

Nitrogen Use Efficiency of Cotton Varies with Irrigation System

By Kevin F. Bronson

Nitrogen use efficiency is generally accepted to be less than 50% for field crops. West Texas is the largest contiguous cotton producing area in the world, with 4 million acres planted annually. Record high N fertilizer prices require better understanding of N use efficiency. Field research from 2000 to 2007 revealed that recovery efficiency of added N fertilizer ranged from a minimum of 12% in furrow irrigated fields to a maximum of 75% in subsurface irrigated, fertigated fields. Regardless of cotton variety or irrigation system, 40 lb of N in the cotton plant was required per bale (480 lb) of lint production.

West Texas plants 4 million acres of cotton yearly within a 100 mile radius of Lubbock (National Agricultural Statistics Service, 2004). Half of this acreage is dryland. About 70% of the irrigated land is center pivot, 25% is furrow-irrigated, and 5% is in subsurface drip irrigation. Nitrogen is the second constraint to this semiarid cotton production after water (Morrow and Krieg, 1990; Bronson et al., 2006). Nitrogen use efficiency will vary depending on how efficient the irrigation system is. The price of N fertilizer has escalated over the past few years resulting in increased interest in improving N efficiency. Understanding how N use efficiency changes from one irrigation mode to another will assist producers in N management decisions that affect profitability and N impact on the environment.

Since 2000, we have routinely analyzed cotton plants for total N uptake at first open boll in our N fertilizer management field studies. Nitrogen uptake is maximum at first open boll, after which N is lost as leaves drop (Li et al., 2001). We also measured N concentration of seed after harvest and ginning. In this paper, we analyze and summarize N uptake and yield data from over 200 plots between 2000 and 2007. We focused on zero-N plots and plots where N fertilizer rates were between 60 and 100 lb N/A. Where there was no statistical difference between N-fertilized and zero-N plots, the data were excluded.

There are several types of N use efficiency measures. The most common is recovery efficiency (Dilz, 1988).

$$\text{Recovery efficiency} = \frac{\text{TNU}_f - \text{TNU}_0}{\text{N fertilizer rate}}$$

Where TNU_F is total N uptake of N-fertilized plots and TNU_0 is total N uptake of zero-N plots.

Agronomic efficiency was calculated by Novoa and Loomis (1981).

$$\text{Agronomic efficiency} = \frac{\text{Lint yield}_f - \text{Lint yield}_0}{\text{N fertilizer rate}}$$

Where Lint yield_F is lint yield of N-fertilized plots and Lint yield_0 is lint yield of zero-N plots.

Internal N use efficiency was calculated by Witt et al., (1999).

$$\text{Internal efficiency} = \frac{\text{Lint yield}_f}{\text{TNU}_f}$$



The Southern Plains of Texas contains the largest contiguous cotton production in the world. About half of this production is irrigated.

Physiological efficiency was calculated by Isfan (1990).

$$\text{Physiological efficiency} = \frac{\text{Lint yield}_f - \text{Lint yield}_0}{\text{TNU}_f - \text{TNU}_0}$$

Urea ammonium nitrate (UAN, 32-0-0) was the N source used in all the studies. Nitrogen fertilizer was knifed-in or spoke-wheel applied 5 in. off the row and 4 in. deep at early squaring in the furrow irrigation studies (Booker et al., 2007). In the low energy precision (LEPA) studies, N was spoke-wheel applied the same way, except it was applied in two splits: one at first squaring and one at first bloom (Bronson et al., 2006). In the 2000-2002 surface and subsurface drip irrigation studies, N was applied in 30 lb/A doses at first square, early bloom, and mid bloom at the emitter during irrigation to simulate fertigation (Chua et al., 2003). In the subsurface drip studies from 2005 to 2007, N was injected into the system from 24 to 30 days between first square and mid bloom (Yabaji et al., 2009). Nitrogen fertilizer rates were based on yield goals (1.5, 2, and 2.5 bales/A for furrow, center-pivot, and drip tape irrigation, respectively) and 0 to 24 in. pre-plant soil test NO_3^- (Chua et al., 2003; Bronson et al., 2006; Booker et al., 2007; Yabaji et al., 2009).

Furrow irrigation consisted of four, 2 in. irrigations on every other furrow. Center pivot irrigation was configured with drop socks in every other furrow or LEPA irrigation (Lyle and Bordovsky, 1981). Irrigation in LEPA was every 2.5 days. Water was supplied through the surface drip system at 1.7 gal/hour every 3 days at 10 psi pressure. There were also furrow dikes in the surface tape furrows. Thus, in effect, this irrigation system

Abbreviations and notes for this article: N = nitrogen; NO_3^- = nitrate;

Table 1. Nitrogen use efficiencies, first open boll N accumulation, seed N uptake, and lint yields as affected by water management, Lubbock, Texas, 2000-2007.

