ABSTRACT

OF THESIS

THE EFFECT OF CERTAIN ELEMENTS ON THE SKIN CHARACTERISTICS AND YIELD OF THE RED McCLURE POTATO

submitted by

Walter C. Sparks

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The production of the Red McClure (Dark Red Perfect Peachblow) potato (_Solanum tuberosum_ L.) is limited to the San Luis Valley of Colorado, and the fading or loss of the dark red skin color of some of the tubers of this variety, while of minor importance to the potato industry as a whole, constitutes a major problem in those sections of the valley where it occurs. The Agricultural Marketing Service and the Annual Report of the American Refrigerator Transit Company have both stated that the San Luis Valley Red McClure has experience a loss of skin color, and due to this loss of skin color, has experienced a decrease in market demand.

This light red skin color of some of the Red McClure potatoes is due to two causes: (a) Genetic differences:--Some of the normally light red potatoes of the variety Peachblow which is genetically different from the Red McClure, are still used for planting. (b) Environmental:--Due to causes other than genetic

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the Red McClure variety loses its dark red skin color and becomes light red in color. It is recognized that environmental factors such as temperature, irrigation, maturity, and fertility may affect the development of color on the underground portion of some plants. However, since preliminary tests in 1941 at the San Luis Valley Demonstration Farm near Center, Colorado, indicated that small amounts of copper, iron, zinc, and manganese increased the red pigmentation of the skin, while boron, mercury, and sodium decreased the redness of the skin; this investigation only deals with the former group of elements and their effect on the skin color, skin thickness, and yield of the Red McClure potato.

A review of the literature shows that in high lime soils, iron and manganese may sometimes be the limiting factors for the normal development of the plant. and since the soils of the San Luis Valley do have a high lime content, a high pH, and a high salt concentration, it appears possible that an insufficiency or a lack of availability of these elements might be the cause for the loss of color on the tubers even though the vines do not show the symptoms of a deficiency.

The plants grown in the field were subjected to different environmental conditions from those grown in nutrient culture in the greenhouse. There was a difference in pH between the two, with the soil in the field having an average pH of approximately 8.5, while that of the nutrient solution ranged between pH 6.8 and 7.2. Differences in salt concentration were also present; that of the soil was often 2000 p.p.m. or more, while that of the nutrient solution was approximately 700 p.p.m. of soluble nutrient salts. Also, the lime content of the field was usually above 250 p.p.m., whereas that of the greenhouse was kept at approximately 50 p.p.m.

Skin color and skin thickness measurements were made on tubers from the greenhouse and field trials, and yield data were taken from the field trials. Skin thickness measurements were made by use of a calibrated microscope. A method of measuring color was evolved wherein a portion of a tuber was compared with standard reproducible colors obtained by revolving together graduated amounts of Light Pinkish Cinnamon and Eugenia Red.

The results obtained in the greenhouse trials in nutrient culture were not identical with those obtained in the field, although certain similarities existed. Some elements reacted differently under greenhouse conditions than they did in the field.

Iron was the best single-element treatment for skin thickness in the greenhouse and second to the copper treatment in the field. The iron treatment produced tubers of a darker red color than any other single-element treatment in both the greenhouse and the field. The yield obtained by the iron plots was less than that of the check.

The copper-iron treatment was the best treatment for skin thickness containing 2 elements in the greenhouse, was second to the copper-manganese treatment in the field, and produced the darkest red tubers of any 2-element treatment in both the greenhouse and field tests. Copper-iron was highest in yield of any treatment containing 2 elements and second only to the copper-iron-manganese treatment.

Of the treatments containing 3 elements, the copper-iron-manganese treatment yielded tubers with the thickest skins in both the greenhouse and field and produced the darkest red tubers of any 3-element treatment in both the greenhouse and field. It also produced the highest yield of any treatment.

The treatment containing 4 elements gave variable results in both the greenhouse and field.

Zinc was present in all treatments in the greenhouse trials except one which yielded tubers with the thinnest skins. In the field, it was present in every treatment which yielded tubers with skins significantly thinner than the check tubers. Zinc alone gave the lowest yield of any treatment.

Boron alone produced tubers with skins significantly thicker than the tubers from the check. Sodium and boron singly reduced color, while sodium and boron together increased skin color over the check.

In the greenhouse 7 treatments produced tubers with significantly thicker skins than those from the check. Of these, 4 contained iron, 4 contained copper, 3 contained manganese, and 3 contained zinc. Copper and iron were together in 3 of these treatments. In the field, 8 treatments resulted in tubers with skins significantly thicker than those of the check. Of these, 5 contained iron, 4 contained copper, 4 contained manganese, and only one contained zinc. Copper and iron, copper and manganese, and iron and manganese were each in 2 of these treatments.

Only the iron treatment yielded tubers which were significantly darker than those from the check in the greenhouse, while in the field, tubers from all treatments were significantly darker.

Three treatments yielded significantly more than the check. These were: Copper-iron-manganese, copper-iron, and iron-zinc-manganese.

The copper-iron-manganese treatment was generally the best of any of the treatments tested. In the field this treatment produced the highest yield, the darkest red tubers which had significantly thicker skins than the check, although it ranked eighth in skin thickness. In the greenhouse this treatment produced tubers which were significantly thicker skinned and were darker red than the check, but not significantly so.

THESIS

THE EFFECT OF CERTAIN ELEMENTS
ON THE SKIN CHARACTERISTICS AND YIELD
OF THE RED McCLURE POTATO

Submitted by

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Walter C. Sparks

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THE EFFECT OF CERTAIN ELEMENTS ON THE SKIN CHARACTERISTICS AND YIELD OF THE RED McCLURE POTATO

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INTRODUCTION

The production of the Red McClure (Dark Red Perfect Peachblow) potato (<u>Solanum tuberosum</u> L.) is limited to the San Luis Valley of Colorado. The cultural practices used here are different from those of other districts of the Rocky Mountain region and probably are specific for this one area. The soil types vary from gravel and sandy loam to adobe and adobe-like aggregates, water is supplied mainly by subirrigation, the salt concentration in these soils is frequently 2000 parts per million or more, and the average pH is about 8.5 as determined by potentiometric measurements.

A fading or loss of the dark red skin color of some of the tubers of this variety, while of minor importance to the potato industry as a whole, constitutes a major problem in those sections of the valley where it occurs. The Agricultural Marketing Service (59)[/1] and the Annual Report of the American Refrigerator Transit Company (16) have both stated that the San Luis Valley

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/1 Numbers in parentheses refer to Literature Cited.

Red McClure has experienced a loss of skin color, and due to this loss of skin color, has experienced a decrease in market demand. During the 1941-42 season, the average increase in top price in favor of dark red skin color over light red skin color was 11 cents per 100 pounds on carlot rail shipments and 19 cents on truck shipments. The bottom price differences in favor of the dark red skin color were 13 cents per 100 pounds on carlot rail shipments and 16 cents on truck shipments. A total of 3018 carlots was shipped through February 28, 1942 (44), and of this number it has been estimated that 40 per cent were shipped as tubers with a light red skin color.

