 7.0 gpm/ac capacity to be sufficient and the 6.5 gpm/ac system to be nearly sufficient **in an average year.**

Maintaining your systems in good condition provides additional protection against water stress from high ET conditions. A well-maintained system is essential for efficient and uniform application of irrigation water. Every extra gallon of water you pump, whether the result of leaks, worn nozzles, or excessive set time, represents water that could be used to grow the crop and is a direct energy cost.

CONCLUSION

Center pivots with design capacity selected to nearly meet peak ET provide a reduced-energy, highly uniform, low- labor irrigation method for irrigating alfalfa and other forages. Adequate system capacity provides more management options around harvest, increases active rooting depth, and reduces water stress throughout the growing season. Managing pivots to provide deeper soil water storage during hay cutting / drying periods reduces potential for water stress and encourages faster re-growth. Surface runoff and resulting excessive wheel rutting can be a problem on low-intake soils. This problem can be reduced by selecting water application packages that spread the water over a large wetted diameter, limiting water application per revolution, using offset booms on the outer spans of the pivot lateral, managing irrigation and field traffic to minimize soil compaction, and by periodic use of aeration equipment to open the soil surface and provide some temporary surface water storage.

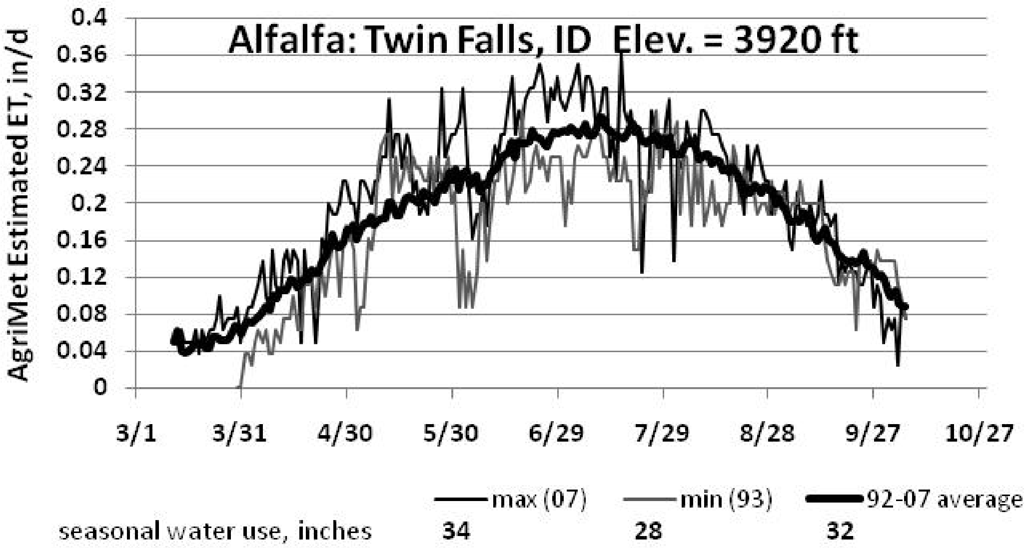

Figure 1. High, low, and average AgriMet-estimated daily and seasonal ET at Twin Falls, ID.

