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Maximizing Water-use Efficiency Key In Cotton Production

Yields nearly double through systems approach to management.

Summary: *Maximizing Water-use efficiency must be the goal of every cotton production system on the semi-arid High Plains of Texas. Compared to current average yields that are highly variable from year to year and from region to region, cotton yields can be almost doubled through a systems approach to management. The system includes: 1) population density management to minimize the risk of excessive plant water stress, 2) partitioning a greater percentage of the water supply to plant use, rather than losing water through free soil evaporation, 3) irrigation scheduling based on crop water requirement, and 4) potential evapotranspiration/ nutrient management—especially N based on growth and yield responses to water supply. To reach cotton's capability of producing 50 pounds of lint per inch of water requires 5 pounds of N and 0.4 pounds of* P_2O_5 *to use water with maximum efficiency. Proper timing of input applications rep-resents the key management strategy for increasing yields within the limits of environmental constrains.*

Achieving consistently high yields requires a systems approach to management, especially on the semi-arid High Plains of Texas. The first component involves water management strategies. Under high evaporative demand conditions, the goal of any water management strategy must be to reduce soil evaporation (E) and maximize plant transpiration (T). Only the water that goes through the plant has any chance of contributing to crop yield.

Two basic approaches have been used to reduce E and increase T in crop production.

Narrower rows. Row spacing experiments across various soil types in the area, which range from clay loams to loamy fine sands, have produced a consistent 10 to 15 percent yield advantage of narrow rows (30-inch) over traditional (40-inch) row patterns (Figure 1). The narrower row yield advantage occurred across all water supplies, revealing the importance of summer rainfall to crop production. Narrower rows resulted in faster canopy closure, reducing soil E and partitioning a greater percentage of the water supply to plant T. This produced greater crop yields with the same water usage.

Ground cover. Wheat sown in the late fall after cotton harvest has been terminated in mid-to-late April. Cotton is then planted into the standing residue. The terminated wheat serves as ground cover to minimize wind erosion throughout the spring. Young seedlings are protected from wind and blowing sand in May and June as the wheat deteriorates. The straw reduces radiant energy reaching the soil surface and also minimizes soil evaporation by increasing resistance to wind movement.

Major concerns

Two major water-related concerns exist relative to widespread adoption of this system.

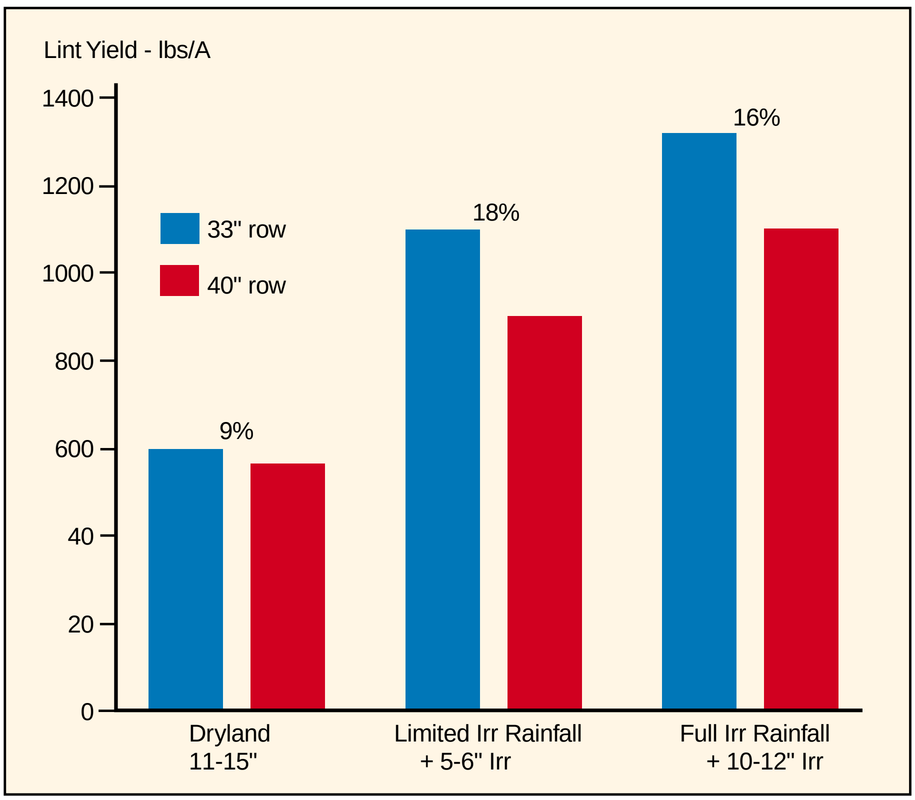

Figure 1. Lint yield response of narrow (30") and conventional (40") row spacings. Yields are averaged across three cultivars from 1983-1989.

