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THE MINERAL CONTENT OF GRAINS

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THE MINERAL CONTENT OF GRAINS[1]

J. E. Greaves and C. T. Hirst

It is generally recognized that shrunken, frosted, or smutty grain is inferior to sound, clean, plump grain. Much has been done on the protein content of grain, and the best millers today purchase grain for its protein content. Few give any consideration to its minerals. Yet do two bushels of sound, plump, clean grain of known protein content grown under the same or different conditions have the same mineral content? If not, it is of importance to both the producer and consumer: to the consumer because it governs the nutritive value of the product; to the producer because it represents the fertility which is being taken from his soil. Consequently, the value of grain produced on an acre of soil should be measured by the quality as well as the quantity.

Composition of grains.—The compounds composing grains can be roughly divided into groups:

(1) Moisture—This is driven off when the grains are heated for from 12 to 16 hours at a temperature of 100° C. The remaining residue is known as dry matter. It is customary to report the composition of grains on their dry basis. This is made necessary by the fact that the moisture of a specific sample of grain may vary from time to time, depending on the age of the grain and the condition under which it has been stored.

(2) Volatile matter—If the dried grain be burned it is decomposed, and the carbon, hydrogen, oxygen, nitrogen, and some of the sulfur pass off as gaseous compounds. It is from this organic part of the grain that the animal obtains its energy when the grain is burned in its body. Some of it is used as building material to construct the muscles, connective tissue, nerves, etc. After the grain has been burned, there remains behind a non-volatile residue, the ash. This is considered often by the laity as a non-valuable constituent of the food. However, it is just as essential as the volatile constituent, for it not only furnishes building material but also regulates body processes. Its importance is indicated by the following: If two groups of animals be chosen and to one there is given a balanced diet cintaining the necessary carbohydrates, fats, proteins, vitamins, and water, all of which have been carefully freed of ash, and to the other group no food is given but water, animals on the ash-free diet will die sooner than the fasting animals. In reality, one of the main causes of malnutrition throughout the country is due to the use of foods containing insufficient or inappropriate ash constituents. The more important elements contained in the ash, so essential to the well-being of man, are calcium, magnesium, potassium, phosphorus, sulfur, and iron. Other constituents, as iodine, for example, are important, and their occurrence in plants, tubers, and grains is to be considered in a later publication. The first three when utilized by animals have the power of neutralizing acids, and consequently are designated as base builders; the second three neutralize alkalies, and hence are designated as acid builders.

The Ash of Grains

Influence of irrigation water on ash of grain.—The great volume of work upon the influence of water on plant growth, which is being conduct-

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ed at the Utah Station, affords excellent opportunity for studying its effect upon the mineral content of grains. The grains were grown on a very productive calcareous loam of sedimentary origin, the surface acre-foot containing 4900 pounds of total nitrogen, 2700 pounds of total phosphorus, 60,000 pounds of total potassium, 434,000 pounds of acid-soluble calcium, and 132,000 pounds of acid-soluble magnesium. Consequently, the soil is well supplied with the essential mineral elements. The limiting factor in its crop-producing power is water. When this is increased up to a certain optimum over the natural annual rainfall of 20 inches, there is a great increase in the yield. The irrigation water, which was used in the growth of the grains, varied annually from zero up to 67.5 inches. The results for wheat, oats and barley grown under these conditions are given in Table 1. They are reported as pounds of ash per 1000 pounds of dry grain, as well as the pounds actually removed by the grown crop.

Table 1. Total ash in crop per acre also pounds ash per 1000 pounds of grain grown with varying quantities of irrigation water on the Central Experimental Farm (Greenville)

Treatment	Wheat		Oats		Barley	
	lbs ash in 1000 lbs.	lbs. ash removed per acre in grain	lbs. ash in 1000 lbs.	lbs. ash removed per acre in grain	lbs. ash in 1000 lbs.	lbs. ash removed per acre in grain
No irrigation water	15.6	35.1	33.4	48.8	23.7	29.9
5 in. " "	15.6	34.2	35.2	65.7	23.4	32.0
10 " " "	15.7	35.9	36.0	74.3	23.3	38.1
15 " " "	17.1	36.4	36.6	87.9	27.2	48.5
20 " " "	20.2	38.5	36.1	81.8	28.1	51.5
35 " " "	22.8	51.1	42.9	110.7	29.8	58.3
45 " " "			43.9	106.3		
52.5 " "					32.3	60.0
67.5 " "	21.9	47.1				

The ash content of the grain of wheat, oats, and barley increases as the irrigation water applied increases. The ash content of wheat grown on land receiving 67.5 inches of irrigation was slightly less than that grown with 35 inches. Probably the maximum ash content is reached when wheat is grown with somewhat less than 67.5 inches of water. It may be that the irrigation water has increased the bacterial activities of the soil, which results in a greater production of acids within the soil. These react with the insoluble plant-food and render it more available to the plant, which in turn means that more is taken up by the growing plant and results in the noted increased ash content. When the application of irrigation water exceeds a certain optimum, the bacterial activity may be decreased, or where there is an increase the heavy applications of irrigation water may carry the plant-food below the feeding area of the plant; consequently, there is a loss of fertility without an increased crop yield or an increase in its ash content.

These results are significant to both the producer and consumer, for the producer would be selling wheat with 46 per cent more ash, oats with 31 per cent more, and barley with 36 per cent more if they were grown with large quantities of irrigation water than when grown with small quantities. This would be 22 pounds for a 50-bushel crop of wheat, 33 pounds for a 10-bushel crop of oats, and 39 pounds for a 75-bushel crop of barley. This excess all comes from the soil and the grain would be produced at a higher cost per unit than would grains produced with less water in which the ash is low.

For the feeding of farm animals in which the production of bone is important, the irrigated grains would be superior to non-irrigated grains. The high ash content of the grains produced in this limestone region may be one of the reasons why the bones and teeth are noticeably better in our western-fed animals than in animals produced in some other districts. Whether or not irrigated grains are more valuable to man will depend primarily on two factors: (1) Does the milling process leave the excess ash in the flour? (2) Is this excess ash more valuable than the excess of protein in the non-irrigated grain? The answer to the latter question will depend upon the nature of the diet. Where the diet consisted primarilw of muscle meats, fleshy tubers, and cereals, especially the highly milled grains, probably the excess ash would be most valuable. Where milk and the leafy plants enter largely into the diet of man the difference in ash may be insignificant. Consequently, where individuals or animals are in need of more ash in the diet the irrigated grains should be chosen in preference to non-irrigated, although by so doing one would be getting less protein. When it is desirable, as may be the case under some pathological conditions, to restrict the mineral intake of an individual, the non-irrigated grains should be used.

Although in the results under consideration larger applications of irrigation water in some cases reduced the yield, yet in all but one case the total ash removed in the grain increased with the increased water applications.

The influence of irrigation water and manure on the ash of corn grown on the same farm is shown in Table 2.

Table 2. Total ash in 1000 pounds of corn grown with varying quantities of irrigation water and manure on the Central Experimental Farm (Greenville)

Treatment	Lbs. Ash
No irrigation water[1]	16.5
5 in. " " [1]	16.6
10 " " " [1]	17.9
20 " " " [1]	17.8
30 " " " [1]	17.6
40 " " " [1]	17.9
No manure[2]	16.5
5 tons manure[2]	17.5
15 tons manure[2]	17.6

[1] and varying quantities of manure

[2] and varying quantities of irrigation water

The corn kernel grown with 40 inches of irrigation water contains 8 per cent more ash than the corn kernel grown with no irrigation water, but the ash is as high with 10 inches of water as with 40. The ash content is highest where the soil receives enough moisture to promote maximum bacterial activity with the resulting liberation of the maximum of plant-food.

That it is the available plant-food which determines the ash content of the grain is well brought out by the results with the manurial treatments. The grain grown on soil receiving 5 tons of manure per acre yearly contains

6 per cent more ash than corn grown under similar conditions but receiving no manure. That grown on soil receiving 15 tons of manure yearly contains only slightly more ash than that grown with 5 tons of manure.

The quantity of ash in the corn kernel removed from the soil increases as the water applied increases up to 20 inches; above this there is a decrease. That removed by the plant markedly increases with increase in manure.

Influence of varieties.—Nineteen varieties of wheat grown on the Nephi Dry-farm Substation were analyzed for ash. This gives a direct comparison of the ash of different varieties and indirect comparision as to the influence of soil, as the Nephi soil is far different in composition from that of the Greenville. The Nephi soil contains in the surface acre-foot 4100 pounds of nitrogen,85,300 pounds of potassium, 7300 pounds of phosphorus, 97,200 pounds of total carbon, 41,800 pounds of organic carbon, 69,300 pounds of magnesium carbonate, and 138,800 pounds of calcium carbonate. The average results of the ash content of different varieties of wheat grown on the Nephi Dry-farm Substation are given in Table 3.