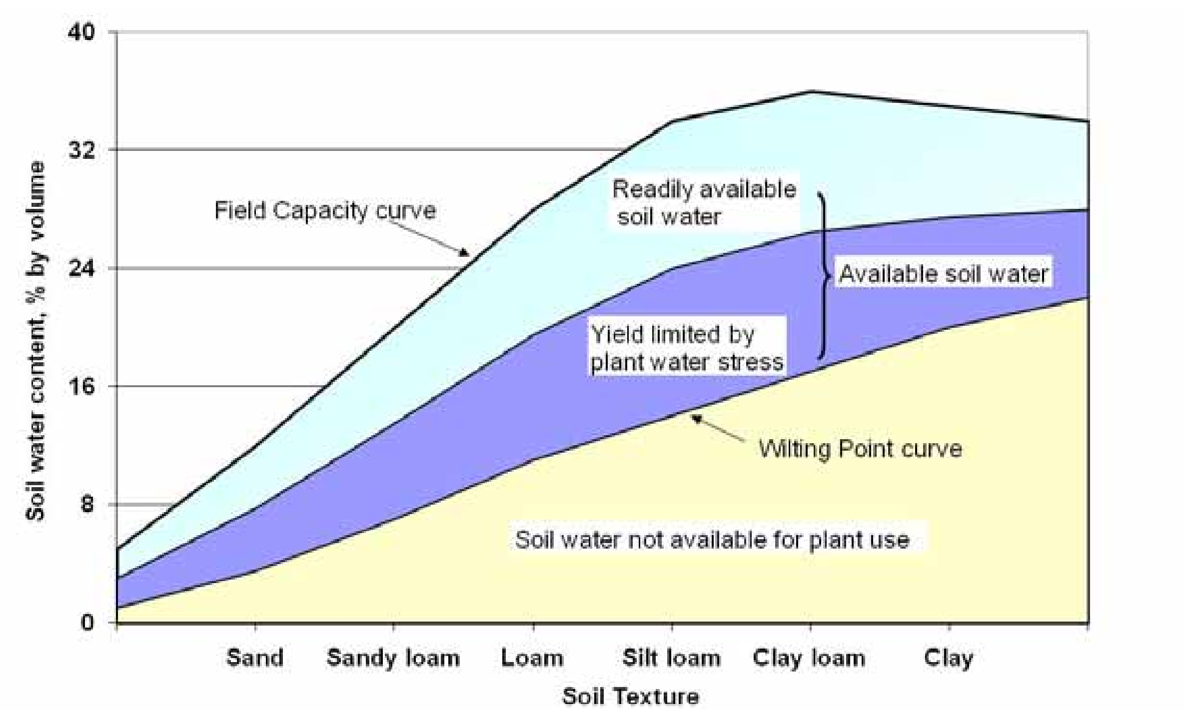

Figure 2. Soil water holding relationships as a function of soil texture. Field capacity increases from sand to silt loam and then levels off. As soil texture becomes finer (more silt and clay), the wilting point is reached at a higher soil water content. Available water (AW) is the amount of soil water held between wilting point and field capacity. Readily available water is approximately one half of AW for pasture and alfalfa. When soil water content falls below 50 percent AW, plant stress will cause yield reduction. Individual soils may differ from this general representation.

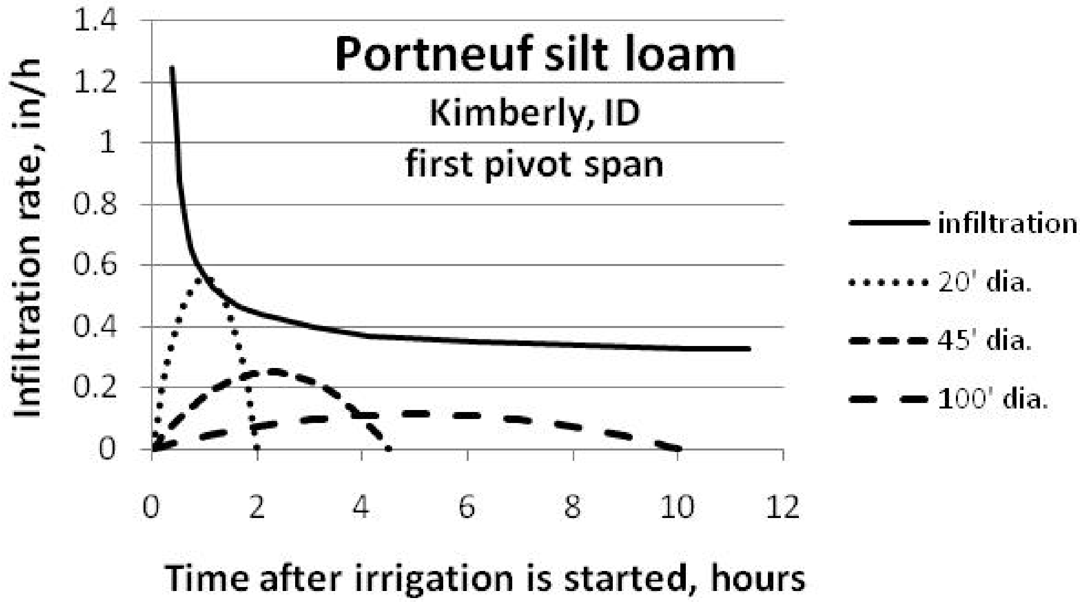

Figure 3a. Infiltration rate and water application rate patterns **under the first (inner) span** of a 1300-foot center pivot lateral. Net application rate (assuming 85% application efficiency) is 0.75 for all water application packages. The pivot is operated to make one complete revolution in 2.5 days.

