Summary

Twenty years of research in central Washington plus some limited data from other areas substantiate these statements.

1. Corn production is profitable at present prices only where at least 4 tons per acre (128 bushels) are obtained.
2. Plant nutrient removal is high—especially where corn is grown for silage.
3. The soil test is the best basis for predicting fertilizer needs.
4. Central Washington soils are extremely variable and require intensive sampling. Taking only one composite sample from a "uniform" area or field is not adequate.
5. "Ideal" soils for corn, physically speaking, are deep, well-drained and of medium texture. A soil should be managed according to its profile characteristics.
6. To get the corn crop off to a good start, soil should be moist and the temperature at seed depth at least 60° F.
7. After about the first month, rate of corn growth is rapid for 70 to 80 days. During this period, nutritional requirements are high.
8. Generally, most fertilizers can be applied before planting and plowed under or shanked in. On deep, sandy soils, sidedress at least half the N.
9. Other factors—moisture, weeds, disease, insects—must be controlled to insure high yields and a high return for fertilizer used.
10. An abundant supply of nitrogen and high plant density both increase yields, but they also increase lodging. For high yields and a minimum of lodging, selection of the hybrid, nitrogen rate, and plant population density must be considered.
11. Some critical plant nutrient levels are known and can be useful in diagnosing nutritional problems and evaluating fertilizer programs.

Considerable research has been conducted on soil fertility management of corn in central Washington during the past 20 years. Results of these studies can be found in various publications, as indicated by the list of references at the end of this bulletin. Some information from the Midwest and other areas is useful in Washington.

This bulletin summarizes available information on soil fertility management of corn in the irrigated areas of central Washington.
SOIL FERTILITY MANAGEMENT OF IRRIGATED CORN

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In 1970, there were 65,000 acres of field corn in irrigated central Washington—42,000 acres for grain and 23,000 for ensilage. In addition, there were 18,000 acres of sweet corn. Information in this bulletin applies primarily to field corn for grain or silage, but much of it is also useful for sweet corn production.

The average yield of field corn for grain in 1970 was 104 bushels (2.9 tons) per acre. The figures in Table 1 indicate that this average yield is not profitable. They also show that it pays to produce high yields.

Higher yields are possible. A few growers have produced more than 200 bushels (5.5 tons) per acre in central Washington.

Plant Nutrient Removal Is High

Table 2 shows the nutrient removal in the grain and stover of a 170-bushel crop of corn.

Nutrient removal in the grain alone, where the stover remains and is returned to the soil, is considerably less than that indicated in Table 2.

Nutrient removal figures have value when considering the long-term fertilizer needs. The figures are not useful for predicting immediate fertilizer needs. This can be demonstrated by looking at both phosphorus (P) and potassium (K) as follows:

1. As shown in Table 2, P removal in a high yield crop of corn for silage may be 40 pounds per acre. However, the efficiency of P uptake is usually very low. For example, to obtain maximum production from a soil testing low in P, as much as 130 pounds of P* may need to be applied per acre, even though the corn will take up only 40 pounds.

2. For K*, the situation is reversed. Removal may be 230 pounds of K per acre. But frequently K fertilizer will not be required in central Washington soils because of the large reserve supply in the soil minerals. However, 230 pounds of K removal per year may eventually lead to K deficiency in some areas where K is now barely in sufficient supply (17).

Table 1. Operator’s Labor and Management Return per Acre at Various Yield Levels of Corn for Grain in Central Washington.

<table>
<thead>
<tr>
<th>Yield (price $50 per ton)*</th>
<th>Return/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>T/A Bu/A</td>
<td></td>
</tr>
<tr>
<td>3.5 126</td>
<td>$-49.91</td>
</tr>
<tr>
<td>4.0 144</td>
<td>-27.51</td>
</tr>
<tr>
<td>4.5 162</td>
<td>-5.11</td>
</tr>
<tr>
<td>5.0 180</td>
<td>16.29</td>
</tr>
<tr>
<td>5.5 198</td>
<td>38.69</td>
</tr>
<tr>
<td>6.0 216</td>
<td>61.09</td>
</tr>
</tbody>
</table>

* Data from E.M. 3483 (8).