This light red skin color of some of the Red McClure potatoes is due to two causes: (a) Genetic differences:--Some of the normally light red potatoes of the variety Peachblow which is genetically different from the Red McClure, are still used for planting. (b) Environmental:--Due to causes other than genetic the Red McClure variety loses its dark red skin color and becomes light red in color. It is recognized that environmental factors such as temperature, irrigation, maturity, and fertility may affect the development of color on the underground portion of some plants (34). However, since preliminary tests in 1941 at the San Luis Valley Demonstration Farm near Center, Colorado, indicated that small amounts of copper, iron, zinc, and manganese increased the red pigmentation of the skin, while boron, mercury, and sodium decreased the redness of the skin (40); this investigation only deals with the former group of elements and their effect on the skin color, skin thickness, and yield of the Red McClure potato.

REVIEW OF LITERATURE

There are few published works which deal with the effect of various elements on the netting and appearance of potato skins, while several deal with the influence of elements upon the skin color of onions.

McLean and Sparks (40) pointed out that there is an apparent increase in the redness of the skin color of the Bliss Triumph and Red McClure varieties in the San Luis Valley of Colorado when certain minor elements were applied to the soil. Muckenhirn (46) found that copper, manganese, zinc, and sodium increased the quality, yield, and appearance of white skinned potatoes on peat soils in Wisconsin and sulfur gave an increased yield but lowered the quality. Harrington, Iverson, and Pollinger (26) in Montana found that phosphorus gave an improvement in type, heavier netting, quicker maturity, and less skin slipping on the Netted Gen potato.

Ellis (14) and Conner (12) in Indiana, Harmer (25) in Michigan, and Knott (31) in New York found that the addition of copper sulfate to acid muck soils resulted in a darker scale color on both yellow and red varieties of onions. Harmer (25) also pointed out that manganese sulfate added to the alkaline mucks in Michigan increased the color on onions, while Binkley and Lorenz (5) in Colorado obtained an increase in color on onions by the addition of phosphorus.

Numerous papers have been presented which deal with the effect of the elements tested herein on plant growth. A few of the more pertinent studies are reviewed in order of the elements considered. In the Third Annual Report of the Delaware Experiment Station (2) in 1890 it was stated that potato tubers from the copper-stained soils of New Jersey indicated forty pounds of metallic copper per one million pounds of skin and Delaware samples only sixteen pounds.

Loew and Sawa (33) in 1903 stated that the stimulating action of copper on fungi had been previously reported by Ono in 1900. Since then many writers have shown that copper is essential for normal growth of the higher plants. Felix (15) found that, in certain New York muck soils, certain types of unproductiveness could be corrected by applying 100 to 200 pounds of copper sulfate per acre. Allison, Bryan, and Hunter (1) have shown that plant growth can be stimulated by the use of copper in the peat soils of the Everglades of Florida. Lipman and MacKinney (32) showed that barley plants were unable to produce seed in the absence of small quantities of copper. Sommer (57) has pointed out that sunflowers, tomatoes, and flax responded to additions of small amounts of copper. Brenchley (8) found copper less toxic to beans than either cobalt or nickel.

Miller (42) stated that plants deprived of iron do not produce chlorophyll, a fact that was first noted by Gris in 1844. That the amount needed by the plant at any one time is very small has been shown by Gile (21) who estimated the amount of available iron in the nutrient solution in which he grew normal healthy rice plants to be always less than one part per 10 million parts of solution. Gines (24) found that the six iron salts used in his experiments appeared capable of supplying iron to young rice plants. That iron within a plant is not mobile was shown by Gile and Carrero (22). Finch, Albert, and Kinnison (17) in Arizona pointed out that chlorotic plants which responded to treatment with iron sometimes actually contained more iron before treatment than did the untreated, green healthy ones. The problem to them appeared to be one of maintaining available iron within the plant. Gile (21), and Gile and Carrero (23), Perold (49, p. 435), Wann (62), and Wilson (63) have pointed out that the presence of considerable lime in the soil causes the iron present to be unavailable to plants.

That the light red skin color on potato tubers might be due to an insufficiency, or unavailability, of iron is suggested when the fact is considered that the soils of the San Luis Valley are high in lime and have a high pH reading.

Aso (3) in 1903 showed that manganese sulfate added in a dilution of one part in 5000 parts to culture solutions exerted a stimulant action upon radish, barley, wheat, and pea. Loew and Sawa (33), also in 1903, stated that the stimulating effect of absorbed manganese was exhibited in an unmistakable manner. Their tables showed that the effect of manganese plus iron was greater than that of iron alone on rice plants, that a stimulating action was produced by manganese on the development of the pea plant, and that a favorable influence was evident on cabbage. Allison, Bryan, and Hunter (1) and Meyer (41) showed that plant growth was stimulated by manganese. Hopkins (29), McHargue (35,37,38,39), and

Samuel and Piper (52) pointed out that manganese is essential for the growth of certain plants and can not be replaced by any other element. Hoffman (28), Gilbert (18), Gilbert and McLean (19), and Gilbert, McLean, and Hardin (20) showed that manganese chlorosis may be closely associated with a high lime content of soils.

While the above workers have found that manganese is apparently stimulatory to plant growth, there are certain sections of the country where plants do not respond to manganese fertilization. Bird (6) found that potatoes on new lands on the Cumberland Plateau gave no response to the addition of manganese. Carlyle (9) found that only one of 21 Texas soils responded to manganese fertilization. He pointed out that upland soils usually contained adequate amounts of available manganese, and that clay loam and clay soils were considerably higher in manganese than sandy and sandy loam soils.

Mowry and Camp (45) stated that the stimulatory action of zinc was first shown by Raulin in 1869. It has been stated (33) that Richards in 1897 found that zinc salts exerted a stimulant action on fungi. Sommer (55,56) and Sommer and Lipman (58), have shown that zinc is essential for plant growth. Young (64) in a review of the rarer elements reported increases in yield of oats on certain soils when zinc was added. Chandler, Hoagland, and Hibbard (10); Finch, Albert, and Kinnison (17); Hoagland, Chandler, and Hibbard (27); and Mowry and Camp (45) found that certain diseases of trees could be corrected by applications of small amounts of zinc. Barnette, Camp, Warner, and Gall (4) were able to correct white bud of corn by applying small quantities of zinc sulfate to the row before planting. Van Schreven (61) found that potato plants were retarded when deprived of zinc, and that differences in height of plant, weight of foliage, and weight of tubers were significantly less. He stated, "Only in a single tuber of the series without zinc a slight affection was locally found in skin and cortex."

Silberberg (53) pointed out that weak solutions of zinc sulfate had a stimulating effect, but that stronger solutions inhibited the respiration of storage tissue of potatoes. Morgan (43), and Bird (6) obtained no significant benefit from zinc, while Brenchley (7) found that zinc sulfate in high concentrations was very toxic to barley and peas, and that no evidence of stimulation had been obtained with any strength of the poison down to a lower limit of 1/200,000,000. Conner (11) found that water-soluble zinc salts caused a crop failure, also, that soil tests showed toxic amounts of zinc in insufficiently limed soils, but not in soils where sufficient lime had been used.