Table 3. Pounds of ash in 1000 pounds of different varieties of wheat grown on the Nephi Dry-farm Substation

Variety	Lbs. Ash
Defiance	17.11
Early Baart	16.45
Chul	16.06
Gold Coin	15.87
Kota	15.48
Kubanka	15.47
Odessa	15.41
Hard Federation	15.23
Kofod	15.09
Kanred	15.05
Marquis Spring	14.75
Kharkov	14.35
Beloglina	14.28
Black Hull	14.26
Ghirka	14.23
Washington Hybrid 128	13.92
Alberta Red	13.66
Turkey	13.66
Saumure	13.05

These results indicate a difference in the ash content of different varieties of wheat grown under the same conditions and on the same soil, the difference in the two extremes amounting to 24 per cent. However, the number of samples analyzed are too small to make it safe to draw definite conclusions as to which varieties are richest in ash since under different conditions and during different seasons these results may be changed; consequently, all that can be concluded is that there is a difference of ash content of wheat due to variety.

Two varieties of barley and two of oats were analyzed—White Smyrna with 2.17 per cent of ash and Coast with 2.66 per cent. Fulgunis oats yielded 4.01 and 60-day oats yielded 3.45. Some of these results are slightly higher than those obtained for the non-irrigated grains from the Central Experimental Farm (Greenville), but they were all considerably lower than the results for the heavily irrigated grains on this farm.

Influence of Locality.—Grains were collected from various parts of the state, care being taken to learn whether they were irrigated or dry-farm grains, and especially whether there were appreciable quantities of alkali present, since it has been found by the senior author (2) that the presence of alkali very materially increases the ash content of barley.

Table 4. Pounds of ash per 1000 pounds of wheat grown in different sections of Utah

Locality	Lbs. Ash
Joe's Valley	29.4
Santaquin	25.6
Grantsville	24.8
Ephraim	24.5
Elberta	23.8
Lewiston	22.5
Henefer	22.3
Fairview	21.9
Stockton	21.8
Kamas	21.8
Heber City	21.5
Richfield	21.4
Wanship	21.1
Price	20.8
Vernon	20.6
Beaver	20.5
Nephi	20.3
Spanish Fork	20.3
Castledale	20.3
Coalville	20.2
Tooele	20.1
Morgan	19.9
Richfield	19.6
Payson	19.2
Nephi Dry-farm Substation	18.4
Salina	15.7
Hill Top	15.0

In interpreting these results it must be borne in mind that the variation in mineral content of grains grown in different localities may be due to numerous factors, such as soil, irrigation water, variety, etc., and not only due to magnitude of climate and environmental factors. Each of the factors can only be determined by future work.

There is a wide variation in the ash content of wheat from different localities. That from Joe's Valley contains about 2.0 times as much ash as that from Hill Top. There are at least two factors governing the ash content of the wheat: (1) Soils of similar content produce grains, the ash of which varies directly with the water applied, either as rain or irrigation water. (2) Wherever the soluble salt content of the soil is high, the ash content of the grains is comparatively high.

Table 5. Pounds of ash per 1000 pounds of barley grown in different sections of Utah

Locality	Lbs. Ash
Kamas	37.1
St. John	34.8
Grantsville	33.4
Vernal	33.4
Hill Top	33.1
Morgan	32.8
Nephi	31.7
Wanship	31.5
Lewiston	31.5
Spanish Fork	30.7
Henefer	30.6
Coalville	29.9
Nephi	20.8

The ash content of the barley varied from 3.71 per cent in the case of sample that grown at Kamas to 2.08 per cent in that grown on the Nephi Dry-farm Substation. Only two of the samples of barley analyzed contained less than 3 per cent of ash, whereas every sample of wheat analyzed contained less than 3 per cent of ash. The average ash content of the wheat analyzed was 2.10 per cent and that of barley 3.16 per cent. Viewed from the standpoint of ash content it is evident that barley is valuable and is needed by the growing or milking animal on account of the large quantity of ash which it contains.

Table 6. Pounds of ash per 1000 pounds of oats grown in different sections of Utah

Locality	Lbs. Ash
Fairview	48.7
Elberta	48.3
Grantsville	48.0
Spanish Fork	46.9
Wanship	44.5
Coalville	44.3
Heber City	44.3
Beaver	43.9
Koosharem	43.2
Vernon	43.2
Ephraim	43.2
Ferron	42.4
Lewiston	41.9
Santaquin	41.1
Tooele	40.2
Payson	40.1
Nephi	38.2
Henefer	37.5
Beaver	37.4
Morgan	35.6
Nephi Dry-farm Substation	16.8

The ash content of the oats varied from 3.56 to 4.87 per cent. Only one sample carried an ash content below 3.70 per cent, whereas in the barley there was only one sample with an ash content over this value. The average ash content of the wheat, barley, and oats analyzed was 2.10, 3.16, and 4.26 per cent, respectively. If an animal is fed 1000 pounds of barley it will receive as an average 10.6 pounds more ash than if it is fed the same quantity of wheat; whereas, if fed oats it will receive 11 pounds more ash than if fed barley. These differences would be especially significant where the animal receives mainly a grain ration. Whether or not the one is superior to the other depends upon the quantity assimilated and especially the mineral elements which constitute the ash. These are considered in the following pages.

Base Builders

Calcium.—Calcium gives tone and vigor to the plant. More occurs in the leaves and stems than in the seed; consequently, there is a great tendency for modern civilized man who lives on a diet composed primarily of highly milled grains, muscle meats, and sugars to suffer from a lack of calcium in the diet. Likewise, animals raised on a grain diet have weak bones.

Calcium phosphate and calcium carbonate compose about 40 per cent of the weight of the bones; consequently, when deficient in the diet of growing animals there results soft and malformed bones, a condition known as rickets. However, an abundance of lime in the diet will not insure proper bone formation unless all other conditions are appropriate. These are: (1) A proper ratio of the calcium to the phosphorus in the diet. An excess either of calcium or of phosphorus in the diet will result in rickets. (2) A sufficient quantity of vitamin D which makes it possible for the animal to metabolize its calcium. (3) An appropriate quantity of the mother substance from which vitamin D is manufactured. In the latter case the animal should also be exposed to sunlight.

Calcium in the form of its salts occurs in the tissues and blood and is absolutely essential to the life and well-being of the animal. An insufficient quantity, or the wrong proportion, results in increased irritability or nervousness which will manifest itself in the case of the child, the calf, or the chick by an excitability.

There is a constant loss of calcium from the body of the adult in the feces and urine, whereas in the lactating animal larger quantities are carried from the body in the milk. The growing animal requires large quantities for the building of new structural tissue, all of which must come from the food; consequently, it is important to know the calcium content of the various grains grown under varying conditions.

Influence of irrigation water on calcium content.—The calcium content of wheat, oats, and barley was determined on grains grown on the Central Experimental Farm (Greenville) and receiving varying quantities of irrigation water. The average results for such determinations are given in **Table 7.**

Table 7. Total calcium in grain crop, also pounds per 1000 pounds of grain grown with varying quantities of irrigation water on the Central Experimental Farm (Greenville)

Treatment	Lbs. Calcium in					
	Wheat		Oats		Barley	
	1000 lbs.	removed in crop per acre	1000 lbs.	removed in crop per acre	1000 lbs.	removed in crop per acre
No irrigation water	1.03	2.31	1.46	2.14	1.07	2.80
5 in. " "	1.07	2.02	1.48	2.88	1.03	2.95
10 " " "	1.22	2.63	1.68	3.54	1.03	3.28
15 " " "	1.65	3.53	1.67	3.60	1.07	4.19
20 " " "	1.95	3.78	1.78	4.04	1.02	3.89
35 " " "	2.11	4.72	1.60	4.13	1.45	5.90
45 " " "			1.36	3.28		
52.5 " "					1.50	5.81
67.5 " "	2.63	5.64				

The calcium content of the wheat increases as the irrigation water increases. This increase is greatest with small applications and is approximately constant for each increase of 5 inches of water up to 20 inches. Wheat raised with 67.5 inches of irrigation water contains 2.55 times as much calcium as does wheat grown with no irrigation water. Such differences as these must have significance in human nutrition, for where the whole grain is used the individual would be getting a much greater quantity of calcium. Whether this difference persists in the milled grains—which it probably does—remains to be answered.

The calcium content of the oats increases until the irrigation water applied reaches 20 inches. With 35 inches and above there is a decrease. The barley shows a persistent gain in calcium with increased irrigation water. That grown with 52.5 inches contains 1.41 times as much as that grown without irrigation water. Even the non-irrigated grains carry from two to three times the calcium usually reported as occurring in grains, which are grown on non-calcareous soils.

The calcium content of corn grown on the same soil with varying quantities of irrigation water and manure is given in Table 8.

Table 8. Pounds of calcium in 1000 pounds of corn grown with varying quantities of irrigation water and manure on Central Experimental Farm (Greenville)

Treatment	Lbs. Calcium
No irrigation water[1]	1.3
5 in. " " 1	1.8
10 " " " 1	1.8
20 " " " 1	1.4
30 " " " 1	1.4
40 " " " 1	1.4
No manure[2]	1.4
5 tons manure[2]	1.5
15 tons manure[2]	1.5

[1] and varying quantities of manure

[2] and varying quantities of irrigation water

The percentage of calcium in the corn kernel increases with the irrigation water applied up to 10 inches yearly; above this it gradually decreases. Corn grown with 10 inches of irrigation water contains 40 per cent more calcium than corn grown without irrigation water; that receiving 40 inches of irrigation water contains only 8 per cent more calcium. Manure also increases the calcium content of the corn, but not to the same extent as does irrigation water.