Year	Irrigation	N fertilizer rate	Seed N uptake	Total N uptake	Seed N Recovery efficiency	Total N Recovery efficiency	Internal N use efficiency	Physiol. use efficiency	Agronom. use efficiency	Plus-N lint yield	Zero-N lint yield	N application details ⁴
		----- lb N/A -----			----- % -----		----- lb lint/lb N -----			----- lb/A -----		
2000	Subsurface drip	90	52	76	17	18	11.7	6.5	1.2	887	783	3, 30 lb N/A doses
2000	Surface drip tape	60	55	77	12	25	12.2	9.3	2.3	941	801	2, 30 lb N/A doses
2001	Subsurface drip	90	77	99	34	38	12.5	5.6	2.1	1,234	1,044	3, 30 lb N/A doses
2001	Surface drip tape	90	80	99	35	41	12.7	6.1	2.5	1,258	1,034	3, 30 lb N/A doses
2002	Surface drip tape	90	–	96	–	40	12.8	7.3	2.3	1,227	1,016	3, 30 lb N/A doses
2002	Furrow	70	62	–	17	24 ¹	12.7 ¹	5.7	1.3	1,124	1,027	Sidedress
2003	Furrow	77	39	–	8	12 ¹	12.0	5.7	0.74	666	609	Sidedress
2003	LEPA	87 ²	54	–	11	16 ¹	11.8	4.9	0.68	910	851	2, 45 lb N/A
2004	LEPA	85 ²	71	–	24	33 ¹	11.5	5.6	2.2	1,162	975	2, 45 lb N/A
2005	Subsurface drip	90	97	160	34	63	11.3	3.4	2.1	1,812	1,620	30 fertigations
2005	Subsurface drip	65 ³	91	143	38	62	12.7	4.9	3.0	1,817	1,620	30 fertigations
2006	Subsurface drip	100	72	120	30	75	12.9	5.5	4.1	1,547	1,140	34 fertigations
2006	Subsurface drip	85 ³	66	107	35	71	13.3	4.7	3.4	1,427	1,140	34 fertigations
2007	Subsurface drip	80	75	128	28	65	10.4	6.0	3.2	1,326	1,068	24 fertigations
2007	Subsurface drip	62 ³	78	120	40	72	11.4	8.5	4.9	1,372	1,068	24 fertigations

¹Assumes seed N uptake is 70% of total N uptake.
²Average variable-rate.
³Reflectance-based.
⁴Drip irrigation N applied between first square and mid bloom; sidedress N applied at first square; knifed-in treatments (LEPA) applied at first square and first bloom.

was very similar to LEPA. In the subsurface (12 in. depth) drip system, water flowed daily at 0.25 gal/hour at 15 psi pressure. Target amounts of irrigation in all systems except furrow was 85% estimated evapotranspiration replacement.

Seed N uptake of mature cotton was about 70% of total N uptake at first open boll (**Table 1**). We used this factor to calculate total N uptake in plots without total N uptake data. Lint yields generally increased in the order: furrow < LEPA < subsurface drip. A noteworthy factor affecting yield was that high-yielding picker cotton varieties were used in 2005 and 2006, with stripper varieties in all other years. Cotton was planted relatively late, i.e. late May to early June in 2000, 2003, and 2007. Early May is the optimum cotton planting time in West Texas.

Recovery efficiency varied from 12% in a furrow-irrigated field in 2003 to 75% in a subsurface drip irrigated field in


2006 (**Table 1**). Clearly, the more efficient irrigation systems had greater N recovery efficiency. This was due in part to more efficient N delivery, e.g. several splits, injection. Most reported N recovery efficiencies for cotton are <50% (Boquet and Breitenbeck, 2000; Rochester et al., 1997). Subsurface drip irrigations with frequent fertigations was clearly the most N fertilizer-efficient system. It also had the greatest zero-N plot yields among the irrigation systems. Yabaji et al. (2009) also reported low residual soil NO₃⁻ leaching below 3 ft. and low denitrification in subsurface drip irrigated cotton. Subsurface drip irrigation is about double the per acre cost of a center pivot, but is rapidly replacing furrow irrigation systems in West Texas. Nitrogen is usually injected in 30 lb N/A doses through center pivots in West Texas, a system we were not able to test. The N recovery of this system probably approaches the 40% recovery, similar to what we achieved by applying

30 lb N/A doses in the surface tape system in 2001-2002. The task then is to further increase water use and N fertilizer use efficiency in center pivot and furrow irrigated cotton. Stabilized or slow-release N products may have potential to increase N use efficiency in furrow-irrigated cotton. Pre-plant soil testing of NO_3^- to 24 in. can greatly improve N fertilizer recommendations and N use efficiency for the western cotton belt.