In 1903 Nakamura (47) reported that borax added to the soil at the rate of 1 mg. per kilogram stimulated the growth of peas. Dennis and O'Brien (13) in their review of the literature and work on boron, state, "Boron is of universal occurrence in living organisms, and flowering plants cannot attain their full development in the absence of traces of that element." Johnston (30) in 1928 was apparently the first to give a description of symptoms attributable to boron deficiency on potatoes grown in water culture, and he pointed out the minute quantity of boron that is required, stating that in his first two experimental series the plants remained healthy without intentional supplies of boron, and only when the same glass jars were used for a third series did symptoms of deficiency develop. Numerous diseases of many crops in the United States have been shown to be due to a deficiency of boron. These include diseases of apples, alfalfa, beets, broccoli, cabbage, carrots, cauliflower, celery, citrus, corn, cotton, eggplant, legumes, lettuce, mangels, narcissus, pears, potatoes, prunes, radishes, rutabagas, strawberries, sugarbeets, tobacco, tomatoes, tung trees, and turnips. Purvis and Hanna (50) pointed out that the potato was one of the crops which shows a boron deficiency in the United States. Neller and Morse (48) obtained a definite increase in yields with light applications of borax to potatoes. Skinner, Brown, and Reid (54) also obtained yield increases by fertilizing with small amounts of borax.

That high lime soils may cause a boron deficiency is discussed by Dennis and O'Brien (13) who state in their summary, "The boron content of soils varies, but its effect on plant growth is masked by secondary factors which control the availability of boron to plants. The most important of these factors are the lime and water contents of the soil."

According to Miller (42, p. 298) the elements needed by plants subserve 2 main functions: (a) Some of them are component parts of the cell structure. The amount of these required is relatively large and any deficiency is soon noticed in the general growth of the plant. (b) Others apparently act as carriers, catalyzers, or antidoting agents. The amount required of these elements is very small.

Several roles have been assigned to the elements discussed above. McHargue (36) has assigned the role of a catalyst to manganese and believes it to be connected with the formation of chlorophyll. Other workers maintain that it acts as an oxidizing agent in the soil solution, destroying toxic organic materials.

Thatcher (60) has proposed a classification of elements according to their functions in plant nutrition. He places them in eight groups as follows: group I--hydrogen and oxygen--energy-exchange elements; group II--carbon, nitrogen, sulphur, and phosphorus--energy storers; group III--sodium, potassium, calcium, and magnesium--translocation regulators; group IV--manganese, iron (cobalt and nickel), copper and zinc--oxidation-reduction regulators. The other elements were placed into four other groups, but their function in the plant was not suggested.

MATERIALS AND METHODS

Seed source

Since the potato is asexually propagated, genetic differences should be of little consequence. However, to eliminate somatic variations, the seed pieces used throughout this investigation were all taken from a single tuber line.

Culture

In the greenhouse

The seed pieces were sprouted in sterilized sphagnum moss. Only the mose vigorous sprouts were selected for planting in washed white quartz in waterproof boxes.

The basic nutrient solution was made from C.P. grade chemicals and had a concentration of 200 p.p.m. nitrate, 100 p.p.m. phosphate, 300 p.p.m. potassium, 50 p.p.m. calcium, and 50 p.p.m. magnesium. The volume was kept constant by adding water daily. The solution was tested each week and the necessary additions were made. Copper, iron, zinc, manganese, boron, and sodium were added to the nutrient solution weekly after the fifth week. Since these elements were allowed to accumulate, they were added at the following low concentrations: 0.5 p.p.m. of Cu as $CuSO_4$, 2.5 p.p.m. of Fe as $Fe_2(SO_4)_3$, 0.5 p.p.m. of Zn as $ZnSO_4$, 1.5 p.p.m. of Mn as $MnSO_4$, 0.5 p.p.m. of B as H_3BO_4, and 10.0 p.p.m. of Na as Na_2SO_4.

The nutrient solution was held in large reservoir bottles and was forced into the boxes daily by means of air pressure, and after each feeding the solution was then allowed to drain back into the bottles.

Copper, iron, zinc, and manganese were thought to increase the skin color, and were considered separately and in all possible combinations in a factorial design. The basic nutrient solution which received no additional minor elements was used as the control. Boron and sodium were thought to remove color, and were considered separately, together, and together with the above copper-iron-zinc-manganese treatment. Each treatment consisted of 6 plants and the treatments were randomized to minimize the effect of position in the greenhouse.

At harvest a random sample of 10 tubers was taken from each treatment and was used for the measurements of color and skin thickness.

In the field

Copper, iron, zinc, and manganese were considered separately and in all possible combinations in a factorial design. The 16 treatments, which included the check, were repeated 5 times on single-row fifty-foot plots.

Technical grade chemicals were applied in the form of the sulfate of the element at the rate of 25 pounds per acre. The amounts of each element added per plot remained the same, regardless of whether it was added singly or in combination with other elements. Single element treatments received 25 pounds per acre, while those containing all elements received a total of 100 pounds per acre of minor elements, *e.g.*, 25 pounds of copper sulfate, 25 pounds of iron sulfate, 25 pounds of zinc sulfate, and 25 pounds of manganese sulfate. The elements were applied at planting time in bands 2 inches from the seed piece on either side of the row.

At harvest the tubers from each treatment in each replication were weighed and sorted for size. Samples were taken from the 1 7/8 inch to $2\frac{1}{4}$ inch size group from each of the 5 replications for each treatment and were consolidated to form one large sample. A random sample of 100 tubers was taken from the large sample for each treatment and was used in the measurements of color and skin thickness.

In determining tuber color

Tuber color was measured by comparing a portion of the tuber with a series of revolving disks (fig. 1) which contained graduated