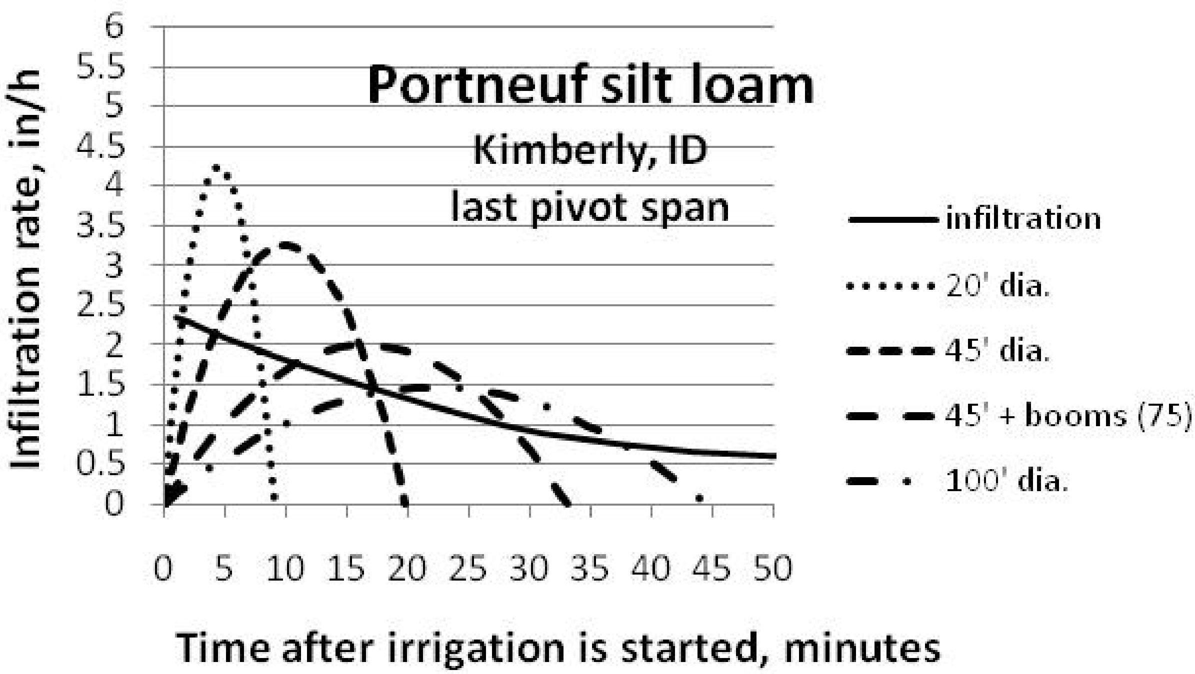

Figure 3b. Infiltration rate and water application rate patterns **under the last span** of a 1300-foot center pivot lateral. Net application rate (assuming 85% application efficiency) is 0.75 for all water application packages. The pivot is operated to make one complete revolution in 2.5 days.

