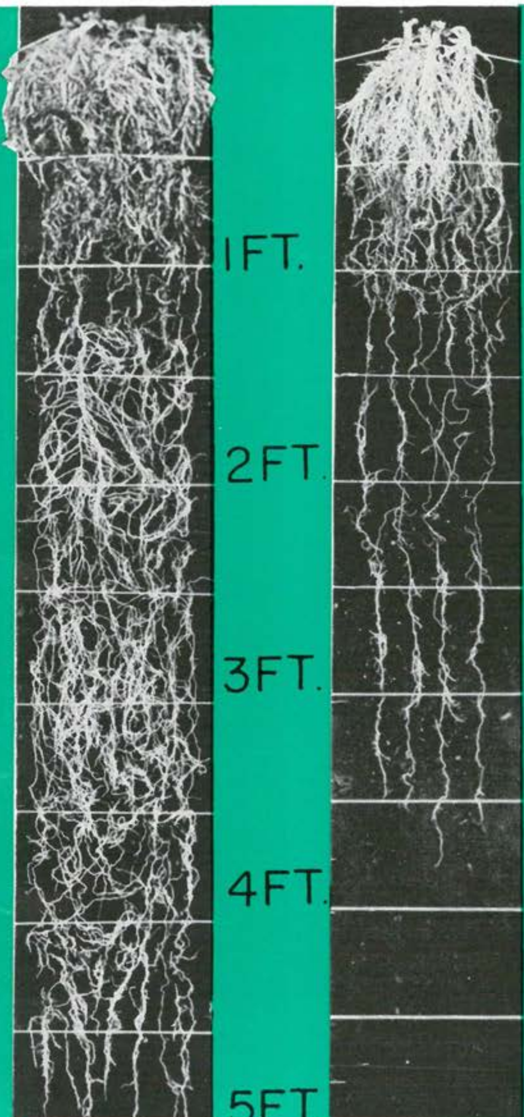
Better Crops WITH PLANT FOOD

January-February 1963 20 Cents



Fertilized Unfertilized

". . . with few exceptions the experiments show a reduction in water requirement accompanying the use of fertilizers. In highly productive soils, this reduction is slight. In poor soils the water requirement may be reduced one-half, or even two-thirds, by use of fertilizers."—*1913*

MOISTURE AND FERTILITY

. . . a special issue

". . . fertilizers may increase root exploration of the soil so that soil water is used to higher tensions and to greater depths. This effect is important to dryland agriculture and even to farming in humid areas during periods of drouth." —*1963*

Better Crops WITH PLANT FOOD

The Whole Truth—Not Selected Truth
$1.00 for 6 Issues, 20¢ Per Copy

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CONTENTS

ON THE COVER

. . . adequate fertilization on infertile soils can extend a plant's root systems, enabling it to tap a larger volume of soil for water. Well fertilized plants weather temporary drouths more successfully. In the University of Illinois tests shown here, the fertilized corn received limestone, phosphorus, and potassium where needed, in amounts adequate to meet or exceed needs indicated by soil tests. A legume was included in each rotation.

In this issue . . .

BETTER CROPS magazine is pleased to present some of the latest findings on moisture and soil fertility, as reported by nationally known agricultural scientists.

A half century ago USDA scientists L. F. Briggs and H. L. Shantz reached the conclusion quoted on the cover, in 1913, after reviewing the work on water requirements of plants up to that time. Last year ARS-USDA scientist Frank G. Viets, Jr. brought the findings on fertilizer and efficient use of water up to date in a superb report for Advances in Agronomy, quoted briefly as a 1963 conclusion on the cover.

In both cases—1913 and 1963—the consensus seemed to be that "fertilizers for the adequate nutrition of all crops play a major role in the efficient use and conservation of water resources."

Special issue chairman is Werner L. Nelson, Midwest Director of the American Potash Institute.

Showing . . .

To begin with . . .

. . . no one has to tell the farmer what sun and water mean to his business of producing food.

Yet, few farmers realize how much of the sun's energy goes to "pump" water out of the soil and to evaporate water from plant leaves and how little goes to make a crop.

In fact, only 1 to 2% of the light energy striking an acre of corn during a whole growing season is converted by the green leaves (through photosynthesis) into chemical energy for plant growth.

Late Ohio State Professor Transeau calculated that for one acre of corn to produce a 100-bushel crop, the leaves of that acre must manufacture 10 tons of glucose (sugar energy) by photosynthesis over a growing season.

Offhand, this amount of sugar—for producing plant substance, meeting respiration demands, and providing chemical energy for grain development—might imply that a high level of conversion (from light energy to chemical energy) occurs in a typical cornfield.

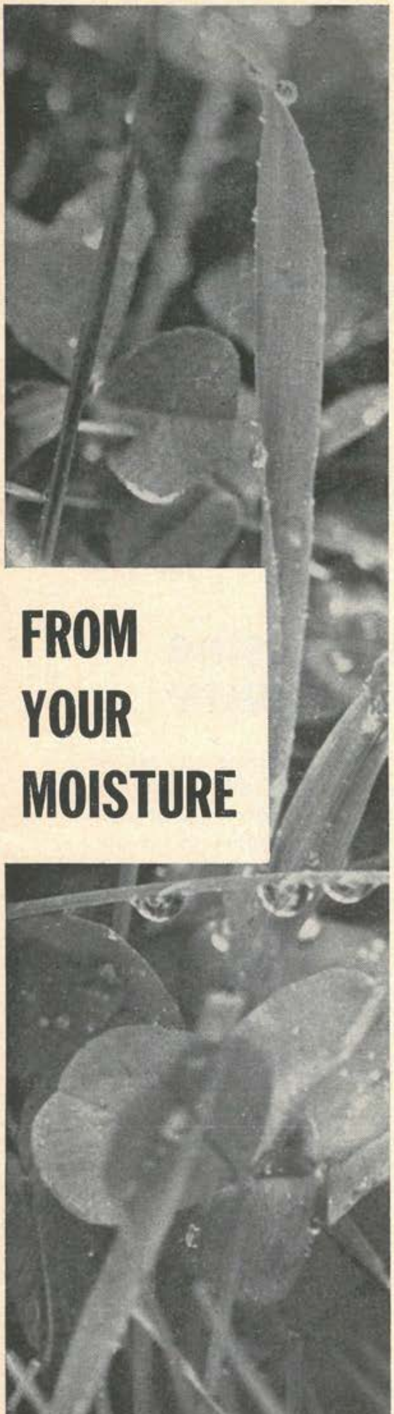
But in reality, the light energy striking one acre of corn during one bright summer day equals the chemical energy in 7 tons of sugar, nearly enough *in one day* for a 100-bushel growing season *if* the green leaves would photosynthesize all of it into energy for the plant. But they don't.

Since corn plants use only 2% or less of the sunlight energy reaching such as acre during a growing season, what happens to the other 98% of radiation striking that acre?

The Other 98%

A small portion heats the surrounding air. Another small portion heats the soil and the plants. The balance—some 80% of the sun's radiation—causes evapotranspiration, a combination of water loss by evaporation from the soil and transpiration through the plant.

In fact, evapotranspiration uses up the lion's share—71%—of the nation's average annual water budget. During an average year, the conterminous United States receives enough water to cover the country to an average depth of 30 inches—4,750,000,000 acre feet in precipitation. This is an abundant supply of water. From this supply, 3,380,000,000 acre feet disappear through evapotranspiration at work on non-irrigated vegetated lands.



FROM YOUR MOISTURE

. . . an introduction

By
Cecil H. Wadleigh

Director
Soil and Water
Conservation Research
Division

Agricultural Research Service
U.S. Department of Agriculture

If our annual water budget were put on a balance sheet, it would look something like this:

NATIONAL WATER BUDGET

	Acre Feet of Water	
Total precipitation	4,750,000,000	
Runoff	1,370,000,000	
Evapotranspiration: (3,380,000,000)		
Non-irrigated cropland	570,000,000	
Pasture	530,000,000	71%
Forest and rangeland	750,000,000	of
Non-economic	1,530,000,000	budget

As our balance sheet shows, the "runoff" water amounts to 1,370,000,000 acre feet per year—or less than a third of the total precipitation received.

When urbanites and industry talk about water, they usually confine their thinking to the "runoff" from our fields, forests, and rangeland that maintain our concentrated supply in rivers, lakes, and reservoirs—with little thought of how land and land cover characteristics affect the quantity and quality of the massed water supply.

Each year we withdraw about 280,000,000 acre feet of this massed water supply—about 46% for irrigation agriculture, 46% for industry, and 8% for residential use. Industrial and urban uses are largely non-consumptive. About 90% of our massed water supply that is consumptively used is so used by irrigation agriculture.

Two Benefits

So, the general public might well realize two important facts about water uses:

1 Benefit from water that infiltrates our soil depends almost entirely on the economic value of the crop produced from that soil.

2 Benefit from runoff water depends greatly on the productivity of irrigated lands which take 90% of our massed water that is consumptively used.

In other words, most of the moisture we receive can be wasted by poor crop management or converted to profits by good crop management, a point that brings us to the purpose of this special issue on Moisture and Soil Fertility.

Four Foundations

Profitable crop production is built on four foundations:

1 A fertile soil.

2 An adequate supply of soil moisture.

3 Good seed of an adapted variety.

4 Protection from crop pests and weeds.

If one or more of these foundations are inadequate, it is futile to expect bountiful yields—as futile as expecting a horse to win a race with a lame leg.

Water is a vital national resource—indeed a first line of survival. To meet our nation's concern with it, we must work always to get full results from it—to correct *any factor* that might prevent maximum beneficial use of the major portion of this resource.

Water-Benefit Insurance

Adequate soil fertility and proper crop protection play a major role in this water-benefit insurance. A tangible example on one acre of potatoes tells the story:

Evapotranspiration from a potato field in New York State during the average growing season will total about 1½ acre feet of water, or about 500,000 gallons of water. A good grower using adequate fertilization and crop protection can produce 500 bushels per acre—or one bushel for each 1,000 gallons of water used in evapotranspiration. If he tried to raise potatoes in this area without fertilizers or pest control measures, he would be lucky to produce 50 bushels per acre—or one bushel for each 10,000 gallons of water used in evapotranspiration.

The latter case does not necessarily constitute maximum beneficial use of water. But the point is clear: to get the most out of your moisture supply, you must be sure all other factors are carrying their share of the load.

THE END

SURPRISING SIMILARITY

Studies in North Dakota on wheat have shown the surprising results that even though fertilizer greatly increases the yield, moisture content of the soil at harvest time is about the same in fertilized as in unfertilized plots. (ave. of 12 trials).

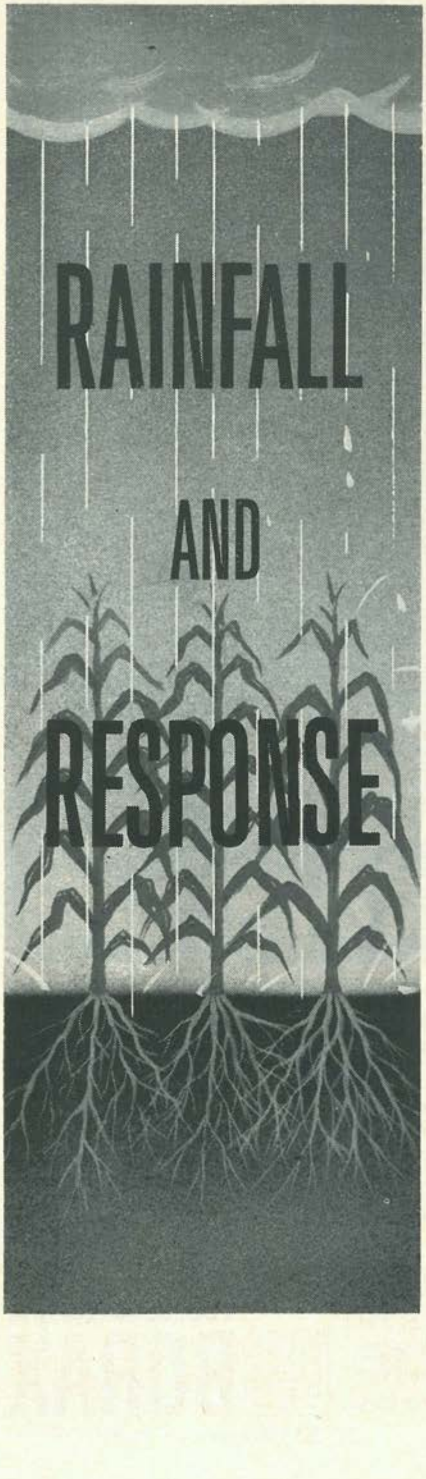
	Check	Fertilized
Yield per acre	13.1 bu.	17.9 bu.
Water in five feet of soil at harvest	7.8 in.	7.8 in.

(North Dakota Bimonthly Bulletin)

North Dakota workers say if there is sufficient moisture in the soil to warrant seeding a crop, appropriate fertilizer should be used on soil believed to be deficient in available nutrients.

They have found that crops usually do better with a high level of plant nutrients even when moisture deficiency is so severe that yields are greatly reduced.

—*Midwest Potash Newsletter*



TESTS SHOW

THE amount of rainfall during a growing season will affect the size of a yield increase from added fertilizer.

In fact, the amount of water in the soil will not only affect yield level, but also the availability of soil nutrients.

This report concerns the indirect effect of rainfall on yield.

How Rainfall Affects Potassium Availability

In a long-range field experiment where various rates of phosphorus and potassium were applied, the added potassium caused a large increase some years, very little in other years. Sufficient potassium (125 lbs. K per acre per year) was used to get maximum yield from the added nutrient.

Corn yields varied from 100 to 160 bushels per acre. Responses were not related to yield levels. Table 1 shows an example of the results. Note how a large response to added potassium occurred in 1956, very little in 1957, another large response in 1959.

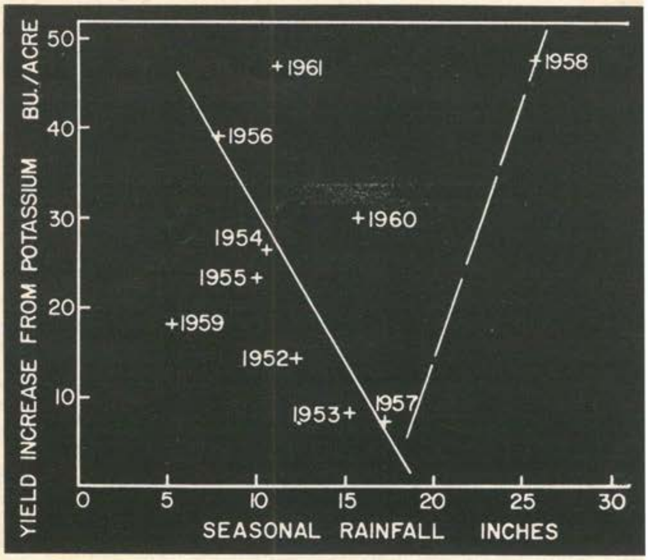
Since summer rainfall (June, July, August) varied widely, we related the yield response to rainfall. In Figure 1, note how added potassium affected yield responses in low-rainfall-year and very-wet-year seasons. For example:

1 With low rainfall (10″ or less), added potassium brought large yield responses—and the potassium in the unfertilized soil was not very available to the corn plant.

By Stanley A. Barber
Purdue University

Figure 1

. . . how added potassium brought large corn yield responses in low-rainfall seasons (10″ or less) and in very wet seasons (20″ or more)



2 With greater rainfall (from 10″ to 20″), response to added potassium was less—and the native soil potassium became more available.

3 With a very wet year (over double the 11.2″ average for the Lafayette area in June, July, August), response to added potassium was again large—believed due to restriction on soil aeration.

The data of the last few years have not fit the relation as well as the earlier data—probably for two reasons: (1) because the low rainfall of 1959 restricted total yield, (2) because the larger responses of 1960 and 1961 are due to the available supply of potas-

. . . how added potassium influenced potato yields in rainless periods—to hold their own or increase generally up to 60 rainless days.