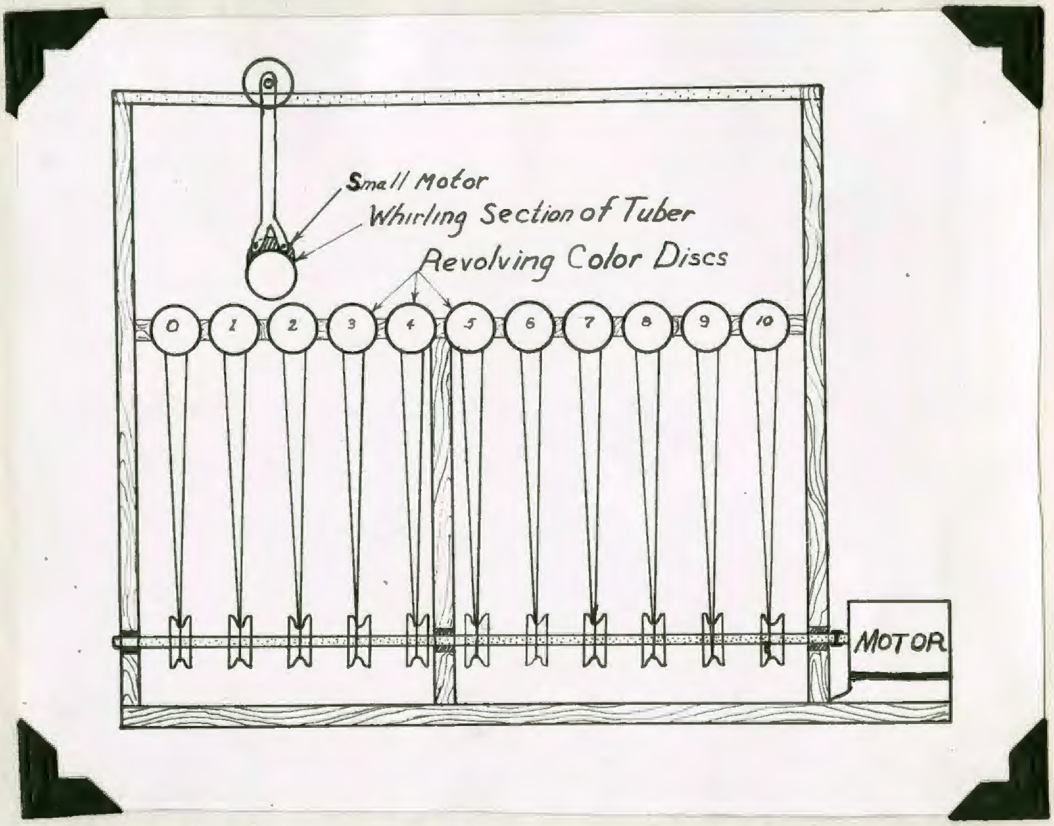

FIGURE 1.--Diagrammatic illustration of the method used in the determination of color. A section of each tuber was revolved by the small movable motor and compared with the revolving color discs. These discs ranged in color from:

Light Pinkish Cinnamon to Eugenia Red

Disk No. 0

Disk No. 10

proportions of Light Pinkish Cinnamon and Eugenia Red (51). The range of colors between these two extremes was obtained by revolving known amounts of these 2 colors which blended them into one solid color. The amounts of each color present varied from 0 to 100 per cent in increments of 10 per cent of each color as follows:

Disk No.	Light Pinkish Cinnamon	Eugenia Red
0	100%	0%
1	90%	10%
2	80%	20%
3	70%	30%
4	60%	40%
5	50%	50%
6	40%	60%
7	30%	70%
8	20%	80%
9	10%	90%
10	0%	100%

In determining the skin color of the tubers the number of the disk which most closely matched the skin color of the tuber was recorded. In all tables and discussion the skin color is given in terms of the disk numbers. All color readings were made in a dark room using a constant light source.[2]

Each treatment was carried under an index number throughout all measurements so that the tuber sample could be measured for color without personal bias.

In determining skin thickness

Skin thickness was recorded in thousandths of an inch. Measurements were taken of the skin from each tuber of each treatment.

/2 The light source was a Daybrite "Two-Forty" Fluorescent Industrial Fixture containing two 40 watt Mazda daylight fluorescent bulbs.

A cross-section of a portion of the tuber which was cut at a point approximately midway between the budeye cluster and the stem end was used for the above measurements. The measurements were made by the use of a calibrated microscope, and recorded in units of 1/1000 of an inch.

In analyzing data

The skin thickness and color data were analyzed by obtaining the means of independent samples. Fisher's *t* test for significance was then applied to determine significance between the means. The yield data were analyzed by the analysis of variance. The minimum significant difference was used in comparing the treatment means.

RESULTS

Skin color

In order to determine which portion of the tuber to use in the color determinations, 15 tubers from each of 7 different treatments were selected at random and color measurements were made on the stem and bud end from each tuber. The stem end of these 105 tubers had a mean skin color of 5.962 and the corresponding bud end, 5.924. The value of *t* was calculated to be 0.2732, while the value of *t* required for significance at 19:1 odds was 1.983. From this it appeared that no significant difference existed between the two ends of the tuber.

In the greenhouse

The mean skin color of the check and the treatments containing copper, iron, zinc, and manganese singly, and in all combinations are compared by the values of t in Table I. The treatment containing only iron produced tubers with the darkest red skin color and it was the only treatment in which the skins were significantly darker. Iron was also contained in each combination of two or more elements which yielded darker red tubers than those of the check. Furthermore, 4 of the 5 treatments that produced tubers with the darkest red skins and 5 of the 8 treatments which produced a higher mean skin color than the check, contained iron. Two iron treatments yielded tubers which had skins equal in color to those of the check, while only one treatment containing iron yielded tubers lighter in skin color than the tubers of the check treatment.

Copper alone produced darker red tubers than did the check. Four treatments containing copper produced tubers darker red than those of the check, and the mean skin color of the tubers from one treatment containing copper was equal in color to that of the tubers from the check. Three treatments containing copper resulted in tubers lighter red than those of the check.

Zinc alone produced tubers which were darker in color than those from any treatment except iron. Only 3 treatments containing zinc yielded tubers which were darker red than those of the check; tubers from two treatments had a skin color equal to those of the check, while from 3 treatments a lighter skin color was observed.

Treatment with manganese resulted in tubers darker red than the tubers from the check. Of the tubers from the 8 treatments containing manganese, those from 3 were darker red than those of the check, while those from one were equal in color to those from the check, and 4 were lighter.

TABLE I. Effect of 4 Elements on the Skin Color of Red McClure Potatoes in Nutrient Culture as Shown by t[1] Values.

Treatment	Zn-Cu	Zn Mn-Cu	Mn-Fe	Zn-Mn	Mn-Cu	Zn Mn-Fe	Zn Cu-Fe	Check	Cu	Zn-Mn Cu-Fe	Mn	Zn-Fe	Mn Cu-Fe	Cu-Fe	Zn	Fe
Mean Color	5.7	5.7	5.8	5.8	5.8	5.9	5.9	5.9	6.0	6.1	6.1	6.3	6.4	6.4	6.5	6.9
Standard Deviation	2.94	2.94	3.38	3.33	2.94	3.63	3.44	3.38	2.93	3.44	2.93	3.44	3.44	2.93	2.93	3.25
Rank	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

Values of t

Zn-Cu	–	0.000	0.300	0.302	0.323	0.574	0.593	0.599	0.970	1.186	1.293	1.779	2.075	2.263	2.586	3.674
Zn-Mn-Cu		–	0.300	0.302	0.323	0.574	0.593	0.599	0.970	1.186	1.293	1.779	2.075	2.263	2.586	3.674
Mn-Fe			–	0.000	0.000	0.271	0.278	0.281	0.600	0.835	0.900	1.391	1.669	1.800	2.100	3.147
Zn-Mn				–	0.000	0.272	0.280	0.283	0.605	0.841	0.908	1.402	1.682	1.815	2.118	3.172
Mn-Cu					–	0.287	0.296	0.300	0.647	0.889	0.970	1.482	1.779	1.940	2.263	3.378
Zn-Mn-Fe						–	0.000	0.000	0.288	0.537	0.576	1.073	1.342	1.439	1.727	2.754
Zn-Cu-Fe							–	0.000	0.297	0.552	0.594	1.103	1.379	1.485	1.781	2.835
Check								–	0.300	0.556	0.600	1.113	1.391	1.500	1.800	2.861
Cu									–	0.297	0.324	0.891	1.188	1.295	1.619	2.676
Zn-Mn-Fe-Cu										–	0.000	0.552	0.827	0.891	1.188	2.268
Mn											–	0.594	0.891	0.971	1.296	2.378
Fe-Zn												–	0.276	0.297	0.594	1.701
Cu-Fe-Mn													–	0.000	0.297	1.417
Cu-Fe														–	0.324	1.487
Zn															–	1.188
Fe																–

1. For significance between treatments at odds of 19:1 and 99:1 tabular t values must exceed 2.101 and 2.878 respectively (18 degrees of freedom).

