Chapter 9

EFFECTS OF NUTRIENT ELEMENTS ON FRUITING EFFICIENCY

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INTRODUCTION

NUTRIENT ELEMENT BALANCE

In order to understand the influence of nutrient elements on flowering and fruiting, it is helpful to review the concept of nutrient element balance as proposed by Shear *et al.* (1946). According to their hypothesis, when all other environmental factors are at optimum conditions, plant growth is a function of two variables of nutrition; intensity and balance. Intensity is the concentration of individual nutrient elements as reflected in the tissue concentration at a given stage of growth. Balance refers to the relation of the concentration of one element to the concentration of all of the other essential nutrient elements. At any given level of intensity (concentration) for one element, the highest yield will be obtained only when all of the other nutrient elements are brought to a level of optimum balance. Maximum yield, which is perhaps a figment of our imaginations, is obtained only upon the coincidence of optimum intensity and balance for all the essential elements. A substantial decrease or an increase of any essential element from its concentration at optimum intensity for a given balance will result in a decrease in yield. A new yield peak is possible only when the concentrations of all the other nutrient elements are adjusted to bring about a new balance. Thus, a change in the accumulation of one element may or may not be in the direction of improving balance. In any respect, that change will be reflected in growth, yield, and sometimes the appearance of other visual symptoms.

MEASUREMENTS OF FRUITING, FRUITING EFFICIENCY, AND EARLINESS

The term, yield, needs clarification since it may refer to vegetative or fruit production depending upon the crop in question. With cotton, we are concerned only with fruit (boll) production and, more often, only a portion of the fruit, the fiber. When a nutritional stress is applied, either intentionally or unintentionally, the effect of that stress may be measured in vegetative and/or fruiting growth. Through the years, several indices have been developed which provide useful information concerning the efficiency of a cotton plant in supporting a boll load.

Eaton (1945) coined the term, relative fruitfulness, and defined it as the number of green bolls per 100 grams of fresh stem and leaves. He used this ratio as an indication of the efficiency of the cotton plant to support a fruit load. Measurements of relative fruitfulness can be made under field conditions with very simple equipment. When using relative fruitfulness to compare varieties, one needs to be aware of the difference in boll size between varieties. Joham (1955) used the ratio dry weight of bolls to dry weight of stems plus leaves to describe fruiting efficiency and termed this ratio the fruiting index. Fruiting index gives a more reliable comparison between varieties than relative fruitfulness, but is more difficult to measure since the plants must be taken to the laboratory for oven drying before weighing. Fruiting index is similar to harvest index (dry weight of grain/total dry weight of plant) commonly used in cereal crops.

Both indices, relative fruitfulness and fruiting index, are measurements of fruiting efficiency and are related to the ability of the vegetative portion of the cotton plant to support a fruit load. One must be aware that neither relative fruitfulness or fruiting index is a measure of yield. Small and large plants may have the same relative fruitfulness or fruiting index measurements, but the yield of the large plant will be much greater than that of the small plant. Depending upon the treatment, plants of equal size may differ considerably in their relative fruitfulness or fruiting index measurements. In this case, the indices are directly related to yield.

Relative fruitfulness and fruiting index may be characteristics which are primarily under genetic control, but we have ample evidence that environmental factors play major roles in the expression of these characteristics. Variations in light intensity, going from shaded conditions to light saturation, are associated with marked increases in relative fruitfulness of cotton. Increases in temperature, from suboptimal to optimal, promote increases in relative fruitfulness and fruiting index. The role of moisture is much more difficult to evaluate, but we know of effects of moisture stress on flowering and square shedding which in turn would influence the indices of fruiting efficiency (Chapter 7). Thus, light intensity, temperature, and moisture are major environmental factors influencing measurements of fruiting efficiency. Within this framework, the supply of nutrient elements plays an important role in the partition of vegetative and fruiting growth.

By using fruiting index or relative fruitfulness, one is able to examine the association of the nutrient element with vegetative or fruiting growth. When this is done, we find we may classify the essential elements into two broad groups. The first group consists of those elements in which a deficiency of the element causes a decrease in fruiting index or relative fruitfulness. Such nutrient elements seem to play a more direct role in flowering or fruiting. A deficiency of such an element limits fruit production to a greater extent than it does vegetative growth. Elements which fall within the above group are P, K, Ca, Mg, B and possibly Zn. The second group are those elements in which a deficiency has little or no effect on the fruiting index or relative fruitfulness. This is not to say that a deficiency of such an element does not decrease yield, but rather the deficiency restricts vegetative and fruiting growth to an equal extent. This group is comprised of N, S, Mo and Mn.