The calcium-low corn in this series contains about six times the quantity reported by Hopkins (2, p. 603), whereas the calcium-rich corn contains nearly nine times the amount.

The calcium content of different varieties of wheat grown at the Nephi Dry-farm Substation is given in Table 9.

Table 9. Pounds of calcium in 1000 pounds of different varieties of wheat on Nephi Dry-farm Substation

Variety	Lbs. Calcium
Beloglina	1.09
Defiance	0.98
Marquis Spring	0.97
Black Hull	0.94
Chul	0.93
Early Baart	0.91
Kota	0.85
Kubanka	0.84
Gold Coin	0.81
Turkey	0.78
Washington Hybrid No. 128	0.76
Alberta Red	0.75
Hard Federation	0.70
Ghirka Winter	0.89
Odessa	0.67
Kharkov	0.62
Kofod	0.60
Saumure	0.54
Kanred	0.53

The extreme difference in calcium content of the various varieties of wheat amounts to 100 per cent. The variety containing the highest calcium content is the same as the calcium content of the non-irrigated wheat grown on the soil of the Central Experimental Farm (Greenville). The highly irrigated wheat from this farm contains four times the calcium content of Kanred grown at the Nephi Dry-farm Substation. Where there exists a difference of 400 per cent in the lime content of wheat it must play a significant part in the nutrition of animals, mainly on grain rations. The results also indicate the influence of soil composition on the calcium content of grain. The average calcium content of oats analyzed from Nephi was 0.103 per cent and the barley 0.110, which is considerably lower than the calcium content of the oats and barley grown on the Central Experimental Farm (Greenville).

Table 10. Pounds of calcium per 1000 pounds of wheat grown in different parts of the state

Locality	Lbs. Calcium in 1000 Lbs. Wheat
Joe's Valley	2.96
Vernon	1.12
Price	1.06
Nephi Dry-farm Substation	1.04
Santaquin	0.95
Fairview	0.89
Ephraim	0.87
Lewiston	0.86
Stockton	0.79
Salina	0.74
Richfield	0.70
Vernon	0.70
Spanish Fork	0.69
Nephi	0.67
Wanship	0.66
Kamas	0.66
Castledale	0.65
Price	0.65
Grantsville	0.64
Heber City	0.63
Coalville	0.63
Morgan	0.62
Richfield	0.62
Hill Top	0.61
Nephi	0.58
Henefer	0.55
Payson	0.52
Tooele	0.52
Elberta	0.50
Beaver	0.28

There was ten times the calcium in the Joe's Valley and the heavily irrigated grain grown on the Central Experimental Farm (Greenville) over that occurring in the Beaver-grown wheat, thus indicating that the nature of the soil on which wheat is grown, as well as the variety and irrigation water applied, plays a part in determining the calcium content of wheat.

Table 11. Pounds of calcium in 1000 pounds of barley grown in different sections of Utah

Locality	Lbs. Calcium in 1000 Lbs. Barley
Nephi Dry-farm Substation	1.35
Fairview	1.03
Kamas	0.99
Hill Top	0.97
Vernal	0.84
Lewiston	0.76
Nephi	0.71
St. John	0.70
Morgan	0.68
Spanish Fork	0.68
Grantsville	0.67
Henefer	0.65
Coalville	0.38
Wanship	0.29

There is a difference of over 450 per cent in the calcium content of the barley from different districts, as shown in this table. The calcium content of the Greenville-grown barley averaged higher in calcium than that grown in any other part of the state.

The calcium content of oats grown in different parts of Utah is given in Table 12.

Table 12. Pounds of calcium in 1000 pounds of oats grown in different sections of Utah

Locality	Lbs. Calcium in 1000 Lbs. Oats
Fairview	1.69
Santaquin	1.28
Elberta	1.26
Nephi Dry-farm Substation	1.25
Heber City	1.24
Wanship	1.24
Spanish Fork	1.22
Ferron	1.21
Morgan	1.03
Coalville	1.01
Lewiston	1.01
Nephi	1.00
Koosharem	0.99
Grantsville	0.95
Henefer	0.93
Vernon	0.93
Ephraim	0.76
Tooele	0.71
Payson	0.55
Ephraim	0.35
Beaver	0.19

There is a difference of nearly 900 per cent in the calcium content of oats collected from different parts of the state. The average calcium content of the oats grown on the Central Experimental Farm (Greenville) was 0.157 per cent, whereas that collected over the state had a calcium content of nearly 0.099 per cent. This wide variation of the calcium content of the grain from the different sections must be significant. If feeding experiments could be conducted using these high and low calcium grains to determine the effects on the growth and metabolism of animals it would be of great practical value.

The average calcium content of all the grains analyzed is considerably higher than that often reported. For the wheats analyzed the average calcium content was 0.086 per cent, for barley 0.091 per cent, and for oats 0.113 per cent.

Magnesium content of grains.—The body of man contains over 2 pounds of calcium, whereas its magnesium content is only slightly over 1 ounce. Small as this is, yet it is absolutely essential to life and wellbeing. It is not only essential that sufficient magnesium be present but that the ratio of the calcium to magnesium be in the right proportion; otherwise, there are metabolic disturbances in both plants and animals.

The wheat, oats, and barley grown on the Central Experimental Farm (Greenville) with varying quantities of irrigation water were analyzed for magnesium and the average results are given in Table 13.

Table 13. Pounds of magnesium in 1000 pounds of grain produced with different quantities of irrigation water on the Central Experimental Farm (Greenville)

Treatment	Wheat		Oats		Barley	
	Mg. in 1000 lbs. grain	Lbs. removed in grain per acre	Mg. in 1000 lbs. grain	Lbs. removed in grain per acre	Mg. in 1000 lbs. grain	Lbs. removed in grain per acre
No irrigation water	1.70	3.82	1.32	1.92	1.72	2.26
5 in. " "	1.71	3.54	1.64	2.77	1.77	2.42
10 " " "	1.72	3.85	1.74	3.47	1.78	2.86
15 " " "	1.73	3.23	1.74	3.91	1.86	2.95
20 " " "	1.98	3.77	1.72	3.90	1.95	3.58
35 " " "	2.07	4.64	1.95	5.03	1.71	3.35
45 " " "			2.18	5.28		
52.5 " "					1.85	3.44
67.5 " "	2.24	4.80				

The magnesium content of all three grains increases as the irrigation water used in their production increases. Wheat showed an increase of 32 per cent; oats, 65 per cent; and barley, 9 per cent. The calcium magnesium ratio grows narrower in the wheat and wider in the oats and barley as the irrigation water used in their production increases. It is narrow in the case of oats (1:1.13). wider in the wheat (1:1.17), and still wider in barley (1:1.60).

The magnesium content of corn grown on the same soil with varying quantities of irrigation water and manure is given in Table 14.

Table 14. Pounds of magnesium in 1000 pounds of corn grown with varying quantities of irrigation water and manure on the Central Experimental Farm (Greenville)

Treatment	Lbs. Magnesium in 1000 Lbs. Corn
No irrigation water[1]	2.0
5 in. " "[1]	2.0
10 " " "[1]	2.0
20 " " "[1]	2.0
30 " " "[1]	2.1
40 " " "[1]	2.0
No manure[2]	1.9
5 tons manure[2]	2.2
15 tons manure[2]	2.1

[1] and varying quantities of manure
[2] and varying quantities of irrigation water

The magnesium content of the corn is nearly constant with all water treatments. It is nearly twice that reported by von Wolff (6, p. 603). Yet when corn is grown on this soil to which manure had been applied the magnesium content of the grain increased 15 per cent.

The calcium-magnesium ratio of corn is 1:1.37. The total quantity of calcium and magnesium removed from the soil increases with the irrigation water and manure applied. The results all tend to bear out the theory that the change in the composition of the grain is due primarily to an increased available supply of plant-food resulting from increased bacterial activity. This in turn is a function of the moisture and organic content of the soil (3, 4).

The magnesium content of the different varieties of wheat grown on the Nephi Dry-farm Substation is given in Table 15.

Table 15. Pounds of magnesium in 1000 pounds of different varieties of wheat on the Nephi Dry-farm Substation

Variety	Lbs. Magnesium in 1000 Lbs. Grain
Black Hull	2.02
Hard Federation	2.00
Washington Hybrid No. 128	1.99
Kanred	1.97
Gold Coin	1.94
Turkey	1.91
Beloglina	1.91
Regenerated Defiance	1.90
Kharkov	1.90
Alberta Red	1.84
Kofod	1.83
Ghirka Winter	1.79
Kota	1.79
Odessa	1.77
Early Baart	1.75
Marquis Spring	1.69
Saumure	1.63
Kubanka	1.61

The variation in magnesium content among different varieties of wheat amounted to 25 per cent; that due to irrigation water, 32 per cent. The average magnesium content of the various varieties of wheat grown in Nephi was 0.184 per cent, whereas the average of the Greenville-grown wheat was 0.188. The calcium content of the Nephi-grown wheats was 0.079 per cent, that of the Greenville-grown wheats 0.167; consequently, while the magnesium content of the grains from the two districts is not far different, yet the calcium content is twice as high in the Greenville grain as it is in the Nephi. This is due to two factors: (1) The greater calcium content of the Greenville soils, and (2) the application of irrigation water.