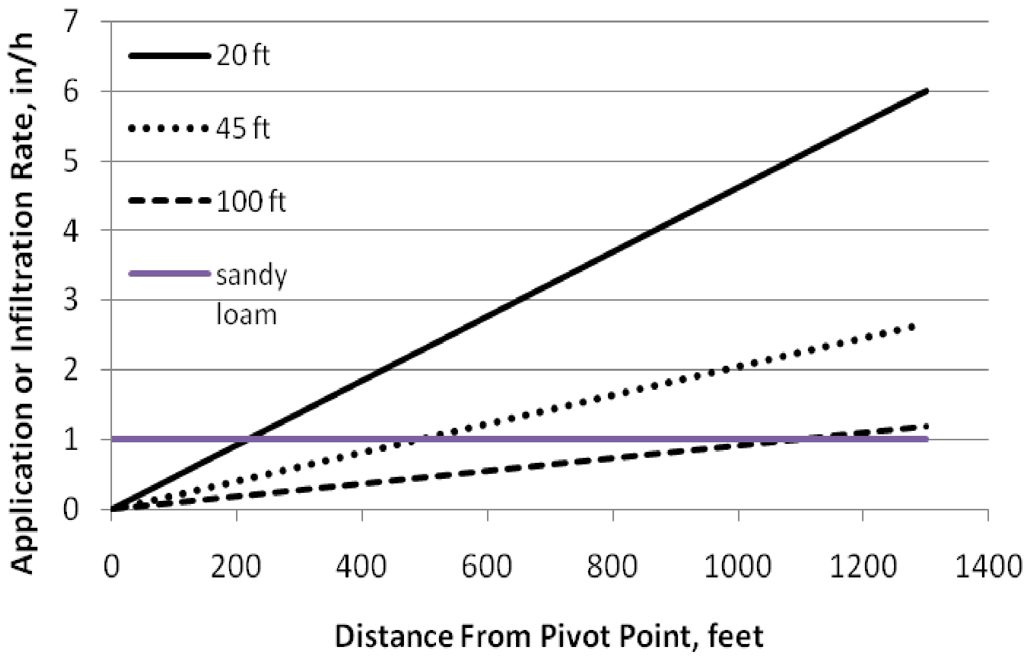

Figure 4. Average sandy loam intake rate and average water application rate outward along a center pivot lateral with application package wetted diameters of 20, 45 and 100 feet. Lateral length = 1320 feet and design flow is 850 gpm.

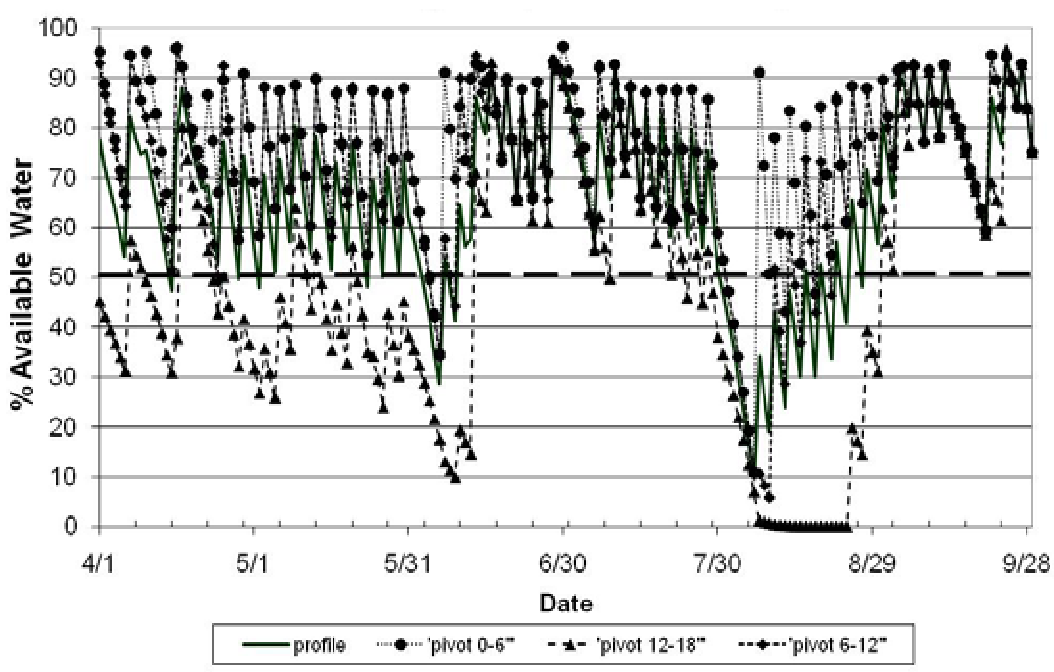

Figure 5. Simulated soil water content at 6-inch depth intervals for alfalfa on sandy loam soil using 1992 Kimberly, Idaho ET and precipitation data. System capacity is **6.5 gpm/ac**, and the pivot was managed to replace ET from April 1 to first cutting, then constant operation for the remainder of the season.