Within the concept of nutrient element balance, we may study the effect of each nutrient element on vegetative and fruiting growth for that particular nutritional environment we impose on our experiment. With all other elements at what we hope is an optimum balance, we then vary the level of our test element and observe the effects of that treatment on growth and fruiting.

Another important aspect of growth and differentiation is earliness. This term has different meanings depending upon the background of the authors and their use of the term. From a physiological point of view, a measure of earliness should involve the changes from vegetative growth to flower and fruit production. Appearance of first squares, open flowers or nodal position of the first fruiting branch might well be yardsticks of earliness in the physiological sense. From an agronomic point of view, earliness may refer to crop production and be measured by the percent of the crop harvested at first picking and the number of days from planting to first harvest. As the flowering period progresses, there is a tendency for flower production to reach a peak and then decline rapidly and even stop. The point at which flowering stops is referred to as cutout. Determinate cotton varieties have short flowering periods with clearly marked cutout points while indeterminate varieties are apt to continue flowering over much longer periods. Eaton (1955) points out that determinateness may be primarily under genetic control, but it is influenced by environmental factors. Temperature and moisture play major roles in expression of determinateness and in some cases, nutrient supply is of equal importance.

EFFECTS OF NUTRIENTS ON FLOWERING AND FRUITING

ELEMENTS AFFECTING THE VEGETATIVE-FRUITING RATIO

Certain nutrient elements have very marked effects on fruiting efficiency, the partition of vegetative and fruiting growth. Changes in the substrate concentration of these elements, especially as their concentrations approach deficient levels, are accompanied by decreases in relative fruitfulness and fruiting index. These elements may or may not have an influence on the various measurements of earliness. Even so, we group these elements together as elements controlling fruiting efficiency.

Phosphorus—A deficiency of phosphorus (P) decreases relative fruitfulness and fruiting index of cotton. In a greenhouse experiment, Ergle and Eaton (1957) varied the P content of nutrient solutions supplied to Empire cotton grown in sand. The nutrient solution designated as low P was supplied 1.4 or 7.8 ppm P on alternate days. The high P supply was maintained as 24 ppm throughout the experiment. The low P treatment caused a 97 percent reduction in yield (dry weight of bolls) of 87-day-old cotton plants. Relative fruitfulness was 4.5 and 1.0 for the high and low P treatments, respectively. Sorour (1963) determined the fruiting index of normal and P deficient Deltapine 15 plants at 130 days after planting. The fruiting index, 0.92 for the normal plants, was reduced to 0.25 by P deficiency (Table 1).

Brown and Pope (1939) studied the influence of P supply on earliness of cotton. They varied the N, P, and K supplied to cotton in a five year field study. Phosphorus was varied from 0 to 144 pounds P_2O_6/acre. Their P treatment had a small effect on yield. The increase from 2061 to only 2268 pounds seed cotton per acre was probably insignificant. Even though P had little effect on yield, increasing P promoted earliness as measured by percent of seed cotton at first picking and percent blooms during the first two weeks of flowering (Table 1).

Table 1. Effect of phosphorus on relative fruitfulness,[1] fruiting index[2] and earliness of cotton.[3]

P supply (ppm)	Fresh weight (g.) leaves & stems	Boll count	Relative fruitfulness
1.4-7.8	71	0.7	1.0
31.0	544	24.5	4.5
	Dry Weight (g.)		Fruiting index
	Leaves & stems	Bolls	
3.1	53	13	.25
31.0	107	98	.92
P_2O_5 (lbs/acre)	Seed cotton (lbs/acre)	% Seed cotton first picking	% Blooms 1st 2 weeks
0	2061	48	29
144	2268	67	40

[1]Data from Ergle and Eaton (1957).
[2]Data from Sorour (1963).
[3]Data from Brown and Pope (1939).

