An Economic Analysis of Fertilizer and Seeding Rates for Spinach Production in Eastern Oklahoma

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This bulletin reports the results of a study for determining the most profitable seeding rates and nitrogen fertilizer levels for growing spinach in eastern Oklahoma. Spinach yield data from an experiment at Bixby, Oklahoma involving different levels of seed and nitrogen were used as a basis for the study. Additional returns and costs from varying levels of seed and nitrogen were estimated, statistically, using selected spinach, seed, and nitrogen prices. Most profitable seed and nitrogen levels were determined for the yield relationships and prices considered.

The Spinach Enterprise in Oklahoma

Spinach is grown commercially on alluvial soils in eastern Oklahoma. Both spring and fall crops are normally grown in this area. The spring crop may be an over-wintered crop or it may be from a new seeding. Approximately 15 percent of the crop is sold on the fresh market and the rest is canned or frozen. Average yields per acre have increased considerably, in the last few years, due to new varieties and improved production practices although the total acreage has remained about the same. Total sales value of spinach, grown commercially in Oklahoma, averaged over $700,000 annually from 1951 to 1960.

Experimental Procedure

A factorial spinach, nitrogen fertilizer and seeding rate response experiment was designed and conducted at the Vegetable Research Station near Bixby, Oklahoma, in the fall of 1958. Spinach was planted September 25 and harvested on December 2. The experiment was accidentally destroyed in February, 1959; thus, no spring harvest was made. A well prepared seed bed of Reinach silt loam, previously planted to snap beans, was used. The soil contained 24 pounds per acre of available nitrogen, 123 pounds per acre of available phosphorous, and 64 pounds per acre of available potassium.

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Table 1.—Yield Estimates ($\hat{Y}$) of Hybrid No. 7 Spinach in Relation to Different Fertilizer and Seeding Rate Combinations*

Pounds of Nitrogen	Pounds of Seed Per Acre (S)									
Per Acre (N)	1	2	3	4	5	6	7	8	9	9.68
					(Tons per acre)					
0	4.274	5.104	5.789	6.330	6.728	6.980	7.089	7.054	6.874	6.669
40	4.286	5.716	6.132	6.692	7.126	7.444	7.506	7.489	7.328	7.136
80	4.820	5.689	6.410	6.988	7.422	7.712	7.858	7.859	7.717	7.537
120	4.996	5.881	6.622	7.219	7.672	7.980	8.144	8.164	8.040	7.873
160	5.106	6.010	6.769	7.384	7.856	8.183	8.365	8.404	8.298	8.144
200	5.151	6.073	6.851	7.485	7.975	3.320	8.521	8.578	8.491	8.350
240	5.130	6.071	6.867	7.520	8.028	8.392	8.612	8.688	8.619	8.490
280	5.044	6.004	6.819	7.490	8.016	8.399	8.637	8.731	8.681	8.565
320	4.893	5.871	6.705	7.394	7.939	8.340	8.597	8.710	8.678	8.575
360	4.677	5.673	6.525	7.233	7.797	8.217	8.492	8.623	8.610	8.519
400	4.395	5.410	6.281	7.007	7.590	8.028	8.322	8.471	8.477	8.398

*$\hat{Y} = 3.3 + \underset{.10}{.008N} - \underset{.06}{.0000204N^2} + \underset{.01}{1.046S} - \underset{.01}{.0721S^2} + \underset{.24}{.000463NS}$ was used to obtain yield predictions.

Numbers under the coefficients indicate significance levels obtained from a "t" test.

A uniform application of 375 pounds per acre of 0-16-8 was broadcast and disked into the soil prior to planting. One hundred pounds (300 pounds of 33-0-0) of nitrogen per acre per week was applied until the treatment level was reached (0 to 400 pounds per acre). Seedings were made in rows 12 inches apart to obtain 1, 2, 4, or 8 plants equally spaced per foot of row. This gave calculated seeding rates of 1.21, 2.42, 4.84, and 9.68 pounds per acre of 90 percent germination Hybrid No. 7 seed (2250 seeds/ounce). Irrigation provided supplemental moisture throughout the season.[1]

Spinach Yield Response to Seeding Rate and Nitrogen Fertilizer Rate

An equation (1)[2] for estimating yield levels resulting from different nitrogen and seeding rates was developed by the least squares regression method from the yield data given in Table 5.