Copper and iron together yielded tubers which were darker than those from any other treatment containing 2 or more elements, and all treatments containing copper and iron produced tubers with skins equal to or darker than those from the check. Of the 4 combination/3 treatments which produced tubers which were darker red than those from the check, 3 of them contained copper and iron, and all of them contained iron. All combination treatments containing iron and zinc had tubers with skins equal to or darker than those of the check. Of the 4 combination treatments containing iron and manganese 2 of them produced tubers darker red than those from the check, one produced tubers equal in redness to those of the check, and one produced tubers lighter red than those of the check. Two of the treatments containing copper and manganese produced tubers darker red than those of the check, and the other 2 treatments produced tubers lighter red. The treatment containing copper and zinc produced the lightest red tubers. Two combinations of copper and zinc ranked below the check, one was equal in color and one produced tubers darker red. Three of the 4 treatments containing zinc and manganese produced tubers either equal to or lighter than those of the check, while only one produced tubers darker red in color.

Of the 4 treatments containing 3 elements, the copper-iron-manganese treatment was the only one that produced tubers with skins darker red than those from the check, the copper-iron-zinc and the iron-manganese-zinc treatments produced tubers with a mean skin color equal to that of the check, and the copper-manganese-zinc treatment produced tubers with skins lighter in color than those of the check.

/3 A combination treatment refers to any treatment containing 2 or more elements as contrasted to single-element treatments.

The treatment containing all four elements in combination produced tubers which were slightly darker red than those tubers from the check.

The mean skin color, rank, and values of t of the tubers from the sodium and boron trials are shown in Table II. The sodium and the boron treatments alone produced tubers lighter in color than the tubers from the check, while the skins of the tubers from the sodium-boron treatment were significantly darker red than those of the check tubers. The treatment combining boron and sodium with copper, iron, zinc, and manganese produced tubers with skins darker than those from the check, but this increase in color was not significant.

All single element treatments except sodium and boron produced tubers with skins darker red than those from the check, but iron was the only one that produced tubers with skins significantly darker red in nutrient culture in the greenhouse. The sodium and the boron treatments produced tubers with a mean skin color equal to that of the tubers from the copper-zinc and the copper-zinc-manganese treatments. The sodium-boron treatment did not produce tubers as dark red as did the iron treatment, but they were darker than those of any other treatment. Three treatments containing copper and iron produced darker tubers than the check. Both treatments containing copper, iron, and manganese produced tubers with a darker red skin color than those from the check.

In the field

Since trials in nutrient culture in the greenhouse resulted in differences in skin color on Red McClure potatoes, these treatments were further tested under natural conditions of environment in the

TABLE II. The Effect of Certain Elements on the Skin Color of Red McClure Potatoes in Nutrient Culture as Shown by t/1 Values.

Treatment	Na	B	Check	Na-B Zn-Mn Cu-Fe	Na-B
Mean Color	5.7	5.7	5.9	6.25	6.7
Standard Deviation	3.38	2.94	3.38	3.38	2.78
Rank	5	4	3	2	1
	Values of t				
Na	-	0.000	0.561	1.381	3.064
B		-	0.599	1.473	3.316
Check			-	0.879	2.451
Na-B-Zn-Mn-Cu-Fe				-	1.234
Na-B					-

/1 For significance between treatments at odds of 19:1 and 99:1 values of t must exceed 2.101 and 2.878 respectively (18 degrees of freedom).

field. All treatments tested in the field trials yielded tubers with skins that were significantly darker red than those from the check as shown in Table III. Treatment with copper alone produced significantly darker red tubers than did treatment with manganese alone, zinc alone, or the check. All combination treatments that contained copper produced tubers which had skins significantly darker red than those from treatments not containing copper with the exception of the zinc-manganese and the iron-zinc treatments. The 5 treatments which produced the darkest red skins all contained copper, and the skin color of the tubers from these 5 treatments was significantly darker than that of the tubers from any of the other treatments.

Iron alone produced tubers with skins significantly darker red than those from the check, from any other single element treatment, and from the iron-manganese and the iron-zinc-manganese treatments. Four of the 5 best treatments for adding color contained iron.

The application of zinc alone yielded tubers which were lighter red in color than those from any other treatment except the check, but 5 of the 7 treatments that produced the best colored tubers contained zinc.

Manganese added alone produced tubers which were darker red than those from the zinc treatment, but this difference was not significant. Four of the 6 best treatments for adding color contained manganese.

Of the treatments containing 2 elements, the iron-manganese treatment was the only one that yielded tubers lighter in color than any single-element treatment, while the copper-iron treatment

TABLE III. Effect of 4 Elements on the Skin Color of Red McClure Potatoes in the San Luis Valley as Shown by t[/1] Values.

Treatment	Check	Zn	Mn	Cu	Zn Fe-Mn	Fe-Mn	Fe	Zn-Fe	Cu-Mn	Zn-Cu	Zn-Mn	Zn-Mn Cu-Fe	Zn Cu-Mn	Cu-Fe	Zn Cu-Fe	Mn Cu-Fe
Mean Color	5.05	5.25	5.27	5.34	5.39	5.39	5.43	5.44	5.46	5.48	5.50	5.56	5.58	5.60	5.64	5.75
Standard Deviation	1.68	1.37	1.38	1.38	1.38	1.14	1.35	1.39	1.38	1.38	1.38	1.38	1.38	1.36	1.39	1.38
Rank	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
							Values of t									
Check	–	10.76	11.81	15.57	18.25	19.54	20.57	20.87	22.01	23.09	24.16	27.38	28.45	29.70	31.58	37.58
Zn		–	1.45	6.51	10.13	11.05	13.17	13.70	15.20	16.64	18.09	22.43	23.88	25.44	28.12	36.18
Mn			–	5.05	8.65	9.43	11.66	12.22	13.70	15.14	16.58	20.91	22.35	23.97	26.60	34.61
Cu				–	3.61	3.93	6.56	7.19	8.65	10.09	11.54	15.86	17.30	18.88	21.57	29.56
Zn-Fe-Mn					–	0.00	2.92	3.60	5.05	6.49	7.93	12.26	13.70	15.25	17.97	25.96
Fe-Mn						–	3.11	3.91	5.50	7.08	8.65	13.37	14.94	16.65	19.56	28.30
Fe							–	0.73	2.19	3.64	5.10	9.48	10.93	12.48	15.25	23.32
Zn-Fe								–	1.44	2.88	4.31	8.63	10.07	11.58	14.32	22.29
Cu-Mn									–	1.44	2.88	7.21	8.65	10.17	12.94	20.91
Zn-Cu										–	1.44	5.77	7.21	8.72	11.50	19.48
Zn-Mn											–	4.33	5.77	7.26	10.07	18.03
Zn-Mn-Cu-Fe												–	1.44	2.91	5.75	13.70
Zn-Mn-Cu													–	1.45	4.31	12.26
Cu-Fe														–	2.89	10.89
Zn-Cu-Fe															–	7.91
Mn-Cu-Fe																–

/1 For significance between treatments at odds of 19:1 and 99:1 values of t must exceed 1.972 and 2.601 respectively (198 degrees of freedom).

yielded tubers which were significantly darker in color than those from any other treatment containing 2 elements.