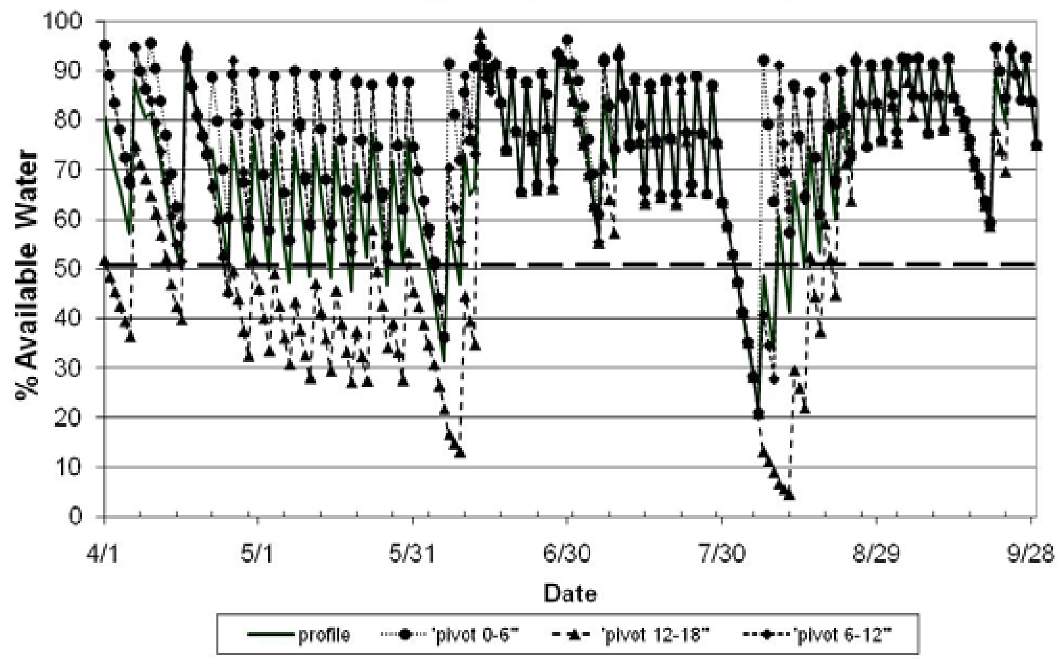

Figure 6. Simulated soil water content at 6-inch depth intervals for alfalfa on sandy loam soil using 1992 Kimberly, Idaho ET and precipitation data. System capacity is **7.0 gpm/ac**, and the pivot was managed to replace ET from April 1 to first cutting, then constant operation for the remainder of the season.

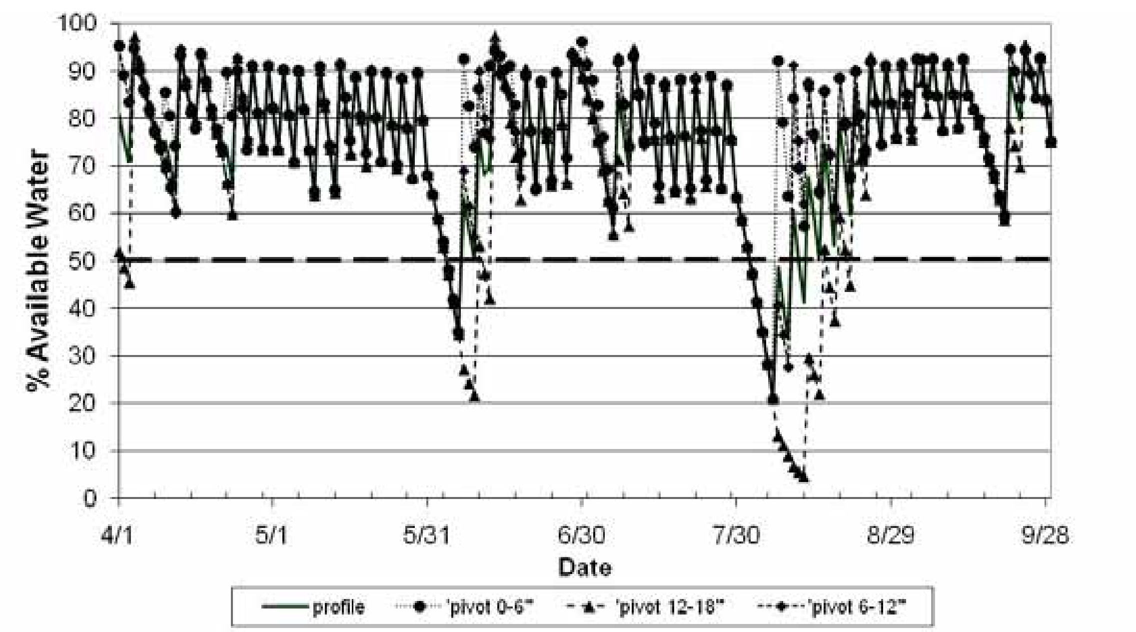

Figure 7. Simulated soil water content at 6-inch depth intervals for alfalfa on sandy loam soil using 1992 Kimberly, Idaho ET and precipitation data. System capacity is **7.0 gpm/ac**, and the pivot was managed to build and maintain a nearly full soil profile from April 1 to first cutting, then constant operation for the remainder of the season.