The average magnesium content of the barley and oats grown on the Nephi Dry-farm Substation was 0.178 and 0.190 per cent, respectively. The magnesium content of grains grown in different sections of Utah is given in Table 16.

Table 16. Pounds of magnesium in 1000 pounds of wheat grown in different sections of Utah

Locality	Lbs. Magnesium in 1000 Lbs. Grain
Nephi Dry-farm Substation	2.78
Santaquin	2.24
Beaver	2.18
Payson	2.11
Elberta	2.11
Vernon	2.03
Richfield	1.96
Grantsville	1.91
Joe's Valley	1.90
Vernon	1.89
Price	1.86
Salina	1.82
Nephi	1.81
Stockton	1.79
Tooele	1.79
Fairview	1.79
Henefer	1.70
Castledale	1.70
Spanish Fork	1.69
Heber City	1.68
Ephraim	1.68
Lewiston	1.66
Wanship	1.65
Kamas	1.64
Coalville	1.61
Nephi	1.38
Hill Top	1.35

There is a variation of 212 per cent in the magnesium content of wheat from different sections of the state, as shown by this table. The results establish three important points: (1) There is a great variation in the magnesium content of wheat from different districts; (2) the magnesium content of wheat varies with the irrigation water used in its production; and (3) the average magnesium content of Utah-grown wheat is higher than usually reported from other districts.

Table 17. Pounds of magnesium in 1000 pounds of barley grown in different sections of Utah

Locality	Lbs. Calcium in 1000 Lbs. Barley
Lewiston	2.73
Coalville	2.06
Wanship	2.06
Nephi Dry-farm Substation	1.80
Fairview	1.79
Spanish Fork	1.77
Nephi	1.76
Hill Top	1.76
St. John	1.75
Henefer	1.75
Grantsville	1.72
Nephi	1.70
Kamas	1.61
Heber	1.58
Vernal	1.47
Morgan	1.47

The variation in the magnesium content of the barley from various sections of Utah is considerably greater than the variation due to irrigation water. The variation due to locality amounted to 86 per cent, that due to irrigation water 11 per cent.

The magnesium content of oats is given in Table 18.

Table 18. Pounds of magnesium in 1000 pounds of oats grown in different sections of Utah

Locality	Lbs. Magnesium in 1000 Lbs. Oats
Nephi Dry-farm Substation	2.78
Beaver	2.37
Kamas	2.35
Elberta	2.21
Santaquin	2.13
Spanish Fork	1.92
Koosharem	1.85
Wanship	1.80
Fairview	1.79
Tooele	1.73
Grantsville	1.70
Henefer	1.70
Ephraim	1.70
Nephi	1.66
Heber City	1.65
Vernon	1.63
Payson	1.53
Lewiston	1.50
Ferron	1.49
Morgan	1.40
Coalville	1.40

There is a variation in the magnesium content of the oats from different parts of the state of 99 per cent, whereas that grown at the Central Experimental Farm at Greenville showed a variation of 65 per cent.

The magnesium content of corn grown at the Central Experimental Farm with varying quantities of irrigation water and with and without manure is given in Table 19.

Table 19. Pounds of magnesium in 1000 pounds of corn grown at the Central Experimental Farm (Greenville) with varying quantities of manure and irrigation water

Locality	Lbs. Magnesium in 1000 Lbs. Oats
No irrigation water[1]	2.0
5 in. " "[1]	2.0
10 " " "[1]	2.0
20 " " "[1]	2.0
30 " " "[1]	2.1
40 " " "[1]	2.0
No manure[2]	1.9
5 tons manure[2]	2.2
15 tons manure[2]	2.1

[1] and varying quantities of manure
[2] and varying quantities of irrigation water

The magnesium content of the corn is nearly constant with all water treatments and is nearly twice that reported by von Wolff (6). This is probably due to the high magnesium content (magnesia, Mg0, 6.10 per cent) of the soil on which this corn was grown. Even with the high magnesium content of this grain grown on unmanured soil, grain grown on manured soil showed a gain of 15 per cent.

The calcium-magnesium ratio of corn is 1:1.37. The results all bear out the theory that the change in the composition of the grain is due primarily to an increased available supply of plant-food resulting from increased bacterial activities of the soil. This in turn is a function of its moisture and organic content (4, 5).

The average magnesium content of the different grains is not far different, that of corn being 0.203 per cent; wheat, 0.190 per cent; oats, 0.181 per cent; and barley, 0.180 per cent.

Potassium content of grains.—Potassium is another element which is essential to the life of every plant and animal. The plants obtain it from the soil. If deficient in the soil, the crop yields are decreased. Potassium-starved plants have a dull, poor color and tend to die early at the tops. Beets are low in sugar. Grains are underweight. Potassium-starved plants are the first to succumb to disease. During the ripening of the plant the potassium of the leaves and stalks becomes soluble and may be washed back into the soil. That within the seed remains and is a vital part, either for the young plant or the animal which feeds upon it.

Table 20 gives the potassium content of the grains grown on the Central Experimental Farm with varying quantities of irrigation water.

Table 20. Total potassium in crop per acre, also pounds potassium per 1000 pounds of grain grown with varying quantities of irrigation water on the Central Experimental Farm (Greenville)

Treatment	Lbs. Potassium					
	Wheat		Oats		Barley	
	in 1000 lbs.	removed per acre in grain	in 1000 lbs.	removed per acre in grain	in 1000 lbs.	removed per acre in grain
No irrigation water	3.97	8.92	4.18	6.09	3.89	4.90
5 in. " "	4.14	8.97	4.83	8.12	4.01	5.47
10 " " "	4.40	9.49	4.83	9.68	4.47	7.22
15 " " "	4.92	10.47	4.74	11.17	4.77	7.24
20 " " "	4.90	9.35	4.74	10.74	5.46	10.02
35 " " "	5.34	11.95	5.21	13.46	5.16	10.10
45 " " "			5.46	13.25		
52.5 " "					4.44	8.26
67.5 " "	5.35	11.50				

The percentage of potassium in the wheat increased progressively with the water applied, so that by the time it was receiving 35 inches of irrigation water it was carrying 35 per cent more potassium than was the wheat grown with no irrigation water.

The oats increase in potassium as the water applied increases. Those grown with 45 inches of water contain 31 per cent more potassium than those grown without irrigation water. The barley increases in potassium as the irrigation water increases up to 20 inches; above this there is a decrease. The average potassium content of the grains grown on the Central Experimental Farm was oats, 0.485; wheat, 0.472; and barley, 0.460.

Corn grown on the Central Experimental Farm, with varying quantities of both irrigation water and manure, was analyzed for its potassium content. The average results are given in Table 21.

Table 21. Pounds of potassium in 1000 pounds of corn grown with varying quantities of irrigation water and manure on the Central Experimental Farm (Greenville)

Treatment	Lbs. Potassium
No irrigation water[1]	3.7
5 in. " " [1]	3.9
10 " " " [1]	4.0
20 " " " [1]	4.0
30 " " " [1]	4.0
40 " " " [1]	4.1
No manure[2]	3.8
5 tons manure[2]	3.9
15 tons manure[2]	4.1

[1] and varying quantities of manure

[2] and varying quantities of irrigation water

The potassium content of the corn kernel increases with increase of the water applied during the growing season. Corn grown with 40 inches of irrigation water contains 11 per cent more potassium than that grown without irrigation water; that grown with 15 tons of manure contains 8 per cent more potassium than that grown without manure.

The potassium content of different varieties of wheat grown on the Nephi Dry-farm Substation is given in Table 22.

Table 22. Pounds of potassium in different varieties of wheat on Nephi Dry-farm Substation

Variety	Lbs. Potassium in 1000 Lbs. Grain
Early Baart	4.38
Regenerated Defiance	4.33
Washington Hybrid	4.17
Saumure	4.08
Kofod	3.94
Chul	3.89
Kubanka	3.85
Odessa	3.82
Marquis Spring	3.73
Ghirka Winter	3.73
Gold Coin	3.67
Kota	3.63
Alberta Red	3.39
Kanred	3.39
Hard Federation	3.33
Beloglina	3.33
Kharkov	3.13
Black Hull	3.24
Turkey	2.87

The variation in potassium content, due to variety, amounted to 52 per cent; the variation due to water, 35 per cent; and the variation due to locality, primarily soil, to but 28 per cent. The average potassium content of the wheats grown on the Central Experimental Farm was 0.472 per cent, and that of the Nephi-grown wheats 0.368. The average potassium content of the Nephi-grown barley was 0.416 per cent, of the oats 0.386 per cent, both of which are lower than the Greenville-grown.

The potassium content of wheat grown in different sections of Utah is given in Table 23.

Table 23. Pounds of potassium in 1000 pounds of wheat grown in different sections of Utah

Locality	Lbs. Potassium in 1000 Lbs. Grain
Nephi	9.71
Fairview	9.60
Hill Top	7.79
Morgan	7.52
Ephraim	6.09
Lewiston	5.82
Richfield	5.79
Spanish Fork	5.77
Grantsville	5.63
Elberta	5.62
Richfield	5.61
Santaquin	5.44
Henefer	5.38
Vernon	5.21
Price	5.20
Castle Dale	5.09
Ephraim	5.04
Joe's Valley	4.98
Vernon	4.75
Kamas	4.73
Tooele	4.64
Coalville	4.62
Spanish Fork	4.51
Wanship	4.48
Heber City	4.27
Stockton	4.20
Nephi Dry-farm Substation	4.09

The two outstanding characteristics brought out by these results are: (1) The great variation in the potassium content of the different grains. The two extremes show a variation of 316 per cent. There is a variation of 254 per cent in the potassium content of the irrigated and dry-farm wheat grown at Hill Top. (2) The very high potassium content of most of the grains or the state. The average for the grain grown on the Central Experimental Farm was 0.472, of the Nephi-grown grain 0.368, and that collected over the state, 0.519.