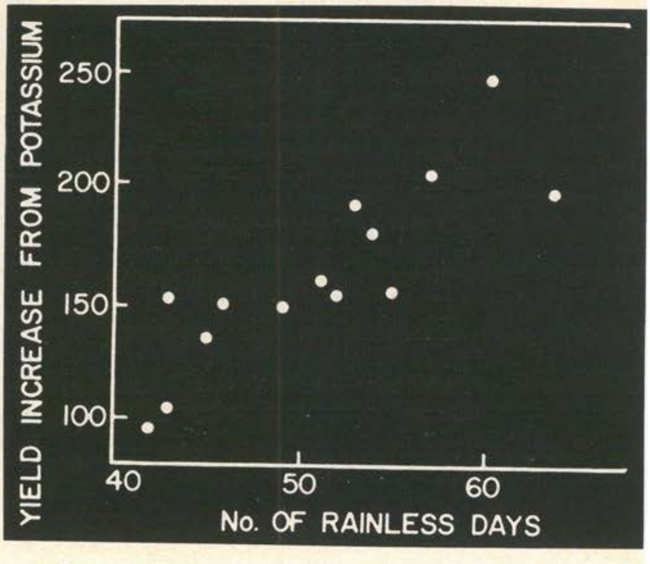


Figure 2

"When surface soil runs out of water in dry periods, the plant roots must feed in the subsoil . . . which usually contains less than half the potassium of surface soil."

TABLE 1—ANNUAL VARIATION OF CORN RESPONSE TO POTASSIUM FERTILIZATION.

Year	Yield		Response (Increase)	Seasonal Rainfall
	−K bu.	K bu.	Bu.	Inches
1956	91	130	39	7.91
1957	148	156	8	17.68
1958	92	140	48	25.73

sium in the untreated plot being depleted since no additions have been made.

How Rainfall Affects Response to Potassium

Examining results from experiments conducted for 14 years, Professor Van der Paauw of the Netherlands has shown the relationship between response of potatoes to added potassium and the number of rainless days.

In Figure 2, as the number of rainless days increase, the added potassium tends to help potato yields hold their own and to increase up to about 60 days. We obtained this same kind of result at lower rainfall rates in Indiana. The increased moisture from rain made the potassium in the soil more available to the plant.

Why Is Soil Potassium Less Available in Dry Years?

There are two reasons for this:

1 Subsoil usually contains less than half the potassium of surface soil. *Figure 3* shows this. When surface soil runs out of water in dry periods, the plant roots must feed in the subsoil where they cannot get as much potassium.

2 Most potassium absorbed by a plant must move through the soil to the plant root. *It moves through water in the soil.* The less water there is the harder it is for the potassium to move—and the less amount the plant receives.

These are two reasons soil potassium is less available in dry years. There may be others.

Why Excess Rainfall Reduces Potassium Availability

Plant roots must respire to get energy to absorb nutrients. They need oxygen for respiration just as humans do. When all the soil air spaces are filled with water after a heavy rain, the roots have trouble getting enough oxygen and potassium uptake by the roots is reduced.

By adding large amounts of potassium in fertilizers, we provide enough

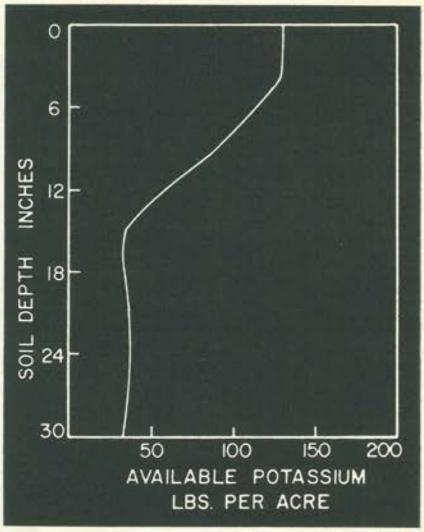


Figure 3—Subsoil usually contains less than half the potassium of surface soil.

"When all soil air spaces are filled with water after a heavy rain, the roots have trouble getting enough oxygen and potassium uptake by the roots is reduced . . . demanding large amounts of potassium in fertilizers to meet plant needs."

for the plant to meet its needs even when root respiration is restricted.

Rainfall Affects Nitrogen Response

Since ammonia forms of nitrogen in the soil are readily converted to the nitrate form, most available nitrogen is present in the soil as nitrates.

Nitrate nitrogen is not held by the soil. It moves with the soil water. After heavy rains fill the soil with water, the excess water moving out the drainage system takes the nitrogen with it.

Table 2 shows how heavy early June rains leached out part of the broadcast nitrogen applied in April, making the side-dressed nitrogen in June more effective. In normal rainfall years, there is little difference between plow-under and side-dress applications of nitrogen.

TABLE 2—HOW METHOD OF APPLYING NITROGEN AFFECTED CORN WHEN 11.7 INCHES RAINFALL FELL IN JUNE.*

Nitrogen lbs. per acre	Yield bu. per acre
0	81
50 plowed under	94
100 plowed under	109
200 plowed under	114
50 side-dressed	110

* Plowed under May 2, side-dressed July 1. Ammonium nitrate used.

Native available nitrogen comes from organic matter decomposed in the soil. If heavy rains come before the crop absorbs the released nitrogen, the nitrogen is lost by leaching.

Responses Vary from Year to Year

Since rainfall affects fertilizer response, we should not base our research program on experimental results from one year alone.

If we can find the relation between weather and fertilizer response, we can determine what will occur on the average. Also, with many years of weather data available, we can determine the frequency with which each size response will occur.

We can then point our fertilization program toward maximum net returns.

THE END

EFFECTIVE 50 YEARS AGO

As far back as 1912 Nebraska workers reported that manure, through the plant nutrients supplied, greatly improved the effectiveness of water for corn. In other words the water went further.

	Lbs. of water per lb. dry ears	
	No Manure	Manure
Infertile soil	2,136	692
Medium fertility	1,160	679
Fertile	799	682

Advances in Agronomy, Vol. VI.
In Midwest Potash Newsletter

When irrigation removes moisture ceiling on crop growth—as this foreground plot shows—plant nutrient demands increase.

Get Full Advantage From Irrigation

SUPPLEMENTAL irrigation not only raises crop yield ceilings, but also increases the crop's demand for plant nutrients—especially for nitrogen and potassium and to less degree for phosphorus.

Demand for Nitrogen

Supplemental irrigation increases the nitrogen requirements of crops more drastically than that of any other nutrient. For example:

With cotton . . .

. . . moisture stress is a bigger factor than generally believed. Once the moisture limitation is removed, large amounts of nitrogen are needed for maximum yield. A 1958 experiment on Greenville sandy loam at Thorsby, Alabama, showed the following yield response to nitrogen and irrigation:

Pounds of N applied per acre	POUNDS OF SEED COTTON PRODUCED PER ACRE	
	Without irrigation	With irrigation
0	2606	2987
120	3941	4395
240	3771	4805
360	3506	5336

Without irrigation, note how 120 lbs. of nitrogen produced maximum yield—in fact, 435 lbs. more seed

Potential yields in the 4-bale range have been made in the humid region.

Supplemental irrigation—with improved practices, including stepped-up fertilization—makes the difference.

By
Robert W. Pearson

USDA and
Research Lecturer

Auburn University

cotton per acre than the 360 lbs. N treatment.

With irrigation, each nitrogen increase brought strong yield response up to 360 lbs. N rate where 5,336 lbs. seed cotton was produced per acre.

Such results show the yield *potential* of humid-region cotton to equal that of the West. But the complex management required by cotton at such yield levels in the humid region makes nitrogen rates above 150 to 200 lbs. per acre impractical in present production.

Obviously, the optimum rate will vary considerably with soil and expected general management level.

High nitrogen and high moisture levels raise several problems associated with rank vegetative growth, including lodging, increased boll rot, and difficulty in controlling insects. Also, a larger portion of the crop matures in late fall when storm damage is more imminent.

In Figure 1, note how the same amount of cotton was picked up to the first part of October regardless of treatment. But between October 6 and November 25, the unfertilized

. . . and more yield per inch of water

CROP YIELD PER INCH OF WATER USED

Crop	Low Fert.	High Fert.
Corn	2.18 bu.	3.57 bu.
Oats	1.89 bu.	4.33 bu.

"Although fertilization cannot change total water supply, it obviously can increase yield per inch of water used, whether rainfall or irrigation."

plots made very little additional cotton, while the high-N plots made 2,800 lbs. more cotton. Thus, this increased yield (from higher N rates and irrigation) was in that part of the crop harvested late in the season and most vulnerable to insect and weather damage.

With corn . . .

. . . irrigation may double the nitrogen requirement in some years on soils with poor moisture characteristics where improved, adapted varieties are planted at proper spacing.

Figure 2 shows typical nitrogen response of irrigated field corn in the Southeast—a definite yield response up to about 150 lbs. of nitrogen per acre during a 5-year period that included years of both good and poor rainfall at 3 widely separated locations.

Recommendations for unirrigated corn usually range from 80 to 100 lbs. of nitrogen per acre.

Moisture limitation is less critical on corn yields in the northeastern and northcentral parts of the humid region, according to official reports, generally requiring small increase in nitrogen fertilization rates.

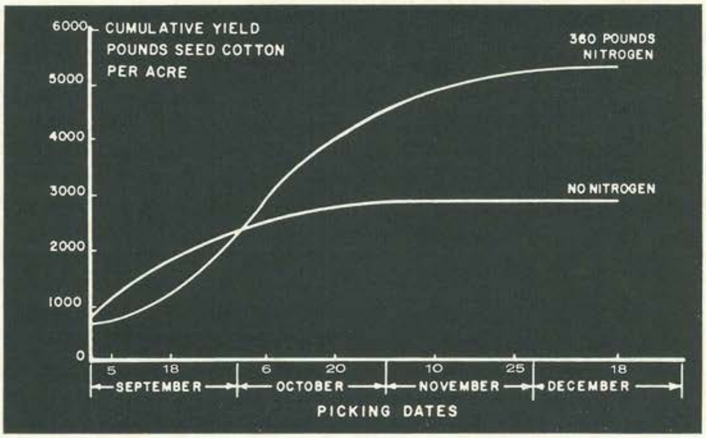
With forage grasses . . .

. . . irrigation of warm-season perennial grasses is a questionable practice since extensive tests have shown no marked yield increases for irrigation regardless of nitrogen fertilization level.

For example, in most years N rates as high as 900 lbs. per acre have increased Coastal Bermuda yields with or without irrigation, though response above about the 600-lb. level is seldom enough to pay for the additional nitrogen.

On the other hand, irrigation greatly increases the nitrogen demands of annual forage crops. Three reasons help account for this: (1) such crops are often seeded during unfavorable moisture periods, (2) they must make their

Figure 1—Here is how high nitrogen fertilization affected the rate at which irrigated cotton matured in Thorsby, Alabama, tests—1958.



Effect on Cotton Maturity

"It is impossible to get efficient crop use of fertilizer either with or without irrigation on soils that need liming."

growth in a short time, (3) they have relatively shallow root systems.

Demand for Potassium

Supplemental irrigation also increases the potassium requirements of crops. The maximum economical rate of potassium varies widely. Among the factors affecting potassium needs, two stand out:

1 Amounts needed for maximum yield are usually much higher on coarse-textured soils than on finer-textured soils.

2 Previous cropping and fertilization history can be extremely important in determining potassium needs.

For example, such crops as Coastal Bermuda grass and alfalfa, if not generously fertilized, can rapidly deplete the soil potassium supply to a level intolerable for row crop production—a real problem when such potassium-sensitive crops as cotton follow inadequately fertilized sod crops.

And supplemental irrigation only intensifies the problem.

With cotton . . .

. . . the extremely high potassium requirement of irrigated cotton was clearly shown by an experiment on Faceville sandy loam at Thorsby, Alabama.

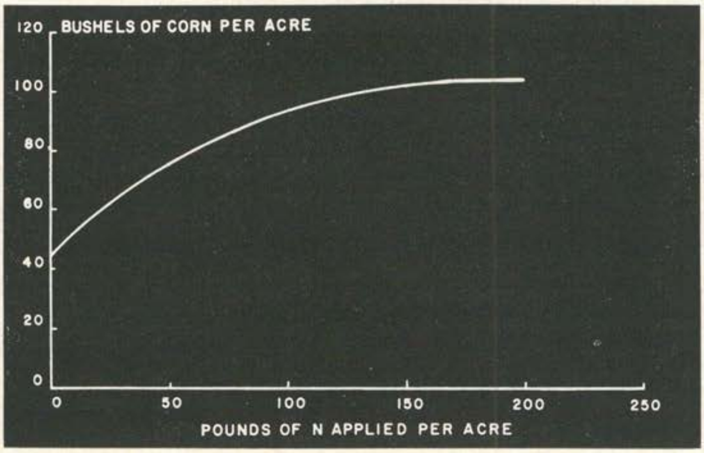
For example, there was a large yield response of cotton to potassium rates up to 300 lbs. and a small response from an additional 300 lbs. of K_2O per acre. As much as 400 lbs. K_2O was found in the above-ground cotton crop where yields were in the 4-bale per acre range.

Since practically all potassium taken up by cotton is found in the vegetative tissue, little is actually removed from the land, even by a 3- or 4-bale harvested crop, if the stalks are returned. The same is true of grain crops when the stover or straw is returned to the soil.

But—the increased requirements of irrigated crops can be met only by maintaining a higher level of available potassium. Actual fertilization requirement can be determined only after

Figure 2—Nitrogen fertilization increased irrigated field corn at 3 locations in the Southeast—fairly typical average for the humid region.

And on Corn Yields



"Previous cropping and fertilization history can be extremely important in determining potassium needs, which supplemental irrigation tends to increase."

considering soil test results and expected management level.

Demand for Phosphorus

Irrigation changes the phosphorus requirement of crops less than either the nitrogen or potassium requirement. This is due largely to two factors: (1) smaller amounts are required, (2) higher application rates in relation to crop removal are commonly used on unirrigated crops.

Although long-time use of phosphorus on many soils in the humid region has created a high residual level, available soil phosphorus is frequently inadequate for maximum yield of some crops under intensive production. Here, again, soil tests are necessary to determine the soil supply.

Lime's Importance

The importance of liming, which is an essential part of any humid region soil management program, is magnified by supplemental irrigation. In fact, it is impossible to get efficient crop use of fertilizer either with or without irrigation on soils that need liming. Careful attention should be given to a liming program for several reasons:

1 Liming in the humid region has been traditionally based on legume requirements in a rotational cropping system, while such crops as cotton, tobacco, and peanuts, typically grown either continuously or in nonlegume-based rotations, seldom receive adequate lime attention.

2 The increasing use of high rates of residually acid nitrogen sources throughout the region intensifies the problem where there is no corresponding increase in limestone usage. For example, every pound of nitrogen fertilizer applied in the ammonium or

---

"TURN THE FAUCET

OFF"

. . . the plant faucet, that is.

Potassium-deficient plants use more water per bushel of grain produced—a fact pointed out in different parts of this issue.

One reason for this higher water usage is that the plants are more wilted and the openings through which the water is lost (the stomata) are open more fully in K-hungry plants.

So—more water naturally leaves the plant.

In a sense, potassium helps "turn the faucet off" when it is available in adequate amounts.

Potassium is an essential "worker" in the cells surrounding the stomata, helping to control the rate of transpiration.

—*Midwest Potash Newsletter*

"Irrigation greatly increases the nitrogen demands of annual forage crops—since they are seeded during unfavorable moisture periods, must make growth in a short time, and have relatively shallow root systems."

amide form requires from nearly 2 to as much as 5 lbs. of limestone to prevent an increase in soil acidity.

3 With cotton, for example, low calcium levels are sometimes responsible for poor seedling survival during low temperature periods.

4 Most crops are sensitive to increased amounts of soluble manganese and aluminum generally found in acid soils.

Thus, the high yield conditions provided by supplemental irrigation and intensive fertilization demand more careful attention to the liming needs of the major crops in the humid region. As with fertilization, a sound liming program must be based on soil test results.

More Yield per Inch—of Water

Improved fertilization and liming practices are essential for efficient water use by crops. This relationship, which has been demonstrated many times in various parts of the humid region, is shown by the Wisconsin results shown at bottom of page 11.

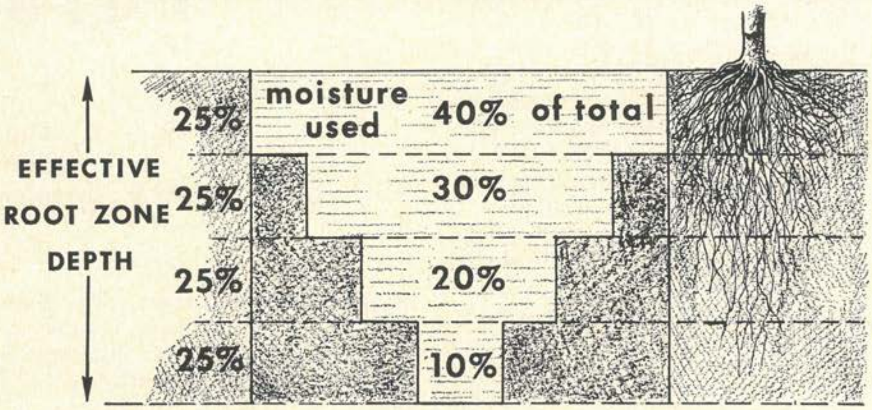
Although fertilization cannot change total water supply, it obviously can increase the yield produced by a given amount of water—in other words, get more yield per inch of water used, whether from rainfall or irrigation.