Table 2. Nutrient Removal in Grain and Stover of a 170-Bushel Corn Crop*

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Lb/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (N)</td>
<td>230</td>
</tr>
<tr>
<td>Phosphorus (P)†</td>
<td>40</td>
</tr>
<tr>
<td>Potassium (K)†</td>
<td>233</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>41</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>45</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>22</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>2.2</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>0.33</td>
</tr>
<tr>
<td>Boron (B)</td>
<td>0.18</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>0.39</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>0.12</td>
</tr>
<tr>
<td>Molybdenum (Mo)</td>
<td>0.009</td>
</tr>
</tbody>
</table>

* Estimates adapted from literature cited (2, 26, 30).
† To convert the value for P to P2O5, multiply by 2.27; to convert K to K2O, multiply by 1.20.
Soil Test Is Best Indicator

After many years of soil fertility research on corn and other crops in central Washington, the soil test has been shown to be a valid basis for determining fertilizer needs. In central Washington, Washington State University uses the sodium bicarbonate (NaHCO₃) extract for P. K is determined on this same extract. For nitrogen (N), the nitrate nitrogen portion of the total N in the rooting zone is used as the soil test index.

Of the elements essential for plant growth, six will need to be added in certain instances in central Washington. These are shown in Table 3 along with the soil test level considered to be a minimum level for crop needs.

Keep Soil Test Values Above “Critical Levels”

The soil test values in Table 3 are “critical levels.” Crops grown on soils testing lower than the values in the table are likely to have less than optimum yields. If the soil test levels are above the critical levels, yields will not be increased by fertilization. A margin of safety has been built into the critical levels shown in Table 3, i.e., the probability of response at soil test levels just below the critical level is very low.

It is important to soil test at least every three years and to keep the soil test values above the critical levels—but not too high. For example, it is advisable to apply P in amounts which will keep the soil test level above 10 ppm. There is no point in keeping the level of soil test P above 15 ppm. It is possible to depress yields with extremely high rates of fertilizer. In addition, excessive use of fertilizer may contribute to pollution of the environment.

Soil Sampling Is a Problem

Research has shown repeatedly that soils are seldom uniform (16, 18). Soils are far more variable than most people think. This means, for example, that the soil test for P is usually not the same from one location in a field to another—even in a field which appears to be uniform. A carefully taken composite sample (a number of "subsamples" or individual small samples) will provide an accurate average condition of the field—but knowing the average condition of a variable field is of little value since the average soil test may call for a fertilizer rate which is too low for parts of the field and too high for other parts.

Separate individual samples are necessary to avoid this problem. This is called intensive sampling. The more individual samples taken, the better will be the basis for a sound fertilizer management program. Whether or not a grower will decide to fertilize a field differentially will depend on the results of intensive sampling. In any case, avoid taking a composite sample unless it has been established by previous sampling that the area or field is uniform.

Sampling for N is a special problem and requires a procedure different from that for P and K. Sampling instructions for the N test are available (10, 21).

Most Soils Aren’t Ideal

An ideal soil for corn production is deep, well-drained and of medium texture with no layers
inhibiting root growth or water movement in the upper 5 feet of the profile. Most soils are not ideal. Considerable deviation from the ideal will probably result in reduced yields. Normal yields may be obtained on soils which deviate slightly to moderately from the ideal, but the cost of production may be greater. In central Washington, two of the main factors, water and fertility, are controlled mostly by the grower. The costs of fertilization and irrigation will usually be greater on less than ideal soils.

For soils information, consult the Soil Guide Sheet series for your county (9).

Consider How the Corn Plant Grows

Proper growing conditions for germination and emergence of corn are important. Two factors, soil moisture and soil temperature, are critical. The soil moisture should be at or near field capacity and the soil sufficiently firm so the corn seed is in good contact with the moist soil.

Rate of germination and emergence relate closely to soil temperature. To get the corn crop off to a good start, average soil temperature for a 24-hour period should be at least 60°F at seed depth.

Rate of corn growth is of interest when considering a soil fertilization program for corn. A curve showing the dry matter production (growth rate) and uptake of nutrients is presented in Figure 1. The growth rate is relatively slow for the first month after the plants emerge. With increased leaf growth, the rate increases. By the time most of the leaves have been formed, growth has become quite rapid.

This rapid growth continues at about the same rate for 70 to 80 days. It is during this period that corn plants require a plentiful supply of nutrients—particularly N, P, and K.

Early requirements for nutrient elements, in terms of per cent of the total, are in excess of the growth rate of the corn plant. Of special interest is the K curve, which indicates that the early requirement for K is very high—80 to 100 per cent of total required within 50 to 70 days following emergence.

