Yield of Cabbage in Relation to Nitrogen and Water Supply[1]

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Abstract. Cabbage yields were significantly related to the frequency of irrigation, evapotranspiration (ET) and the rate of N fertilization. Irrigating when the mean soil water suction in the upper 24 inches of soil approached 1.6 bars insured an adequate supply of soil water. The N-ET-marketable cabbage yield surface showed that yields did not change greatly for many combinations of ET and N. Yield isoquants suggest possible combinations of N and ET which will produce the same yield.

Numerous fertilizer trials in the Lower Rio Grande Valley of Texas and elsewhere have demonstrated the need for N in cabbage production. Nitrogen fertilization has increased yields, plant uniformity, and cabbage quality (1, 2, 3, 5, 6, 7). Irrigation, however, an important management factor affecting the N fertilization program, has received very little attention (6, 7).

The purpose of the study reported here was to investigate the relation between the availability of water, rate of N application, and cabbage yield.

Materials and Methods

The experiment was conducted on a Hidalgo sandy clay loam. This soil is a member of the fine-loamy, mixed, hyperthermic family of Typic Haplustolls. The surface foot of soil contained 3.7 to 7.4 ppm NO_3–N, 4.0 to 13.8 ppm $NaHCO_3$–soluble P, and had a saturated paste pH of 7.8 when the study was initiated.

Cabbage (*Brassica oleracea* var. *capitata* L. *f. alba* DC.) cv. Greenback was planted 2 rows to a 38-inch bed on September 10, 1966, and harvested in January and February 1967. Each plot consisted of 6 double-row beds, 50 ft long. Following thinning, the spacing between the plants in the row was approximately 10 inches. Marketable cabbage was harvested from 380 square ft of plot area (30 ft of the 4 center beds). All cabbage was considered to be marketable except split and soft heads.

A 3 × 5 factorial design with 3 replications was used. There were 3 irrigation and 5 N treatments. Nitrogen as ammonium nitrate was applied at rates of 0, 80, 160, 240, and 320 lb. per acre. Eighty pounds N per acre was applied to all plots, except the check plots, before seeding. When the plants were about 4 inches tall, the remainder of the fertilizer was applied and the plants thinned. All fertilizer was band-placed to a depth of 4 to 6 inches in the middle of the beds.

The 3 irrigation treatments (I–1, I–2, and I–3) were irrigated when the average soil water suction of the surface 2 ft of soil approached 0.8, 1.6, and 3.6 bars, respectively. This corresponds to average water contents of 60, 40, and 20% available water. The irrigation treatments were initiated on October 16, 1966 after thinning. All plots were irrigated twice to insure good germination and stand establishment. Mean electrical conductivity of irrigation water was 1.2 mmhos/cm.

Soil water was measured weekly or more often throughout the growing season by the neutron scattering technique. Access tubes were installed in each plot and the water content measured at 1-foot increments to a depth of 4 ft. Irrigation water was applied to the plots entirely through meters in amounts calculated to bring the 0–4-foot soil profile to field capacity.

Evapotranspiration (ET) was determined from October 15, 1966, when the plants were thinned, until the last harvest on February 27, 1967. The evapotranspiration values include the 0- to 4-foot soil profile water changes during this time period plus the inches of irrigation water used and 2.09 inches of rainfall. The rainfall was received between January 8 and February 5, 1967.

Results and Discussion

Irrigation. Irrigation significantly increased cabbage yields (Table 1) when plant growth was not limited by an inadequate supply of N. Maintaining the mean soil water suction in the upper 24 inches of soil within the range of 0 to 0.8 (I–1), 0 to 1.6 (I–2), and 0 to 3.6 (I–3) bars resulted in mean yields of 22.8, 20.1, and 15.3 tons, respectively. The number of irrigations needed to maintain the soil water suction within the desired ranges was affected by the application of N (Table 2). This reflects the larger size and faster rate of development of N-fertilized plants

Table 1. Effect of N fertilization and irrigation regime on yield[1] of marketable cabbage.

Nitrogen applied	Irrigation regime			Nitrogen mean
	I-1	I-2	I-3	
Lb./acre	Tons/acre			
0	15.3	16.9	14.6	15.7 a[2]
80	23.7	19.3	15.1	19.4 b
160	23.0	19.4	16.7	19.7 b
240	27.3	23.4	15.4	22.0 c
320	24.6	21.5	14.9	20.3 bc
Irrigation mean	22.8 a	20.1 a	15.3 b	

C.V. = 13.2%.
[1]Total yield of 3 harvests and average of 3 replications.
[2]Values in same comparison followed by same letter not significantly different at 5% probability level by Duncan's multiple range test.