In Conclusion . . .

. . . wherever irrigation removes the moisture ceiling on crop yield, other management practices such as fertilization, liming, and insect and disease control become more critical.

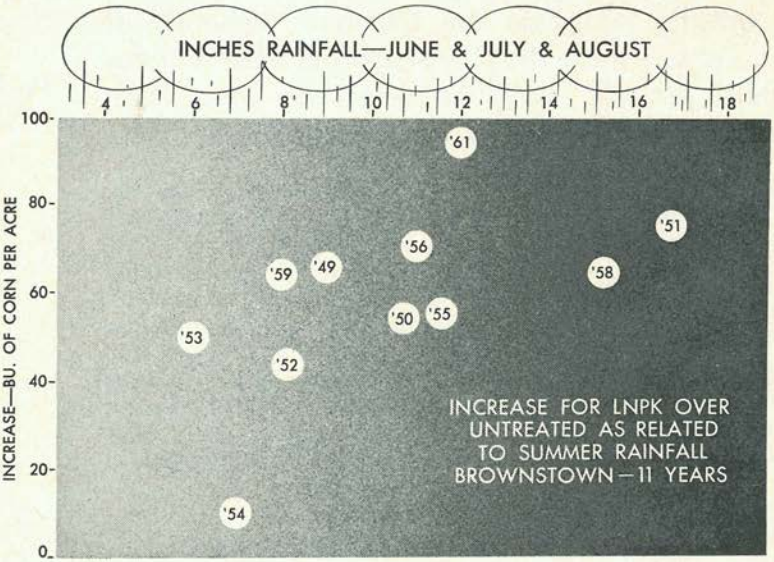
Failure to follow through with all required practices can offset the advantages of irrigation.

THE END



Most crops in deep, uniform soils use moisture more slowly from the lower root zone than from the upper soil as shown. The top quarter is the first to be exhausted of available moisture. The plant then has to draw its moisture from the lower three-quarters of root depth. This places a stress on the plant, and adequate moisture to sustain rapid growth cannot be extracted by the roots.
—*SCS Bulletin 199*

Figure 1



Both at Brownstown

Increases from complete treatment . . .

FERTILITY PAYS

By A. L. Lang
L. B. Miller
P. E. Johnson

IN SPITE of weather hazards, a long-time soil fertility program is necessary and profitable on the flat "clay-pan" soils of southern Illinois.

To determine any relation between rainfall and increased corn yields from different fertility treatments, we arranged corn yield data from our Brownstown and Toledo Soil Experiment Fields by descending yields on the complete (LNPK) treatment plots —shown in Tables 1 and 2.

Yield increases from limestone, phosphorus, and potassium (nitrogen at Brownstown), as well as rainfall data, were arranged accordingly. We plotted the increases—for LNPK over no treatment and for LPK—against the June-July-August rainfall data, as shown in Figures 1-4.

A corn-soybean-wheat-hay rotation was used.

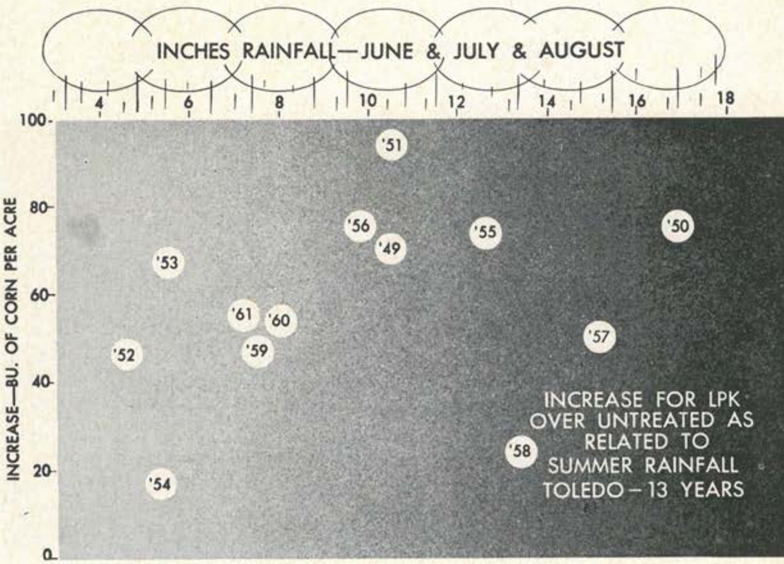
Such comparisons fail to show uniformly good relation between rainfall and top corn yield in different years —or with increases from individual nutrients. But proper treatment combinations increased corn yields most years and were profitable in spite of some low yields from too little or too much water at critical periods.

Soil and Rainfall Characteristics

Physical Conditions:

The Cisne, Hoyleton, and Renard silt loam soils, represented in the Brownstown and Toledo Soil Experi-

Figure 2



And at Toledo

. . . showed some positive relation to rainfall

... in flood ... or drouth

University Of Illinois

ment Fields, are planosols, often called "clay-pan" soils because of an impervious layer with high clay content 20 to 28 inches down. Subsoils are also generally impervious.

Topography is flat. Surface drainage is largely used. Water infiltration is slow. Heavy rains may be lost by run-off before water is absorbed. Such traits make crops vulnerable to extreme drouth or rainfall.

Chemical Conditions:

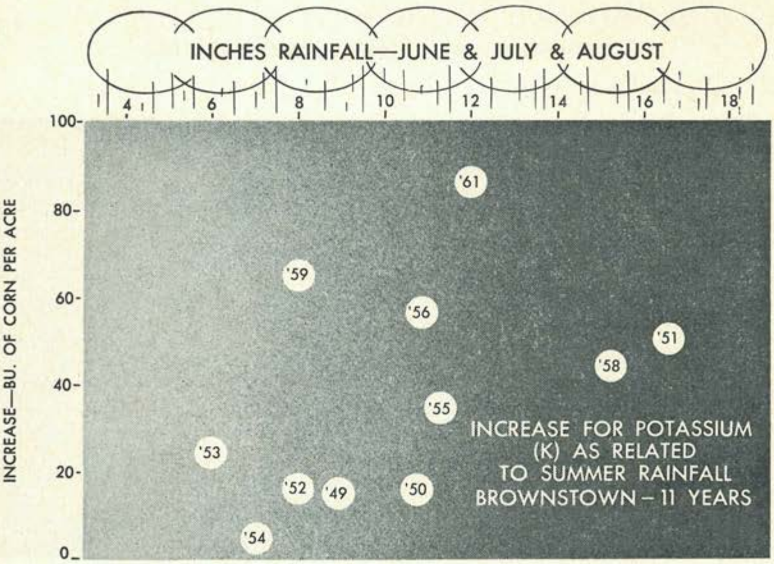
Soils are originally quite acid, demanding 4 to 6 tons limestone to correct, plus 2 tons about every 8 years to maintain. Native organic matter is low—surface 2.6% o.m., with less than 1% o.m. at 20-30 inches. Phosphorus content is low, especially for wheat and legumes.

Potassium is very low, especially after liming and cropping a few years. Annual *K* release from the soil is low. Fifty or more pounds of K_2O (42 lbs. K) per acre per year of rotation are needed to maintain yields.

Why Low Yields

On such impervious soils, *abnormal rainfall within critical periods* (either

Figure 3



Both at Brownstown

Increases from potassium showed . . .

too little or too much) may retard corn yields greatly. For example, note Tables 1 and 2:

The 1957 corn failure at Brownstown was due to delayed planting because unlimed plots were too wet to plow long after adjacent limed and fertilized plots could have been planted. Over 80 bushels of corn per acre were produced on other series planted on time.

The 1960 corn failure at Brownstown was due to a heavy rain just after planting, though the total summer rainfall was low.

The 1958 corn at Toledo was ruined by continued wet and warm weather during the first month after planting.

Though 1953 summer rainfall was less than in 1954, the '53 crop produced fair yields and good increases from treatments, due to a 4-inch rain in June and less hot winds than in '54. The 1954 low yields were due to drouth and hot winds at pollination time.

Obviously, on such soils one must learn to distinguish between (1) water deficiencies, sometimes confounded by high temperatures and winds at pollination time and (2) damage caused by excess rainfall at critical periods, especially just after planting corn or soybeans.

In fact, weather conditions within critical periods must be pin-pointed more closely than mere monthly rainfall totals, it seems, if we hope to explain yield differences.

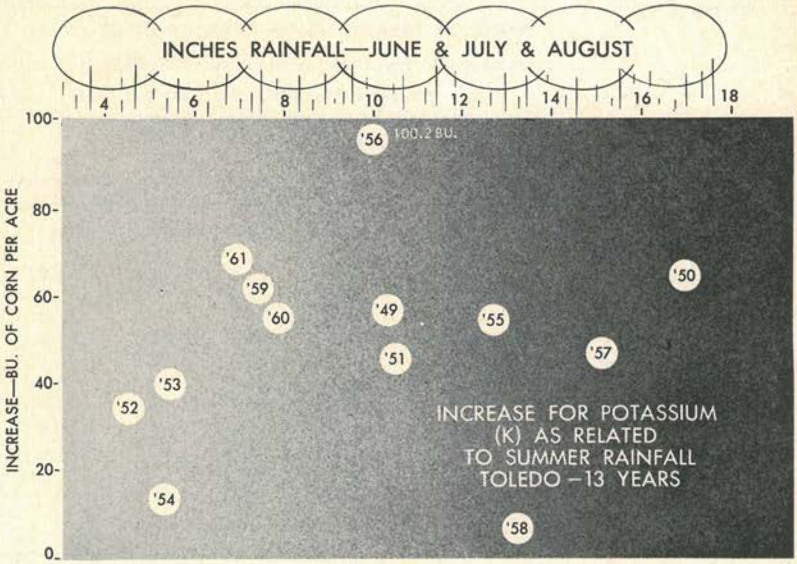
What Relation to Rainfall

Discarding some of the data from

"Weather conditions within critical periods must be pin-pointed more closely than mere monthly rainfall totals, if we hope to explain yield differences."

Figure 4

And at Toledo



. . . very irregular relation to rainfall

these obviously abnormal years, we see these relations:

1 Responses to LNPK (the complete treatment) at both fields show some positive relation to rainfall—Figures 1 and 2.

2 Increases from potassium show very irregular relation to summer rainfall—Figures 3 and 4.

3 Increases from limestone or phosphorus show little if any relation to the rainfall data—Tables 1 and 2.

When water deficiency becomes a major limiting factor, crop yields and responses should logically correlate with rainfall during critical growth periods. Many tests have shown such correlations.

When water excess reduces yields at critical periods, yields will not correlate with rainfall. In fact, any factor limiting yields should reduce the correlation between yields and amount of rainfall.

Relating corn and soybean yields to 50-year weather records in central Illinois, an Odell study offered these pointers:

1 Below-normal rainfall is desirable from planting time to mid-June for corn—and through June for soybeans.

2 Abundant rainfall during July enables both corn and soybeans to thrive when crops are growing rapidly.

"Complete treatment (LNPK) averaged nearly $20 net income per acre per year of rotation over 8-year period, despite two corn failure years from excess moisture and one low yield year from drouth and hot winds."

Table 1

EFFECT OF TREATMENT ON YIELD OF CORN

Brownstown Soil Experiment Field, 1949–1961

	Yield of LNPK	Yield of no Treatment	Average Increases—Bu. Corn per acre: for LNPK	for Limestone	for Nitrogen	for Phosphorus	for Potassium	Rainfall: June July Aug.
	Bu.	Bu.	Bu.	Bu.	Bu.	Bu.	Bu.	In.
1961	128.1	33.4	94.7	56.1	19.5	28.6	88.2	12.0
1951	109.6	31.8	77.8	47.0	15.0	18.5	52.4	16.6
1956	103.9	34.6	69.3	27.4	− 1.4	11.3	47.8	10.9
1959	98.7	35.0	63.7	5.9	14.7	13.9	65.0	8.1
1949	83.4	17.5	65.9	46.8	4.8	16.1	16.1	8.9
1952	79.4	35.9	43.5	16.6	−14.8	1.5	18.1	8.1
1958	72.2	11.7	60.5	49.0	−10.3	− 3.2	42.2	15.3
1955	69.3	13.0	56.3	32.1	27.3	9.2	32.2	11.2
1950	66.0	11.2	54.8	35.1	6.2	3.4	17.7	10.7
1953	56.5	7.0	49.5	40.6	24.7	14.0	22.7	5.9
1954	35.5	25.7	9.8	7.1	3.9	8.0	2.1	7.0
1960	——							10.3
1957	——							19.9
Ave.*	69.4	19.8	49.8	28.0	6.9	9.3	31.1	

* Averages for 13 years, including failures in 1957 and 1960.

L=limed; N=80# N on corn; 40# N on wheat; P=80# P_2O_5 on wheat, 40# P_2O_5 on Corn; K=50# K_2O/A per year of rotation.

Both at Brownstown Increases from limestone or phosphorus showed . . .

3 Above-average rainfall in early August may increase corn yields but reduce soybean yields, which are usually in the early pod stage.

4 Cooler-than-normal temperatures during July and early August help produce high yields of both corn and soybeans.

Corn follows legume-grass in these studies, with only one hay crop removed. Regrowth is plowed under for corn, supplying considerable nitrogen and explaining why response to 80 lbs. N on corn is not as great as in cropping systems without legumes. Wheat responded relatively better than corn to nitrogen.

Reducing the Hazards

Growing more than one crop each year reduces moisture hazards, because critical periods of different crops may not coincide. For example, when the 1957 and 1960 Brownstown corn failed from excess moisture just after planting, wheat and hay (1 cutting only) produced fairly well. Soybeans were retarded some (Table 3).

Paying Off in Profits

Through a cost and net income analysis of different fertilizing systems at Brownstown, an 8-year average showed what limestone, potassium, phosphorus, and nitrogen meant to this corn-soybeans-wheat-hay rotation:

	Annual net income per acre
No treatment	−$25.30
LNPK	19.75
–NPK (no lime)	−13.64
L–PK (no N)	13.38
LN–K (no P)	1.24
LNP– (no K)	−2.67

Table 2

EFFECT OF TREATMENT ON YIELD OF CORN

Toledo Soil Experiment Field, 1949–1961

	Yield of LPK	Yield of no Treatment	Average Increases—Bu. Corn per acre for LPK	for Limestone	for Phosphorus	for Potassium	Rainfall June July Aug.
	Bu.	Bu.	Bu.	Bu.	Bu.	Bu.	In.
1956	113.0	35.5	77.5	34.2	− 3.2	100.2	9.8
1961	112.3	35.8	56.5	28.4	6.7	65.9	7.1
1951	110.7	17.8	92.9	33.1	17.2	44.7	10.4
1955	101.1	27.4	73.7	15.2	3.8	55.4	12.7
1959	99.6	48.6	51.0	17.0	2.4	61.7	7.5
1949	97.6	26.0	71.6	32.5	8.2	58.4	10.2
1953	85.0	17.1	67.9	19.9	19.9	40.4	5.5
1960	83.2	27.8	55.4	22.4	14.4	57.0	7.8
1950	76.6	.5	76.1	73.2	50.6	61.0	17.0
1952	69.0	20.4	48.6	12.9	5.9	31.9	4.4
1957	53.0	2.9	50.1	19.3	14.7	48.1	15.2
1954	33.5	15.7	17.8	2.5	2.2	11.2	5.2
1958	23.0	.3	22.7	22.8	21.4	5.6	13.3
Ave.	81.4	22.8	58.6	25.6	12.6	49.1	

L=limed; P=Rock phosphate; K=50# K_2O/A per year of rotation.

And at Toledo

. . . little if any relation to rainfall

Complete treatment (LNPK) averaged nearly $20 net income per acre per year of rotation, despite two corn failure years from excess moisture and one low-yield year from drouth and hot winds.

Long-Time Investment Plans

Farming is a long-time investment in capital and labor. Most investments in limestone, phosphorus, or potassium fertilizers involve long-time benefits over a wide range of weather conditions.

Liming is an 8 to 10-year investment, potashing at least a 2-year investment, phosphorus usually a residual and cumulative investment.

Farming systems—including cropping, cultural practices, chemical treatments—can vary in their long-time benefits or adverse effects. Chemical needs may change gradually. Some long-time physical effects may not show measurably until 10 years after a new or changed practice has been used.

Obviously, superior management practices cannot often be built on one or two-year experiments. Long-time observations are necessary to get the complete facts.