Internal N use efficiency was remarkably similar for all irrigation systems, averaging 12 lb lint/lb N in the plant. This is illustrated in a plot of total N uptake vs. lint yield in bales (Figure 1). The slope of the regression line is 40 lb N/bale, which is a very efficient internal N use efficiency. This compares to 100 lb N/bale in Alabama (Mullins and Burmester, 1990) and 50 lb N/bale in California (Bassett et al., 1970).

Physiological efficiency of N was more variable than internal efficiency, because it incorporates N response (Table 1). However, no real trends with irrigation systems could be observed. Agronomic N use efficiency is the most important to producers. Subsurface drip irrigation with fertigation (2005-2007) had the greatest agronomic efficiencies, while furrow and LEPA irrigations had the lowest.

Summary

Nitrogen fertilizer recovery in cotton ranged from 12 to 75% for furrow and subsurface drip irrigation systems, respectively. Nitrogen fertilizer in furrow-irrigated fields was sidedressed in one dose at first square. In subsurface drip irrigation, low, frequent doses of N were fertigated between squaring and mid bloom. Recovery efficiency for surface drip tape that is similar to LEPA irrigation was 40%. Stabilized or slow-release N products may increase N use efficiency in furrow-irrigated cotton, although such products were not evaluated here. Internal N use efficiency was not affected by irrigation system and averaged 40 lb lint/bale. Pre-plant soil testing of NO_3^- to 24 in. can help improve N use efficiency in all irrigation systems, increase cotton growers' profits, and reduce export of N to soil, water, and air. 

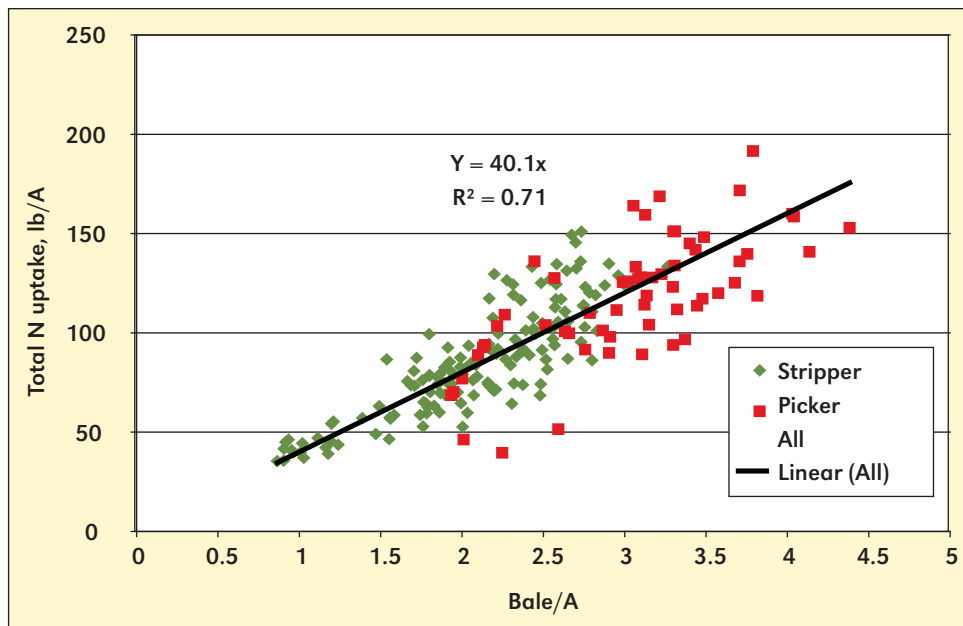
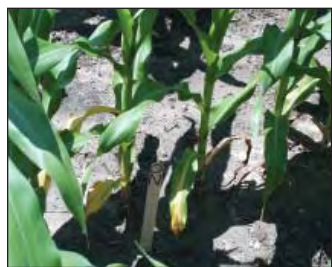


Figure 1. Total N uptake vs. cotton lint yields, West Texas, 2000-2007.

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Nitrogen deficiency in corn.

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