Table 2. Number of irrigations and total amount of water applied[1] (irrigation + rainfall) as affected by N fertilization.

Nitrogen applied	Irrigation regime					
	I-1		I-2		I-3	
Lb./acre	No.	Inch	No.	Inch	No.	Inch
0	3	13.6	1	6.1	0	2.1
80	3	11.6	1	6.1	0	2.1
160	4	16.2	1	6.1	0	2.1
240	5	20.0	3	12.7	0	2.1
320	3	12.4	1	5.8	0	2.1

[1]Two irrigations (approx. 6 inches) needed to germinate seed and establish plants are not included.

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and the accompanying higher ET rates. Growing season water use averaged 0.12, 0.10, 0.13, 0.16, and 0.11 inches per day for the respective 0-, 80-, 160-, 240-, and 320-lb. N applications under the I–1 irrigation regimes. Corresponding water use per day with the I–2 irrigation regime was 0.06, 0.07, 0.06, 0.11, and 0.06 inch. Water use was 0.03 inch per day for the zero N rate and 0.04 inch per day for all other N rates in the I–3 irrigation regime. The rate of water use was lowest in January, a period of lowest temperatures. Cabbage grown under the I–3 irrigation regime was not irrigated after the crop was established. The I–2 irrigation regime apparently insured an adequate supply of soil water for plant development (Table 1), as the yields with the I–1 irrigation regime were not significantly greater.

Irrigation significantly increased the average head weight. Heads weighed approximately 2.0, 1.9, and 1.5 lb. with the I–1, I–2, and I–3 irrigation regimes, respectively. The irrigation regimes also affected the number of marketable heads. Approximately 22,445; 21,459; and 20,530 heads per acre were harvested from the I–1, I–2, and I–3 irrigation regimes, respectively.

Nitrogen response. The application of N fertilizer significantly increased cabbage yields (Table 1). A significant N-irrigation regime interaction reflected the lack of response to N by the cabbage under the I–3 irrigation regime. The increase in the number of marketable heads with an increase in the rates of N contributed more to the total yield than the increase in the average head size. Under the I–1 irrigation regime the number of marketable heads increased from 18,455 per acre without the addition of N to 22,209, 22,209, 25,448, and 23,923 heads per acre with the application of 80, 160, 240, and 320 lb. N per acre, respectively. The application of 80 lb. N per acre increased the average head weight from 1.7 to 2.1 lb. Higher rates of N did not further increase the head weight. Similar results were found in the I–2 irrigation regime, whereas without irrigation (I–3) the application of N had no effect on either head weight or on the number of marketable heads. There was some evidence that the 320-lb. N addition depressed yields at the I–1 and I–2 irrigation regimes, but results were not statistically significant.

The relationship between cabbage yields and N fertilizer applications was best described by second-degree polynomial functions (Table 3). As the application rate of N increased, yields increased, but at a diminishing rate. The magnitude of the coefficients of determination reflect the relation of soil water availability to the cabbage yield response to N. Comparison of the first-order partial regression coefficients suggests that N was 2.5 and 3 times more effective in increasing yields with the I–1 irrigation regime than with the I–2 and I–3 irrigation treatments, respectively. Lack of response to N in the I–3 irrigation regime reflects the low availability of the soil water. Also, dry soil in the upper 6 inches of the nonirrigated plots would restrict N uptake from the banded N application.

Table 3. Regression equations relating cabbage yields (Y ton/acre) to the N fertilizer applied (X lb./acre) at different irrigation regimes.

Irrigation regime	Regression model $Y = b_0 + b_1X - b_2X^2$	s_Y	R^2
I-1	$Y = 16.16 + 0.0862\ X - 0.00018\ X^2$	±2.19	0.8728**
I-2	$Y = 16.76 + 0.0335\ X - 0.00005\ X^2$	±1.56	0.7999**
I-3	$Y = 14.27 + 0.0289\ X - 0.00005\ X^2$	±0.76	0.6253**

**Significant at 1% probability level.

Mean N uptake by the cabbage heads was 156, 138, and 105 lb. per acre on the I–1, I–2, and I–3 irrigation regimes, respectively. The percent N in the cabbage was not significantly affected by the irrigation regimes.