Limed Soils Dry Faster

Limed plots in these experiments can usually be spring plowed one to two weeks before unlimed plots are dry enough to support a tractor. The faster drying limed soil is probably due to the improved physical structure, including (1) more organic residues to plow under, (2) greater root volumes, (3) deeper root penetration. Such soil condition improves water infiltration rate.

Proper liming, fertilization, and

TABLE 3—SOYBEAN, WHEAT AND HAY YIELDS IN 1957 AND 1960 WHEN CORN FAILED IN A CORN-SOYBEAN-WHEAT-HAY ROTATION AT BROWNSTOWN.

	Yield of no Treatment	Increases from various treatments*				
		LNPK	L	N	P	K
1957						
Soybeans (Bu.)	2.5	13.5	4.2	−4.0	−.3	3.1
Wheat (Bu.)	.9	37.9	17.9	9.8	29.0	22.1
Hay (Tons)	.0	2.6	2.6	.2	.6	1.4
1960						
Soybeans (Bu.)	8.8	13.9	7.4	6.3	1.4	11.8
Wheat (Bu.)	.0	43.0	27.4	14.0	17.6	7.2
Hay (Tons)	.3	3.5	3.0	.3	1.2	1.0

* No N on soybeans or hay, residual effects only.

management help conserve and utilize available moisture. In fact, Fehrenbacher's root studies have shown how root penetration is deeper on limed and fertilized soils—with treated crops producing more per inch of available water, untreated crops apparently unable to utilize available water.

. . . In Summary

1 In the reviewed experiments, improved fertility on claypan soils paid off in spite of critical dry and wet periods.

2 In unirrigated areas, the farmers' long-time problem is two-fold: to make the most efficient use of available water, to avoid damage during heavy rainfall periods.

3 In solving this problem, two parts of the solution are: (1) to plan a cropping and fertility program that fully utilizes the available water, (2) to maintain or improve the soil physical condition through attention to drainage, aeration, and water-holding capacity.

4 In building long-time management practices, single-year experiments are not a reliable foundation for logical plans and treatments—instead, long-time observations are imperative, as shown by the varied responses of these experiments.

THE END

STRETCH IT On Corn & Hay

Corn:

In Iowa increased fertility (in this case nitrogen) caused corn to pull water out of a soil to a depth of 7 feet. The unfertilized corn got its water from less than 5 feet of soil. Since this soil contained about 2 inches of available water per foot, the amount of extra water used was about 4 inches.

The fertilized corn produced more bushels per inch of water used than the unfertilized corn did—64 bushels from fertilized crop, 19 bushels from unfertilized.

Hay:

Legume hay fertilized with phosphorus and potassium also was found to use water more effectively than unfertilized hay.

Of course, in extreme drouth where the subsoil is dry or at least dry below 2 or 3 feet, increased fertilization will not help crops to penetrate the soil further and get more moisture.

—Midwest Potash Newsletter

BREAKTHROUGH IN CORN PRODUCTION

The yield in the test field above was 161 bushels per acre—or about 50 percent above what is usually considered an excellent yield. The hybrid was Funk's G-96, one of a family of new high capacity hybrids. One hundred pounds of nitrogen was applied, plus phosphate and potash. The plant population was 22,000 stalks per acre.

Here you have the three key elements of the corn growing plan which has become the biggest news in corn farming. (1) A high capacity hybrid, (2) well fed, and (3) planted thicker. This system has produced record big-acreage corn yields—and, as in the field above, permits you to set your sights on yields 20 to 50 percent above present average yield levels in your area.

1 Your Funk's-G dealer has the **high capacity hybrids.**

Don't settle for less. Funk's G-Hybrids* have the capacity to yield more under this new high-profit system. Hybrids not bred for thicker planting and high fertility will not respond—often go barren and lodge badly at higher populations.

2 The amount of **extra plant food** you will need depends upon how much you expect to increase yields. Here is a handy guide—for each 10 bushels increase per acre, apply 20 to 30 extra pounds of actual N, about 10 to 15 extra pounds of phosphate (P_2O_5) and 10 to 15 extra pounds of potash (K_2O). For higher or lower goals, reduce or increase accordingly.

3 **Higher plant populations** raise your yield potential when plant food and moisture are adequate. If you are aiming in the over-100-bushel area, you may want to plant 18,000 to 24,000 kernels per acre. Where moisture is limited, 12,000 to 16,000 plants per acre would be more practical.

Naturally, you need to do a good job of planting and caring for the crop; rainfall and waterholding capacity of your soil must be carefully considered in setting your yield goal. Start by seeing your Funk's-G dealer today.

FUNK'S G HYBRID ®

In 1963, Plant the Hybrids with

MORE CAPACITY TO PRODUCE

THE PRODUCERS OF FUNK'S G-HYBRIDS

*Funk's G-Hybrid is the registered trademark of Funk Bros. Seed Co., Bloomington, Ill.

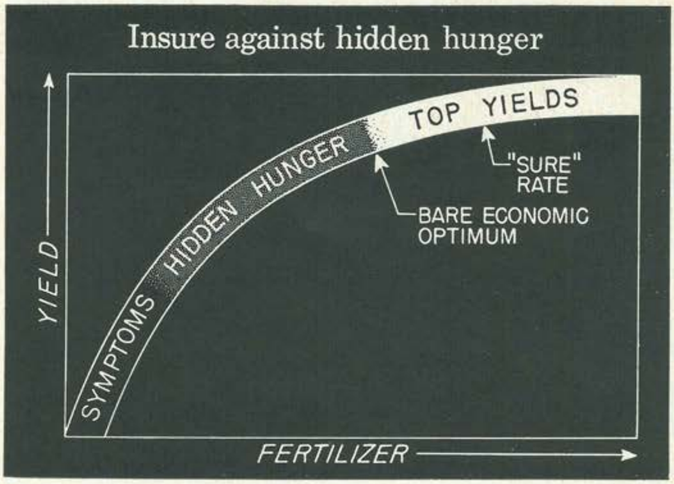


Figure 1

When reduced growth rates are coupled with the higher respiration rates, the plant damage is done . . . giving real meaning to the hidden hunger zone at left, truly a zone of nutrient deficiency where crop production is curtailed before visual symptoms of distress are evident.

POTASSIUM and WATER ECONOMY of PLANTS

IN RECENT years, we have gained much knowledge of potassium-moisture relationships within the plant and between the plant and the soil.

A detailed look at the effect of potassium on the water economy of plants must include many functions vital to plant life:

1 How potassium affects photosynthesis, respiration, and transpiration—processes vital to the internal water balance in plants.

2 How potassium supply affects carbohydrate metabolism and protein synthesis.

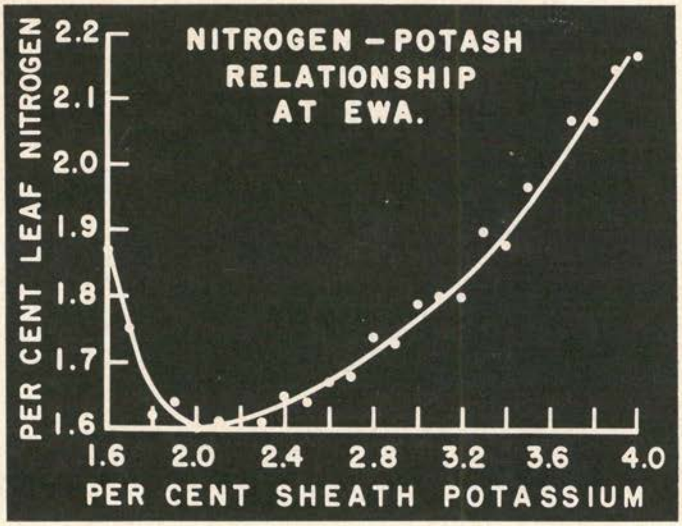
3 And how it activates enzymes, promotes young meristem growth, and adjusts stomatal movement and water relationships.

Moisture Relations in Cells and Plant Tissues

Many workers have found that increased water tension causes a decrease in rate of photosynthesis and an increase in respiration. (Kramer 1949)

Investigators of moisture relationships in cells generally agree that water is held in colloids of the protoplasm under high tension, requiring much energy

Figure 2



When potassium hunger occurs, nitrogen accumulates in plants and is not used in further vegetativegrowth. Thousands of sugarcane analyses at Ewa Plantation in Hawaii shows N and K declining similarly until critical K hunger occurs, below which "unused" N accumulates.

By Roger P. Humbert
Los Gatos
California

a definitive report

to displace it. This is "built in" protection for the physiological and biochemical processes that occur in the cells.

Potassium cations are known to increase the hydration (the chemical combining of water with other substance) of the protoplasm in the plant cell.

The internal water balance is the most important aspect of plant-water relations because internal water balance and turgidity (normal distention and resiliency of plant cells) are closely related to the rates of various physiological processes that control the quantity and quality of plant growth. Internal water balance is controlled by the relative rates of water absorption and water loss.

How *water deficits* affect physiological and biochemical processes is reasonably well known—but how *potassium supply* affects moisture availability within plant tissues is less readily understood.

Water is the solvent through which potassium enters the plant and in which it moves from cell to cell and from tissue to tissue.

As K hunger develops in plants growing in acid to neutral soils under humid conditions, K migrates from the older tissues to satisfy the demands of rapidly growing younger tissues, leaving the older leaves to dry rapidly from the tips toward the centers and to show gradual aging.

Potassium hunger signs have occurred in the youngest tissues at the top of some plants grown in alkaline soils in arid climates. This condition is associated with a moisture supply inadequate for normal turgidity and growth.

Such moisture stress is associated with potassium deficiency, according to plant analyses of California potatoes and cotton. As potassium levels fall much below 1.0 percent, water in the tissues becomes too inadequate to hold turgidity for cell growth or to maintain the form and position of leaves, new shoots, and other slightly lignified structures. Growth immediately declines or ceases from this lack of turgidity.

One of the plant processes most sensitive to internal water deficits seems to be stomatal opening—the minute "breathing pores" (stomata), most numerous on under surface of leaves, with "guard cells" that form an automatic valve for opening and closing each pore by swelling or shrinking according to varying plant conditions, especially where evaporation is concerned.

As turgidity decreases slightly, stomatal opening often increases. But further reduction in turgidity is nearly always accompanied by a decrease in stomatal openings, protecting the plant against excessive transpiration and increasing drought resistance and survival.

Many investigators have reported that potassium increases the water-holding capacity of plant tissues.

Where K concentrations are present in the root zone, osmotic pressure of the soil solution rises, decreasing water availability as the plant encounters difficulty in its uptake.

A high K concentration in the soil increases osmotic pressure of the cell solute and consequently the plant's ability to withstand high water tension in the soil.

Hudson reports that saline soil, with high osmotic concentration from increased K salts, is less dangerous to plants than soils in which sodium is the dominant cation. This helps explain why Heimann and Ratner (1962) in Israel improved sugar beet quality by raising the K-Na ratio in the beets.

K is reported to influence the permeability of root cells to water, while additional K increases the penetration of the protoplasmic membranes to water.

As the thickness of moisture films around soil particles *decreased*, Reitemeier found, the concentrations of certain cations and polyvalent anions in the outer layers *diminished relatively*. This may explain why plants subjected to low soil moisture also tend to have relatively few of these ions. Such condition may also encourage potassium ions to enter the lattice of the clay and become "fixed."

Cells and tissue are turgid, or properly distended and resilient, when K supply and moisture are adequate. This turgor is important to the structure and functions of plants. For example:

1 The quality of many succulent vegetables (such as celery, lettuce, cucumbers) depends greatly on their state of turgor. Such vegetables with adequate K ship more easily, spoil less frequently, retain good condition longer in the fresh produce markets than K-deficient vegetables.

2 Studies with California peaches show potash-deficient peaches breaking down very quickly under normal storage conditions, potash-fed peaches remaining in saleable condition for many weeks. The accelerated respiration in the K-deficient tissue causes a more rapid breakdown of tissue.

Water deficits affect all processes of cell growth—cell division, enlargement, differentiation, and maturation—with cell enlargement drastically reduced by moisture stress. For example:

1 In potash-deficient sugar cane, the elongating section of the stalk is severely shortened, leaving a "bunched" appearance of the cane top as new leaves continue to emerge every 10 to 12 days. Moisture levels in these young tissues are always subnormal.

2 Berger (1958) found cell division was inhibited in potash-deficient tobacco plants—and the growth of cells already formed was also stopped.

3 Cooil (1952), in studies with rye, reported potassium catalyzes the process of cell growth.

4 Ordin (1958) found under high water tension that water loss from the cell occurs and cell wall synthesis (or "building up") is delayed.

Potassium-Moisture Relationships in Plants

Rate of photosynthesis is influenced by potassium supply, increasing with adequate K fertilization, decreasing with deficient K.

Eckstein (1939) found the rate of photosynthesis in sunflowers increasing as potash fertilization increased. This occurred in all stages and ages of plant development.

Gregory and Richards (1929) found potassium deficiency increasing the respiration rate and decreasing the photosynthesis rate of barley leaves, which depressed the rate of dry matter production.

Rate of photosynthesis is often limited by dehydration of protoplasm (the essential matter of all plant cells) which reduces its photosynthetic capacity. Many investigators have reported large photosynthetic decreases in wilting, potash-deficient leaves. Schneider and Childers (1941) reported photosynthesis of apple leaves declined 50% before wilting was visible, while in wilted leaves it fell to only 15% of the expected rate.

Burr, Hartt, and coworkers (1960) have shown how potash deficiency reduced photosynthesis in sugar cane grown under otherwise optimum conditions. In older plants they found photosynthesis rates decreasing as potash deficiency became more severe. For example:

1 A leaf showing no visible K deficiency, but having 0.91 K percentage, declined 10% in photosynthesis compared to control leaves with 1.70 and 1.89 K percentages.

2 Leaves with edges dry and brown, and having 0.40 K percentage, declined 84 to 98% in photosynthesis compared to control leaves with 1.70 and 1.73 K percentages.

These data were obtained from tests with radiocarbon tagging with photosynthesis chambers clamped across the middle of attached leaves.

Respiration is highly accelerated by potash-deficiency—ultimately shifting plants into a lower gear of growth rate and production.

Noguti et al. (1952) in experiments with paddy rice reported larger respiration in K-deficient plots than in K-fertilized plots.

Amberger (1954) observed lower respiration of spinach, sugar beet, and

Turn to page 32

An Editorial Viewpoint

A DROP at a time.

That is the way it comes.

To a few soils too much. To som
others too little. To some none at all.

Whether man drinks it, bathes in it,
by it, grows his food and fiber throu
dustrial needs with it—regardless of h
—it is perhaps his most vital natural

A look at the water cycle here (s
hydrologic cycle) shows how water b
resource for man to use, how nature
how it returns to man to use again.

If nature should grow weary of t
to return the water, the multiple soc
litical, religious differences plaguing
would likely dissolve overnight into
fraternal efforts to convince nature to
once again.

But that's beside the point—so lo
livers" and man continues to try t
means of using water more efficien
use efficiency is becoming a prime
culture, as pointed out by the scienti
ing in this issue.

Speaking to the 1962 International
and Soil Utilization, Federal Adminis
of the Agricultural Research Service s

"Agriculture has so far had first c
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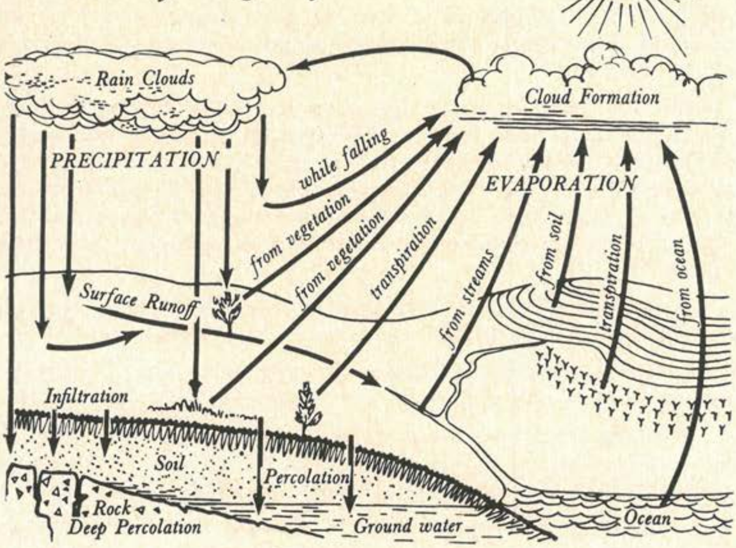
The Hydrologic Cycle



of water, agriculture increasingly will have to justify every acre-foot of water it uses. We will have to balance agricultural needs against other demands—something we haven't had to do in the past."