The treatment which yielded tubers with skins significantly darker red than those of all other treatments was the combination of copper-iron-manganese. Next in rank was the copper-iron-zinc treatment. Of the 5 treatments that yielded tubers significantly darker than those of all other treatments 4 of them contained 3 or more elements and all except one contained copper and iron. The iron-zinc-manganese treatment was the only treatment that contained three elements which had a relatively light red skin color. The tubers from the treatment containing 4 elements were not as good for color as those from the treatments containing 3 elements.

The tubers from the treatments containing only one element were better for color than the check, but not as good for color as those containing 2 elements, while treatments containing 3 elements were generally the best. The exceptions to the above were the tubers from the iron and the copper-iron treatments, which were better for color than the other treatments containing only one or 2 elements, respectively, and those from the iron-zinc-manganese treatment which were lighter in color than the other treatments containing 3 or more elements. Of the 5 treatments that produced the darkest red tubers, all contained copper, 4 contained iron, 3 contained manganese, 3 contained zinc, and 4 contained both copper and iron.

The iron treatment which produced tubers of a darker red color than any other treatment containing only one element in the field, also produced darker red tubers than any other single-element treatment in the greenhouse. The copper-iron treatment which produced tubers of a darker red color than any other treatment containing 2 elements in the field, also produced darker red tubers than any other treatment that contained 2 elements in the greenhouse. The same was true of the copper-iron-manganese treatment, which produced tubers of a darker red than any other treatment containing 3 elements in both the field and greenhouse trials.

Skin Thickness

In the greenhouse

Increasing the color of the tubers would be of no value if the tubers with a dark red color had such thin skins that ordinary handling practices caused them all to be more easily skinned. The ideal treatment would, then, increase the thickness of the skins as well as redness of color. Table IV presents the mean skin thickness, the rank, and the calculated values of *t* for comparing the mean skin thickness.

All 15 treatments containing copper, iron, zinc, and manganese produced tubers with skins which were thicker than those of the tubers from the check, but only 7 treatments yielded tubers with skins significantly thicker. Of these 7 treatments, the zinc, the manganese, and the iron treatments contained only one element; the copper-zinc and the copper-iron treatments contained 2 elements; the copper-iron-manganese treatment contained 3 elements; and the copper-iron-zinc-manganese treatment contained 4 elements. Iron was present in 4 of these treatments, copper in 4, zinc in 3,

TABLE IV. Effect of 4 Elements on the Skin Thickness of Red McClure Potatoes in Nutrient Culture as Shown by t [1] Values.

Treatment	Check	Zn Cu-Fe	Zn Cu-Mn	Zn-Fe	Cu-Mn	Zn-Mn	Zn Fe-Mn	Cu	Fe-Mn	Zn	Mn	Zn-Cu	Mn Cu-Fe	Cu-Fe	Zn-Mn Cu-Fe	Fe
Mean Skin Thickness	2.7	2.75	2.8	2.9	2.9	3.0	3.1	3.1	3.2	3.3	3.4	3.5	3.5	3.5	3.8	3.8
Standard Deviation	2.63	2.70	2.61	2.61	2.61	2.61	2.61	2.61	3.82	3.82	4.02	3.95	3.82	3.82	5.55	3.95
Rank	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
							Values of t									
Check	-	0.225	0.512	1.024	1.024	1.536	2.048	2.048	2.042	2.450	2.619	3.198	3.267	3.267	3.398	4.398
Zn-Cu-Fe		-	0.226	0.678	0.678	1.130	1.582	1.582	1.633	1.996	2.143	2.660	2.722	2.722	2.887	3.724
Zn-Cu-Mn			-	0.514	0.514	1.028	1.542	1.542	1.640	2.051	2.250	2.806	2.871	2.871	3.095	4.009
Zn-Fe				-	0.000	0.514	1.028	1.028	1.230	1.640	1.875	2.405	2.461	2.461	2.785	3.608
Cu-Mn					-	0.514	1.028	1.028	1.230	1.640	1.875	2.405	2.461	2.461	2.785	3.608
Zn-Mn						-	0.514	0.514	0.820	1.230	1.500	2.004	2.051	2.051	2.476	3.207
Zn-Mn-Fe							-	0.000	0.410	0.820	1.125	1.604	1.640	1.640	2.166	2.806
Cu								-	0.410	0.820	1.125	1.604	1.640	1.640	2.166	2.806
Fe-Mn									-	0.351	0.648	1.036	1.054	1.054	1.690	2.072
Zn										-	0.324	0.691	0.702	0.702	1.408	1.726
Mn											-	0.385	0.395	0.395	1.049	1.541
Zn-Cu												-	0.000	0.000	0.812	0.990
Mn-Cu-Fe													-	0.000	0.845	1.036
Cu-Fe														-	0.845	1.036
Zn-Mn-Cu-Fe															-	0.000
Fe																-

[1] For signifcance between treatments at odds of 19:1 and 99:1 the values of t must exceed 2.101 and 2.878 respectively (18 degrees of freedom).

manganese in 3, copper and iron together in 3, and iron and manganese together in 2.

The iron-zinc-manganese, the copper, and the iron-manganese treatments produced tubers with skins definitely thicker than the skins from the check tubers, but not significantly thicker. Iron was present in 2 of these treatments, manganese in 2 of them, copper in one, zinc in one, and iron and manganese in combination in 2 of them.

Of the remaining 5 treatments, none of which produced tubers with skins much thicker than the skins of the check tubers, 4 contained zinc, 3 contained manganese, 2 contained iron, and 2 contained copper. Not in one of these treatments was the iron and manganese combination present, while in only one treatment were copper and iron present in combination with each other.

The results from skin thickness measurements from the greenhouse trials in which sodium and boron were added to the nutrient solution are presented in Table V. The boron treatment was the only one which produced tubers with skins significantly thicker than the skins of the tubers from the check.

In all of the greenhouse trials, the treatment containing only one element which yielded tubers with the thickest skins was the iron treatment, the treatment containing 2 elements which yielded the thickest skinned tubers was the copper-iron treatment, and the treatment containing 3 elements which yielded tubers with the thickest skins was the copper-iron-manganese treatment. Each of these 3 treatments yielded tubers which had skins significantly thicker than the skins from the tubers of the check.

TABLE V. The Effect of Certain Elements on the Skin Thickness of Red McClure Potatoes in Nutrient Culture as Shown by t[1] Values.

Treatment	Check	Na-B Zn-Mn Cu-Fe	Na-B	Na	B
Mean Skin Thickness	2.7	2.75	2.8	3.1	3.3
Standard Deviation	2.63	2.70	2.61	3.82	2.61
Rank	5	4	3	2	1
	Values of t				
Check	-	0.225	0.512	1.633	3.073
Na-B-Zn-Mn-Cu-Fe		-	0.226	1.270	2.486
Na-B			-	1.230	2.570
Na				-	0.820
B					-

[1] For significance between treatments at odds of 19:1 and 99:1 values of t must exceed 2.101 and 2.878 respectively (18 degrees of freedom).