Potassium—Variations in the potassium (K) supply of the substrate are associated with marked changes in the fruiting index. In a greenhouse experiment (Joham, 1955) in which cotton plants were grown for 45 days in complete nutrient solution and then for an additional 45 days in nutrient solution with and without K the fruiting index was 0.89 for the plus K treatment as compared to 0.34 for the

Table 2. Effect of potassium on fruiting index[1] and earliness[2] of cotton.

Nutrient treatment	Dry weight (g.) Leaves & stems	Bolls	Fruiting index
Control	28.7	25.4	.89
-K	36.4	12.5	.34
-K+Na	28.5	24.0	.84
K (lbs/acre)	Seed cotton (lbs/acre)	% Seed cotton first picking	% Blooms 1st 2 weeks
0	1998	62	33.4
72	2454	56	33.4

[1]Data from Joham (1955).
[2]Data from Brown and Pope (1939).

K deficient series (Table 2). The minus K (-K) plants produced considerably more vegetative dry weight than did the plus K plants, but the -K treatment caused a 51 percent reduction in boll load. When considering the influence of K on fruiting, one must be aware of the sodium (Na) content of the nutrient medium. A number of investigators have reported that the addition of Na on K deficient soils increases yield of cotton (Cooper *et al.*, 1953; Lancaster *et al.*, 1953; Marshall and Sturgis, 1953). Joham (1955) and Joham and Amin (1965) demonstrated the partial substitution of Na for K in the nutrition of cotton under controlled conditions. When Na was added to K-deficient nutrient solution, the fruiting index was increased to a level equal to the control plants (Table 2). It is interesting to note that the -K plants produced more vegetative dry weight than the control or -K+Na series. Thus, in K deficiency the addition of Na promoted fruiting.

In the field study conducted by Brown and Pope (1939), K did not influence earliness. Even though they obtained a significant 456 lbs/acre increase in seed cotton when K_2O supply was raised from 0 to 72 lbs/acre, there was no difference in the percent seed cotton harvested the first picking nor the percent blooms produced the first two weeks of flowering (Table 2).

Calcium and Magnesium—Deficiencies of either calcium (Ca) (Joham, 1955) or magnesium (Mg) (Helmy *et al.*, 1960) decrease relative fruitfulness and fruiting index. In an experiment in which calcium supply was drastically restricted during the flowering period, flowering and fruiting was almost completely stopped and fruiting index fell from 0.89 for the control plants to 0.06 for the -Ca treated plants (Table 3). It is reasonable to ask, if under a different set of circumstances, where the deficiency of Ca was not so severely limiting, would we observe a similar effect on fruiting index?

Calahan (1977) varied the calcium content of his nutrient solution and recorded yield and fruiting index of Deltapine 16 cotton. His lowest Ca level (1 me/L) was sufficient to promote good growth and fruiting. Increasing Ca from 1 to 10 me/L increased yield and fruiting index. With an additional increase in substrate Ca, yield remained essentially constant, but a further increase in fruiting index was recorded. Thus, the effect noted by Joham (1955) was shown (Calahan, 1977) to be valid for the more normal ranges of Ca nutrition. Under Ca deficient conditions, the addition of modest amounts of Na increased the fruiting index.

Helmy *et al.* (1960) found a positive association between substrate Mg levels and both relative fruitfulness and fruiting index of Stoneville Z106 (Table 3). A similar trend was noted in Pima S-1 cotton, but the experiment was not conducted over a sufficient period to collect reliable data from the Egyptian-type cotton. Helmy noted that Mg deficiency delayed flowering of the Pima S-1 plants. His data show that the control plants started flowering 55-58 days after planting while the first flowers were noted on the Mg deficient plants some 20 days later. There is good evidence that Ca and Mg are active in controlling the vegetative-fruiting growth ratio, but we do not have sufficient data on either element to firmly establish their relationships to earliness.

Table 3. The influence of calcium[1] and magnesium[2] on relative fruitfulness and fruiting index of cotton.

Ca level	Dry weight (g.)		Fruiting
	Stems & leaves	Bolls	index
Control	28.6	25.4	.89
-Ca	23.2	1.1	.06
-Ca+Na	24.9	10.3	.41

Relative Mg level	Relative fruitfulness	Fruiting index
1	3.2	.40
1/4	2.7	.28
1/16	1.9	.26
1/64	1.8	.18

[1]Data from Joham (1955).
[2]Data from Helmy *et al.* (1960).