This "first call" on water supplies has included huge quantities per crop. For example:

1 Corn planted at normal populations uses about 461,500 gallons of water per acre each year, scientists estimate—or on a 40-acre cornfield about 18,560,000 gallons. Put another way, each

---

A MILLION DOLLAR RAIN

When one inch of rain falls on a 160-acre farm, it delivers this quantity:

In volume: 4,356,000 gallons
In weight: 36,300,000 pounds

To evaporate it from the Gulf of Mexico, over 1,000,000 horsepower of energy was used and an equal amount was transferred to the cold air mass which caused the rain to fall over the quarter-section of land.

To transport this 18,150 tons of water would require 544 tankcars of four trains, each over a mile long.

—Roy M. Moffitt
Pass Christian, Miss

corn plant can pump 5 pints of water out of the soil every day during July. With 14,000 plants per acre, your crop is pulling 8,750 gallons of water from the soil each day on each acre, some agronomists figure.

2 It takes 115 gallons of water to grow enough wheat to make one loaf of bread. Ever counted the loaves of bread on just one shelf of a single supermarket near you?

When Dr. Shaw spoke of agriculture eventually having to justify the water it uses, he may have had in mind (though we can't say) one state where farmers are already losing the right to irrigate from two sources formerly open to them: (1) water from underground storage and (2) runoff water accumulated in streams and rivers. Why? Because both sources supply most of the water needed by cities and towns and industries growing around them. People. People. People.

Former soils editor T. L. Wainscott of *Successful Farming* magazine explains the problem and agriculture's one trump card this way:

"In the end, legislation decides who gets this water. Democratic legislation follows the line of the greatest use to the greatest number of people.

"Agriculture has one trump card—and only one. The water falls first on farms. Every drop a farmer can store in his soil, every inch of runoff he can put into a lake, legislation cannot touch. All rights to it are his."

So, anything that can be done to increase the efficiency of water use by plants deserves careful study. One factor is soil fertility, for crops cannot use water efficiency if they lack fertility.

That idea—the basic theme of this issue, perhaps—is not a new concept by any means. Fifty years ago L. F. Briggs and H. L. Shantz, in a comprehensive review of 23 separate investigations on water requirements of plants as affected by fertilization, said:

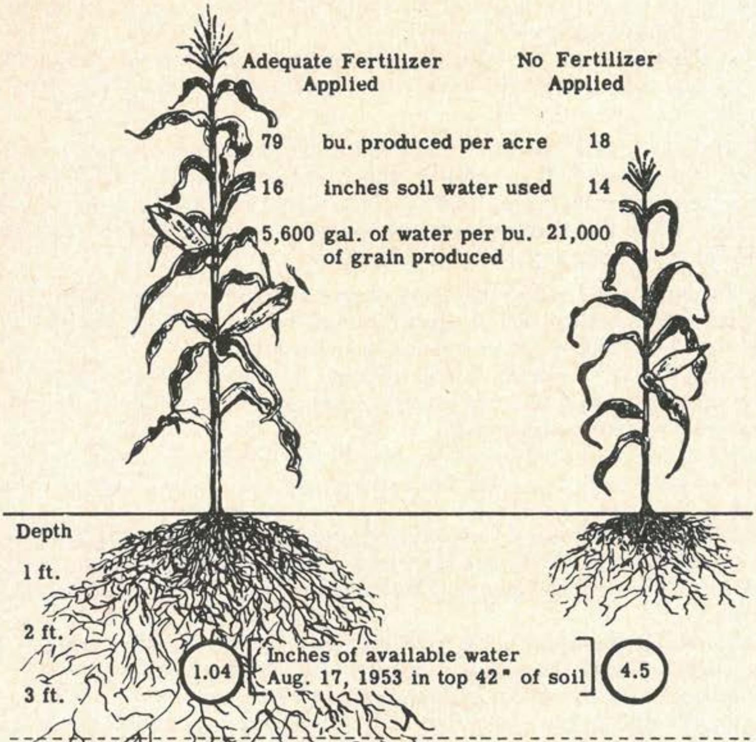
"Almost without exception the experiments herein cited show a reduction in the water requirement accompanying the use of fertilizers. In highly productive soils, this reduction amounts to only a small percentage. In poor soils, the water requirement may be reduced one-half or even two-thirds by the addition of fertilizers.

"Often the high water requirement is due to the deficiency of a single plant food element. As the supply of such an element approaches exhaustion, the rate of growth as measured by the assimilation of carbon dioxide is greatly reduced but no corresponding change occurs in the transpiration. The result is inevitably a high water requirement."

Today, 1963 specialists are finding the same thing—and then some—that adequate fertilization encourages a vigorous root system, produces leaf and stem growth for protecting the soil surface, and insures efficient use of available soil moisture.

When one farmer uses 17 inches of water to grow 50 bushels of corn while his neighbor uses 17 inches to grow 120 bushels per acre, someone is wasting valuable moisture. Proper fertilization can be the difference.

Such claim is not idle talk. During a very dry year, Missouri corn growers saw the difference in work on farms and in experimental plots, conducted by G. E. Smith and associates and cited by W. L. Nelson and G. Stanford.



Corn on soil with inadequate nutrients cannot develop sufficient root system to utilize moisture in subsoil.

The growers saw that corn on a Missouri claypan soil could not use subsoil moisture effectively unless fertilized. They saw adequately fertilized corn push its roots four or more feet into the ground for that hidden reservoir of needed moisture and then use it much more economically than the unfertilized corn—the fertilized corn taking only 5,600 gallons of water per bushel to produce 79 bushels, the unfertilized corn taking 21,000 gallons per bushel to produce 18 bushels.

Sound fertilization is not the complete answer to more efficient moisture utilization, of course. Much research is now being conducted on methods to control part of the moisture lost by surface evaporation—using plastic coverings, mulch tillage, synthetic sprays, and producing a soil mulch.

Covering corn plots with plastic to reduce soil moisture evaporation, South Dakota soil scientist J. R. Runkle produced 99 bushels of corn per acre with only seven and a half inches of water or nearly 13 bushels for each inch of water the soil had stored—in contrast to only 6 bushels per inch of water for the uncovered plots.

Such approaches and materials for controlling some of the moisture lost by surface evaporation are costly and, so far, economically questionable. So, still one of the great bargains for getting the most out of your soil moisture—today as in 1913—apparently is sound fertilization.

THE END

pasture grass leaves when potash was applied to these crops than when only nitrogen and phosphate were applied.

Since the substrates for plant respiration are derived from photosynthesis, it is assumed that most of the energy to respire comes from carbohydrates. For example:

1 Helmut (1953) assumed that the K ion affects carbohydrate metabolism through the enzymes that catalyze the transformation of carbohydrates. He reports amylase saccharase, and B-glucosidase are highly activated by K deficiency, while the starch/glucose and sucrose/glucose ratios rise as K supply increases for potatoes, sugar beets, and barley.

2 Pirson (1958) made the same observation. In algae lacking potassium, he found increased respiration that returned to normal only after additional potash had been added. The response was very rapid.

Richards (1956) reported that respiration increased in barley plants during potash deficiency, but decreased again when the deficiency was exaggerated and external symptoms appeared.

Similar results were observed by Fujiwara (1955) and others in tomatoes, Noguti and others in rice, and Amberger in spinach, sugar beets, and pasture grasses.

The damage is done when reduced growth rates are coupled with the higher respiration rates. Plants shift into a lower production gear and adjust to a lower photosynthesis rate and carbohydrate production based on available potassium.

Such results, therefore, give real meaning to the "hidden hunger" zone diagramed in Figure 1 as truly a zone of deficiency *where production is curtailed before visual symptoms of distress are evident.*

In plants subjected to water deficits, the proportion of starch to sugar often decreases because of the increased hydrolysis of starch. In sugar cane, water deficits can cause reducing sugars to transform to sucrose, as vegetative growth slows down.

Protein synthesis (or "build up") may be affected by potassium deficiency, since K-deficient plants generally contain much more soluble non-protein N than those generously supplied with K.

Wadleigh and Ayers (1945) are convinced that growth is retarded by a decrease in hydration of the proteins of the protoplasm. They found no changes in the protein content of young tissues.

Richards and Coleman (1952) have shown that K deficiency in barley causes putrescine, and possibly *other toxic amines,* to accumulate in the leaves.

Potash deficiency results in a relative increase in amino acid nitrogen and a decrease in protein—believed due to breakdown of protein and not a reduction in synthesis. But Pirson (1955-58) believes there is a connection between the carbohydrate accumulations and delayed protein synthesis in plants lacking potash.

K-deficient plants generally contain much more soluble non-protein N than those generously supplied with K. The amides in the K-deficient stunted plants represent a larger proportion of the amino-acid-N than in normal plants.

Nitrogen accumulates in plants and is not used in further vegetative growth when potassium deficiencies occur. Figure 2 plots thousands of analyses of sugar cane at Ewa Plantation in Hawaii. Note how nitrogen and potassium levels decline similarly until critical potassium deficiency occurs, below which "unused" nitrogen accumulates.

This "unused" nitrogen at harvest means a higher percentage of reducing sugars and lower recoverable sucrose.

Transpiration can increase plant uptake of mineral salts under some conditions, when nutrient requirements of a plant are high.

Transpiration—the process by which the plant exhales water-vapour while stomata are open during interchange of gases between plant and atmosphere in photosynthesis and respiration—can materially affect solute uptake under some conditions.

Stresses of water flowing to newly forming tissues removes the ions that have been transported across the barriers in plant roots, enabling additional nutrients to move into the plants.

When more potassium, sodium, or other cations than necessary for normal growth occur, water availability is decreased, nutrient uptake is disturbed, and growth is reduced.

We know that salts can be actively transported into plant cell vacuoles—the relatively clear, bubblelike cavity in the protoplasms of a cell, containing air, water, or partially digested fluid, and believed to have the function of discharging wastes—for both ions of such a salt as KCl can be accumulated to concentrations higher than in the external medium.

Salt uptake against concentration is characteristic of rapidly growing and metabolizing tissues such as meristems—the region of young, growing tissue as at the apex of young leaves and stems—but is not observed in mature and aging tissues. This high internal K concentration leads to enzyme adaptation to a K environment.

Burr and Tanimoto (1955) demonstrated that a potassium-starved sugar cane plant and a well-fed plant containing three times as much potassium had comparable percentage composition in the young, growing tissue. But the lower, older leaves of the deficient plant had progressively less potassium than those of the well-fed plant. The old cane and the roots suffered the greatest potassium depletion at the expense of new tissue production.

The role of potassium in the water economy of plants is very important.

While calcium promotes water reduction in plant tissues, potassium promotes the turgidity of the plant cells, maintaining the internal pressure of the plant tissue.

Potassium applications increase the moisture content, rendering sugar cane more succulent. Humbert (1958) grew cane in a normal nutrient solution for 6 weeks and then with various treatments of potassium for 6 weeks. Figure 3 shows the results:

1 Plants maintained on high potassium level kept moisture levels high throughout the top 13 leaves.

2 Plants fed only 39 ppm potassium in 6 weeks showed moisture levels dropping in leaves below number 7. Leaves 12 and 13 lost their turgidity and eventually died from marginal drying.

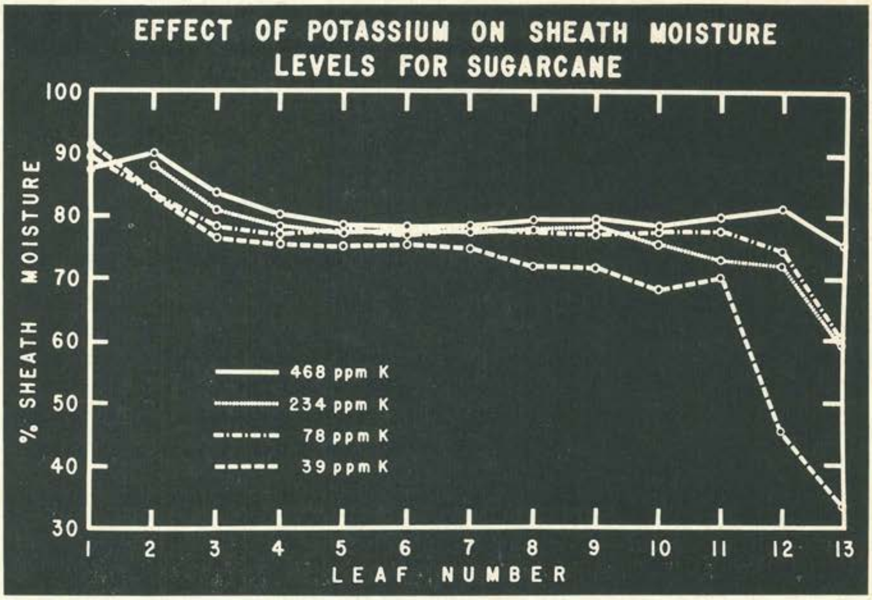


Figure 3—Potassium applications increase the moisture content, in this case rendering sugar cane more succulent. Plants maintained on high K level kept moisture levels high throughout the top 13 leaves. Plants fed only 39 ppm K in 6 weeks showed moisture levels dropping in leaves below number 7 . . . and leaves 12 and 13 losing their turgidity and eventually dying from marginal drying.

Leaves of potassium-deficient cane possess low turgidity, their tips often becoming frayed from blowing in the wind—especially cane on the gray hydromorphic and dark magnesium clay soils often moderately high in exchangeable potassium but very high in exchangeable calcium and magnesium.

Reducing irrigation intervals from a normal 15 to 7 days at Kahuku Plantation in Hawaii failed to increase the moisture levels in the cane. Sprays of 19 lbs. K_2O per acre from muriate of potash improved moisture relationships in the plants, resulting in normal, turgid leaves.

Most researchers conclude that potash reduces the evaporation and increases the uptake of water by plants.

Hartt (1934) first showed that K-deficient sugar cane transpired more water than plants adequately fed potassium.

Warne (1936), working with cotton and beet plants, found higher moisture in plants adequately fed potash, stressing the point that plants lacking potash tended to an unfavorable water balance.

Rogalev's (1958) studies with sunflower, wheat, barley, corn, and clover showed that plants lacking K were conspicuous for their large water losses from evaporation. He suggests such increased evaporation is connected with the movement of K from the older leaves to the growing points of the plants.

The wilting or withering appearance often observed very early in K deficiency may indicate potassium has a regulatory function on stomatal openings and transpiration. Respiration intensity of K-starved plants falls quickly with time, due to rapid consumption of stored carbohydrates.

Plants supplied ample K appear to have higher resistance to unfavorable environments. Even after wilting, if the plant is supplied water the cell walls show no appreciable damage except where collapse and death of cells has destroyed the organized structure. Without adequate potassium, cell walls break down faster and at lower stress levels than in plants with adequate potassium.

Fujiwara and Iida (1955) showed transpiration intensity of K-deficient rice plants to be much higher than that of K-enriched plants. Through microscopical studies, they found the stomatal openings wider and the vacuoles of perdermal cells larger in K-deficient leaves than in K-enriched leaves.

The withering process is caused by a loss of water from the plant tissue—including free water within cells, in the vacuolar sap, or combined in cellular material. Potassium-deficient plants have less control over stomatal movements than K-enriched plants. Both loss of water from stomata and loss of carbohydrates on respiration cause rapid withering of K-starved plants.

The "marginal burning" or "scorch" typical of most potassium-deficient crop leaves is caused by the K in the plant migrating from older tissue to newly forming tissue, leaving the older tissues to lose their turgidity, dry prematurely, and die from inadequate K supply.

Potassium Fertilization & Increased Water Efficiency

Balanced feeding—or fertilization—usually results in lower water usage per unit of dry matter produced.

Indirect effects of K on moisture are observed when patassium fertilization increases plant yield.

Plants are known to vary in efficiency of water use when subjected to drought. Koch (1957) in Germany describes daily changes in the ratio of photosynthesis to transpiration and discusses the possibility of modifying this relationship.

Humbert and McVickar (1962) have summarized research showing that proper fertilization and other cultural practices that increase yields usually increase the efficiency of water use by crops.

Growth is controlled directly by the rate of synthesis (or build-up) of proteins and carbohydrates. Since potassium supply contributes to these processes, its presence often determines the rate of food and fiber production. Moisture within the plant also conditions growth rate. Changes in moisture content can delay or stimulate any of the plant processes.

Work by Akune and Koga (1955) indicates a definite relationship between the quantity of potassium and water in mulberry leaves, showing how moisture content increases with increasing potash fertilization in all 5 varieties studied.

Humbert (1958) found that without adequate potassium in sugar cane, irrigation changes would not result in optimum moisture level within the plant. But when potassium supply was increased, moisture percentage increased to the higher levels for maximum growth.