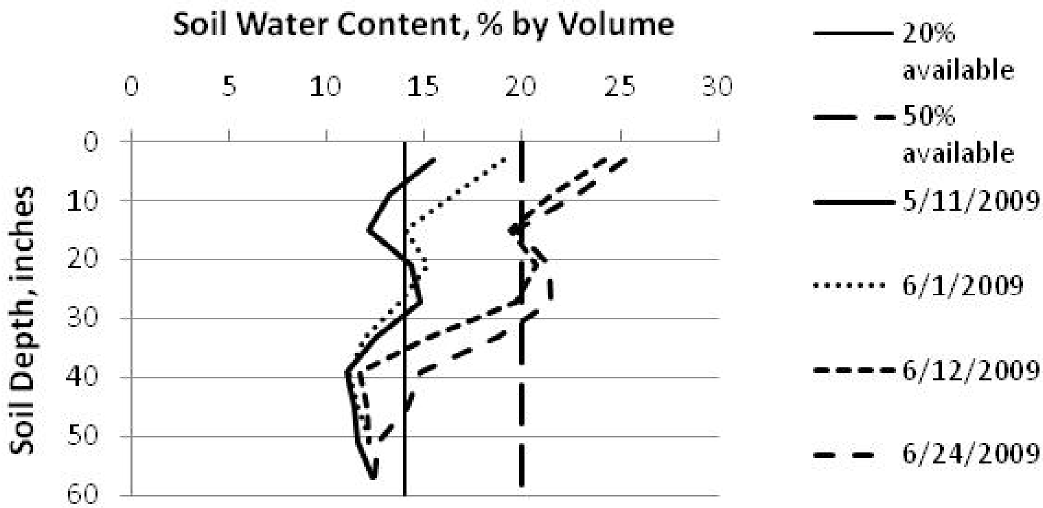

Figure 8. Measured 2009 soil water content with depth using a CPN nuclear soil moisture gauge. The mature stand of alfalfa was located near Declo, Idaho on a silt loam soil with a sand lens at about 12 – 18 inch depth.