Total yield predictions for different levels of nitrogen and seed, based on Equation (1), are presented in Table 1. For example, the yield ($\hat{Y}$) expected from 120 pounds of nitrogen and seven pounds of seed is about 8.1 tons. Equation (1) may also be used to predict changes in yields resulting from changes in applications of nitrogen and seed. This can be done by comparing yields before and after changing the input levels (Table 2).

Since the data cover only one season, the residual effects of fertilizer and effects of climatic variables other than soil moisture cannot be determined. It was assumed that soil moisture could be controlled by irrigation and held constant at a nonlimiting level. If other variable natural factors do not interact strongly with fertilizer and seed response, the limited number of observations is not a serious shortcoming. That is, the optimum rates presented would remain optimum. Ranges over which Equation (1) applies are limited to experimental treatments of 0 to 400 pounds of available nitrogen and a calculated seeding rate of 1.21 to 9.68 pounds per acre. Frequently, 15 to 18 pounds of seed per acre are planted because 50 percent or more of the seeds planted often do not grow into mature plants due to competition. Later experiments have utilized higher rates of seeding and will provide a basis for further analysis when results are available.

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[1]Additional details of the experimental procedure may be found in Oklahoma Agricultural Experiment Station Processed Series P-339.

[2]Equations cited may be found in the appendix, page 15.

Table 2.—Additional Spinach Yields from Adding Nitrogen and Seed, Given Initial Levels of Nitrogen and Seed*

	Seed					
Nitrogen	6.8	7.0	7.2	7.4	7.6	7.8
			(Tons Per Acre)			
100	.0071 .1117	.0072 .0829	.0073 .0541	.0073 .0252	.0074 —.0036	.0075 —.0325
120	.0063 .1210	.0063 .0922	.0064 .0633	.0065 .0345	.0066 .0056	.0067 —.0232
140	.0054 .1303	.0055 .1014	.0056 .0726	.0057 .0437	.0058 .0149	.0059 —.0139
160	.0046 .1395	.0047 .1107	.0048 .0818	.0049 .0530	.0050 .0242	.0051 —.0047
180	.0038 .1488	.0039 .1199	.0040 .0911	.0041 .0623	.0042 .0334	.0043 .0046
200	.0030 .1580	.0031 .1292	.0032 .1004	.0033 .0715	.0034 .0427	.0035 .0138

*The lower figure in each cell of the table is the change in yield per pound of seed when seed is increased by a small amount. The upper figure is the change in yield per pound of nitrogen when nitrogen is changed by a small amount. For example, when nitrogen application is 160 pounds and seeding rate is 7.2 pounds, a small increase in the seeding rate would give .0818 tons of additional spinach. The .0818 corresponds to $\frac{\Delta Y}{\Delta S}$ discussed elsewhere in this bulletin. If $.0818 = \frac{P_s}{P_y}$, more or less seed would not be profitable. If $.0818 > \frac{P_s}{P_y}$, more seed would be profitable and if $.0818 < \frac{P_s}{P_y}$, less seed would be profitable. If $.0818 > \frac{P_s}{P_y}$ (N = 160, S = 7.2) and $.0530 < \frac{P_s}{P_y}$ (N = 160, S = 7.4), the optimum seeding rate is between 7.2 and 7.4 pounds per acre. The table also indicates that negative additions to yield may result from additional seed.

Spinach, Nitrogen, and Seed Prices

Ranges and usual prices of spinach, nitrogen, and seed used in this study are:

Spinach Price (P_y) : Range, \$17.00-\$54.00 per ton; Usual, \$30.00.
Nitrogen Fertilizer Price (P_n) : Range, \$.120-\$.145 per pound; Usual, \$.126 per pound.
Spinach Seed Price (P_s) : Range, \$.85-\$1.10 per pound; Usual, \$1.00 per pound.

Computations of optimum input levels, in this bulletin, utilize prices within these ranges. Spinach prices (P_y) are net of harvesting charges (i.e., market price minus $20 per ton for harvesting) so that net additions to returns from use of additional nitrogen (ΔN) and seed (ΔS) can easily be figured. In addition to covering variable fertilizer costs (P_n), returns from applying nitrogen must be sufficient to pay small fixed machinery and labor costs for applying fertilizer. (Custom charges for nitrogen application are $1.00 to $1.50 per acre and will be fairly constant over a wide range of application levels.) Planting costs are initially assumed to be equal for all seeding rates. Spinach producers know seeding costs and fertilizer costs at the time decisions are made, however, spinach prices must be anticipated.