Micro Nutrients Boron and Zinc—Eaton (1932, 1944) grew Acala cotton plants in gravel supplied with nutrient solutions. He varied the boron (B) content of the solutions from a trace ($< .5$ppm) to 25 ppm and measured growth and fruit production. From his data, it is possible to calculate both relative fruitfulness and fruiting index. Yield increased with increasing B to 10 ppm then decreased as B was raised to 25 ppm (Table 4). Both relative fruitfulness and fruiting index increased sharply when B was raised from a "trace" to 1 ppm. Further increases in B caused a small rise in the relative fruitfulness with the highest reading

Table 4. Growth and fruiting of cotton as influenced by boron[1].

Boron ppm	Dry weight (g/plant) Stems & leaves	Dry weight (g/plant) Bolls	Relative fruitfulness	Fruiting index	% Open bolls
Trace	47.0	4.0	1.6	.09	0
1	78.3	37.3	5.4	.48	25
5	108.5	39.5	5.8	.36	13
10	136.5	56.5	6.2	.41	12
15	78.8	31.0	6.7	.39	13
25	93.3	37.5	4.6	.40	21

[1]Data From Eaton (1932, 1944).

coming at the 15 ppm B level, a point which was just past the point of maximum yield in Eaton's experiment. No consistent trend was noted in fruiting index when B was increased above the 1 ppm level. Thus, in the deficiency range, a "trace" to 1 ppm, B played a major role in the partition of vegetative and fruiting growth.

Eaton (1932) implied that B plays an important role in earliness. From his data we can calculate the percent of mature crop at harvest (about 150 days). Plants grown in the "trace" treatment had only green bolls at harvest while 25 percent of the crop was mature on plants treated with 1 ppm B (Table 4). Eaton's comment that the "plants in the '0' bed shed most of their floral buds and bolls . . . no bolls set previous to October were retained" supports the data on percent mature crop. In a field test, Anderson and Boswell (1968) applied B at the rates of 0.0, 0.45, and 0.89 kg/ha as a side dressing to cotton. Over a three year period the 0.45 kg/ha rate of B caused a 7.3 percent increase in cotton harvest at the first picking. Thus, we do have some information supporting a relationship between B and earliness of cotton.

In controlled experiments involving variations in zinc (Zn) supply and mini-

Table 5. The effects of zinc supply and early season temperature control on yield and fruiting index of cotton[1].

Zn ppm	15C Dry wt. (g.) bolls/plants	15C Fruiting index	19C Dry wt. (g.) bolls/plants	19C Fruiting index	23C Dry wt. (g.) bolls/plants	23C Fruiting index
1	49.9	.35	90.0	.70	115.8	.69
5	62.1	.46	115.6	.88	—	—
25	82.7	.71	111.3	.96	109.4	.73
75	—	—	—	—	106.0	.75
125	4.7	.17	6.4	.24	—	—

[1]Data from Joham and Rowe (1975).

mum temperature, Joham and Rowe (1975) noted that the Zn treatments had a marked influence on the partitioning of vegetative and fruiting growth, and this relationship was influenced by temperature. With a 15C early season minimum temperature, increasing substrate Zn from 1 to 25 ppm was associated with an increase in fruiting index (Table 5). When the minimum temperature was raised to 23C, the effect of Zn on fruiting index was eliminated. In the above experiment increasing substrate Zn to the 25 ppm level increased yield at the two lower temperatures, but there was no effect on earliness as measured by appearance of first flowers. When Zn was raised to a toxic level, yield was reduced and flowering was delayed. Increasing Zn levels and temperature influenced flowering, causing a shift from an indeterminate to a more determinate flowering pattern. It is reasonable to assume that severe deficiencies of Zn would delay flowering and fruiting, and such has been reported by Brown and Wilson (1952). In a critical study of the Zn nutrition of several species of cotton, the above authors reported that Zn deficient *G. barbadense* plants did not produce any squares and *G. hirsutum* and *G. arboreum* plants produced only a few squares, all of which shed at or during anthesis.

