

Lecture 14

Center Pivot Uniformity Evaluation

I. Introduction

- The calculation of an application uniformity term must take into account the irrigated area represented by each catch container
- It is more important to have better application uniformity further from the pivot point than nearer, because the catch containers at larger distances represent larger irrigated areas
- If the catch containers are equally spaced in the radial direction, the area represented by each is directly proportional to the radial distance

II. Equation for Center Pivot CU

- The equation for CU proposed by Heermann and Hein is (ASAE/ANSI S436):

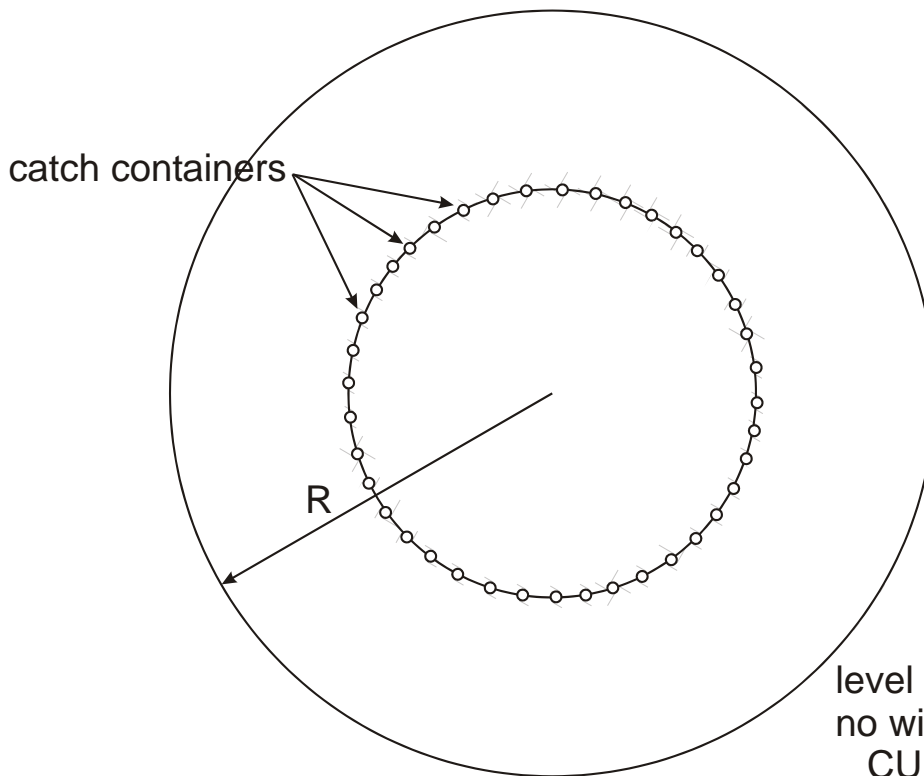
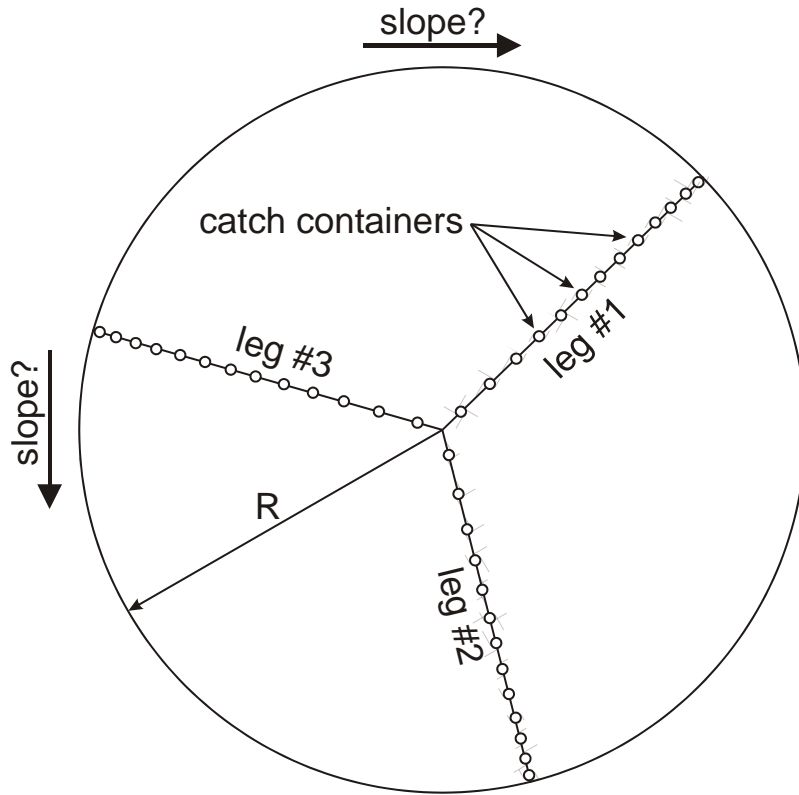
$$CU = 100 \left(1.0 - \frac{\sum_{i=1}^n \left(r_i \left| d_i - \frac{\sum_{i=1}^n (d_i r_i)}{\sum_{i=1}^n r_i} \right| \right)}{\sum_{i=1}^n (d_i r_i)} \right) \quad (295)$$