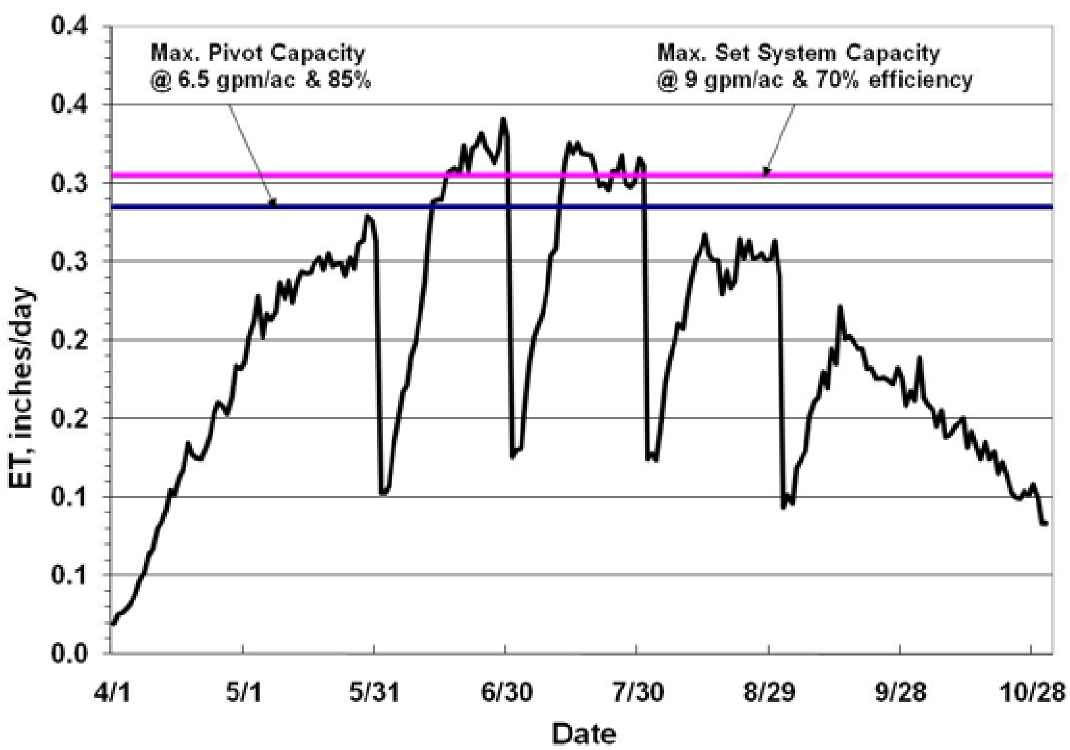

Figure 9. The 30-year average ET for alfalfa cut four times for hay is graphed as a function of calendar date. The source of the average ET data is the Kimberly Penman ET from J.L. Wright, Northwest Irrigation and Soils Research Laboratory.

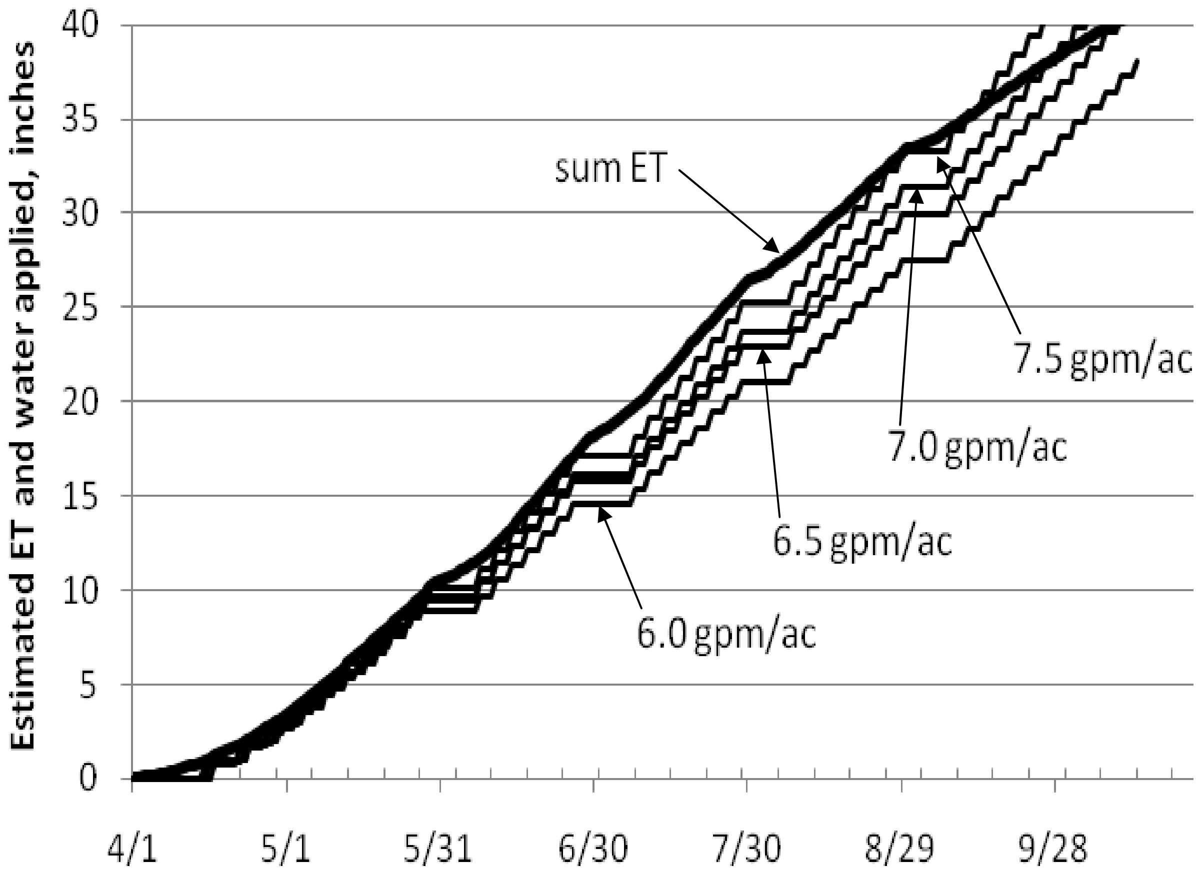

Figure 10. Cumulative average 30-year estimated ET, including cutting effects, and irrigation water applied by center pivot at 4 irrigation system capacities for Kimberly, ID conditions.