Water requirements. The real question is: How much water is required to grow ground cover? Current estimates are at least 3 to 3.5 inches to termination. An additional 1 to 2 inches are lost due to the "wick effect" after the wheat ground cover has been chemically terminated. Average precipitation from November through March is usually only 0.5 inch/month and is highly unreliable. Water for seedling establishment and early spring growth is required to get the required benefits from this system—thus irrigation (center pivot preferred) is essential for success. If water returns are not equivalent, however, the use of 4 to 5 inches of this very precious water to grow wind protection in this semi-arid region may not be justified. A reduction in soil E with a concomitant increase in T and no difference in total ET has been documented for the growing season water use, resulting in yield increases. However, yield increases have not been consistent in all studies.

Table 1. Yield and yield components of cotton produced at two populations within two different water supplies–dryland (12 inches) and irrigated (20 inches).

Plant Density	1st Pos. Bolls		2nd Pos. Bolls		Yield
plants/A	No.	Size (g)	No.	Size (g)	(lbs/A)
12 inches water					
40,000	5	1.2	1	1.1	625
80,000	2	1.1	—	—	321
20 inches water					
40,000	7	1.4	2	1.2	1,284
80,000	4	1.2	1	1.0	974

Table 1. Cotton yield response to irrigation frequency and volume.

	- - - - - - - - Irrigation Frequency - - - - - - - -			
% ET replace	3 days	6 days	12 days	18 days
	- - - - - - - - - - lbs/A* - - - - - - - - - -			
.04	850	875	780	700
.06	1,050	1,080	950	750
.08	1,100	1,120	1,050	790
1.00	1,000	1,020	1,000	820
Average	1,000	1,024	945	765

*Average across 3 years.
1.0 ET = 0.25 inches/day averaged across growing season.
Soil at field capacity in top three feet prior to planting.

Table 1. Nitrogen requirements for various yield levels, depending on water supplied.

Water Supply	Lint Yield	Seed Yield	Total Biomass	N in Plant
- - - - - - - - - lbs/A - - - - - - - - -				
Dryland (8-12")	200-500	300-800	2,000-3,000	30-65
Limited Irrigation (14-18")	500-800	700-1,250	3,000-6,000	60-125
Full Irrigation (20-24")	800-1,200	1,150-1,200	5,000-8,000	125-250

Dryland conditions. The wheat cover system simply will not work under rain-fed (dryland) conditions due to the uncertainty of precipitation during the fall for establishment and insufficient precipitation during early spring when growth resumes. Under dryland conditions, two options are available to minimize the potential damage of plant water stress.

One strategy fits a variety's growth habits to cultural practices. A slightly more indeterminate growth habit is preferable under dryland conditions whereas a slightly more determinate growth habit is preferred under irrigated conditions. The indeterminate growth habit allows the plant to suspend reproductive development during the stress period but resume development when rain occurs. If the growing season is sufficiently long, good yields can be achieved. However, if the fall is wet and cool, not only will yields be low but fiber quality will also be very poor.

The other option is to optimize plant density relative to water supply. We have determined the water requirement per plant to reach flowering without suffering water stress. Based upon the plant-available volume of stored soil water at planting and the probability of a given volume of rainfall during the next 60 days, seeding rates can be adjusted to provide a final stand that will not limit yield if rainfall exceeds expected levels nor will it suffer excessive stress if rain-fall is less than expected. We have based the water requirements per plant on one-half the genetic yield potential of the cotton plant to allow flexibility in the production capacity of the plant. In most years, the soil profile is only 50 to 60 percent full at planting and the probability for 3 to 4 inches of rain from planting to first flower is greater than 60 percent. A final plant density of 25,000 to 30,000 plants per acre is the optimum for this water supply. Each plant should be capable of producing 6 to 7 mature fruit with this water supply, resulting in 400 to 500 pounds of lint per acre. If plant density exceeds 60,000 plants per acre, production capacity per plant drops to 2 fruit per plant, resulting in yields in the 250- to 300-pound per acre range with the same water supply (Table I).