Most experimental evidence associates a decreasing moisture supply with a definite decrease in K content of plants. In the slower-growing plants, the rate of K entry decreases more than the rate of utilization. The nitrogen, phosphorus, and potassium nutrition of pineapple and sugar cane in Hawaii is conditioned by soil moisture supply and other environmental factors.

The influence of potash on drought resistance—such as increasing plant resistance to wilting—is a big asset to growers in dry regions.

On the Hamakua Coast of Hawaii, an area subject to summer droughts, the potassium levels of sugar cane are carefully checked early in the spring while adequate moisture is still available. If K levels are low, additional potash is applied by plane to raise both the potassium and moisture levels in the cane for surviving the drought in good condition.

Black (1957) reported interactions between potash and water on yield, comparing yields in dry and wet years at two K levels. The literature is full of examples where fertilization has increased yields and lowered the water used per unit of crop production.

One factor relating potassium to yield should be emphasized—K's dominant role in determining plant leaf area, the factory.

Gregory and Baptiste (1936) concluded the chief effect of potassium on barley was probably to increase leaf size and not leaf numbers.

With inadequate potassium, the older leaves of corn, sugar cane, and many other crops dry from the leaf margins to the midrib and die prematurely. With adequate potassium, aging of older leaves is delayed, resulting in greater leaf number and leaf size and in greater total leaf area. The greater leaf area keeps plants active.

Sax (1962) writes that rapidly dividing undifferentiated cells do not age, but when growth ceases, aging and death must follow. In deciduous fruit trees, the leaves from trees with adequate potash remain green, turgid, and active longer in the season resulting in larger prunes, peaches, and pears of better quality.

The common occurrence of nutritional disorders in diseased plants stresses the need for continued research in this field.

Hooker (1962) reports from Illinois that frequently stalk rot in corn is more severe when potassium is low in relation to nitrogen. Similar findings have been reported from Iowa, New York, Ohio, and Pennsylvania.

Over twice as much corn leaf blight developed in the absence of potassium than in plots fertilized with muriate of potash. In the greenhouse, bacterial wilt is usually most severe under low potassium and high nitrogen levels.

Increased respiration rate normally accompanying infection of plant cells by a wide range of pathogens continues to attract attention. Through respiration in plant tissues, starch and sugars are broken down to smaller carbon compounds and eventually to carbon dioxide and water. Disease disrupts this metabolism, often causing sluggish stomatal responses to changing environment and increased transpiration.

Cotton infected with verticilium wilt has lower potassium and moisture levels than healthy plants. Chemical composition and internal moisture balance varies so greatly between resistant and susceptible varieties of the same crop that this should be a fruitful research field.

And it is unnecessary to conclude that insect and disease control are necessary for high water-use efficiency.

In Conclusion . . .

. . . potassium has been shown to affect photosynthesis, respiration, and transpiration, as well as carbohydrate metabolism, protein synthesis, enzyme activity, meristem growth, stomatal movement, and water relationships in plants—all important to optimum plant growth.

Potassium fertilization and other cultural practices that promote plant growth and make more efficient use of the sun's energy will increase water-use efficiency.

Fertilizers increase root development within the soil so more water is available in an expanded root zone. This is very important in dryland agriculture, in humid areas subject to drought, and in irrigated lands.

And a favorable water balance is essential to growth and development of all plants.

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THE END

Limiting Factor	% of total
Low Soil Fertility	16.0
Poor rainfall distribution	14.5
Inadequate plant populations	13.3
Poor cultural practices	11.7
Using hybrids of wrong maturity	7.8
Yielding capacity of hybrids	6.6
Inadequate total rainfall	6.3
Diseases	5.5
Insects	5.1
Miscellaneous other factors	4.6
Susceptibility to lodging	4.3
High seasonal temperatures	3.9
Dropped ears	0.4

Factor Watching

TO MEET today's cost-price squeeze, farmers are rapidly coming to the point where they must eliminate any limiting production factors over which they have control.

Fertility is high on the list.

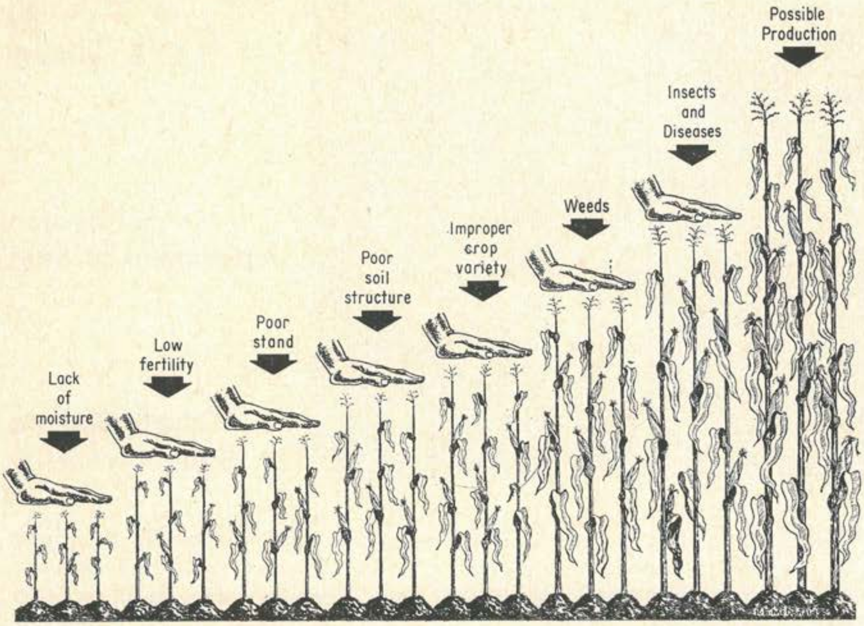
When USDA Agricultural Research Service scientists asked 58 experiment station and USDA corn research workers to list the 5 most important factors limiting corn production in their respective states, 52 replies were received, with low soil fertility and poor rainfall distribution heading the factors in order of frequency mentioned—as shown in the 13 factors summarized at left.

Dr. M. S. Zuber, who reported the information assembled at Missouri Agricultural Experiment Station in Columbia, said at the time:

"Yield-limiting factors such as low soil fertility, inadequate plant population, poor cultural practices, and use of hybrids of the wrong maturity can be overcome to some extent by adopting currently recommended practices.

"Factors governed by the weather are the most difficult to surmount. For example, rainfall distribution and total amount can be corrected in some areas by irrigation—but many farmers do not have a source of water for irrigation.

"However, farmers can use certain practices to overcome poor rainfall distribution. In certain areas of Missouri, they plant as early as weather and soil conditions permit, enabling corn to pollinate before the annual lack of rainfall in July becomes a major factor. These earlier planting dates have consistently returned the highest yields."



—Sketch from SCS Bulletin 199

Are any of these factors holding down your crop production? After the lack of moisture is eliminated by irrigation, a great number of things may limit your yield. Your farming income is often determined by the practices you use to eliminate those factors which hold down the yield and quality of crops.

One important relationship of moisture and fertility is in irrigated fields, the Midwest Potash Newsletter has emphasized. The farmer striving for 150 bushels of corn rather than 75 or for 6 tons of alfalfa rather than 3 must realize that twice as many nutrients will be removed under the doubled production.

For example, the higher alfalfa yield will remove about 250 lbs. K_2O instead of 125 lbs. So, the soil must supply more from some source—either from native supply or from the fertilizer bag.

Before a grower invests in irrigation, agricultural leaders advise him to try to bring all his production factors—such as stand, nutrient supply, and pest control—up to top level. With most growers, these practices (cheaper than irrigation) are much below adequate.

As far as moisture and fertility are concerned in the overall limiting factor picture, the grower will do well to remember that fertilizer is not a substitute for moisture—nor is moisture a substitute for needed fertility.

But well nourished crops make more efficient use of the soil moisture available—a point emphasized throughout this issue.

In fact, experiments have shown that crops usually do better with high plant nutrient levels even when moisture deficiency is so severe that yields are greatly reduced.

THE END

FERTILIZED GRAIN

By
E. B. Norum

Chairman
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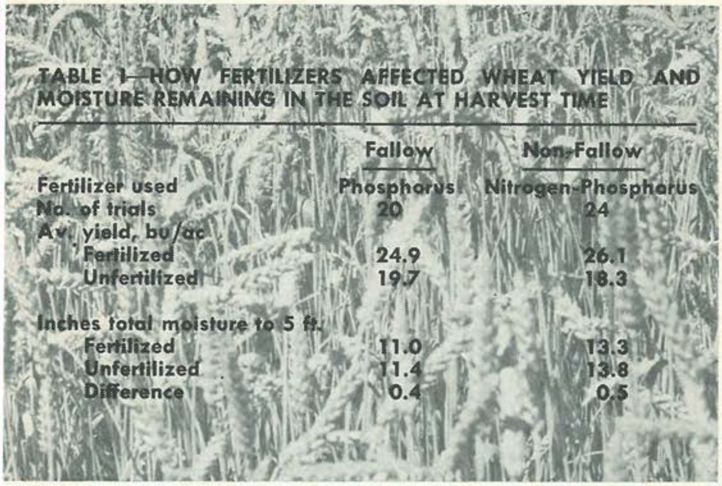


TABLE 1—HOW FERTILIZERS AFFECTED WHEAT YIELD AND MOISTURE REMAINING IN THE SOIL AT HARVEST TIME

	Fallow	Non-Fallow
Fertilizer used	Phosphorus	Nitrogen-Phosphorus
No. of trials	20	24
Av. yield, bu/ac		
Fertilized	24.9	26.1
Unfertilized	19.7	18.3
Inches total moisture to 5 ft.		
Fertilized	11.0	13.3
Unfertilized	11.4	13.8
Difference	0.4	0.5

THE relationship between moisture and crop production—both with and without fertilizers—has been widely reported over the years.

Studies exploring the disappearance of water from soil-plant systems under varied conditions have gone a long way toward explaining what proper fertilization can mean to crops under great moisture stress.

The problem with small grains is as intricate as with any other crop, especially in areas of concentrated grain production. Relatively few fields go through the growing season under optimum fertility and moisture conditions.

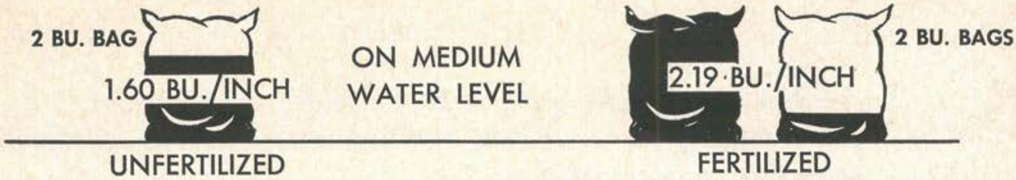
With some exceptions, of course, rainfall in major grain-producing areas generally is not only inadequate in quantity, but also erratic in distribution. Also, moisture in the soil profile at seeding time (an important factor) fluctuates widely, some years filled to capacity, other years virtually dry.

Sometimes adequate or even excess moisture exists, but usually drouths of varying lengths limit crop performance. The effect on a grain crop depends on many factors, including stage of crop growth and degree of moisture stress. Since grains (unlike forages) are grown for seed production, the plant must complete its growth to produce anything marketable.

A Convenient Scapegoat

Compared to better-watered areas producing crops of high value per acre, the small grains area was slow in developing fertilizer usage and in building field experience from it. Nutrient deficiency symptoms were once confused with moisture deficiency. Benefits from fallow were usually credited to improved moisture without much attention to available nitrogen.

Until rather recent years, water stress was a convenient scapegoat on which to blame any poorly growing



MORE BUSHELS PER INCH OF WATER

TABLE 2—WHEAT YIELD AND WATER USE UNDER 3 SEEDING TIME MOISTURE LEVELS (1961)

TREATMENT	WATER LEVEL	AVAILABLE WATER TO 5 FEET AT SEEDING (INCHES)	RAINFALL (INCHES)	AVAILABLE WATER TO 5 FEET AT HARVEST (INCHES)	WATER USED (INCHES)	YIELD BU./A	WATER USE EFFICIENCY BU./INCH
WITHOUT FERTILIZER	LOW	4.00	4.69	1.97	6.72	6.7	1.00
	MEDIUM	6.87	4.69	3.56	8.00	12.8	1.60
	HIGH	7.27	4.69	3.82	8.14	14.6	1.79
	MEAN						1.46
WITH FERTILIZER	LOW	4.00	4.69	2.00	6.69	6.8	1.02
	MEDIUM	6.87	4.69	3.16	8.40	18.4	2.19
	HIGH	7.27	4.69	3.00	8.96	18.7	2.09
	MEAN						1.77

S-T-R-E-T-C-H-E-S MOISTURE

grain crop under dryland conditions, *even though nutrient deficiency, certain insects and diseases were often full-fledged accomplices.*

The first breakthrough came with spring wheat growers. Using relatively small applications of phosphorus (by drill attachment), they increased yields significantly on fallow where moisture supply and available nitrogen were generally at their best. Even under relatively low yield conditions, profitable yield increases were common.

On phosphorus deficient soils phosphorus fertilizer usually increased yields unless drought became severe enough to limit harvests to only 4-6 bu. per acre.

Phosphorus improved early growth and vigor. Stands improved, probably from a variety of effects. Tillering was encouraged. The characteristic influence of phosphorus on root system development probably helped the crops in resisting diseases and insects that attack roots and in marshalling nutrients and moisture necessary for rapid growth.

"Few enterprises give as much return for time spent as soil sampling for available nutrient tests and soil moisture appraisal before seeding."

Advanced Maturity—a Bonus

The most spectacular improvements came under spring drought conditions. For some reason, the feared effects of moisture deficiency didn't occur even under comparatively warm, dry conditions. A 1952 wheat trial on fallowed, moderately coarse-textured soil near Dickinson, N. D. gave valuable facts on this point:

1 With unusually great early growth response, the fertilized crop had drawn moisture somewhat more rapidly than the unfertilized crop.

2 Although moisture conditions were very unfavorable until late June, the fertilized crop had progressed so much by then that it did not benefit from late rain as much as the less developed unfertilized crop, which was nearly 2 inches taller at harvest time *but a week later in maturity.*

3 Even under such unfavorable conditions, the fertilized wheat yielded 2.4 bushels per acre more than the unfertilized wheat.

4 And at harvest time the soil profile to a depth of 4 feet contained 4.1 inches total water for the fertilized plots, 3.7 inches for the unfertilized plots.

Little Additional Moisture Removed

Table 1 shows how fertilizers affected both wheat yield and the amount of moisture remaining in the soil at harvest time, as found in a large number of trials on both fallow and non-fallow land.

These widely distributed trials, running from 1952 to 1959, indicate that even though growth and yield of wheat are substantially improved by use of fertilizer, there is relatively little effect on the moisture status of the soil.

When applying such findings to a field situation, remember that weeds which flourish in light grain stands may increase transpiration as much or more than a vigorously growing grain crop. On sloping land, a thick vegetative cover from well nourished grain crop may insure less runoff and more infiltration to support plant growth.

Any difference between total evapotranspiration on fertilized and unfertilized grain crops is comparatively small. In fact, agricultural climatologists have found the amount of growth of a crop presenting comparable ground cover affects evapotranspira-

TABLE 3. MAXIMUM RESPONSE[1] OF WHEAT TO PHOSPHORUS FERTILIZER ON FALLOW LAND TESTING VERY LOW IN PHOSPHORUS IN RELATION TO STORED SOIL MOISTURE AT SEEDING TIME AND RAINFALL DURING THE GROWING SEASON (26 TRIALS 1958–1960)

Rainfall from Seeding to 20 days Before Harvest	Available Soil Moisture (Inches per 4 ft. of soil) 0–2	2–4	4–6
		Bushels per acre	
More than 8 inches	7.0	13.6	15.8
6 to 8"	6.9	6.2	10.2
Less than 6 inches	2.1	2.3	9.2

[1] Highest response value in rate trials.

"Adequate fertilization on deficient soils often gives more bushels per inch of water—a big factor to the farmer."

tion very little. This does not mean the amount of water available to a crop is of little importance. High level moisture is definitely desirable.

Fertilizer Stretches Moisture

Table 2 shows how fertilizer affected wheat yield and water use under three seeding time moisture levels in 1961 tests—*how proper fertilization can mean more bushels per inch of water.*

When there is potential moisture deficiency, the available soil moisture at seeding time is very important for two reasons: (1) as a contribution to the total moisture available for crop use, (2) as a supply on which plant survival may depend in unfavorable rainfall seasons.

Table 3 shows the importance of both these sources in determining wheat response to phosphorus fertilizer on fallow.