Table 24. Pounds of potassium in 1000 pounds of barley grown in different sections of Utah

Locality	Lbs. Potassium in 1000 Lbs. Barley
Fairview	9.23
Hill Top	9.16
Spanish Fork	7.58
Lewiston	6.91
Wanship	6.41
Morgan	6.45
St. John	5.96
Coalville	5.93
Henefer	5.91
Vernal	5.60
Nephi	5.51
Grantsville	5.23
Kamas	5.02
Heber	4.83
Nephi Dry-farm Substation	3.90

The maximum potassium content of these grains was 0.923 per cent, the minimum 0.390, a difference of 236 per cent. The average is 0.62 per cent. This is 74 per cent greater that that reported by Hopkins (6)

The results for oats from different sections of Utah are given in Table 25.

Table 25. Pounds of potassium in 1000 pounds of oats grown in different sections of Utah

Locality	Lbs. Potassium in 1000 Lbs. Oats
Fairview	10.00
Spanish Fork	7.26
Elberta	6.85
Henefer	6.42
Wanship	6.32
Grantsville	6.32
Ephraim	6.19
Lewiston	6.16
Beaver	6.06
Tooele	5.67
Kamas	5.60
Koosharem	5.50
Payson	5.50
Morgan	5.48
Coalville	5.37
Nephi Dry-farm Substation	5.34
Vernon	5.28
Ferron	5.13
Nephi	4.66
Heber City	4.56

The potassium content of the oats is higher than either the wheat or barley. The average potassium content of the oats is 0.6 per cent. There is a difference of 219 per cent in the potassium content of the highest and lowest potassium-containing grain.

The results of the study of the potassium content of grains point to a number of valuable conclusions: (1) The potassium content of the grains grown in Utah is high as compared with results reported from elsewhere. (2) There is a great variation in the potassium content of grains, due to irrigation water, soil, variety, and kind of grain. The average potassium content of the grains was found to be: Wheat, 0.453 per cent; oats, 0.484 per cent; barley, 0.499 per cent; and corn, 0.394 per cent.

Acid Builders

The elements so far considered when ingested by animals in their food are changed during the process of digestion and on assimilation become bases; consequently, they possess the power of neutralizing acids. Their absence from the diet of an animal soon results in the animal's death. In fact, animals given a diet, ideal in every other respect, die sooner than do fasting animals. Insufficient quantities of the base builders cause profound disturbances. Moreover, an excess of the base builders is to be avoided. They are neutralized by the group about to be considered, the acid formers.

Phosphorus.—In comparison with some elements, phosphorus is rare. It is twelfth in the order of abundance, as it constitutes only about 0.14 per cent of the earth's crust. Even this is very unevenly distributed. Some virgin soil contains enough for only a limited number of crops, whereas others contain sufficient for hundreds of crops. It also occurs in large natural deposits. It exists primarily as phosphates both in the soil and the natural deposits. The phosphorus resources of the United States are superior to those of any other nation. Although it is well distributed east and west, the bulk of it occurs in Utah, Idaho, Wyoming, and Montana. In these states are billions of tons of high-grade phosphate. The tendency is to mine and ship most of the highest grade to foreign countries. This is a wrong practice, because in the future it will be needed at home for the production of food for the ever-increasing population.

Next to nitrogen, phosphorus is the limiting element of crop production in most soils. Furthermore, the nitrogen supply is inexhaustible since it forms four-fifths of the earth's atmosphere and can be obtained cheaply by straight processes of industrial chemistry, or, better still, by the nitrogen-gathering bacteria. On the other hand, Hopkins has calculated from thousands of analyses that the average supply of phosphorus in the two million pounds of soil covering an acre of land to the usual plowed depth of 6-$^{2}/_{3}$ inches is only 2200 pounds, or enough for 130 crops of corn at the rate of 100 bushels per acre.

Phosphorus in organic union is an essential constituent of all living protoplasm. It occurs in every cell, both plant and animal. On hydrolysis nucleoproteins (which constitute such a large part of the cell nucleus) yield nuclein, and nuclein contains as high as 10 per cent of phosphorus. It constitutes over 20 per cent of the ash of corn, 19 per cent of the ash of wheat, 12 per cent of the ash of barley, and over 9 per cent of the ash of oats; hence, there are millions of pounds of it in each yearly harvest. The mineral part of animal bones consists largely of tricalcium phosphate. In 100 pounds of raw bone there are approximately 10 pounds of phosphorus. An adult contains in his body about one one-half pounds of phosphorus. If one-half of this amount is allowed for each individual it would mean that there are approximately 700,000 tons of it tied up in the bodies of individuals living upon the earth at the present time, to say nothing of the far greater quantity bound up in the bodies of animals. Thus, it may be seen that phosphorus follows close to nitrogen after carbon, oxygen, and hydrogen as a structural material in biological chemistry.

The wheat, oats, and barley grown on the Central Experimental Farm, with various quantities of irrigation water, were analyzed for phosphorus. The average results are given in Table 26.

Table 26. Total phosphorus in crop per acre, also pounds phosphorus per 1000 pounds of grain grown with varying quantities of irrigation water on the Central Experimental Farm (Greenville)

Treatment	Phosphorus					
	Wheat		Oats		Barley	
	lbs. in 1000 lbs.	lbs. per Acre	lbs. in 1000 lbs.	lbs. per Acre	lbs. in 1000 lbs.	lbs. per Acre
No irrigation water	2.95	6.64	2.79	4.07	3.09	3.90
5 in. " "	3.01	6.38	2.87	5.84	3.02	4.30
10 " " "	3.06	6.38	3.13	6.23	3.00	4.70
15 " " "	3.23	6.87	3.18	7.51	3.16	5.59
20 " " "	3.71	7.08	3.40	7.71	3.35	6.14
35 " " "	4.58	10.24	3.78	9.77	4.02	7.88
45 " " "			3.69	8.94		
52.5 " "					3.75	6.97
67.5 " "	4.25	9.12				

Wheat, oats, and barley all show a gradual progressive increase in phosphorus as the quantity of irrigation water used in their production increases up to 35 inches yearly. Above this there is a decrease. The increase in the case of wheat amounts to 55 per cent, oats 35 per cent, and barley 30 per cent. This means that it would require for a 50-bushel crop of wheat 4.9 pounds, a 100-bushel crop of oats 2.9 pounds, and a 75-bushel crop of barley 4.2 pounds more of phosphorus if grown with large quantities of water than if grown with small quantities. Conversely, it indicates that the user of grains obtains these greater quantities of phosphorus if he purchases grains grown with these quantities of water. However, this increase of phosphorus may not have the same nutritive value as the phosphorus occurring in grains grown with small quantities of water.

However, this extra phosphorus would not be without value, for animals kept on a grain diet grown on irrigated grain would probably find the extra quantities sufficient to build strong bones, and if fed to milk cows it might modify the calcium and phosphorus content of the milk (6). This in turn would modify the nutritive value and might modify the digestibility of the milk. Whether this increase would more than offset the value of the extra protein in the wheat remains to be determined. It does indicate, however, that the feeder may often use a calculated mixed ration of the irrigated and nonirrigated grains, depending upon whether more ash or more protein is needed in the food.

The ratio of phosphorus to potassium where grown with no irrigation water is 1:1.34. This ratio becomes wider as the water used increases to 15 inches where the ratio is 1:1.53. Above this it grows narrower, and wheat grown with 67.5 inches of water has a phosphorus-potassium ratio of 1:1.26, Therefore, water has a greater influence on the phosphorus content of wheat than it has on its potassium content. The ratio of phosphorus to potassium in the oats is wider than in the wheat, and the variation in this ratio is in the same order as in the wheat. The ratio of phosphorus to potassium in the barley is narrower than in the wheat and oats, but follows the same order of variation as it does in these grains, thus indicating that the same law is operating in all three grains in the uptake of phosphorus and potassium and is probably correlated with the available constituents of the soil. Both are rendered more available by an increased bacterial activity due to increased water content of the soil. Consequently, the total quantity of phosphorus taken from the soil varies with the quantity of water used in its production up to 35 inches yearly. Above this there is a decrease. Very likely the increase in phosphorus is associated with an increase in the available phosphorus of the soil, for as the water content of the soil increases up to a certain level there is a proportional increase of the soil microflora (2) which would increase the quantity of acids. These in turn liberate phosphorus from its difficultly soluble forms. When the optimum moisture (5) is exceeded there is a proportional decrease in bacterial acids. This would result in less available phosphorus which manifests itself in a grain with a lower phosphorus content. Wheat is modified in phosphorus content to a greater extent than either of the other grains. It also carries greater quantities of total phosphorus from the soil under all the irrigation treatments than does either oats or barley.