Determining Fertilizer and Seeding Rates

The additional return from adding nitrogen is $\Delta Y \bullet P_y$;—where, ΔY is read "change in Y", and P_y is the value of spinach per ton after harvesting, hauling, and marketing costs are paid. The additional cost is $\Delta N \bullet P_n$;—where, ΔN is read "change in N" and P_n is the cost of nitrogen per pound. Additional nitrogen will be added until $\Delta Y \bullet P_y = \Delta N \bullet P_n$, or $\frac{\Delta Y}{\Delta N} = \frac{P_n}{P_y}$.[3] Similarly, seed will be added until $\Delta Y \bullet P_y = \Delta S \bullet P_s$, or $\frac{\Delta Y}{\Delta S} = \frac{P_s}{P_y}$; where, ΔS is read "change in S" and P_s is cost of seed per pound.[3]

Most profitable levels of nitrogen and seed for selected spinach, nitrogen fertilizer, and seed prices are given in Table 3. These levels were obtained by applying the economic choice guides presented above to Equation (1). The best nitrogen rates vary markedly as nitrogen and spinach prices vary. For example, with seed and spinach prices of 90 cents per pound and $30 per ton, respectively, optimum nitrogen rates decrease from 201 pounds to 166 pounds per acre as nitrogen prices increase from 10 to 14 cents per pound. In contrast, seeding rates are not often changed by seed prices, however, seeding rates do vary with spinach prices. The small changes suggested by this study would be difficult to achieve with present planting techniques.

Additional Returns from Fertilizer and Seed

Constant attention to production details, such as adjusting seed and nitrogen use as prices change, requires time and effort on the part

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[3]Table 2 provides estimates of $\frac{\Delta Y}{\Delta N}$ and $\frac{\Delta Y}{\Delta S}$, where ΔN and ΔS are small and initial levels of nitrogen and seed are given. These estimates can be used in applying economic choice criteria.

Table 3.—Profitable Levels of Nitrogen Fertilizer (N) and Seeding Rate (S) For Selected Prices of Spinach, Nitrogen Fertilizer, and Seed (Pounds per Acre)

Nitrogen	Seed (S)	Spinach Price Per Ton			
(Per Pound)	Nitrogen (N)	$20	$30	$40	$50
		Seed $.90 Per Pound			
.10	S	7.4	7.7	7.8	7.9
	N	156	201	225	237
.12	S	7.4	7.6	7.8	7.9
	N	133	185	209	228
.14	S	7.3	7.6	7.7	7.8
	N	108	166	197	215
		Seed $1.00 Per Pound			
.10	S	7.4	7.7	7.8	7.9
	N	156	202	224	235
.12	S	7.3	7.6	7.7	7.8
	N	133	183	212	226
.14	S	7.2	7.6	7.7	7.8
	N	107	167	199	216
		Seed $1.10 Per Pound			
.10	S	7.4	7.6	7.8	7.9
	N	156	203	223	236
.12	S	7.3	7.6	7.7	7.8
	N	133	184	208	226
.14	S	7.2	7.5	7.7	7.8
	N	106	168	198	216
		Seed $2.00 Per Pound*			
.10	S	7.0	7.4	7.6	7.7
	N	154	199	221	235
.126	S	6.9	7.4	7.6	7.7
	N	120	177	205	222
.14	S	6.9	7.3	7.5	7.7
	N	103	165	196	214

*This price may represent higher seed prices, additional seeding costs or use of extra seed because of mechanical seeding limitations.

of the manager. Thus, the manager is interested in probable effects of his efforts on returns. Table 4 provides estimates of per acre returns from different levels of seed and fertilizer. Column 1 shows an example of a hypothetical "low" level of management input where available price or production data and economic analysis are not utilized. Columns 2, 3, and 4 estimate results of selecting the best seed and nitrogen inputs under different price levels or capital changes.

Columns 1 and 2 indicate that added returns of $7 to $36 per acre may be obtained by using price and production data and economic criteria provided in this bulletin. If the "low" level practice did not differ from the optimum by much, returns from managerial activities would be less significant. Raw experimental data in Table 5 could be used to choose seed and fertilizer levels on the basis of (1) maximum expected yields or (2) profits from a low input treatment compared to higher ones. However, if actual responses are more nearly predicted by Equation (1), returns would be $5 to $15 per acre lower than those for input levels indicated in Table 3.