Table 4 shows very similar results for use of nitrogen-phosphorus on non-fallow land.

Both tables 3 and 4 seem to emphasize two lessons:

1 If available soil moisture is low at seeding time, high rainfall during growing season is all-important.

2 If available soil moisture is high at seeding time, modest rainfall during growing season may bring large response—though high rainfall is still preferred.

Two Keys to Treatment Decisions

Few enterprises give as much return for time spent as (1) soil sampling for available nutrient tests and (2) soil moisture appraisal before seeding.

By diligent application, farmers can learn enough about appraising the moisture content of their soils and prospects of growing season rainfall to help make profitable fertilizer decisions.

From such data, the farmer can develop probable physical response curves. By adding input costs and product prices, he can choose treatment rates that point toward maximum profits from fertilizer usage.

In Summary . . .

1 Fertilizer improves grain yields, where moisture supply is well below optimum levels.

TABLE 4—AVERAGE MAXIMUM RESPONSE[1] OF WHEAT TO NITROGEN-PHOSPHORUS ON NON-FALLOW LAND (66 TRIALS 1958–1960)

Rainfall from Seeding to 20 days Before Harvest	Available Soil Moisture (Inches per 4 ft. of soil) 0–2	2–4	4 or more
	Bushels per acre		
More than 8 inches	7.1	10.0	15.0
6 to 8"	5.0	9.5	16.4
Less than 6 inches	2.4	5.9	10.5

[1] Average of most responsive treatment in rate trials.

"Soil moisture at seeding time and rainfall during growing season are important in determining the most profitable treatment."

2 Fertilizing grains removes little additional moisture from the soil, even when yield increases are relatively large.

3 Although very strong response may accelerate withdrawal, advanced maturity helps compensate for this. And even with generally poor moisture conditions during the rest of the season, some yield increase usually occurs.

4 Soil moisture at seeding time and rainfall during growing season are important in determining the most profitable treatment.

5 Adequate fertilization on deficient soils gives more bushels per inch of water—a big factor to the farmer.

THE END

Guide For Judging Available Moisture For Crops

Available soil moisture remaining	FEEL OR APPEARANCE OF THE SOIL			
	Coarse texture	Moderately coarse texture	Medium texture	Fine and very fine texture
0 to 25 percent	Dry, loose, single grained, flows through fingers.	Dry, loose, flows through fingers.	Powdery dry, sometimes slightly crusted but easily broken down into powdery condition.	Hard, baked, cracked, sometimes has loose crumbs on surface.
25 to 50 percent	Appears to be dry, will not form a ball with pressure.[1]	Appears to be dry, will not form a ball.[1]	Somewhat crumbly but holds together from pressure.	Somewhat pliable, will ball under pressure.[1]
50 to 75 percent	Appears to be dry, will not form a ball with pressure.	Tends to ball under pressure but seldom holds together.	Forms a ball somewhat plastic, will sometimes slick slightly with pressure.	Forms a ball, ribbons out between thumb and forefinger.
75 percent to field capacity (100 percent).	Tends to stick together slightly, sometimes forms a very weak ball under pressure.	Forms weak ball, breaks easily, will not slick.	Forms a ball, is very pliable, slicks readily if relatively high in clay.	Easily ribbons out between fingers, has slick feeling.
At field capacity (100 percent).	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.

[1] Ball is formed by squeezing a handful of soil very firmly.

SCS Bulletin 199

Save soil

and water

VIGOROUSLY growing crops intercept and de-energize the beating action of falling raindrops. The energy of falling raindrops tears soil particles loose from clods and other structural aggregates, carrying them into the air in suspension. These particles often move through the air for distances of several feet and fall into the shallow rivers of moving water.

The pores of the soil surface become plugged by individual particles which orient themselves on settling, reducing the rate of entry of water into the soil. This process of surface sealing develops very quickly in certain types of soil and, by destroying the water-absorbing potential of the soil, sets the stage for accelerated erosion.

Fertilized crops offer more foliage that protects the soil from the falling raindrops and insures a greater percentage of the falling rain seeping into the underlying subsoil for future use.

The fertilized crops develop more vigorous root systems that help keep the soil in good physical condition. The increase in plant residues associated with increased crop production also contributes valuable organic matter to the soil, that further increases water utilization.

Adapted from CFA Handbook

WATER-HOLDING VARIES

Illinois workers report approximately 20 acre-inches of water is used to produce 100 bushels of corn. Rainfall supplies part, but the soil must store and release water also.

Water-holding capacity. Soils vary greatly in waterholding capacity, depending on texture, structure, and organic matter. For example, in the surface 5 feet the following was noted:

Oquawka sand	5 inch capacity
Ridgeville fine sandy loam	7 inch capacity
Swygert silt loam	9 inch capacity
Muscatine silt loam	12 inch capacity

Depth of rooting of crops. The moisture-holding capacity of many soils is satisfactory but plants may not use all available moisture. Crops root differently in various soils because of *tightness of the soil or nutrient supply*. For example:

	Depth of rooting	Water available
Clarence silt loam	3 feet	6½ inches
Saybrook silt loam	4½ feet	10½ inches
Muscatine silt loam	5+feet	14 inches

(Illinois Agronomy Facts—SP16—In Midwest Potash Newsletter)

Requires overcoming factors limiting crop growth

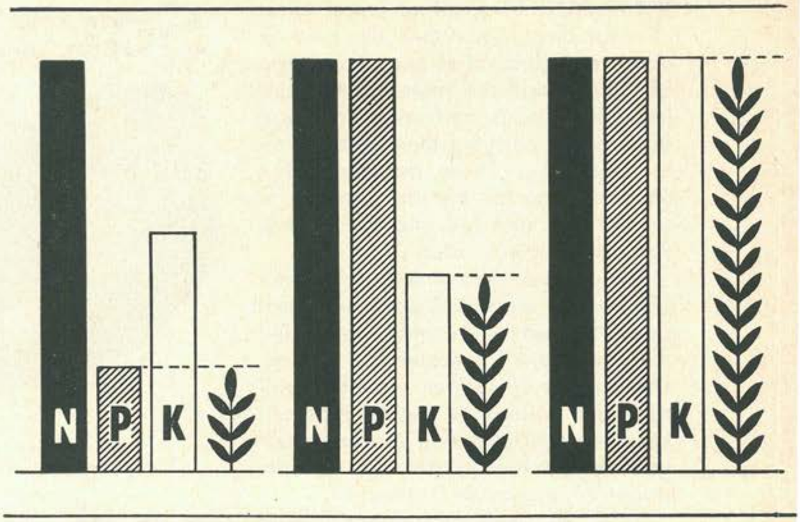


Figure 1—Whether it applies to water stress, disease problems, or plant food limitations, the Law of the Minimum (or of Limiting Factors) is basic to plant growth. The principle is illustrated with three plant nutrients above—nitrogen (N), phosphorus (P), potassium (K). Each nutrient has a specific job to do in plant life. When one element is missing or short, the plant's whole development can be affected. The same law applies to all other practices the farmer follows to produce a successful crop.

Water Use Efficiency In Irrigation Agriculture

EVERY *successful* farm is built on high acre yields and efficient production.

To get such production, each resource—such as fertilizer, water, good seed, pesticides, good management, etc.—must be adequate and must complement each other.

In irrigated agriculture, the relationships between water and soil fertility are very important—to the biological water demands of plant growth and cellular functions and to the heavy evaporation losses from crop and soil surfaces. For example:

1 The plant root zone must have adequate moisture to permit good root growth, insure favorable water balances within the plant, and enable roots to absorb plant nutrients efficiently.

2 The soil fertility level often influences both the amount of water a plant can successfully take from the soil and the yields a crop can return per increment of water used.

3 As yields increase with adequate water, nutrients needed for growth and removed in harvested crops *also* increase.

. . . to increase crop production per unit of water

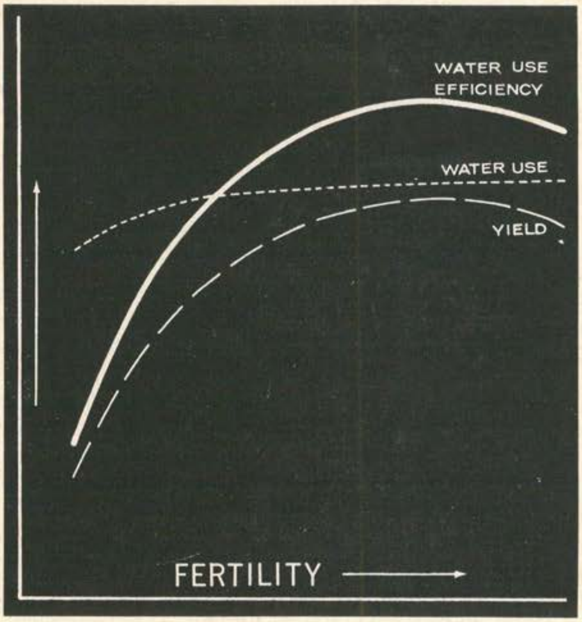


***Figure 2*—Fertilization and other cultural practices for top crop yield usually increase water use efficiency, because crop yields generally increase relatively more than crop water use. Any increases in water use accompanying fertilization are often negligible, as shown by this diagram.**

By D. W. Henderson, R. M. Hagan, D. S. Mikkelsen
University of California
At Davis

Specific fertilizer-irrigation practices necessary for desired crop production vary by situations. For example:

1 Where water is scarce or expensive, the aim should be maximum crop production per unit of applied water.

2 Where good land is more scarce than water, the aim should be maximum production per unit of planted area.

3 Where irrigation labor is costly or capital is scarce, the aim should be maximum production per unit of labor or cost of land and facilities.

Fertilizer-Soil-Crop Relation

To determine the best fertilization practices requires keen farm observations—and often soil and plant tissue tests.

As fertilization rate increases beyond a point, each additional increment gives a smaller yield increase. When several nutrients are in limiting supply, adding each alone may produce much less results than the proper combination.

The most economical fertilizer usage generally occurs somewhere below maximum yield. Such a response is shown by the "Balanced" curve (A) in Figure 3.

"The soil fertility level often influences both the amount of water a plant can successfully take from the soil and the yields a crop can return per increment of water used."

Excessive or unbalanced fertilization is seldom economical and may lead to reduced yields through such factors as these:

1 Upset nutritional relations—accentuating deficiencies of other elements in marginal supply, toxicities, etc.

2 Excessive nitrogen—resulting in mechanical breakdown of the crop (such as lodging), disturbed reproductive development, and delayed maturity.

3 Sometimes increased incidence of crop pests and diseases.

Such possibilities—from excessive or unbalanced fertilization—can play havoc with yields, as shown by the "Unbalanced" curve (B) in Figure 3.

Whether applied to maintain annual crops or to increase general soil fertility level, fertilizer practices often affect crop quality, a matter deserving much more attention than it now receives.

Water-Soil-Crop Relations

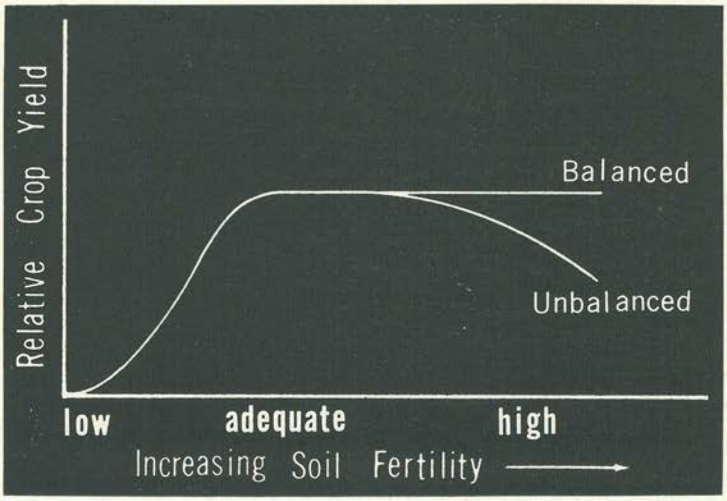
"When should I irrigate?" That is a very real and practical question asked by the working farmer.

To answer it, we must have some understanding of water-soil-crop-relations. We know the gross effects of deficient and excessive soil water on plant growth and crop yield.

But what about water held in soil above the wilting point—so-called "available water"? Is it equally available for plant growth or is it available with such increasing difficulty that plant growth functions are retarded before the wilting point is reached?

Figure 4 diagrams some possible crop yield responses caused by allowing the available soil water to be depleted to given levels within each irrigation cycle. The different relations

***Figure 3*—The most economical fertilizer usage generally occurs somewhere below maximum yield, while excessive or unbalanced fertilization may lead to reduced crop yields.**



"To determine the best fertilization practices requires keen farm observations—and often soil and plant tissue tests."

show that crop production is not a single-valued function of soil water content or soil water stress.

Obviously, crop yield depends on many physiological processes going on within the plant, and these processes are greatly influenced by water deficits within the plant.

Water deficits in the plant do not depend on soil water supply alone, but are determined by three basic influences:

1 The rate of soil water supply —which depends on soil water stress, water conductivity in soils, and the extent and rate of root growth.

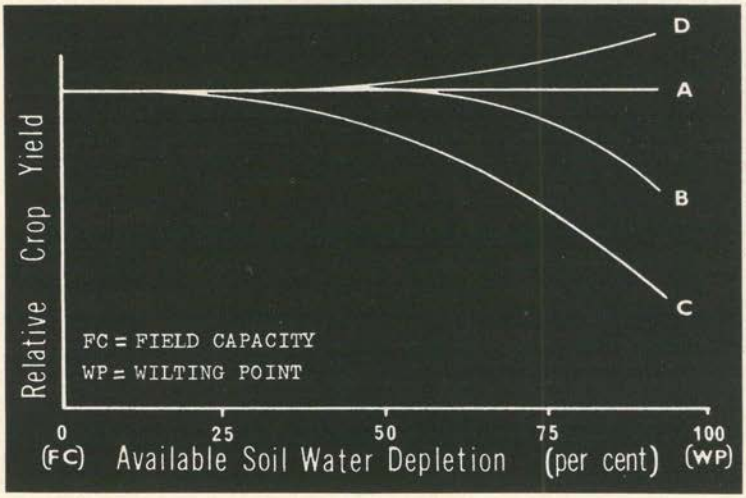
2 The rate of water loss from shoot to atmosphere—which depends on radiation, wind, humidity, etc.

3 The duration of unbalance between rates of water supply and loss.

Although crop plants experience some water deficit every day, they can usually absorb enough water at night to counteract the daytime deficit, recovering turgor and continuing normal growth. But when soil water depletion is so great that plant water deficits are not restored during the night, plant growth and yield decline progressively.

How much of the available water can be depleted without reducing crop yields? This cannot be answered simply, in such values as "50% of available range or 1 bar of soil water stress." Each irrigation situation has its own limit of soil water depletion, depending on the interactions of the

***Figure 4*—These curves summarize some possible crop yield responses caused by allowing the available soil water to be depleted to given levels within each irrigation cycle. CURVE A: represents cases where no appreciable yield increases can be obtained by irrigating before soil water content falls to near the wilting point. CURVE B: cases where yield diminishes as soil water stress begins to increase rapidly. CURVE C: cases where yield declines even in relatively wet soil and falls markedly as soil water is depleted. CURVE D: cases where recoverable yield of harvested plant organ or plant constituent increases as available soil water is depleted.**



"Water use efficiency should be measured in terms of crop yield per unit of water *used* by the crop, *lost* by evaporation, and *wasted* during irrigation."

soil, plant, climatic, and management factors involved.

Fertilizer-Water-Crop Yield Interrelations

Crop responses to water and fertilizers are complex when each is considered alone. But when we attempt to predict combined responses of water and fertilizers on various crops, the complexities multiply.

Many interacting factors are not well understood—as (1) leaching losses and nitrogen volatilization, (2) the influence of soil water conditions on availability of nutrients from the soil, (3) modifications in plant root characteristics that affect nutrient supply and absorption, and (4) the interrelated physiological effects of both water and nutrients on the vegetative and reproductive phases of plant growth.

With such complexities in mind, let's examine some general concepts. The Law of the Minimum (or of Limiting Factors) is such a concept. When applicable, the Law works this way: Where water is limiting, response to applied fertilizer is dwarfed but increases with adequate water . . . where fertility is limiting, response to irrigation is dwarfed but increases with adequate fertility. Figure 1 illustrates the Law in terms of deficient nutrient elements.