The ratio of magnesium to phosphorus is quite uniform for the various grains grown with different quantities of water. The magnesium-phos phorus ratio in all the samples for wheat is 1:1.88, for oats 1:1.87, and for barley 1:1.84. This is considerably narrower than is the calcium-phosphorus ratio which is as follows: Wheat, 1:2.12; oats, 1:2.06; and barley, 1:2.86.

The calcium-magnesium ratio grows narrower in the wheat and wider in the oats and barley as the irrigation water used in their production increases. It is narrow in the case of oats (1:1.11), wider in the wheat (1:1.13), and still wider in barley (1:1.56).

The ratio of calcium to the phosphorus is greatest in the barley and least in the oats. There is a marked uniformity between the increase in calcium and of phosphorus of the various grains where grown with increased irrigation water which may indicate that the increase of these elements occurs as inorganic calcium and phosphorus.

The nitrogen content varies inversely with the water applied, but the phosphorus content of the grains varies directly with the water. Consequently, one may conclude that the increased phosphorus due to irrigation water is mainly inorganic phosphorus.

In order to test this supposition, quantitative determinations were made of the inorganic phosphorus in wheat, oats, and barley grown with varying quantities of irrigation water. The average results are given in Table 27.

Table 27. Total phosphorus and inorganic phosphorus in wheat, oats, and barley grown with varying quantities of irrigation water on the Central Experimental Farm (Greenville)

Treatment	Wheat			Oats			Barley		
	Inorganic Phosphorus	Total Phosphorus	Percentage Inorganic P.	Inorganic Phosphorus	Total Phosphorus	Percentage Inorganic P.	Inorganic Phosphorus	Total Phosphorus	Percentage Inorganic P.
No irrigation water	0.295	0.0186	6.3	0.279	0.0337	12.1	0.309	0.0232	7.5
15 in. " "	0.323	0.0192	5.9						
20 " " "				0.340	0.044	12.9	0.335	0.0211	6.3
35 " " "	0.458	0.026	5.7	0.378	0.033	11.7	0.402	0.0376	9.4
52.5 " "						8.8	0.375	0.0314	8.5
67.5 " "	0.424	0.021	5.0						

The wheat showed an increase in total phosphorus as the irrigation water applied increased up to 35 inches; 67.5 inches of irrigation water causes a decrease. Although there is an increase in the inorganic phoshporus as shown by this method yet the main increase is organic phosphorus. Between 5 and 6.3 per cent of the total phosphorus is in the inorganic form.

The oats increase in phosphorus as the irrigation water applied increases. Practically all of the increase, according to these results, is in the form of organic phosphorus. More of the phosphorus in the oats is inorganic than is the case with the wheat, there being as an average 11.2 per cent of the total phosphorus occurring in the organic form.

There is a marked increase in the total phosphorus of barley, due to irrigation water, only a small portion of the increase being inorganic phosphorus. The inorganic phosphorus varied from 6.3 to 9.4 per cent of the total.

Corn grown with varying quantities of irrigation water on the same farm as the wheat, oats, and barley yielded as an average the results given in Table 28.

Table 28. Total and inorganic phosphorus in corn grown with varying quantities of irrigation water on the Central Experimental Farm (Greenville)

Treatment	Total Phosphorus	Inorganic Phosphorus	Percentage of Total Phosphorus Inorganic
No irrigation water	0.32	0.040	12.2
5 in. " "	0.33	0.041	12.3
20 " " "	0.33	0.050	15.3
30 " " "	0.35	0.055	15.6
40 " " "	0.33	0.051	13.4

There is only a slight increase in the total phosphorus of corn, due to the use of irrigation water, but nearly all of the increase according to these results is in the inorganic form. From 12.2 to 15.6 per cent of the total phosphorus of the corn kernel is in the inorganic form.

The average phosphorus content of corn grown on land with varying quantities of farmyard manure is given in Table 29.

Table 29. Total and inorganic phosphorus in corn grown on soil receiving varying quantities of manure on the Central Experimental Farm (Greenville)

Treatment	Total Phosphorus	Inorganic Phosphorus	Percentage of Total Phosphorus Inorganic
No manure	0.33	0.050	15.2
5 tons manure yearly	0.34	0.054	15.9
15 tons manure yearly	0.33	0.055	16.0

In order to learn the phosphorus content of grains grown throughout the state samples were collected from various sections and analyzed for phosphorus. The average results are given in Table 30.

Table 30. Total and inorganic phosphorus in wheat from different sections of Utah

Locality	Total Phosphorus	Inorganic Phosphorus	Percentage of Total Phosphorus Inorganic
Richfield	0.455	0.015	3.3
Vernon	0.448	0.021	4.7
Kamas	0.444	0.033	7.4
Grantsville	0.442	0.022	4.9
Coalville	0.432	0.027	6.2
Elberta	0.430	0.030	6.9
Lewiston	0.415	0.023	5.4
Wanship	0.396	0.028	9.6
Vernon	0.392	0.018	4.6
Payson	0.390	0.017	4.4
Beaver	0.386	0.026	6.6
Castle Dale	0.380	0.017	4.5
Henefer	0.378	0.026	6.9
Tooele	0.372	0.023	6.3
Santaquin	0.367	0.026	7.1
Heber City	0.369	0.040	11.0
Joe's Valley	0.352	0.024	6.7
Stockton	0.351	0.031	3.7
Ephraim	0.346	0.024	6.9
Price	0.335	0.015	4.4
Nephi	0.326	0.016	6.3
Fairview	0.305	0.024	7.7
Salina	0.297	0.013	5.5
Morgan	0.293	0.019	6.5
Spanish Fork	0.270	0.020	7.4
Nephi Dry-farm Substation	0.209	0.013	6.4
Hill Top	0.205	0.022	13.5

There is a wide variation in the phosphorus content of grains from different sections. The wheat from Richfield contains 2.2 times the phosphorus contained in the Hill Top-grown grain. The others range between these two extremes. The grain from Richfield has approximately the same phosphorus content as that grown on the Central Experimental Farm, which received 35 inches of irrigation water. The non-irrigated grain contained 1.5 times the phosphorus contained in the Hill Top-grown grain. It is evident that irrigation water, soil, and possibly climate each influence the phosphorus content of wheat.

There is no direct relationship between the total and inorganic phosphorus content of wheat. The Richfield wheat, with 0.455 per cent of total phosphorus, contained only 3.3 per cent of it as inorganic phosphorus, whereas the Hill Top grain containing only 0.205 per cent of total phosphorus had 10.7 per cent of it as inorganic phosphorus. With a few exceptions the percentage of inorganic phosphorus is low and does not vary greatly in different samples.

The total phosphorus in different varieties of wheat grown at the Nephi Dry-farm Substation is given in Table 31.

Table 31. Pounds of phosphorus in 1000 pounds of different varieties of wheat grown on the Nephi Dry-farm Substation

Variety	Lbs. Phosphorus in 1000 lbs. Wheat
Regenerated Defiance	3.26
Gold Coin	3.24
Kota	3.10
Marquis Spring	2.96
Hard Federation	2.90
Ghirka Winter	2.88
Kanred	2.87
Chul	2.86
Kofod	2.81
Turkey	2.79
Kubanka	2.78
Kharkov	2.76
Alberta Red	2.60
Odessa	2.58
Beloglina	2.56
Black Hull	2.47
Early Baart	2.43
Washington Hybrid 128	2.36
Saumure	2.32

Four varieties of wheat grown at Nephi carried more phosphorus than the unirrigated grain grown at Greenville. There is a variation of 40 per cent in phosphorus between the highest and lowest variety. All but seven varieties carry a higher phosphorus content that the wheat reported by Sherman (8).

The total and organic phosphorus content in oats grown in different sections of Utah is given in Table 32.

Table 32. Total and inorganic phosphorus in oats from different sections of Utah

Locality	Total Phosphorus	Inorganic Phosphorus	Percentage of Total Phosphorus Inorganic
Spanish Fork	0.451	0.048	10.7
Koosharem	0.437	0.032	7.5
Henefer	0.421	0.047	11.2
Ephraim	0.420	0.043	10.3
Grantsville	0.413	0.036	8.8
Lewiston	0.404	0.051	12.5
Elberta	0.395	0.049	12.3
Beaver	0.390	0.042	10.7
Coalville	0.385	0.039	10.2
Kamas	0.380	0.036	9.4
Wanship	0.383	0.054	14.2
Morgan	0.374	0.021	5.5
Nephi	0.373	0.039	10.4
Santaquin	0.369	0.028	7.6
Payson	0.369	0.032	8.6
Vernon	0.368	0.033	8.9
Heber City	0.351	0.040	11.5
Ferron	0.335	0.036	10.9
Fairview	0.268	0.029	10.9
Nephi	0.267	0.023	8.7

There is a variation of the total phosphorus content of the oats, grown in different localities, of 69 per cent, and of the inorganic phosphorus of 257 per cent. There is, however, a closer correlation between the total phosphorus and the inorganic phosphorus of the oats than there is in the case of the wheat. The inorganic phosphorus varies from 5.5 per cent to 12.5 per cent of the total phosphorus. There is a greater variation in the phosphorus content of oats from different localities than was found due to irrigation water.

The phosphorus content of barley from different localities in Utah is given in Table 33.