At this point, one may speculate as to the association of the above nutrient elements (P, K, Ca, Mg, B, Zn) in control of vegetative-fruiting growth. Eaton (1955) stated that the notable effect of B on controlling relative fruitfulness was understandable due to the role of B in control of carbohydrate translocation. We now know that Ca (Joham, 1957, 1974; Joham and Johanson, 1973) K (Ashley and Goodson, 1972), and Mg (Helmy *et al.*, 1960) function in the control of carbohydrate translocation. With deficiencies of each of these elements, carbohydrate movement from the leaves of cotton plants is restricted both in rate and distance moved. Such a restricted flow of carbohydrates could have an influence on the number and size of the bolls formed. Even so, this leaves unanswered the question as to why a deficiency of these elements causes a greater reduction in fruiting than in vegetative growth. Curtailment of carbohydrate flow out of the leaves should and does cause a decrease in vegetative growth. Perhaps the answer lies in a proximity of the growing points to the leaves and in the relative polarity of carbohydrate movement to the vegetative or fruiting points. Phosphorus and Zn have not been shown to control carbohydrate translocation in cotton, yet, they exert profound effects on the indices of fruiting. The effects of P are similar to those of light and temperature in promoting fruiting and earliness, and these effects may be mediated through the well-known association of P in energy reactions. Auxin may inhibit or stimulate flowering depending upon its concentration in the plant. Thus, the effect of Zn on the partition of vegetative-fruiting growth may be brought about by the requirement of Zn for tryptophan synthesis (Tsui, 1948) and the role of Zn in maintaining auxin in an active state (Skoog, 1940).

ELEMENTS NOT AFFECTING FRUITING INDICES

Nitrogen—Eaton and Rigler (1945) studied the influence of nitrogen (N) levels on growth and fruiting of Stoneville 2B cotton. The range of nitrogen varied from a deficient to an excessive level (Table 6). Even though they obtained an excellent

Table 6. The influence of nitrogen treatment on growth and fruiting of cotton[1].

Nitrogen	Fresh wt. (g.)		Relative	Fruiting
Me/L	Stems & leaves	Bolls	fruitfulness	index
1	107	170	1.59	6.8
4	382	458	1.20	6.4
16	367	468	1.28	6.4
64	252	370	1.47	7.6

[1]Data from Eaton and Rigler (1945).

curvilinear yield response, fruiting index and relative fruitfulness remained essentially constant over the entire range of nitrogen levels studied. In a later article, Eaton (1955) noted that "Both the low and high nitrate levels depressed growth and increased relative fruitfulness". An examination of his data indicates that the changes in relative fruitfulness associated with nitrogen level were small, and in all probability, they were not significant. The results of Eaton and Rigler (1945) agree with those presented earlier by Wadleigh (1944); thus, we have ample evidence indicating that nitrogen deficiency reduces vegetative and fruiting growth to the same extent (see Chapter 10).

There seems to be a general misconception that increasing nitrogen levels causes a delay in fruiting and an increase in the vegetative character of the plant. No such effect was observed by either Eaton and Rigler (1945) or Wadleigh (1944). In their field study, Brown and Pope (1939) increased the yield of seed cotton from 1662 lbs/acre for the zero N plots to 2292 lbs/acre for plots receiving 48 lbs N/acre. There was no change in earliness as measured by percent seed cotton harvested at first picking and percent blooms the first two weeks of flowering. The above observations were supported by the data of Perkins and Douglas (1965). Wadleigh (1944) recorded flowering as influenced by a wide range in N treatment. Regardless of N treatment, all plants started flowering on about the same date. Nitrogen had a marked influence on the termination of flowering; thus, nitrogen deficient plants exhibited a very determinate flowering pattern. High nitrogen treated plants flowered over a much longer period and produced a flowering pattern characteristic of indeterminate cotton.

Sulfur—Ergle and Eaton (1951) varied the sulfur (S) content of nutrient solutions supplied to Stoneville 2B cotton grown in the greenhouse. Increasing sulfur had no effect on relative fruitfulness. Growth and yield increased with each increment of substrate sulfur but the partition between vegetative and fruit production remained nearly constant.