Evapotranspiration-yield relationships. Cabbage yields increased significantly with an increase in evapotranspiration (ET) when an adequate amount of N was supplied but increased at a reduced rate for higher N levels (Fig. 1). The point corresponding to an ET of 15.7 inches and a yield of 15.6 tons per acre was omitted from the regression analysis. The association between ET and yield accounted for 90% of the yield variability. Under low soil fertility conditions, a large change in ET had very little effect on yield. Evapotranspiration from the no-N plots was 15.7, 8.7, and 4.6 inches on the I–1, I–2, and I–3 irrigation regimes, respectively. The corresponding yields were 15.6, 16.9, and 14.6 tons per acre of marketable cabbage.

The regression equation predicts a maximum yield of 26.7 tons per acre with 24.7 inches of ET. This compares favorably with the measured maximum ET of 22.1 inches and a yield of 27.3 tons on the I–1 irrigation treatment with 240 lb. of N. The high ET reflects the additions of irrigation water. Pan evaporation during the corresponding period was 21.6 inches. The similarity between an ET of 22.1 inches on the I–1, 240-lb. N treatment and the 21.6 inches of pan evaporation suggests that this treatment was overirrigated and that water may have been lost through deep drainage.

The effect of varying ET and N on yield is shown in Fig. 2. The quadratic prediction equation is $Y = 9.71 + 1.2075\ ET - 0.0468(ET)^2 + 0.00515N - 0.00007N^2 + 0.00293\ ETN$ [1], where Y is the estimated yield in tons per acre. ET and N refer to inches of water lost from the soil as evapotranspiration and lb. per acre of applied N fertilizer, respectively. This equation has a highly significant R value of 0.9510.

The yield response surface shows a greater rise in yields from ET than from N, especially at the lower levels of the two variables. Standard partial regression coefficients of 1.53, 0.14, and 1.16 for ET, N, and ETN, respectively, also suggest that ET had a greater effect on yields than the N fertilizer additions. Within the range of N tested, the response to N is almost linear, whereas the effect of ET is more curvilinear. However, the relatively flat surface within the limits of observation (shaded

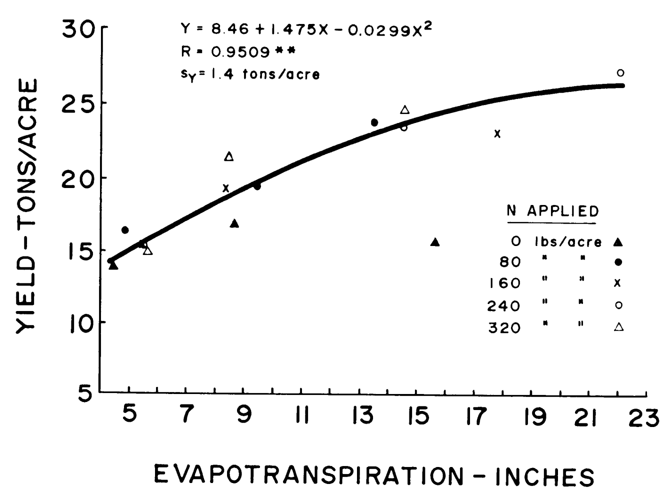

Fig. 1. Relationship between evapotranspiration (X) and yield (Y) of marketable cabbage.

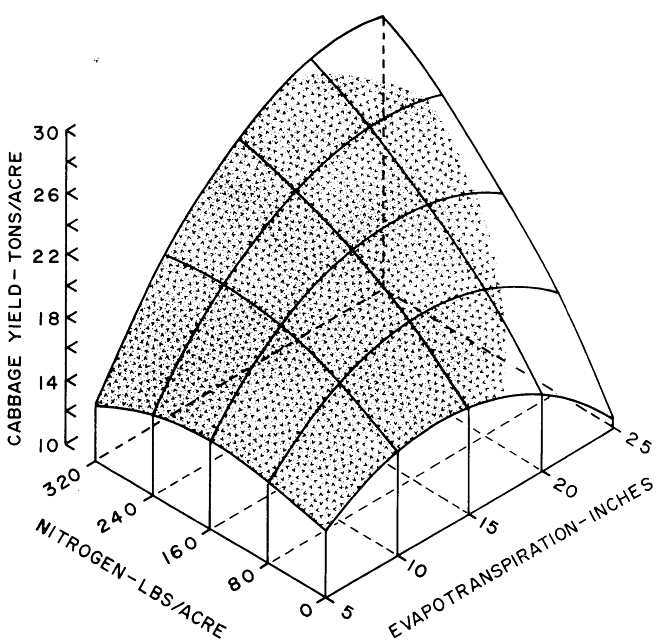

Fig. 2. Predicted N-evapotranspiration marketable cabbage yield surface.

area) indicate that yields did not change greatly for many combinations of ET and N.