Gains in returns obtained by adjusting to changes in prices can be estimated by comparing returns from optimum inputs for new prices with returns from old inputs with new prices. For example, if 7.2 pounds of seed and 108 pounds of nitrogen (optimum for Column 3, Table 4, with $20 spinach) were maintained after spinach prices increase to $30 per ton, expected per acre returns would be about $220 compared to about $222 if input adjustments are made. Thus, an additional $2 is gained by handling larger quantities of fertilizer and seed.

Similar small returns are obtained when input levels are adjusted for changes in input prices, with product prices constant. Thus, a reasonable grower strategy is to choose seed and nitrogen rates for typical product and input prices and to ignore changes in prices between years. Such strategy is especially practical when input levels are not accurately measurable or controllable and response expectations are rough, best estimates. A manager's willingness to change seeding or fertilizer rates is determined finally by the importance attached to small, expected additional returns and his confidence in the production, price, and return estimates available.

Seed and Planting Costs Under Present Technology

The preceding analysis assumes that, within limits, a desired stand can be obtained by applying 90 percent germination seed quantities indicated. However, available planting equipment or plant competition may require more seed than necessary to get a good stand. Although labor and machine planting costs do not increase with higher seeding rates, effective seed costs are increased. For example, if two pounds of seed are required to get the effects of one pound, seed costs are doubled. In this case, excess plants could be eliminated during weed control operations or by intentional thinning.

Table 3 indicates the effects of higher seed costs on optimum seeding rates and nitrogen levels. The $2 per pound seed cost may be interpreted as reflecting a number of additional seed-thinning cost combinations for different seed prices. Optimum seeding rates are typically decreased less than .5 pounds and nitrogen less than 5 pounds as seed prices in-

Table 4.—Optimum Nnitrogen Levels, Seeding Rates, and Per Acre Returns* For One Acre of Spinach Under Varying Interest Rates (Or Input Prices)**

		Interest Rate (or Input Price)**		
Interest Rate; Per Cent	0	0	10	30
(Seed; Per Pound)	1.00	1.00	1.10	1.30
(Nitrogen; Per Pound)	.126	.126	.139	.164
Seed and Nitrogen Levels, Yield, and Per Acre Return	"Low" Level (1)	Optimum for Prices Assumed (2)	Optimum for Prices Assumed (3)	Optimum for Prices Assumed (4)
	Spinach Price $20.00 Per Ton			
Seed (lb./A.)	5	7.3	7.2	7.0
Nitrogen (lb./A.)	100	124	108	75
Yield (Tons/A.)	7.56	8.20	8.08	7.82
Returns ($/A.)	134.00	141.00	139.00	135.00
	Spinach Price $30.00 Per Ton			
Seed (lb./A.)	5	7.6	7.5	7.4
Nitrogen (lb./A.)	100	179	168	146
Yield (Tons/A.)	7.56	8.50	8.44	8.33
Returns ($/A.)	209.00	225.00	222.00	216.00
	Spinach Price $50.00 Per Ton			
Seed (lb./A.)	5	7.8	7.8	7.7
Nitrogen (lb./A.)	100	223	216	203
Yield (Tons/A.)	7.56	8.65	8.63	8.59
Returns ($/A.)	360.00	396.00	393.00	386.00

*Returns are gross spinach receipts per acre less harvest, seed, nitrogen, and interest charges. Yields and returns are rounded to nearest .01 ton and dollar, respectively.

**Interest rates of various levels may be interpreted as an increase in input price with no interest charge. Thus, equivalent seed and nitrogen prices for different interest rates are given in parenthesis.

crease from $1.10 to $2 per pound. Application techniques probably do not allow calibration of inputs within bounds closer than these deviations. Effects on returns are also negligible. Thus, the producer can safely devote a major effort to initial choice of fertilizer and seeding practices which will remain invariant over a wide range of product, seed, and nitrogen prices.

Opportunity Cost of Money Invested in Fertilizer

The amount of fertilizer and seed which can be applied profitably may depend on the availability and cost of short-term capital. Whether the producer borrows or supplies his own capital, the cost is either (1) its opportunity cost (i.e., the level of returns to capital in its best alternative use if capital is limited) or (2) the interest charge on the capital, if the capital supply is unlimited.