Table 33. Total and inorganic phosphorus in barley from different sections of Utah

Locality	Total Phosphorus	Inorganic Phosphorus	Percentage of Total Phosphorus Inorganic
Morgan	0.444	0.051	11.5
Spanish Fork	0.433	0.036	8.2
St. John	0.427	0.044	10.4
Henefer	0.407	0.040	9.9
Kamas	0.399	0.044	11.0
Lewiston	0.378	0.040	10.6
Wanship	0.367	0.041	11.2
Coalville	0.363	0.042	11.5
Nephi	0.341	0.024	7.1
Vernal	0.317	0.031	9.8
Grantsville	0.314	0.029	0.3
Hill Top	0.276	0.021	7.5
Fairview	0.270	0.015	5.6
Nephi	0.238	0.020	8.5

The variation in the total phosphorus of barley from the different localities is 86 per cent. This is less than was found in the case of the wheat, but slightly greater than in the case of the oats. The inorganic phosphorus shows a wide variation and is not correlated with the total phosphorus of the barley. It is evident from these results that the total phosphorus of grains, wheat, oats, and barley increases as the irrigation water applied during the growing stage increases. The total phosphorus of these grains also varies with the soil on which the grain was grown. The maximum, minimum, and average phosphorus content of the different grains were:

	Wheat		Oats		Barley	
	Total	Inorganic	Total	Inorganic	Total	Inorganic
Maximum	0.455	0.040	0.451	0.051	0.444	0.051
Average	0.363	0.023	0.377	0.037	0.355	0.034
Minimum	0.205	0.013	0.267	0.021	0.238	0:015

As an average in the wheat 6.3 per cent of the total phosphorus was inorganic; in the oats, 9.8 per cent; and in the barley, 9.6 per cent of the total phosphorus was inorganic. Corn grown under different conditions of water and manure contained from 0.32 to 0.35 per cent of total phosphorus, 12.2 to 16 per cent of which was inorganic. Apparently the addition of barnyard manure to a soil growing corn increases the proportion of inorganic phosphorus in the corn kernel.

Sulfur.—Sulfur constitutes 0.08 per cent of igneous rock. It is estimated that 0.12 per cent of the earth is sulfur, where it occurs in both the free and combined form. Inorganically, it occurs mainly as sulfates combined with calcium, magnesium, sodium and other common bases. Its origin is native rock, organic manures, and rain water. It is one of the ten essential elements of plant-food and is necessary for the formation of certain essential soils. It enters into the composition of the proteins; consequently, it is required by all plants and animals. The plants can use it in the inorganic form, but animals require their sulfur in the organic; hence, it is important to know the quantity occurring in various grains.

The wheat, oats, and barley grown on the Central Experimental Farm (Greenville) were analyzed for sulfur. The determinations were made by fusing with sodium peroxide and then precipitating as barium sulfate. The average results are given in Table 34.

Table 34. Pounds sulfur per 1000 pounds of grain grown with varying quantities of irrigation water on the Central Experimental Farm (Greenville)

Treatment	Sulfur in 1000 Lbs. of		
	Wheat	Oats	Barley
No irrigation water	1.44	2.38	1.52
5 in. " "		2.19	1.56
10 " " "		2.05	1.32
15 " " "	1.97	2.01	1.26
20 " " "		2.21	1.13
35 " " "	2.13	1.83	1.15
52.5 " "		1.91	1.31

The sulfur content of the wheat increases progressively with the irrigation water, whereas the oats and barley show an irregular decrease. The oats carry 12 per cent more sulfur than the wheat and 58 per cent more than the barley.

The non-irrigated wheat carries sulfur and nitrogen in very nearly the ratio in which they occur in the vegetable proteins. This ratio decreases as the quantity of irrigation water applied to the growing crop increases. It is permissible to conclude from the nearness borne to the ratio found in native vegetable proteins, that if the unirrigated wheat contains all its sulfur in the unoxidized form then the irrigated grain contains only 58 per cent of it in the unoxidized form. The oats have a nearly constant sulfur-nitrogen ratio, and judged from the same viewpoint as the wheat, they contain 67 per cent of their sulfur in the unoxidized form. The barley carries a smaller percentage of oxidized sulfur than either the wheat or oats.

These grains were all low in sulfur compared with results reported by others (2, 8). This may be due to the very small quantities of sulfur occurring in the Greenville soil. The Nephi soils, on the other hand, are high in sulfur. The sulfur content of different varieties grown on this soil is given in Table 35.

Table 35. Total sulfur pounds per 1000 pounds different varieties of wheat grown on the Nephi Dry-farm Substation

Variety	Lbs. Sulfur in 1000 Lbs. Wheat
Black Hull	2.87
Hard Federation	2.80
Regenerated Defiance	2.66
Kubanka	2.65
Kota	2.57
Turkey	2.50
Early Baart	2.45
Chul	2.35
Kharkov	2.33
Kanred	2.32
Beloglina	2.31
Odessa	2.29
Washington Hybrid 128	2.27
Saumure	2.28
Ghirka Winter	2.25
Gold Coin	2.25
Alberta Red	2.15
Kofod	2.10
Marquis Spring	2.07

A study of the results given in this and the preceding table shows a great variation in sulfur of grains grown under different conditions. The figures indicate a variation, due to soil, of 30 per cent; due to variety, of 40 per cent; and a variation due to irrigation water of 42 per cent.

Wheat from various secitons of Utah was also analyzed for sulfur. The average results are given in Table 36.

Table 36. Total sulfur pounds per 1000 pounds of wheat grown in different sections of Utah

Locality	Lbs. Sulfur in 1000 Lbs. Wheat
Ephraim	2.37
Salina	2.30
Vernon	2.29
Castle Dale	2.29
Grantsville	2.16
Stockton	2.13
Joe's Valley	2.05
Price	2.04
Spanish Fork	2.02
Fairview	2.00
Nephi	1.96
Hill Top	1.95
Wanship	1.89
Beaver	1.85
Coalville	1.81
Richfield	1.74
Kamas	1.66
Henefer	1.60
Salina	1.58
Elberta	1.58
Nephi Dry-farm Substation	1.56
Payson	1.54
Lewiston	1.50
Santaquin	1.40
Tooele	1.24
Morgan	1.23
Heber City	1.20

There is a variation in the sulfur content of the wheats from various sections of Utah of 97 per cent. It is evident that there is a marked variation in the sulfur content of wheat, depending upon the kind of soil on which it is grown and also the irrigation water applied during the growing period.

In Table 37 is given the sulfur content of barley grown in various sections of Utah.

Table 37. Total sulfur pounds per 1000 pounds of barley grown in various sections of Utah

Locality	Lbs. Sulfur in 1000 Lbs. Barley
Nephi	2.16
Fairview	1.96
Spanish Fork	1.84
Grantsville	1.83
Hill Top	1.77
Heber	1.74
Vernal	1.74
Kamas	1.63
Wanship	1.61
Henefer	1.54
St. John	1.48
Coalville	1.41
Wanship	1.28
Lewiston	1.21
Nephi Dry-farm Substation	1.12
Morgan	0.82

There is a difference in the sulfur content of barley from different sections of Utah of 163 per cent. The difference found in the Greenville-grown barley and attributable to irrigation amounted to only 17 per cent; consequently, it is evident that while irrigation water modified the sulfur content of barley, yet there are other factors, possibly soil, which play a more profound part. All except one of the samples analyzed carried a sulfur content of between 1 and 2 per cent.

The sulfur content of oats from different sections of Utah is given in Table 38.

Table 38. Total sulfur pounds per 1000 pounds of oats grown in different sections of Utah

Locality	Lbs. Sulfur in 1000 Lbs. Oats
Ephraim	2.94
Fairview	2.59
Grantsville	2.40
Nephi	2.24
Spanish Fork	2.22
Heber City	2.15
Wanship	2.06
Koosharem	2.05
Ferron	1.91
Beaver	1.86
Coalville	1.77
Vernon	1.60
Henefer	1.59
Payson	1.55
Morgan	1.55
Elberta	1.52
Kamas	1.46
Santaquin	1.44
Lewiston	1.37
Nephi Dry-farm Substation	1.31
Tooele	1.15

There were eight localities from which oats were obtained with a sulfur content of over 0.2 per cent and none which went below 0.1 per cent. The extreme variation in sulfur content of the oats from different localities was 1.55 per cent. The extreme variation in the Greenville-grown oats and attributable to irrigation water was less than 25 per cent. It is, therefore, likely that in the modification of the sulfur content of wheat, oats, and barley, locality, principally soil, is playing an even greater role than irrigation water. The average sulfur content of all the samples of wheat analyzed was 0.204 per cent; oats, 0.190 per cent; and barley, 0.150 per cent total sulfur.

Iron.—Iron constitutes 4.5 per cent of the earth's surface. Aside from oxygen it is the most abundant of the life elements and is required by plants and animals in smaller quantities than is the case with any of the other elements. A 50-bushel crop of wheat contains 100 times as much nitrogen, 10 times as much phosphorus, and 8 times as much sulfur as iron. Yet small as the quantity of iron may be, it is absolutely essential to the life and wellbeing of plants and animals.