In the field

Table VI presents the mean skin thickness, the rank, and the calculated values of t which were obtained by comparing the mean skin thickness of each treatment with that of each other treatment of the field experiments.

Eight treatments resulted in tubers with skins whose mean skin thickness was significant over that of the check tubers. Of these 8 treatments, the copper, the iron, and the zinc treatments were single-element treatments; the copper-manganese, the copper-iron, the iron-manganese, and the iron-zinc treatments contained 2 elements; and the copper-iron-manganese treatment contained 3 elements. Five of these 8 treatments contained iron, 4 contained copper, 4 contained manganese, and only one contained zinc. Copper and iron in combination, copper and manganese in combination, and iron and manganese in combination were present in 2 of these treatments, but the iron and zinc combination was present in only one of the 8 treatments. The copper-iron-manganese treatment was the only one containing 3 elements which was included in the 8 highest treatments.

Five treatments yielded tubers with skins which were significantly thinner than the skins of the check tubers. All of these treatments contained zinc, and only 3 of them contained any copper, iron, or manganese. Present in this group were 3 of the 4 treatments containing 3 elements, the only treatment containing 4 elements, and the zinc treatment which was the only single-element treatment.

The 2 remaining treatments, zinc-copper and zinc-manganese, produced tubers which had skins which were neither significantly

TABLE VI. Effect of 4 Elements on the Skin Thickness of Red McClure Potatoes in the San Luis Valley as Shown by t[1] Values.

Treatment	Zn Cu-Fe	Zn-Mn Cu-Fe	Zn	Zn Mn-Fe	Zn Mn-Cu	Zn-Cu	Check	Zn-Mn	Mn Cu-Fe	Zn-Fe	Mn	Fe-Mn	Cu-Fe	Cu-Mn	Fe	Cu
Mean Skin Thickness	3.27	3.33	3.38	3.38	3.40	3.44	3.45	3.45	3.55	3.56	3.58	3.61	3.63	3.64	3.71	3.75
Standard Deviation	.725	.725	.932	.725	.725	.725	.879	.732	.941	.725	.725	.729	.729	.747	.725	.725
Rank	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
							Values of t									
Zn-Fe-Cu	–	8.23	13.11	15.09	17.83	23.32	18.43	24.59	33.18	39.78	42.52	46.51	49.25	50.00	60.36	65.84
Zn-Fe-Cu-Mn		–	5.96	6.86	9.60	15.09	12.28	16.39	26.07	31.55	34.29	38.30	41.04	41.89	52.13	57.61
Zn			–	0.00	2.38	7.15	6.37	8.41	18.07	21.45	23.84	27.68	30.08	30.62	39.33	44.10
Zn-Fe-Mn				–	2.74	8.23	7.17	9.56	20.14	24.69	27.43	31.46	34.20	35.14	45.27	50.75
Zn-Cu-Mn					–	5.49	5.12	6.83	17.77	21.95	24.69	28.73	31.46	32.43	42.52	48.01
Zn-Cu						–	1.02	1.37	13.03	16.46	19.20	23.36	25.99	27.03	37.04	42.52
Check							–	0.00	9.06	11.26	13.31	16.34	18.38	19.21	26.61	30.71
Zn-Mn								–	11.81	15.03	17.76	20.03	22.53	25.57	35.52	40.98
Cu-Fe-Mn									–	1.18	3.55	7.09	9.46	10.54	18.96	23.70
Zn-Fe										–	2.74	6.84	9.58	10.81	20.58	26.06
Mn											–	4.10	6.84	8.11	17.83	23.32
Fe-Mn												–	2.73	4.04	13.68	19.15
Cu-Fe													–	1.35	10.94	16.42
Cu-Mn														–	9.46	14.86
Fe															–	5.49
Cu																–

[1] For significance between treatments at odds of 19:1 and 99:1 the values of t must exceed 1.972 and 2.601 respectively (198 degrees of freedom).

thicker nor significantly thinner than those from the check tubers. Each treatment contained 2 elements and both contained zinc.

Zinc was present in all treatments, except for the copper-manganese treatment, that yielded tubers with the thinnest skins in the greenhouse, and in the field it was present in every treatment which yielded tubers with skins significantly thinner than the skins of the check tubers.

Iron was the best single-element treatment for skin thickness in the greenhouse and second to the copper treatment in the field. The copper-iron treatment was the best treatment for skin thickness containing 2 elements in the greenhouse, and was second in this group for skin thickness in the field, being exceeded by the copper-manganese treatment. The copper-iron-manganese treatment was the best treatment for skin thickness which contained 3 elements in the greenhouse and also in the field.

Yield

The ideal treatment would be one which would produce a large quantity of tubers which had dark red, thick skins. Due to the small number of plants grown in the greenhouse, yields were not recorded. Table VII presents the mean yield, the rank, and significance of the mean yield of any treatment over that of the check treatment in the field.

Only three treatments resulted in yields which were significant over the check. These three treatments were the copper-iron-manganese, the copper-iron, and the iron-zinc-manganese treatments. Two of these contained 3 elements and the other one contained

TABLE VII. Effect of 4 Elements on the Yield of Red McClure Potatoes in the San Luis Valley.

Treatment	Rank	Mean Yield pounds per plot /1
Cu-Fe-Mn	1	93.4
Cu-Fe	2	91.4
Fe-Zn-Mn	3	91.2
Mn	4	87.6
Cu-Zn-Mn	5	87.2
Cu-Fe-Zn-Mn	6	83.6
Cu	7	83.6
Cu-Zn	8	83.0
Cu-Mn	9	82.8
Cu-Fe-Zn	10	80.6
Check	11	78.8
Zn-Mn	12	75.8
Fe-Zn	13	73.8
Fe	14	72.0
Fe-Mn	15	71.2
Zn	16	69.2

/1 For significance between treatments at odds of 19:1 the yield differences must exceed 11.95 pounds per plot.

2 elements. All 3 of these treatments contained iron, 2 contained copper, 2 contained manganese, and only one contained zinc.

All other treatments resulted in yields which were not significant from the check, but 7 of these yielded more than the check and 5 yielded less. No treatment containing copper yielded less than the check, only 2 treatments containing manganese yielded less than the check, and three containing zinc and 3 containing iron yielded less than the check. The zinc treatment, which resulted in the lightest yield, and the iron treatment were the only single-element treatments yielding less than the check, while the iron-manganese, the iron-zinc, and the zinc-manganese treatments were the only ones containing 2 or more elements which yielded less than the check.

Of the 7 treatments which yielded more than the check, but not significantly more, the copper and the manganese treatments contained only one element, the copper-manganese and the copper-zinc treatments contained 2 elements, the copper-iron-zinc and the copper-zinc manganese treatments contained 3 elements, and the copper-iron-zinc-manganese treatment contained 4 elements. Copper was present in 6 of these treatments, manganese in 4, zinc in 4, and iron in 2.

Only the copper-iron-manganese, the copper-iron, and the iron-zinc-manganese treatments yielded significantly more than the check, but no treatment yielded significantly less than the check. The zinc treatment yielded the least of any treatment. Copper was not present in any treatment that yielded less than the check.