where CU is the coefficient of uniformity; d_i is the depth from an individual container; r_i is the radial distance from the pivot point; and n is the number of containers

- First calculate the summations:

$$\sum_{i=1}^n r_i \quad \text{and,} \quad \sum_{i=1}^n (d_i r_i) \quad (296)$$

- Then, perform the outer summation to determine the CU value
- That is, don't recalculate the inner summation values for every iteration of the outer summation – it isn't necessary
- It is usually considered that a center pivot CU should be greater than 85%
- If the radial distances, r_i , are equal, the sequence number of the can (increasing with increasing radius) can be used instead of the actual distance for the purpose of calculating application uniformity
- Consider the following two figures:



III. Standard Uniformity Values

- You can also calculate the “standard” CU or DU if you weight each catch value by multiplying it by the corresponding radial distance
- To obtain the low ¼, rank the unweighted catches, then start summing radii (beginning with the radius for the lowest catch value) until the cumulative value is approximately equal to ¼ of the total cumulative radius
- This may or may not be equal to ¼ of the total catch values, because each catch represents a different annular area of the field
- Finally, divide the sum of the catches times the radii for this approximately ¼ area by the cumulative radius
- This gives the average catch of the low ¼
- Don't rank the weighted catches (depth x radius) because you will mostly get the values from the low r values (unless the inner catches are relatively high for some reason), and your answer will be wrong
- Don't calculate the average of the low ¼ like this...
(because the lowest ¼ of the catches generally represents something different than ¼ of the irrigated area):
- Actually, the equation at the right is all right, except for the value “n/4”, which is probably the wrong number of ranked values to use in representing the low ¼
- You can set up a table like this in a spreadsheet application:

Ranked Center Pivot Catches				
Radius, r	Cumulative r	Depth, d	d*r	Cumulative d*r
		<i>smallest</i>		
		<i>largest</i>		
Totals:	----			----

- Note that when you rank the depths, the radius values should stay with the same depth values (so that the radius values will now be “unranked”; all mixed up)
- To get the average weighted depth for the whole pivot area, divide the total “Cumulative d*r” by the total “Cumulative r” (column 5 divided by column 2)
- Find the row corresponding closest to ¼ of the total “Cumulative r” value, and take the same ratio as before to get the weighted average of the low ¼ area
- Look at the example data analysis below:

Ranked catches				
Radius, r	Cum. r	Depth, d	d*r	Cum. d*r
120	120	0.52	62.6	62.6
900	1,020	0.95	851.9	915
160	1,180	1.29	205.8	1,120
340	1,520	1.31	445.6	1,566
1000	2,520	1.46	1,456.3	3,022
1040	3,560	1.46	1,514.6	4,537
240	3,800	1.48	355.3	4,892
800	4,600	1.50	1,203.9	6,096
860	5,460	1.53	1,315.0	7,411
480	5,940	1.58	757.3	8,168
1280	7,220	1.58	2,019.4	10,188
980	8,200	1.60	1,569.9	11,758
540	8,740	1.63	878.2	12,636
360	9,100	1.65	594.2	13,230
460	9,560	1.67	770.4	14,000
880	10,440	1.70	1,495.1	15,496
320	10,760	1.72	551.5	16,047
1140	11,900	1.75	1,992.2	18,039
1160	13,060	1.75	2,027.2	20,067
280	13,340	1.82	509.7	20,576
720	14,060	1.82	1,310.7	21,887
1300	15,360	1.82	2,366.5	24,253
200	15,560	1.84	368.9	24,622
420	15,980	1.84	774.8	25,397
440	16,420	1.89	833.0	26,230
1020	17,440	1.89	1,931.1	28,161
1200	18,640	1.92	2,301.0	30,462
600	19,240	1.94	1,165.0	31,627
640	19,880	1.94	1,242.7	32,870
1060	20,940	1.94	2,058.3	34,928
1100	22,040	1.94	2,135.9	37,064
220	22,260	1.97	432.5	37,497
1080	23,340	1.97	2,123.3	39,620
380	23,720	1.99	756.3	40,376
740	24,460	1.99	1,472.8	41,849
920	25,380	1.99	1,831.1	43,680
1220	26,600	1.99	2,428.2	46,108
300	26,900	2.01	604.4	46,713
180	27,080	2.03	364.8	47,077
820	27,900	2.04	1,671.8	48,749
1260	29,160	2.04	2,568.9	51,318
660	29,820	2.06	1,361.7	52,680
1180	31,000	2.06	2,434.5	55,114
680	31,680	2.09	1,419.4	56,534
940	32,620	2.11	1,985.0	58,519
560	33,180	2.14	1,196.1	59,715
260	33,440	2.16	561.7	60,276
1120	34,560	2.18	2,446.6	62,723
700	35,260	2.23	1,563.1	64,286
760	36,020	2.23	1,697.1	65,983
100	36,120	2.25	224.5	66,208
960	37,080	2.26	2,167.0	68,375
520	37,600	2.28	1,186.4	69,561
620	38,220	2.28	1,414.6	70,976
1240	39,460	2.28	2,829.1	73,805
500	39,960	2.33	1,165.0	74,970
140	40,100	2.35	329.6	75,300
400	40,500	2.40	961.2	76,261
780	41,280	2.52	1,968.9	78,230
40	41,320	2.57	102.9	78,333
80	41,400	2.57	205.8	78,538
840	42,240	2.79	2,344.7	80,883
580	42,820	2.82	1,633.0	82,516
60	42,880	3.23	193.7	82,710
1320	44,200	3.79	4,998.1	87,708
20	44,220	3.83	76.7	87,784

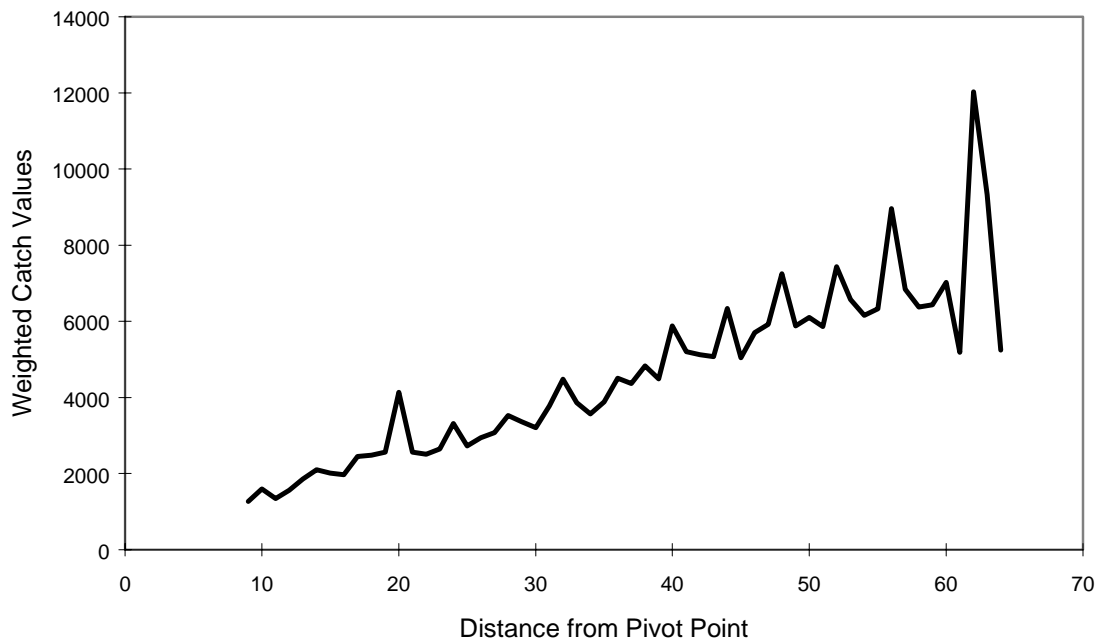
1/4 area (11,055)