Table 1. Average water holding capacity and soil moisture content impact on depth of wetting by a 1-inch net water application (assuming uniform soil properties and uniform soil moisture with depth) for common soil textures.

	Sand	**Sandy Loam**	**Silt Loam**	**Clay**
Average Water Holding Capacity (in/ft)	1.0	1.7	2.1-2.4	2.2
Moisture Content (% Depleted)	**Soil Depth (Inches)**			
25	48	28	20	22
35	34	20	14	16
50	24	14	10	11
75	16	9	7	7
100	12	7	5	5

Table 2. Suggested maximum water application rates (in inches per hour) for sprinklers for average slope, soil and cultural conditions.* (Source: *USDA-NRCS National Engineering Handbook*, Chapter 11, 1983.)

Soil Texture and Profile	0-5 % Slope (inch/hour)	5-8 % Slope (inch/hour)	8-12 % Slope (inch/hour)	12-16% Slope (inch/hour)
Coarse sandy soil to 6 feet	2.0	1.5	1.0	0.5
Coarse sandy soils over more compact soils	1.5	1.0	0.75	0.4
Light sandy loam to 6 feet	1.0	0.8	0.6	0.4
Light sandy loam over more compact soils	0.75	0.5	0.4	0.3
Silt loam to 6 feet	0.5	0.4	0.3	0.2
Silt loam over more compact soils	0.3	0.25	0.15	0.1
Heavy-textured clays or clay loam	0.15	0.1	0.08	0.06

* For average soil conditions on all crops except grasses and alfalfa. For grass and alfalfa, values may be increased by 25 percent. For bare ground and poor soil conditions, reduce values by 25 percent.

Table 3. Approximate depth of water to add and resultant depth of wetting for alfalfa with peak ET of about 0.25 in/day on a silt loam soil in southern Idaho.

Irrigation interval	Net mid-season water required, inches	Actual water to apply, inches	Soil Water Depletion, %	Approx. depth of wetting (inches) silt loam soil
Daily	0.25	0.36	10	3
Every-other-day	0.5	0.72	21	6
Every 3rd day	0.75	1.07	31	9
Every 4th day	1.0	1.43	42	12
Every 5th day	1.25	1.79	52	15

Table 4. Inches of water that must be applied to refill one foot of soil with a **pivot or linear**. Numbers shown are larger than net plant water requirements because they include losses such as evaporation and wind drift.

% Available Soil Water	Fine-textured Silt Loam 2.25 in/ft	Coarse-textured Silt Loam 1.97 in/ft	Loam 1.41 in/ft	Sandy Loam 1.67 in/ft	Fine Sand 0.6 in/ft
100	0	0	0	0	0
85	0.42	0.37	0.26	0.32	0.11
80	0.56	0.49	0.35	0.42	0.15
75	0.70	0.62	0.44	0.52	0.19
70	0.84	0.74	0.53	0.63	0.22
65	0.98	0.86	0.62	0.73	0.26
60	1.12	0.98	0.70	0.84	0.30
55	1.26	1.11	0.79	0.94	0.34
50	1.41	1.23	0.88	1.04	0.38
40	1.69	1.48	1.06	1.25	0.45
30	1.97	1.72	1.23	1.46	0.52

Table 5. Kimberly, ID 30-year average ET (inches) for the pre-cut period required to reduce soil moisture in the top 1 foot to about 75% available for silt loam, sandy loam, and sandy soil textural classes and a 7-day drying period. This assumes that the soil profile is filled to field capacity by the last irrigation before cutting, and that 60% of total ET comes from the top foot of soil.

Cut #	Silt loam (2.4 in/ft)			Sandy loam (1.8 in/ft)			Sandy (1.0 in/ft)		
	ET and days before cut ( )	ET drying	Total	ET and days before cut ( )	ET drying	Total	ET and days before cut ( )	ET drying	Total
1	0.6 (4)	0.9	1.5	0.45 (3)	0.9	1.35	0.25 (2)	0.9	1.15
2	0.6 (3)	1.1	1.7	0.45 (3)	1.1	1.55	0.25 (2)	1.1	1.35
3	0.6 (3)	1.1	1.7	0.45 (3)	1.1	1.55	0.25 (2)	1.1	1.35
4	0.6 (4)	0.8	1.4	0.45 (3)	0.8	1.25	0.25 (2)	0.8	1.05