How to Fertilize*

When. Figure 1 indicates that soils should be high in fertility during the period of rapid corn growth. Normally adequate nutrition can be supplied during this period by applying all fertilizer materials before planting. However, when soils are sandy or otherwise subject to leaching losses, sidedress or apply in the irrigation water at least half the N during the early growth stages.

P, K, and Zn can be applied in the fall. Normally N is best applied in the spring. Research has shown that in many cases, N losses can occur during late fall, winter, and early spring. Incorporate fall-applied N in the soil in the NH₄ form during late fall or early winter to avoid such losses.

* This paper does not provide complete instructions on how to fertilize. See the Fertilizer Guide for corn (11).

Figure 1. Relative uptake of primary nutrients and dry matter production by corn (13).
Method. Plow under, shank in, sidedress, or in some way place corn fertilizers beneath the soil surface. Normally, surface-applied fertilizers for corn are ineffective. An exception would be that N can be surface applied under sprinkler irrigation, or part of it applied through the sprinkler system. Under rill irrigation, most of the surface applied N will become isolated in the dry surface soil in the corn row and thus, will be positionally unavailable to the crop.

Kind. In general, the source of fertilizer is not important as long as equivalent amounts of the necessary plant nutrient elements are present. There is little or no difference between liquid and dry forms of fertilizer in terms of crop response. A great deal of recent research comparing various sources of P has shown that, of the commonly used sources, one is not consistently better than another.

Amount. Information on the amounts of different elements to use is provided primarily by the soil test as interpreted in FG 6 (11). However, some additional comments on nitrogen fertilization will follow.

Research in central Washington by Nelson (21) shows that testing for the total nitrate nitrogen (NO₃-N) in the rooting zone is an effective means of predicting N needs for corn. Figure 2 shows that a good relationship exists between the total amount of soil NO₃-N plus fertilizer N and the yield of corn. The data also show that:

1. 2.1 pounds of soil NO₃-N from the soil and fertilizer are needed to increase the corn yield 1 bushel per acre.
2. There was sufficient release of N from soil organic matter to produce 43.7 bushels per acre. It can be estimated that about 90 pounds of N were released during the growing season from organic matter.

Figure 3 shows a curvilinear relationship of the data of Figure 2 plus some data from additional levels of N. The maximum yield of 175 bushels per acre corn is reached at about the 320-pound level of N.

Seldom, if ever, is it necessary to apply 300+ pounds per acre of N to corn under normal farming conditions because residual N is nearly always present from previous cropping.

Assume under average conditions, 40 pounds from organic matter and 80 pounds of residual NO₃-N (a soil test N index of 20 is approximately equivalent to 80 pounds per acre of N). The required amount of fertilizer N would be 200 to 220 pounds per acre for maximum yield. Sometimes very little fertilizer N is needed.

![Figure 2](image1.png)

Figure 2. Relationship between soil nitrate nitrogen plus fertilizer nitrogen and yield of corn (21).

![Figure 3](image2.png)

Figure 3. Curvilinear relationship between soil nitrate nitrogen plus fertilizer nitrogen and yield of corn (21).
amount of available residual N varies a great deal and can be determined only by soil test which has previously been correlated with crop response.

The importance of measuring the soil test N as a basis for predicting fertilizer N needs can be seen from the foregoing data. Sampling instructions and further interpretation regarding soil test N can be found in E.M. 3076 and FG 6 (10, 11).

**Proper Irrigation Is Important**

Occasionally maximum yields of irrigated corn are not obtained unless excessive rates of nitrogen are applied (300 to 400 pounds per acre). Nearly always this is because of some N loss from leaching either on sandy soils or from over-irrigation, or both. N fertility management is closely related to water management. On sandy soils, use special care to apply only sufficient water to fill the rooting zone of soil. It is advisable on sandy soils to apply at least half the N by side-dressing or by sprinkler applications early in the growth of the corn. N can also be applied in water under rill irrigation. However, careful application of irrigation water with low concentrations of fertilizer and little runoff is necessary to keep fertilizer loss to a minimum.

Proper irrigation is an extremely important factor in corn production and in maximum efficiency of fertilizer use. Money invested in fertilizer is wasted if yields are low due to poor irrigation. The water requirement for corn is particularly critical during the silking-tasseling period (27, 28).