1/2 area (22,110)

- Notice that the depth values (3rd column) are ranked from low to high
- Notice that the maximum value of cumulative r is 44,220 & maximum cumulative d*r is 87,784. Then, the weighted average depth for the entire center pivot is equal to $87,784/44,220 = 1.985$ (whatever units)
- One quarter of 44,220 is equal to 11,055 which corresponds most closely to the row in the table with depth = 1.72. For the same row, divide the two cumulative columns (Col 5/Col 2) to get $16,047/10,760 = 1.491$, which is approximately the average of the low ¼.
- Finally, estimate the distribution uniformity for this data set as:

$$DU \cong 100 \left(\frac{1.491}{1.985} \right) \cong 75\% \quad (297)$$

- Note that in this example, the average of the low ¼ was, in fact, based on approximately the first n/4 ranked values
- Consider the weighed catch-can data plotted below:



- As in any application uniformity evaluation, there is no “right” answer. The results are useful in a comparative sense with evaluations of other center pivots and other on-farm irrigation systems.
- However, a plot of the catches can give indications of localized problems along the center pivot radius

IV. The Field Work

- It may take a long time for the full catch in containers near the pivot point, and because these represent relatively small areas compared to the total irrigated area, it is usually acceptable to ignore the inside 10% or 20% of the radius
- The pivot quickly passes the outer cans, but takes longer to completely pass the inner cans, so you can collect the data from the outer cans sooner
- The pivot should not be moving so fast that the application depth is less than about 15 mm
- Catch containers can be placed beyond the physical length of the lateral pipe, but if they are so far out that the catches are very low, these can be omitted from the uniformity calculations
- Catch containers should be spaced in the radial direction no further than about 30% of the average wetted diameter of the sprinklers
- There is often an access road leading to the pivot point for inspection, manual operation, maintenance, and other reasons
- If the crop is dense and fairly tall (e.g. wheat or maize) it will be difficult to perform the evaluation unless the cans are placed on the access road
- Otherwise, you can wait until the crop is harvested, or do the test when the crop is still small
- Some people recommend two radial rows of catch cans, or even two parallel rows, to help smooth out the effects of the non continuous movement of towers (they start and stop frequently to keep the pivot lateral in alignment)
- Some have used troughs instead of catch cans to help ameliorate this problem.
- Note that if the field is sloping or undulating, the results from one radial row of catch cans may be quite different from those of a row on another part of the irrigated circle
- See Merriam and Keller (1978)

Linear Move Systems

I. Introduction

- Mechanically, a linear move system is essentially the same as a center pivot lateral, but it moves sideways along a rectangular field, perpendicular to the alignment of the lateral pipe
- The variation of flow rate in a linear move lateral is directly proportional to distance along the lateral pipe, whereas with center pivots it is proportional to a function of the square of the distance from the pivot point
- A center or end tower sets the forward speed of the machine, and the other towers just move to keep in line with the guide tower (this is like the far end tower on a center pivot)
- Usually, each tower is independently guided by cables and micro-switches as for a center pivot – this keeps the lateral pipe in a straight line (aligned with itself)
- Alignment with the field is usually not mechanically “enforced”, but it is “monitored” through switches in contact with a straight cable along the center of the field, or along one end of the field
- The center tower has two "fingers", one on each side of the cable, usually slightly offset in the direction of travel (they aren't side by side). The fingers should be in constant contact with the cable – if one is lifted too far a switch will be tripped, shutting the system down (because the whole lateral is probably getting out of alignment with the field)
- If the cable is broken for any reason, this should also shut the system down because the fingers will lose physical contact
- If the lateral gets out of alignment with the field and shuts off, it will be necessary to back up one side and or move the other side forward until it is in the correct position
- This can involve electrical “jumps” between contacts in the control box, but some manufacturers and some installers put manual switches in just for this purpose
- Some linear moves are fitted with spray nozzles on drop tubes or booms
- If they are spaced closely along the lateral, it may be necessary to put booms out beyond the wheels at tower locations, either in back of the lateral or on both sides of the lateral