This Law especially holds when the lowest levels of water and fertilizer are severely limiting yields. But extreme deficits and excesses of water and fertilizer are usually avoided in agricultural practice. So, we might

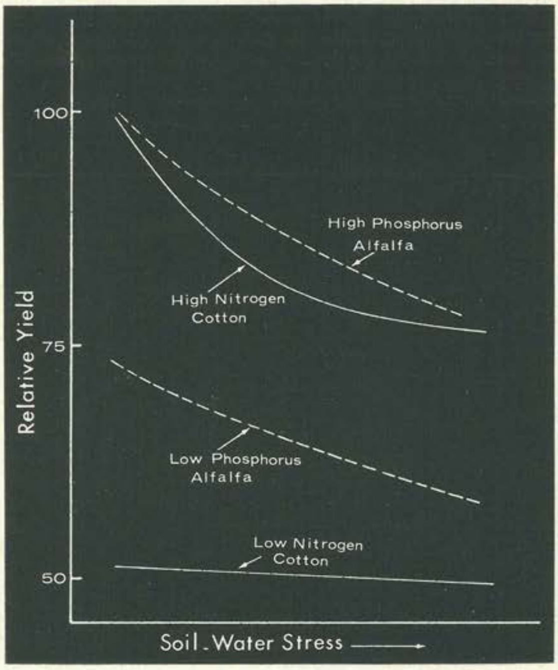


***Figure 5*—This shows fertility-irrigation relationships for alfalfa and cotton yields on a very sandy Arizona soil—how increasing water stress reduced alfalfa hay yield about the same proportion under high and low P treatment, while it reduced cotton yields sharply under high N treatment but showed virtually no yield effect at the low N level.**

examine crop responses between the two extremes of water and fertilizer levels.

Figure 5 diagrams Stanberry's fertility-irrigation relationships for alfalfa and cotton yields on a very sandy Arizona soil—showing that high N or high P gave greater yields at both low and high water stress than the low N or P treatments. Note how increasing water stress reduced alfalfa hay yields about the same proportion under high and low P treatments, while it reduced cotton yields sharply at high N treatment but showed virtually no yield effect at the low N level.

Figure 6 diagrams a good example of the complex interrelations involved when choosing nitrogen fertilization and irrigation practices—showing how Hohn et al. of Texas got highest cotton yields under low water stress through very high nitrogen treatments (160 to 240-320 lbs./A). Note how the best yields from low and intermediate N treatments (0, 40, and 80 lbs./A) occurred with moderate irrigation rates, while low and high water stress reduced yields under these treatments.

Stockton in the San Joaquin Valley of California found moderate soil water stress gave optimum yields over a wide range of nitrogen fertility.

These experiences might raise an important question: If the farmer now irrigating for maximum yields under specific fertilizer program decides to increase his fertilizer applications, should he change his irrigation practice to get maximum benefit from the additional fertilizer? No general answer can be given, except at very low fertility levels which limit yields drastically.

Much more research is needed to determine the reasons for such divergent responses now reported.

Water Use Efficiency

While there are several ways to define water use efficiency, it is fre-

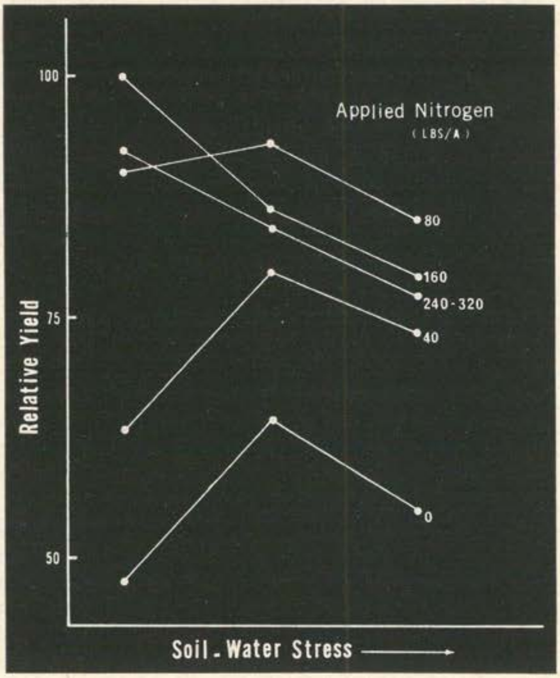


***Figure 6*—This shows the complex interrelations involved when choosing nitrogen fertilization and irrigation practices for cotton —how the best yields from low and intermediate nitrogen rates (0, 40, 80 lbs. N/A) occurred with moderate irrigation rates, while low and high water stress reduced yields under these treatments.**

"The Law of the Minimum: Where water is limiting, response to applied fertilizer is dwarfed but increases with adequate water . . . where fertility is limiting, response to irrigation is dwarfed but increases with adequate fertility."

quently taken as *crop yield per unit of water actually used by the crop plus unavoidable evaporation losses from the soil.*

It is difficult to predict effects of irrigation practice on water use efficiency. If vegetative growth is retarded by lack of adequate water, then water use by the crop is also reduced. Consider these possible conditions:

1 If vegetative yield is reduced proportionally less than water use, then water use efficiency *increases.*

2 If change in yield and water use is proportionally the same, then water use efficiency *does not change.*

3 If yield is decreased proportionally more than water use, then water use efficiency *decreases.*

The last two possibilities seem most common. Generally where vegetative growth is harvested, irrigating for maximum water usage by the crop will likely give high yields and high water use efficiency.

Yields of some fruit, seed, sugar, and fiber crops are essentially proportional to vegetative growth. In others, moderate water stress will not reduce yields, under certain conditions, and may even increase yields of certain products while reducing water use. In such cases, top water use efficiency usually occurs as yields approach a maximum but may occur when yields are reduced appreciably by water stress.

Fertilization and other cultural practices for top crop yield usually increase water use efficiency. Why? Because crop yields generally increase relatively more than crop water use. And any increases in water use accompanying fertilization are often negligible—as shown in Figure 2.

In other words, water use efficiency is invariably high with maximum yields. So, a grower might approach top water efficiency by combining fertilization and irrigation to produce top crop yields.

Some Practical Factors

In practice, the problem of combining optimum water and fertilizer is often complicated by other factors. Some of the problems include:

1 Water Wastage

When it is necessary to apply shallow, frequent irrigations for maximum yields, much water can be wasted—especially with surface irrigation on permeable soils. Serious water losses may also occur with sprinkler irrigation systems as commonly designed and operated.

So, water use efficiency should be measured in terms of crop yield per unit of water *used* by the crop, *lost* by evaporation, and *wasted* during irrigation.

2 Harmful Effects

Striving for maximum yields via irrigation can be harmful in some cases. Temporary waterlogging of soil can cause crownrot and rootrot of susceptible crops and speed denitrification losses.

Excess water can leach mobile nutrients below crop roots or aggravate drainage and salinity problems.

Maximum yields are not always compatible with best crop quality (now as important as yield in many crops), especially when delayed maturity loses timely markets or increases harvesting costs.

Even pest control problems may be increased by poorer spray coverage of denser foliage or by irrigation conflicts with control measures.

3 Impractical Economic Aims

As maximum yields are approached, each increment of added water or fertilizer increases the yield less. The best economic return occurs at yields slightly below the maximum.

The present cost of conserving water may be greater than the value of water saved, causing some water supplying organizations and farmers not to strive for maximum water use efficiency.

Nevertheless, in water-scarce areas, agriculture will face increasing demands for high water use efficiency. The sorry state of irrigated agriculture in some areas of the world should warn man that he must use sound fertilization, water management, and cultural practices if irrigation agriculture is to be permanently successful.

THE END

MORE COLORADO CORN WITH NITROGEN AND WATER

ACRE INCHES WATER	NITROGEN PER ACRE [2]		INCREASED RETURN PER ACRE [3] FROM N
	0 LBS.	150 LBS.	
4.8 (dry)	75 bu.	114 bu.	$46.80
9.6 (med.) [1]	91	147	67.20
12.8 (wet)	96	152	67.20

[1] Applied in equal amounts on June 30, July 21, August 4, and again August 26 for wet. [2] Based on 25,000 plants per acre. [3] Corn priced at $1.20 per bushel.

NPFI Source: Colorado State University.

STARVED CORN IS THIRSTY

Starved corn is really thirsty. In Colorado, 150 pounds of nitrogen increased corn yields 56 bushels for $67.20 additional profit when 9.6 acre inches of water was applied. Even under dry conditions, corn yields went up 39 bushels when 150 pounds of nitrogen was used, giving extra returns of $46.80 per acre. Two and one-half bushels more corn were produced per acre inch of water when soil fertility and moisture were not limiting.

—Richard Bahme, NPFI
In Agricultural Ammonia News

FERTILIZER GIVES MORE CORN PER ACRE INCH OF WATER IN COLORADO

WATER—ACRE INCHES	CORN PER ACRE INCH	
	0 LBS.	150 LB. N
4.8 (dry)	4.82 bu.	7.48 bu.
9.6 (med.) [1]	4.86	7.44
12.8 (wet)	4.68	6.98

[1] Produced 33 bushels per acre more than dry for most profitable yield.

NPFI Source: Colorado State University.

BUSHELS PER INCH UP

In Wisconsin under unirrigated conditions, raising the nitrogen level increased the number of bushels produced per inch of water.

	Bushels per inch of water	
	Low N	High N
Corn	2.7	3.6
Oats	1.8	4.0

Under irrigation the following results were obtained:

Corn	2.7	3.9
Oats	2.6	4.1

Advances in Agronomy, Vol. VI.
In Midwest Potash Newsletter

FLOOD LOSSES

THE loss of fertilizer nutrients from a soil during flooding can be sizeable, according to Purdue University extension agronomist Cliff Spies. But it varies widely, depending on the amount of sedimentation, erosion, soil texture, and water movement, he points out.

Leaching losses are influenced by soil texture and water movement. The extent of leaching is determined by how much water moves down through the soil rather than over the surface. This loss will be greater where water is trapped, or ponded and must drain down through the soil. Leaching is also greater in sandy soils than in clay soils.

Sandy soils will show greater losses of nitrogen in the nitrate form, and possibly potash, than heavier-textured soils. Phosphorus will not be lost, unless the topsoil is scoured away by erosion or buried under sediment, Spies explains.

Where corn must be replanted after flooding, the use of row fertilizer and supplemental nitrogen and potash will usually give increased yield, earlier maturity, and improved quality.

—*Crops and Soils*

ON COTTON

IN CALIFORNIA, cotton growers are combining heavy stands, high fertility, and ample moisture to get four-bale cotton. When nitrogen is well supplied, potash has been shown to be deficient in many San Joaquin Valley soils.

Even when irrigation is adequate, potash deficiencies result in stunted, moisture-starved plants. Potash deficient leaves are small, yellow with marginal scorch, and so dry they crumble and crackle when crushed. Potash deficiencies appear to limit water uptake and to induce drouthiness.

K_2O NEEDS

GOOD SOIL MOISTURE INCREASES NUTRIENT UPTAKE BY GRAPES

ACRE INCHES WATER	PPM [1] NITRATE	PER CENT PHOSPHATE	PER CENT POTASSIUM	AVERAGE [2] LBS. VINE	
				1959	1960
0 in.	780	0.27	0.29	22.7	15
6 in.	1020	0.33	0.84	26	31
18 in.	1210	0.5	1.5	37.3	48

[1] Petioles of leaves opposite cluster taken on September 5, 1959.
[2] Harvested at 21 per cent sugar.
ALL DIFFERENCES ARE SIGNIFICANT.
NPFI Source: University of California—1961.

ON GRAPES

The interaction between potash and moisture may be shown in a different way when potash deficiencies are induced in California vineyards by insufficient moisture.

Nitrogen, phosphate, and potash levels were increased significantly in grape vines and berries with irrigation, according to recent research by the University of California.

Without irrigation, wine grape yields were 15 pounds per vine. *With six inches of water,* yields doubled to 31 pounds. *When 18 inches was applied* during the growing season, grape yields jumped to 48 pounds.

All treatments were harvested at equivalent maturity of 21 per cent sugar content. The delayed harvest readiness (at 21 per cent sugar) for the irrigated vines produced over a three-fold increase in high quality grapes.

It also seems likely that moisture limitations in many non-irrigated vineyards may be partially overcome by fertilizer.

—Richard Bahme, NPFI
In Agricultural Ammonia News

REDUCE WATER DEMANDS

Under irrigated conditions in the West, on a low phosphorus soil, phosphorus decreased the amount of water required for each ton of hay.

lbs. P_2O_5 Acre	Ave. Yield Ton/A	Inches of H_2O per ton of hay
100	8.2	11.7
200	9.1	9.5
400	10.7	8.2
600	11.1	7.7

Advances in Agronomy, Vol. VI.
In Midwest Potash Newsletter

FOUR times MORE efficient

RECENT USDA-California Experiment Station studies showed that annual range plants treated with moderately high applications of nitrogen and phosphorus produced a more extensive root system and used moisture four times more efficiently than untreated plants.

The fertilized plants, using the extra nutrients and moisture, produced more luxuriant growth, matured earlier, and eliminated competition from annual weeds, says C. D. Leedy, soil conservationist with the New Mexico Extension Service.

Earlier research indicated that amount and distribution of moisture throughout the growing season are critical factors in plant growth on rangelands. Their effects may be significantly altered by the application of fertilizer.

Studies were begun in 1956 by ARS and California Experiment Station researchers to determine effects of fertilization on depletion of soil moisture and on yields of forage, the soil conservationist states. Fertilizer treatments, applied before the first fall rain, included 150 pounds of nitrogen per acre, 200 pounds of phosphorus, and 150 pounds of nitrogen plus 200 pounds of phosphorus. Plots with no added fertilizer were used as controls.

Plants on plots treated with nitrogen and nitrogen plus phosphorus responded sooner to the first rain and grew faster during the winter months than plants treated with phosphorus or with no added fertilizer.

This increased growth did not drain the moisture reserve from the soil. Early in March, all plots had moisture at field capacity, even though the nitrogen and nitrogen-phosphorus plots were supporting luxuriant stands of annual forages.

As spring temperatures rose, plants on all plots began using soil-moisture reserves. The nitrogen and nitrogen-phosphorus treated plants reduced the moisture below field capacity earlier and continued using it at a higher rate. By early May, plants with roots at depths of 6, 12, and 20 inches had wilted.

Excavated soil columns 20 inches in depth showed that roots in the non-fertilized plots were abundant at the surface of the soil, with little penetration to 20 inches.

The roots in the nitrogen-phosphorus plots were uniformly abundant at the 20-inch level. Some roots had penetrated to 36 inches.

This research indicates that fertilized annual range plants develop strong, vigorous roots that will extract deep soil moisture that may otherwise be used by summer weeds, Leedy says.

Arizona Farmer-Ranchman

PROGRESS OVER DROUTH

Nebraska workers recently made an interesting summary on average state yields in two bad drouth years—1934 and 1956.

	Corn	Wheat	Grain Sorghum	Alfalfa
	bu/A	bu/A	bu/A	T/A
1934	3.2	7.8	4.5	1.1
1956	22.0	19.0	14.0	1.5

Considering all crops, rainfall was about as limited in 1956 as in 1934, yet yields were much higher. Improved practices resulting from research have been a big factor in this effect.

Nebraska Exp. Sta. Quarterly, Winter-Spring, 1957
In Midwest Potash Newsletter

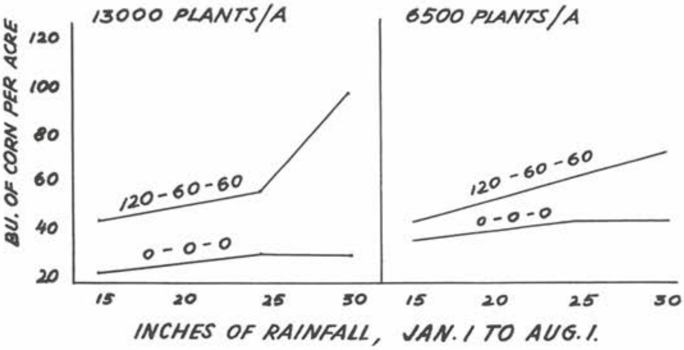
THREE-WAY INFLUENCE ROCKETS YIELDS

Yields rocketed with fertilization and high plant population at the higher rainfall levels in Texas tests. The graphs below show how the soil nutrient balance had to be maintained along with at least 10,000 plants per acre to get good corn yields.

Such yields were a function of plant population, amount of summer rainfall, and fertilization.

These studies also stressed the importance of potash in reducing plant lodging. Applying 40 lbs. K_2O decreased lodging by 26%, while 80 lbs. K_2O decreased it 31%—with the 40-lb. treatment increasing yields by 18 bu. of corn, no doubt contributing to better moisture utilization.

California Fertilizer Association Handbook, The Perfect Western Team, Water & Fertilizer



Better Crops WITH PLANT FOOD

AMERICAN POTASH INSTITUTE, INC.
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