Scheduling/fertility

Under irrigated conditions, irrigation scheduling and fertility management become critical considerations. Considerable evidence is emerging that suggests "high frequency/lower volume" applications of irrigation water can increase yield and water-use efficiency compared with "less frequent/higher volume" applications.

In our own work, we have found that a 3- to 6-day frequency replacing *75* to 80 percent potential ET produces the highest yields (Table 2). These types of application frequencies and volumes can be readily achieved using center pivot sprinklers and a volume equivalent of 3 to 3.5 gallons per minute per acre. For instance, a 125-acre center pivot pack-aged for 450 gallons per minute can apply one inch per acre every 5.2 days at 100 percent efficiency. Although 100 percent application efficiency probably can't be achieved, efficiencies greater than 90 percent are possible.

Nutrient requirements

In order to maximize water-use efficiency of the cotton production system, adequate nutrient supplies must be provided to allow the plant to produce maximum yields within limits of the water supply. It takes about 4 inches of water to get the plant big enough just to begin to reproduce. For each inch of water above 4 inches, approximately 50 pounds of lint (by-product of seed production) can be produced. For each pound of lint, approximately 1.6 pounds of seed are produced.

Nitrogen. Cottonseed is approximately 25 percent protein, which requires about 35 pounds of N per bale of lint (500 pounds) just to produce seed (Table 3). N requirement for vegetative material is another 15 pounds per bale. Therefore, if each inch of water is capable of producing 50 pounds of lint, N required to support this production is 5 pounds per inch of water. We use this guideline for N management under both irrigated and rainfed conditions.

Preplant N applications are based on the stored soil water supply at a rate of *5* pounds N per inch of stored water. Supplemental N is applied based upon rainfall and irrigation provided. We want 90 percent of the total applied N to be in the soil by first flower (usually 60 days after planting), such that we apply N during the season at the rate of 10 pounds of N per inch of water supply up to first flower. We then stop soil N applications if dryland or apply at the rate of 5 pounds per inch under irrigated conditions for an additional three weeks (peak flower period). N applications based on water supply optimize N-use efficiency.

Phosphorus. Due to the calcareous nature of soils in Texas and on the southern High Plains in particular, phosphorus is rapidly tied up as calcium phosphate and reaches an equilibrium with the soluble pool, which can't be influenced to any great degree. We use a maintenance approach to phosphorus fertilization. Each bale of cotton removes about 20 pounds of P2O5. We recommend replacing the phosphorus removed by last year's crop.

Zinc. Clay loam soils average 0.5 to 0.7 ppm extractable zinc, whereas sandy soils (loamy fine sand) average 0.2 to 0.3 ppm. We find a foliar application of zinc to be more effective than a soil application of $ZnSO_4$. We recommend about 0.1 pounds of Zn per application, with the first application during early square development (6- to