The various combinations of ET and N that will give a specified yield (Fig. 3) were computed from the isoquant equation:

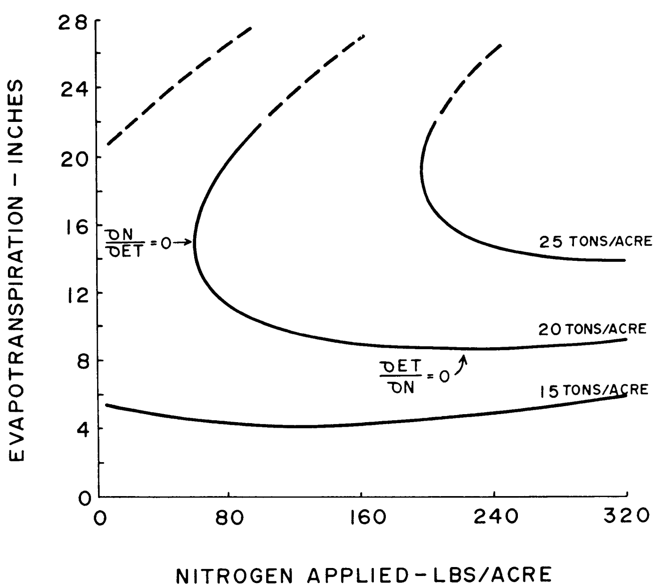

Fig. 3. Yield isoquants for marketable cabbage with variable levels of N and evapotranspiration.

$$ET = 12.9006 + 0.0314N \pm \sqrt{373.9041 + 0.92028N - 0.005096N^2 - 21.3675Y}.$$

This equation was derived from the production function equation [1]. The isoquant curves show combination of ET and N required to produce 15, 20, and 25 tons per acre of marketable cabbage. The minimum amount of ET needed to produce a specified yield occurs when $\frac{\partial ET}{\partial N} = 0$. This was approximately 4, 9, and 14 inches of ET for the 15-, 20-, and 25-ton per acre yields, respectively. Note the small response to N at these ET levels. The contours also indicate that yields of 20 and 25 tons per acre required at least 60 and 196 lb. of N fertilizer, respectively. Within the limits $\frac{\partial ET}{\partial N} = 0$ and $\frac{\partial N}{\partial ET} = 0$, N may be substituted for ET without a reduction in yield. Considering the 20-ton per acre yield isoquant, it is evident that by increasing the N supply from 60 to 218 lb. per acre the ET requirement could be reduced from 15 to 8.6 inches. If N fertilizer is cheaper than water, such a substitution may be economically profitable. The curves also indicate that at high levels of ET, the rates of N must be increased to maintain yields.

Economic optima. Estimates of obtainable yields at various rates of N under different irrigation regimes are provided by the production functions presented in Table 3. The N rates that will result in maximum profit may be computed from these equations by taking the derivative of yield (4) with respect to N and equating to various N:cabbage price ratios (Table 4). As the relative prices of cabbage increased or N decreased, the optimum rate of N and profits increased even though the yields increased only slightly. Profits from the application of N decreased as the frequency of irrigation decreased, because more N was required to produce optimum yields. Harvest and fertilizer application costs were not considered.

An inaccurate estimate of the expected cabbage price affects the return from N fertilizer (Table 5). Over-application of 20.8 lb. N per acre resulted in a direct cost of \$1.12 per acre, while underapplication of 10.4 lb. N per acre caused an indirect loss in return above the cost of the N fertilizer of \$2.44 per acre.

These optimum rates of N are higher than N fertilizer rates generally used and should be modified when soil test information indicates a higher initial soil N supply than was present in this study.

Table 4. Optimum N rates for specified price ratios of N to cabbage (P_N/P_C) at two irrigation regimes.

Irrigation regime	Prices: Cabbage	Prices: N	P_N/P_C	Optimum N rates	Cabbage yield	Return from N per acre[1]
	Per ton	Per lb.		Lb./acre	Tons/acre	Dollars
I-1.........	\$10	\$0.10	0.010	211.7	26.3	80.63
	20	.10	.005	225.6	26.4	182.24
	40	.10	.0025	232.5	26.5	390.35
	10	.15	0.015	197.8	26.2	70.73
	20	.15	.0075	218.6	26.4	172.01
	40	.15	.00375	229.0	26.5	379.25
I-2.........	\$10	\$0.10	0.010	235.0	21.9	16.15
	20	.10	.005	285.0	22.2	80.30
	40	.10	.0025	310.0	22.3	190.60
	10	.15	0.015	185.0	21.3	17.65
	20	.15	.0075	260.0	22.1	67.80
	40	.15	.00375	297.5	22.3	176.98

[1]Value of nonfertilized cabbage deducted.