Manganese—Joham and Amin (1967) studied the influence of a wide range of manganese (Mn) concentrations on the growth and fruiting of cotton (Table 7). Fruiting index remained essentially constant when Mn was increased from 1 to 27 ppm. Although yield (dry weight bolls) decreased over the same Mn range, the difference was small and not significant. When substrate Mn was increased to 81 ppm, an obviously toxic level, there were sharp reductions in growth, yield, and fruiting index. Taylor (1965) extended the observation on Mn into the deficiency range. With concentrations of Mn in nutrient solutions of 0.005 and 0.5 ppm, he obtained a 10-fold increase in yield while the fruiting index measured 0.50 and 0.51 respectively. Below 0.005 ppm the plants did not survive.

Joham and Amin (1967) reported that increasing Mn from 1 to 27 ppm increased earliness. The 27 ppm plants produced one flower per plant four and nine days earlier than the 9 ppm or the 3 ppm and 1 ppm plants, respectively. Anderson and Boswell (1968) obtained field data which support the observations on the effect of Mn in promoting earliness. In their study, Mn applied at 2.23 Kg/ha gave a 22.2 percent increase in cotton harvested at the first picking.

Table 7. Growth and fruiting of cotton as influenced by manganese[1].

Manganese	Dry weight (g.)		Fruiting
ppm	Stems & leaves	Bolls	index
1	51.4	30.0	.58
3	60.3	27.1	.44
9	45.6	26.6	.58
27	49.2	23.3	.47
81	7.1	0.7	.10

[1]Data from Joham and Amin (1967).

Molybdenum—Although the evidence is not complete concerning the influence of molybdenum (Mo) on the partition of vegetative and fruiting growth in cotton, it seems likely that wide variations in Mo supply do not affect fruiting index. In a greenhouse experiment employing complete nutrient solutions, Joham (1952) supplied Mo at rates varying from 0 to 35 ppm to cotton plants grown in sand. Since the salts employed in his experiment were not purified, the 0 treatment actually contained about 1 ppm Mo, which was sufficient to promote good growth and fruiting. The 35 ppm Mo treatment approached a toxic level and caused a 22 percent reduction in growth. In a later experiment Amin and Joham (1960) extended their observations into the Mo deficiency range. Using highly purified salts, they grew cotton plants in nutrient solutions containing <1.5 ppb Mo. The low Mo supply caused a 20 percent reduction in seed cotton yield. Thus, in experiments in which the Mo supply was varied from mild deficient to near toxic levels, the fruiting index of cotton remained nearly constant (Table 8).

Table 8. Growth and fruiting of cotton as influenced by substrate molybdenum level.

Mo supply	Dry weight (g.) Stems & leaves	Bolls	Fruiting index
Hydroponics experiment[1]			
<1.5 ppb	45.1	21.9	.49
1.0 ppm	52.5	27.3	.52
Sand culture experiment[2]			
0 ppm	83.2	41.5	.50
5	77.1	42.5	.55
15	83.3	43.1	.52
25	71.5	35.5	.49
35	62.7	34.6	.55

[1]Data from Amin and Joham (1960).
[2]Data from Joham (1952).

SUMMARY

In this paper we have covered the influence of most of the nutrient elements on the partition of vegetative and fruiting growth. Two indicators of plant efficiency in relation to the vegetative-fruiting partition were presented and discussed. Fruiting index and relative fruitfulness are measurements of the relationship between vegetative and fruiting growth. Certain nutrient elements (P, K, Ca, Mg, B, Zn) have marked effects on the indices of fruiting efficiency. Increases in the substrate level of the above elements, going from deficient to near toxic levels, cause corresponding increases in fruiting index or relative fruitfulness. It is interesting to note that four of the above elements (K, Ca, Mg and B) have been closely implicated with translocation of carbohydrates and that deficiencies of these elements cause carbohydrates to accumulate in the leaves. Other nutrient elements (N, S, Mn, Mo) seem to have little or no influence on the partition of vegetative and fruiting growth. For example, a deficiency of N causes a reduction in both vegetative and fruiting growth, and as a result the fruiting index or relative fruitfulness remains unchanged.

Five elements (P, Mn, B, Zn and possibly Mg) have been shown to play a role in earliness. The means used to measure earliness varies from paper to paper and may refer to days to first flower or percent of crop harvested at first picking. Both P and Mn have been shown to promote earliness under field conditions. It might well be that other elements, when brought into proper balance, will be shown to have an influence on earliness.

Notably absent from our list are references to iron, copper and chlorine. Work is needed to establish the effect of these elements on the partition of vegetative-fruiting growth and earliness.