Although iron does not enter into the composition of chlorophyll, it plays an important part, directly or indirectly, in the production of chlorophyll; for, if iron is withheld from the plant, the leaves do not become green. Later, if the iron is supplied, the chlorophyll soon appears. In animals, iron plays a vital part. In the body of the human adult there are about 4.5 grams, contained for the most part, in the hemoglobin of the red corpuscles. The importance of iron arises from the fact that it plays the essential role of an oxygen carrier. It acts as a catalyst causing the transfer of oxygen from the air in the lungs to the various tissues of the body through the blood stream. Probably in many of the oxidation changes going on in the plant and animal cell, iron acts as the catalyst which speeds up the reaction.

Although iron is abundant and is required by plants and animals in such small quantities, nevertheless, it is not an uncommon thing to see both plants and animals suffering from iron starvation. The plant gets its iron from the soil; consequently, if the iron is lacking or unavailable the plant starves. The animal gets its iron from the plant and if iron be deficient in the plant or if the iron carrying part of the food be separated by man artificially the animal suffers from iron starvation; therefore, it is essential to know the amount of iron carried by different plants.

The iron was determined in the wheat, oats, and barley grown on the Central Experimental Farm and the results are given in Table 39.

Table 39. Pounds of iron occurring in 1000 pounds of wheat, oats, and barley grown with varying quantities of irrigation water on the Central Experimental Farm (Greenville)

Treatment	Lbs. Iron in 1000 lbs.		
	Wheat	Oats	Barley
No irrigation water	0.19	0.21	0.28
15 in. " "	0.25	0.21	0.27
35 in. " "	0.32	0.18	0.26

In iron content the barley averages highest, the wheat second, and the oats lowest. The iron content of these grains is from four to six times that reported by Sherman (8) and the barley is 33 per cent higher than the values reported by Petit (7). The greater quantity of iron found in these grains is due to two factors: (a) The high iron content of the soil, and (b) the active microflora of the soil (3). The highest lime content of these soils would tend to keep the soluble iron very low were it not for an active microflora. Moreover, it is quite likely that in the absence of optimum moisture, temperature, or organic content the microflora may be so influenced as to result in chlorosis.

Only 100 grams of either of these grains would be required to meet Sherman's estimate (8) of man's daily iron requirements of 15 mgm. However, if the milled product contains only one-fifth of the total iron, the requirement would be correspondingly increased.

The iron content of different varieties of wheat grown at the Nephi Dry-farm Substation is given in Table 40.

Table 40. Pounds of iron in 1000 pounds of different varieties of wheat grown on the Nephi Dry-farm Substation

Varieties of Wheat	Lbs. Iron in 1000 Lbs. Wheat
Turkey	0.048
Odessa	0.045
Black Hull	0.044
Alberta Red	0.044
Beloglina	0.043
Kanred	0.043
Early Baart	0.042
Regenerated Defiance	0.041
Washington Hybrid 128	0.040
Kota	0.039
Ghirka Winter	0.039
Chul	0.035
Kharkov	0.035
Kofod	0.034
Saumure	0.031
Marquis Spring	0.030
Hard Federation	0.030
Gold Coin	0.028

There is a variation in the iron content of these grains of approximately 70 per cent. However, all are much lower in iron than those grown on the Central Experimental Farm. This raises the question as to whether the grains on this station are outstanding in their high iron content, or if there is a similar condition in other sections of the state. To answer this question, wheat, oats, and barley were analyzed from different sections of the state. The results are given in Tables 41, 42, and 43.

Table 41. Pounds of iron occurring in 1000 pounds of wheat grown in different sections of Utah

Locality	Lbs. Iron in 1000 Lbs. Wheat
Joe's Valley	0.159
Ephraim	0.130
Santaquin	0.117
Price	0.089
Vernon	0.080
Spanish Fork	0.076
Richfield	0.075
Beaver	0.075
Lewiston	0.074
Salina	0.073
Nephi Dry-farm Substation	0.070
Castledale	0.067
Stockton	0.065
Coalville	0.062
Henefer	0.060
Wanship	0.060
Hill Top	0.058
Fairview	0.057
Elberta	0.057
Morgan	0.054
Grantsville	0.054
Kamas	0.052
Heber City	0.052
Tooele	0.046
Vernon	0.046
Nephi	0.038
Payson	0.037

The extreme variation in these samples is 430 per cent. The variation among varieties was 70 per cent and the variation due to irrigation water was 68 per cent. The cause of this wide variation in the iron content of wheat is due first to water and second to soil. The average iron content for the wheat is 0.00695 per cent.

Table 42. Pounds of iron in 1000 pounds of oats grown in different sections of Utah

Locality	Lbs. Iron in 1000 Lbs. Oats
Ferron	0.215
Wanship	0.162
Nephi Dry-farm Substation	0.114
Beaver	0.108
Koosharem	0.082
Ephraim	0.082
Kamas	0.079
Nephi	0.075
Heber City	0.074
Coalville	0.072
Vernon	0.070
Spanish Fork	0.068
Grantsville	0.068
Morgan	0.064
Elberta	0.064
Santaquin	0.057
Lewiston	0.050
Payson	0.041
Tooele	0.041

There is over five times the iron in the oats from Greenville and Ferron over what there is in the Tooele samples. Consequently, there is a wide variation in the iron content of oats raised in different localities. The maximum iron content found in any of the samples of oats analyzed was 0.0215 per cent; the minimum 0.0041 per cent; and the average for all of the samples analyzed, 0.0099 per cent. Animals feeding on oats with a low iron content would require nearly four times the quantity of oats to meet the body requirements of iron over animals fed on a grain with the highest iron content.

The iron content of barley from different sections of Utah is given in Table 43.

Table 43. Pounds of iron in 1000 pounds of barley grown in different sections of Utah

Locality	Lbs. Iron in 1000 Lbs. Barley
Kamas	0.134
Vernal	0.124
Grantsville	0.087
Lewiston	0.083
Nephi Dry-farm Substation	0.078
Wanship	0.073
Fairview	0.070
Spanish Fork	0.064
Henefer	0.057
Heber	0.055
Morgan	0.051
Nephi	0.048
Hill Top	0.047
St. John	0.045
Coalville	0.044

There is a variation of over 200 per cent in the iron content of the lowest and highest. The average iron content of the barley from the different sections is 0.098 per cent. This is lower than the average iron content of the oats which is 0.099 per cent, but is practically the same as the wheat.

SUMMARY

The application of irrigation water to growing wheat, oats, barley, and corn increased the ash content of the grain 46, 31, 36, and 8 per cent respectively. Manure increased the ash content of the corn kernel 6 per cent.

There was a difference of 31 per cent in the ash content of different varieties of wheat grown on the Nephi Dry-farm Substation.

A variation in the ash content of grains from different localities in the state was found to be as follows: Wheat, 118 per cent; barley, 78 per cent; and oats, 185 per cent.

The average ash content of the wheat, barley, and oats analyzed was 1.85, 3.00, and 4.05 per cent, respectively.

Irrigation-grown wheat, barley, oats, and corn contain 157, 40, 22 and 38 per cent more calcium than corresponding non-irrigated grain.

The extreme difference in the calcium content of different varieties of wheat grown on the Nephi Dry-farm Substation was 100 per cent. Wheat, oats, and barley grown in different localities of Utah showed an extreme variation of their calcium content of wheat of approximately 950 per cent; oats, 800 per cent, and barley, 365 per cent.

Wheat showed an increase in magnesium of 32 per cent, oats 65 per cent, barley 9 per cent, and corn zero per cent, due to the use of irrigation water. The extreme variation in the magnesium content of grains from various sections of Utah was for wheat, 212 per cent; oats, 99 per cent; and barley, 86 per cent. The average magnesium content of the different grains tested was found to be: Corn, 0.203 per cent; wheat, 0.184 per cent; oats, 0.181 per cent; and barley, 0.180 per cent.

The increase in the potassium content of grains due to irrigation water was: Wheat, 35 per cent; oats, 31 per cent; barley, 40 per cent; and corn, 11 per cent. The variation in potassium content due to variety amounted to 53 per cent.

The potassium content of grains grown in Utah is high in comparison with other reported analyses. There is a great variation in the potassium content of grains due to irrigation water, soil, variety, and kind of grain. The average potassium content of the different grains was found to be: Wheat, 476 per cent; oats, 570 per cent; barley, 561; and corn, 394 per cent.

Grains grown with irrigation water registered the following gains in phosphorus over similarly grown dry-farm grains; Wheat, 55 per cent; oats, 35 per cent; barley, 30 per cent. This increase is mainly in inorganic form.

The percentages of the total phosphorus of the irrigation-grown grains occurring in the inorganic form were found to be: Wheat, 5-6.3 per cent; oats, 8.8-12.9; barley, 6.3-9.4; and corn, 12.2-15.6 per cent. Apparently manure increases the inorganic phosphorus of the corn kernel.

Irrigation water, soil, and variety all influence the phosphorus content of grains.

The sulfur content of wheat, oats, and barley analyzed varies with the soil on which they are grown and the quantity of water applied during the growing season. The sulfur content of wheat also varies with the variety. The average sulfur content of wheat, oats, and barley grown in Utah was: Wheat, 0.204 per cent; oats, 0.190 per cent, and barley 0.155 per cent.

The iron content of wheat, oats, and barley varies greatly, depending upon the locality, variety, and irrigation water applied during the growing season.

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