DISCUSSION

The literature previously reviewed (18), (19), (20), (21), (23), (28), (49), (62), and (63) shows that in high lime soils, iron and manganese may sometimes be the limiting factors for the normal development of the plant, and since the soils of the San Luis Valley do have a high lime content, a high pH, and a high salt concentration, it appears possible that an insufficiency or a lack of availability of these elements might be the cause for the loss of color on the tubers even though the vines do not show the symptoms of a deficiency.

The plants grown in the field were subjected to different environmental conditions from those grown in nutrient culture in the greenhouse. There was a difference in pH between the two, with the soil in the field having an average pH of approximately 8.5, while that of the nutrient solution ranged between pH 6.8 and 7.2. Differences in salt concentration were also present; that of the soil was often 2000 p.p.m. or more, while that of the nutrient solution was approximately 700 p.p.m. of soluble nutrient salts. Also, the lime content of the field was usually above 250 p.p.m., whereas that of the greenhouse was kept at approximately 50 p.p.m.

The tubers produced in the greenhouse when iron was added had the thickest skins and darkest red color. All the treatments containing only one element, except the sodium and the boron treatments, produced tubers which were darker red and had thicker skins than the check, and, in general, these tubers were darker red and had as thick skins as those from the treatments containing two or more elements. In the field the single-element treatments other than the zinc treatment appeared to produce tubers with thicker skins, but of a lighter red color than the treatments containing more than one element. The action of single elements on the yield was varied, as was that of 2 elements, with the manganese and the copper treatments yielding more than the check, and the zinc and iron treatments yielding less.

The treatmmnts containing two elements in general produced tubers lighter in color and less in yield, but with thicker skins than the treatments containing three or more elements. The treatments containing 3 or more elements in general produced the best yields, the tubers with the thinnest skins, and the tubers with the darkest red color. The reason these treatments produced tubers with thin skins is probably due to the fact that all of them except the copper-iron-manganese treatment contained zinc which appears to cause tubers to be thin skinned. The copper-iron-manganese treatment which was the only treatment containing 3 or more elements that did not contain zinc, produced a higher yield, tubers with a darker color than any other treatment, and even though the skins of these tubers were not the thickest, they were significantly thicker than those of the check.

Some of the treatments such as zinc, produced results very different from those produced by other treatments such as copper and iron, but these differences between elements in the field can not be attributed to the concentration of the elements applied because the copper-iron treatment which has only 2 elements ranked third in color, fourth in skin thickness, and second in yield, while the copper-iron-zinc treatment which contained both of these elements, ranked second in color, sixteenth in skin thickness, and tenth in yield. At the same time the copper-iron-manganese treatment which also contained copper and iron, ranked first in color, eighth in skin thickness, and first in yield, and the copper-iron-zinc-manganese treatment ranked fifth in color, fifteenth in skin thickness, and sixth in yield.

Some of the treatments produced results in the field similar to those produced under entirely different conditions in the greenhouse, and of these, the copper-iron and the copper-iron-manganese are the best. These two treatments produced tubers in the greenhouse which had a dark red color with thick skins, and in the field produced the highest yields and the tubers were of a dark red color with thick skins. The iron treatment produced tubers with thick skins in both the greenhouse and field and produced tubers of a dark red color in the greenhouse, but they ranked tenth in color in the field. With the exception of a few treatments, those containing zinc produced tubers with thin skins and of a light color in both the greenhouse and field trials. Every treatment containing zinc in the field produced tubers with skins thinner than those from the check, and in the greenhouse 5 of the 6 treatments which produced tubers with the thinnest skins contained zinc.

The treatments which yielded the tubers with the darkest red color also seemed to be the ones that produced tubers with the thickest skins, but a correlation coefficient calculated from the data found this assumption to be non-significant, i.e., the correlation coefficient was calculated to be 0.47206, with a value of *t* equal to 1.579, but the value of *t* required for significance at 19:1 odds was 2.145. The treatments which seemed to defy this correlation were the treatments containing zinc which produced tubers with good color, but with thin skins.

Since the copper-iron and the copper-iron-manganese combinations produced the highest yields and at the same time the darkest red tubers which also had thick skins, it appears probable that these treatments mixed with a complete fertilizer might have a definite place in the fertilizer program for the San Luis Valley.

SUMMARY

Color and appearance are important considerations in the marketing of Red McClure potatoes. Preliminary trials in the field indicated that copper, iron, zinc, and manganese increased the red color of the skins of the Red McClure. These four elements were tested in the field and in nutrient culture in the greenhouse. In addition, boron and sodium, two elements suspected of reducing the color, were tested in the greenhouse.

Skin color and skin thickness measurements were made on tubers from the greenhouse and field trials, and yield data were taken from the field trials. Skin thickness measurements were made by use of

a calibrated microscope. A method of measuring color was evolved wherein a portion of a tuber was compared with standard reproducible colors obtained by revolving together graduated amounts of Light Pinkish Cinnamon and Eugenia Red.

The results obtained in the greenhouse trials in nutrient culture were not identical with those obtained in the field, although certain similarities existed. Some elements reacted differently under greenhouse conditions than they did in the field.

Iron was the best single-element treatment for skin thickness in the greenhouse and second to the copper treatment in the field. The iron treatment produced tubers of a darker red color than any other single-element treatment in both the greenhouse and the field. The yield obtained by the iron plots was less than that of the check.

The copper-iron treatment was the best treatment for skin thickness containing 2 elements in the greenhouse, was second to the copper-manganese treatment in the field, and produced the darkest red tubers of any 2-element treatment in both the greenhouse and field tests. Copper-iron was highest in yield of any treatment containing 2 elements and second only to the copper-iron-manganese treatment.

Of the treatments containing 3 elements, the copper-iron-manganese treatment yielded tubers with the thickest skins in both the greenhouse and field and produced the darkest red tubers of any 3-element treatment in both the greenhouse and field. It also produced the highest yield of any treatment.

The treatment containing 4 elements gave variable results in both the greenhouse and field.

Zinc was present in all treatments in the greenhouse trials except one which yielded tubers with the thinnest skins. In the field, it was present in every treatment which yielded tubers with skins significantly thinner than the check tubers. Zinc alone gave the lowest yield of any treatment.

Boron alone produced tubers with skins significantly thicker than the tubers from the check. Sodium and boron singly reduced color, while sodium and boron together increased skin color over the check.

In the greenhouse 7 treatments produced tubers with significantly thicker skins than those from the check. Of these, 4 contained iron, 4 contained copper, 3 contained manganese, and 3 contained zinc. Copper and iron were together in 3 of these treatments. In the field, 8 treatments resulted in tubers with skins significantly thicker than those of the check. Of these, 5 contained iron, 4 contained copper, 4 contained manganese, and only one contained zinc. Copper and iron, copper and manganese, and iron and manganese were each in 2 of these treatments.

Only the iron treatment yielded tubers which were significantly darker than those from the check in the greenhouse, while in the field, tubers from all treatments were significantly darker.

Three treatments yielded significantly more than the check. These were: Copper-iron-manganese, copper-iron, and iron-zinc-manganese.

The copper-iron-manganese treatment was generally the best of any of the treatments tested. In the field this treatment produced the highest yield, the darkest red tubers which had significantly thicker skins than the check, although it ranked eighth in skin thickness. In the greenhouse this treatment produced tubers which were significantly thicker skinned and were darker red than the check, but not significantly so.

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