**Control Weeds**

Weeds rob the corn crop of valuable moisture and nutrients. Good weed control is especially important during the early rapid growth of corn, because this is the period when adequate nutrition is needed by the crop. Proper use of cultivation and herbicides to essentially eliminate weed competition is necessary if profitable yields are to be produced. The effect of weed growth on corn as seen in Figure 4 was shown by Aldrich et al. (1). Griffin (14) obtained similar results in central Washington.

**Cultivate at Proper Depth**

Nelson (24) has shown that tractor wheel compaction can be a problem in central Washington corn fields. It is commonly known that one must be careful to avoid deep cultivation of corn because of the danger of root pruning. However, Nelson showed that by cultivating 5 inches deep, to break up a compacted zone, yields were increased from 116 to 131 bushels per acre. Yields were lower where cultivation was either 2 or 12 inches deep.

**Control All Production Factors**

Control of all production factors during this period of maximum growth rate is important. Any factor—moisture stress, disease, insects, weeds—which delays growth during this period and beyond tasseling is likely to result in reduced yields of grain or silage. Failure to control any one factor can result in reduced yields and much less return realized from the fertilizer investment.

![Figure 4. Effect of weed growth on the yield of corn.](image-url)
Plant Density and Nitrogen Need Balance

The effects of plant population and N on lodging and yield are very important. Increasing plant population and N rate both increase yield, but they also both increase the amount of lodging.

Nelson's data (Figure 5) show that lodging is markedly increased by increasing both N fertilization and by population density (20). Figure 6 shows the effect of increasing plant density on yield of corn for ensilage (dry matter) and for grain (22).

The figure also shows the effect on TDN produced in the ensilage. It can be seen that the effect of population is great on dry matter and TDN, but not so great on the production of corn for grain within certain plant population limits. When the effects of high plant density on lodging are considered, populations of 22,000 to 28,000 plants per acre in 22-inch rows may be optimum, depending on the variety and other management factors.

High rates of N and high population density are wasted investments if all other management factors for high yields are not present. For high density plantings, it is important to use high-yielding hybrids, of proper maturity, that are adapted to, and take advantage of, high population density.

Tissue Tests Can Be Useful

Considerable research has been done in the Midwest and in central Washington on establishing critical nutrient levels in corn leaf tissue (3, 6, 12, 29, 31). Sampling was done at silking or tasseling and the tissue sampled has been the ear leaf or the fifth or sixth leaf up the stalk from ground level. The following can be considered as fairly well established critical levels:

N—2.9%
P—0.3%
K—1.5%

Ellis (12) and Viets (30) have shown that normal N concentrations were highest—3.0 to 3.5 per cent—when the plants were 3 to 4 feet high. Ellis showed that the leaf N levels dropped to 2.0 per cent during early ear formation.

Boawn indicated that a level of 20 ppm Zn is a desirable minimum level in the second leaf below the upper ear during silking (5).

Figure 5. Effect of nitrogen fertilization and population density on lodging (20).

Figure 6. Relationship between population density and yield of dry matter (ensilage), TDN, and grain (22).
Plant analysis can be used to supplement soil testing in determining whether or not the plant is receiving adequate nutrition during the growing season.

Boawn showed that tissue testing in the field could be of value in monitoring the N status of the corn plant during the season (6). He developed arbitrary tissue test values based on visible color from the application of alpha-naphthylamine to the sap from the leaf midrib. Boawn found that there was a good correlation between tissue test values at various stages of growth and the N level in the second leaf below the upper ear at tasseling.

"Quick" tissue testing in the field is quite subjective and probably requires considerable experience before it can be of value. The tests for various elements should correlate with laboratory analysis before using them for these elements.

**Nitrogen May Increase Protein Content**

It is known that N fertilization which increases yield will usually increase the protein content in the grain. For example, Viets (30) working in central Washington, increased the protein content of corn grain from 7.3 per cent to 9.1 per cent with N fertilizer, while at the same time, increasing yields by 30 bushels per acre.

**References and Literature Cited**

17. James, D. W., W. H. Weaver, and R. L. Reeder, 1968. Soil test index of plant-available potassium and the effects of cropping and fertilization in cen-


Phosphorus deficiency symptoms may depend on plant varieties or species. All corn shown is stunted, but sweet corn (left) exhibits more severe symptoms than field corn (right).

Phosphorus-deficient leaf of field corn (left) compared to zinc-deficient leaf and normal leaf. Note the slight purple coloration on margins of the phosphorus-deficient leaf.

Extreme nitrogen deficiency of corn. Compare with normal corn in background.

Stunting and typical symptoms in corn deficient in zinc.

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