Water Supply

- Water is usually supplied to the lateral via:
 1. a concrete-lined trapezoidal-sectioned ditch, or
 2. a flexible hose (often 150 m in length), or
 3. automatic hydrant coupling devices with buried mainline

- Hose-fed systems require periodic manual reconnection to hydrants on a mainline – it is kind of like a period-move system, and you have to ask yourself whether the linear move machine is worth the cost in this case!
- With the automatic hydrant coupling machines (see Fig. 15.3) there are two arms with pipes and an elbow joint that bends as the linear move travels down the field. The two arms alternate in connecting to hydrants so as not to disrupt the irrigation nor the forward movement of the machine. These are mechanically complex.
- The advantage of hose-fed and automatic coupling linear moves is that you don't need to have a small, uniform slope in the direction of travel, because water is supplied from a pressurized mainline instead of an open channel
- On ditch-fed systems there can be a structure at the end of the field that a switch on the linear move contacts, shutting down the pump and reversing the direction of movement so that it automatically returns to the starting end of the field.
- The advantages and disadvantages of the ditch-feed system are:

Pros

- Low pressure (energy) requirement
- Totally automated system
- More frequent irrigations than hose-fed, since no one needs to be available to move the hose

Cons

- Trash and seeds and sediment pass through screen and may plug nozzles
- The pump must be on (move with) the lateral, causing extra weight
- Should have uniform slope along the lateral route

Pros and Cons Compared to a Center Pivot

Pros

- Easy irrigation of a rectangular field (important if land is expensive, but not important if land is cheap and water is scarce)
- Application rate is uniform over length of lateral, rather than twice the average value at the end of the center pivot
- No end gun is required

Cons

- The lateral does not end up right back at the starting point immediately after having traversed the irrigated area – you either have to “deadhead” back or irrigate in both directions
- May be more expensive than a pivot due to extra controls, pump on ditch feed, or more friction loss in the flexible feed hose (the hose is fairly expensive)

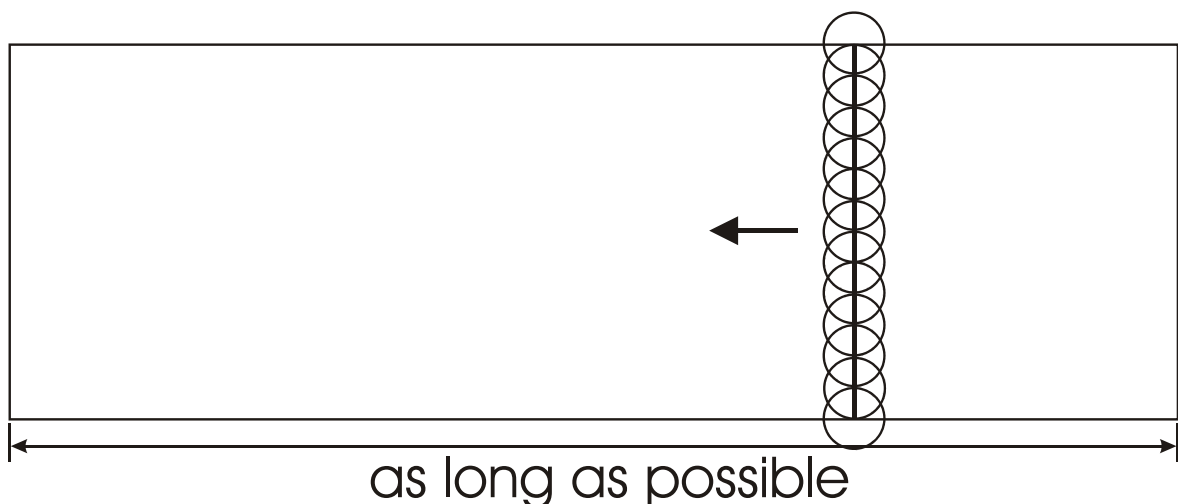
II. System Costs

Relative costs for linear move systems are:

- \$50,000 for a 1,280-ft hose-fed machine (perhaps 160 acres)
- \$55,000 for a winch-tow hose fed 1,280-ft machine (perhaps 160 acres)
- \$55,000 for a center pivot (1,280 ft) with a corner system (about 150 acres)
- \$140,000 for a ½-mile (2,560-ft) linear with automated hydrant coupling system (no ditch or hose required). The mainline is down the middle (a ¼-mile lateral on each side). Perhaps 320 acres or more irrigated.

III. System Design

- A main strategy in linear move design is to minimize the cost per unit area. This is done by maximizing the area covered per lateral (length of field)
- Generally, the lateral length is limited to 400 to 800 m. Therefore, the major difficulties and objectives in linear design are to:
 1. Maximize the irrigated area per lateral (this minimizes \$/area). In other words, how large a field can be irrigated by one machine?
 2. Prevent runoff by matching AR_x with $I_{soil} + SS/t_i$ (this tends to limit the field length, because if AR is small, it won't be possible to finish in f' days), where SS is the *allowable surface storage* in (mm or inches); and, t_i is the *time of irrigation*
 3. Determine whether spray nozzles can be used without causing runoff
 4. Minimize labor (for moving hoses and supervising)



- The allowable surface storage, SS , is the maximum amount of ponding without incurring surface runoff
- SS is a function of the general topography and the microtopography, and of the amount of foliar interception (water can “pond” on the crop leaves too)

- SS is usually less than about 5 mm unless small basins are created along furrows, for example
- AR_x limits the field length because it corresponds to some minimum time to finish an irrigation, for a given gross application depth, whereby a maximum interval (f) is calculated in the preliminary design steps

Lateral Inlet Head

- This is the same as for periodic-move systems
- The pressure balance equation for linear move systems is similar to set systems (both are linear, with uniform discharge from each outlet).

$$H_l = \frac{P_a}{\gamma} + \frac{3}{4}h_f + H_r + \frac{1}{2}\Delta H_e + (h_f)_{\text{minor}} + (h_f)_{\text{hose}} \quad (298)$$

- Or, if using flow control nozzles, with a minimum pressure required at the end (assuming the minimum pressure occurs at the end):

$$H_l = \frac{P_{\text{end}}}{\gamma} + h_f + H_r + \Delta H_e + (h_f)_{\text{minor}} + (h_f)_{\text{hose}} \quad (299)$$

where H_r is the height of the lateral or spray boom above the ground; and, $(h_f)_{\text{minor}}$ are the hydrant coupler and tower connection losses.

- The parameter $(h_f)_{\text{hose}}$ is the loss in the flexible hose connection on a hose-fed system
- Note that $(h_f)_{\text{hose}}$ may be a major loss, since the hose diameter is usually less than 5" or 6".

$$h_f = k_h FL \left(\frac{Q}{C} \right)^{1.852} D^{-4.87} \quad (300)$$

where $k_h = 10.50$ for h_f and L in ft, Q in gpm, and D in inches; $K_h = 1.21(10)^{10}$ for h_f and L in m, Q in lps, and D in mm. F is the multiple outlet friction factor for a linear move ($F \approx 0.36$).

- For hose-fed systems, the maximum hose length for dragging the hose is 220 ft. Therefore, there could be about 400 ft between hydrants.
- For hose-fed systems with a cable/winch system for assisting in dragging the hose (towers only have a moderate amount of tractive power), the maximum hose length is 330 feet (640 feet between hose hydrants).
- Flexible hoses normally come in 5-inch (\$18/ft) and 6-inch (\$25/ft) diameters
- The Hazen-Williams C value for the hose can usually be taken as 150