Table 5. Effect of inaccurate estimate of cabbage price on return above cost to N fertilizer.

Price of cabbage per ton	Most profitable rate of N	Difference in cost of N applied[a]	Yield at most profitable N rate	Value of yield difference	Loss in return to N
Dollars	Lb./acre	Dollars	Tons/acre	Dollars	Dollars
10	197.8	+3.12	26.2	+2.00	+1.12
20[b]	218.6	0	26.4	0	0
40	229.0	–1.56	26.5	–4.00	–2.44

[a]N at 15 cents per lb.
[b]Assumed price of cabbage at time N applied.

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Additional Allelic Genes in *Malus* for Scab Resistance of Two Reaction Types[1]

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Abstract. A gene conditioning the 3-type resistance reaction to *Venturia inaequalis* Cke. (Wint.), recovered from *M. micromalus* Mak., is shown to be carried at the V_f locus, and thus allelic with similar genes recovered from 10 other *Malus* species and forms. *Malus micromalus* and *M. atrosanguinea* (Spaeth) Schneid. 804 are shown to carry allelic genes conditioning the pit-type of resistant reaction. The symbol V_m is assigned to this locus.

Ten *Malus* species and forms carry a common gene, designated V_f, which confers resistance to *Venturia inaequalis* Cke. (Wint.), the fungal incitant of apple scab (6, 7). A gene conditioning a pit-type of resistant reaction, recovered from *M. atrosanguinea* 804[4], is independent of the V_f gene (2). The 3-type resistant reaction of V_f, as well as the pit-type reaction of genes carried by *M. micromalus* and *M. atrosanguinea* 804, were described by Shay and Hough (4). We report evidence demonstrating 1) the allelism with V_f of a 3-type gene recovered from *M. micromalus,* and 2) allelism of pit-type genes carried by this species and by *M. atrosanguinea* 804.

Materials and Methods

Methods of crossing, handling seeds and seedlings, and determination of resistance are the same as described earlier (7). Additional gene sources are *M. micromalus* 3-type and pit-type. Scab resistance genes recovered from *M. atrosanguinea* 804 were described earlier (2).

Results

Based on the hypothesis previously described (7) interspecific resistant segregates, if carrying allelic genes (AA or Aa), should yield progenies with resistant: susceptible segregation ratios of 1:0 or 1:1 when crossed with a homozygous susceptible (aa) testcross parent. If carrying nonallelic and independent genes (AaBb, aaBb or Aabb) they should yield segregation ratios of 3:1 or 1:1. The segregation ratios obtained in this study conform to this hypothesis.

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[2]Purdue University, Lafayette, Indiana and U.S. Department of Agriculture.

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[4]Identifies a specific clone.

Table 1 shows the ratios from crosses of interspecific selections with 'McIntosh'. With *M. floribunda* Sieb. 821/*M. micromalus* (3-type), 3 segregates gave 1:0 and 6 gave 1:1 resistant: susceptible ratios when crossed with 'McIntosh'. With *M. prunifolia* 19651/*M. micromalus* (3-type), 2 gave 1:0 and 3 gave 1:1 ratios. The resistance

Table 1. Segregation in test cross progenies resulting from crosses of resistant selections with the susceptible cv. McIntosh.

Resistant parent seedling number	Number seedlings tested	Resistant		Ratio R:S
		No.	%	
M. floribunda 821/*M. micromalus* (3 type)				
TSR21T29	370	368	99	1:0
45	262	261	99	1:0
46	317	157	50	1:1
47	368	170	46	1:1
49	377	375	99	1:0
50	292	151	52	1:1
51	97	52	54	1:1
56	376	186	49	1:1
TSR25T18	299	155	52	1:1
M. prunifolia 19651/*M. micromalus* (3 type)				
TSR8T191	215	214	99	1:0
194	359	194	54	1:1
TSR26T103	341	337	99	1:0
116	385	192	50	1:1
117	306	153	50	1:1
Russian /*M. micromalus* (3 type)				
TSR21T173	337	259	77	3:1
179	67	32	48	1:1
180	251	120	48	1:1
182	255	191	75	3:1
184	194	101	52	1:1
186	224	111	50	1:1
188	515	252	49	1:1
190	120	92	77	3:1
195	237	121	51	1:1
197	111	88	79	3:1
M. micromalus (pit)/*M. atrosanguinea* 804 (pit)				
TSR22T22	683	666	98	1:0
23	566	540	95	1:0
26	137	66	48	1:1