For example, suppose a farm manager pays 10 percent interest on operating capital but can borrow no more than $30,000. If, in investing the full $30,000, the farm manager gets $1.20 on the last dollar invested, then the opportunity cost of capital is $1.20 and $K = 1.2$:—where $K \geqslant 1$ is cost of capital. Capital would not be reallocated unless it would return more than $1.20 in the new use. However, if the manager can borrow all he wishes at 10 percent interest, he will use capital to the point where the last dollar invested yields $1.10. For this farmer the cost of capital is simply what he must pay for it, i.e., $1.10 and $K = 1.1$.

Choice guides presented earlier can be modified to take into account the cost of capital by increasing the effective price of nitrogen and seed.[4] For example, with $K = 1.1$ and nitrogen at $.10 per pound, the effective price of nitrogen is 11 cents per pound. If nitrogen and seed prices are assumed to remain constant, Table 3 may be interpreted as reflecting the effects of increasing interest rates. Thus, as interest rates increase (P_n increases), optimum levels of nitrogen decrease. On the other hand, seeding rates are not affected much by increased interest rates (higher P_s).

Summary

A spinach experiment conducted near Bixby, Oklahoma was used as a basis for estimating the profitability of applying varying rates of nitrogen fertilizer and spinach seed.

[4]See Equations (2) and (3), page 15.

Table 5.—Hybrid No. 7 Spinach Yields* of Different Seeding and Nitrogen Fertilizer Rates

No. of plants per foot of row**	Calculated seeding rate (pounds per acre of 90 percent germination seed)	Nitrogen (Pounds per Acre) 0	100	200	300	400
				(Tons Per Acre)		
1	1.21	3.70	5.08	4.61	5.74	4.47
2	2.42	6.53	6.32	7.26	5.96	5.95
4	4.84	6.54	6.82	7.58	8.53	7.01
8	9.68	6.46	8.64	7.08	9.29	8.35

*Average of six replications.
**Rows 12 inches apart.

Spinach yield was explained as a function of seed and nitrogen, given other production inputs, irrigation, and 1958 climatic, insect, and disease conditions. Additional nitrogen and seed can profitably be added as long as the value of additional yield ($\Delta Y \bullet P_y$) is greater than the additional cost of the fertilizer and seed ($\Delta N \bullet P_n$ or $\Delta S \bullet P_s$). Prices of nitrogen and seed (P_n and P_s) are known at the time the decision is made but the price of spinach (P_y) must be estimated.

One hundred sixty to one hundred eighty pounds of nitrogen and 7.6 pounds of seed per acre produced the greatest profits in this study. This was based on an estimate of one year's experimental results and "usual" prices. The estimated yield, for this combination, was about 8.5 tons per acre. A decrease to five pounds of seed and 100 pounds of nitrogen decreased returns about $15 per acre. However, 7.6 pounds of seed and 100 pounds of nitrogen would only drop returns $4 lower than the optimum input combination. Thus, nitrogen levels of 100 to 180 pounds could apparently be considered in the optimum range. Best nitrogen and seed levels are presented for a number of spinach, seed, and nitrogen prices and different capital costs.

Per acre return gains were not increased by varying seed and nitrogen application as spinach prices changed. Even when seed prices were doubled optimum seeding rates remained about the same. Thus, carefully chosen seeding and fertilizing levels could be adopted and maintained over a wide range of prices.

Additional experiments are being conducted using higher seeding rates achieved by closer row spacing. These experiments will allow observation of between-year variation in spinach response to nitrogen and seed. Results presented here apply particularly to one type of year and given experimental conditions and are subject to limitations of experimental methods and statistical techniques employed.

APPENDIX

(1) $\hat{Y} = 3.3 + .008N - .0000204N^2 + 1.046S - .0721S^2 + .000463NS$

$R^2 = .81$

where: $\hat{Y}$ = predicted yield of spinach in tons per acre
N = pounds of nitrogen added per acre (0 to 400 pounds)
S = calculated pounds of seed per acre (1.21 to 9.68 pounds of Hybrid No. 7, 90 percent germination)

Coefficients attached to N, N^2, S, and S^2 were significant at the 90 percent level or higher. Only the coefficient attached to the cross-product term (NS) had a very high probability of actually being zero. However, the cross-product term is presented because of expected physiological relationships. Eighty-one percent of variation in the experimental data is explained by this equation.

(2) $\frac{\Delta Y}{\Delta N} = \frac{P_n K}{P_y}$, or $\Delta Y \bullet P_y = P_n K \bullet \Delta N$

(3) $\frac{\Delta Y}{\Delta S} = \frac{P_s K}{P_y}$, or $\Delta Y \bullet P_y = P_s K \bullet \Delta S$