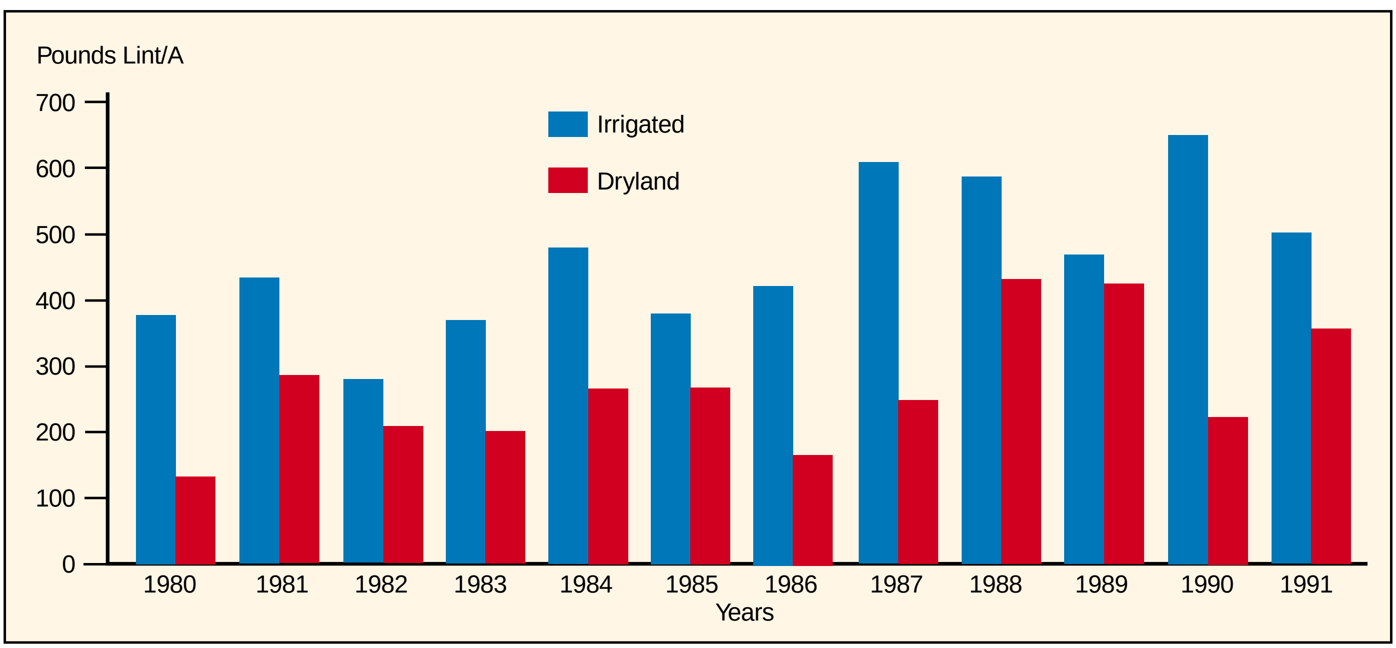

Figure 2. Historical cotton lint yield for irrigated and dryland production on the southern High Plains of Texas.

8-leaf stage) and a second application during early flowering.

Economics

If the growing season provides 2,100 to 2,300 heat units, which is what can be expected, dryland yields should average better than 400 pounds per acre and irrigated yields better than 800 pounds per acre—nearly 70 to 80 per-cent more than current averages. The only additional cost (approximately $10 per acre more) to produce these kinds of yields is 30 to 50 pounds more nitrogen per acre. The key management strategy is timing of inputs relative to growth stage of the plant and not an "after-it's-too-late" approach.

An increase of 150 to 200 pounds of lint per acre, under dryland conditions represents an additional $75 to $100 income per acre.

The 250- to 400-pound per acre yield increase under irrigated conditions represents an additional income of $125 to $200 per acre. Current yield levels represent "break even" levels.

Cotton provides the only crop that can be grown on a large scale with real profit potential. The additional yield realized through better management strategies represents the primary approach to realizing that potential.

Cotton reigns

Cotton is king in Texas. Over five million acres of fiber crop are usually planted across the state. Texas represents nearly 40 percent of the total U.S. acreage. The southern High Plains region (within a 75-mile radius of Lubbock, TX) plants about 3.5 million acres annually and is commonly referred to as the "world's largest cotton patch." Annual precipitation averages 18 to 20 inches. Precipitation to evapotranspiration (P:ET) ratio is 0.25 or less. Over 65 percent of the annual precipitation occurs during the growing season from late April through mid-September.

Only about 50 percent of the cotton acreage in the High Plains area has supplemental irrigation capabilities, with the application volume equal to less than 50 percent of potential evapotranspiration or about 0.15 to 0.20 inches per day per acre.

Lack of an adequate water supply to meet transpirational demand represents the single greatest limitation to crop production. When water supplies can be properly managed through irrigation or when timely rains occur during the growing season, soil fertility becomes the limiting factor to crop yields (N in particular) and growing season length is measured in heat unit accumulation rather than calendar days.

Average yields for the area (Figure 2) reflect rainfall patterns to a large extent, but also are strongly influenced by growing season length. Potential yields, given precipitation and normal heat unit patterns, are approximately twice the average yields. Dryland yields should average close to I bale per acre (500 pounds per acre) and irrigated yields should average close to 2 bales per acre (1,000 pounds per acre).

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