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Experiments were established on a Warden soil on Lower Klamath Lake area to evaluate the effect of Mn and Cu, and Band applications of ammonium sulfate on the uptake of micronutrients and response from Mn and Cu applied for the production of small grain crops.

Band application of ammonium sulfate gave higher barley yields and Mn concentrations in barley leaves than broadcast application or zero nitrogen treatments. Since an application of N as anhydrous ammonia had been applied on all plots, it was assumed that the major difference between the band and preplant broadcast application of ammonium sulfate was to increase uptake of Mn.

Concentrations of Mn, Cu, Zn, Ca, Mg, K and P present in leaf tissue were measured for barley, oats, wheat, and triticale at seedling, tillering, boot, and flowering stages of growth. Band application of ammonium sulfate increased Mn concentrations of barley leaves

an average of 2.89, 2.02, 2.28, and 2.02 ppm, in comparison with broadcast application of ammonium sulfate, at seedling, tillering, boot, and flowering stages of growth, respectively. Mn and Cu applications did not effect Mn concentrations found in the leaves. The levels of Mn in leaf material of these crops decreased as the crops matured. For example average Mn concentration of the barley leaves was 15.7, 13.9, 10.4, and 9.0 ppm at seedling, tillering, boot, and flowering stages of growth respectively.

Concentrations of other nutrients were not significantly affected by the fertilizer treatments applied.

Concentrations of all nutrients measured changed as the crops matured. Cu concentrations increased throughout the season; Cu concentrations of barley leaves averaged 5.3 and 9.9 ppm at seedling and flowering stages of growth, respectively. Concentrations of Zn and P increased until the tillering stage of growth, then decreased. Zn concentrations of barley leaves were 31, 36, and 27 ppm, and P concentrations were 0.32, 0.49, and 0.29 percent at seedling, tillering, and flowering stages of growth, respectively. Ca decreased until the tillering, and Mg decreased until the boot stages of growth, then both nutrients increased. Ca concentrations of barley leaves were 0.31, 0.29, 0.49, and 0.75 percent, and Mg concentrations were 0.33, 0.31, 0.26, and 0.31 percent at seedling, tillering, boot, and flowering stages of growth, respectively. K levels decreased until

the boot stage of growth, then remained more or less the same. K concentration of barley leaves decreased from 6.1 percent at seedling stage to 2.2 percent at boot stage. The same general trend for changes in nutrient concentrations were present for wheat, oats, triticale, and barley.

Barley and triticale were more efficient in taking up Mn from these soils than oats and wheat; Mn concentrations of the plant leaves were 19.5, 17.0, 14.4 and 13.3 ppm at the seedling stage of growth for triticale, barley, oats, and wheat, respectively. Cu concentrations of oats were lower than those of the other species. At seedling stage of growth, Cu contents of leaves were 5.4, 4.3, 5.5 and 5.3 ppm for barley, oats, wheat, and triticale, respectively. At flowering stage of growth, however, wheat leaves had the lowest Cu level with 6.7 ppm, and barley, oats, and triticale leaves had 9.8, 7.7, and 9.0 ppm Cu, respectively.

Differences in Zn and Mg concentrations among species were variable with stage of growth. Barley and triticale generally had higher Ca concentrations in their leaf material. There were no real differences in K and P contents among species.

Effect of N, Mn, and Cu Treatments on Nutrient Uptake by Barley, Oats, Wheat, and Triticale

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INTRODUCTION

Manganese, copper and zinc deficiencies on cereal crops produced on the peat and muck soils of lower Klamath Lake were recognized by Halvorsen about 1951.[1] These micronutrients have been applied for the production of cereal crops on these soils since that time. However, recent exploratory experiments and plant analysis results have indicated[2] that manganese and copper deficiencies might be a problem in the production of cereal crops on many soils in this area.

Following the identification of these problems, experiments were established on a Warden soil series on the Lower Klamath Lake area to evaluate the response of barley (Hordeum vulgare L.), oats (Avena sativa L.), wheat (Triticum vulgare L.) and triticale to applications of manganese and copper, and the effect of band application of ammonium sulfate on uptake of micronutrients.

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[1] Klamath Experiment Station reports.

[2] Personal communication with E. A. Tross and T. L. Jackson.

LITERATURE REVIEW

Manganese in Soils

The total Mn content of most soils is in the range of 200 to 3000 ppm (Swaine, 1955). Total Mn includes water-soluble, exchangeable Mn^{++}, and easily reducible manganic oxides which are available to plants, plus other unavailable forms.

For satisfactory crop production, at least 3 ppm exchangeable and 100 ppm easily reducible Mn must be present in soils (Sherman and Harmer, 1943). Cereals growing on mineral soils containing less than 1 ppm exchangeable Mn showed deficiency symptoms (Coppenet and Voix, 1951). Total dissolved Mn is generally less than 1 ppm and a large part of this (84-99%) may be present in complexes (Geering, Hodgson and Sdano, 1969).

Factors Affecting Manganese Nutrition of Plants

Soil Factors

Soil pH. There is a dynamic equilibrium among the various forms of Mn in soils and the state of this equilibrium is largely dependent on soil pH. Soils with pH values lower than 5.5 may contain a large part of their Mn in water-soluble or exchangeable form. With increasing pH,

Mn is converted to manganic oxides, and its availability will decrease (Mulder and Gerretsen, 1952).

The substrate pH also affects the rate of Mn absorption by plant roots. Manganese uptake of barley has been found to increase with increasing pH up to 6, and uptake was sharply reduced below pH 4 in nutrient solution experiments (Maas, et al., 1968). Optimum Mn uptake by barley was reported to take place between pH values 6 and 7 by Olsen (1934). Mulder and Gerretsen (1952) attributed the increased uptake of Mn at decreasing hydrogen ion concentrations to the enhanced affinity of Mn for the root surface as a result of increased Ca/H ratio on the root surface exchange complex.

Liming a granitic soil from pH 4.5 to 7.5 produced a considerable decrease in Mn concentration of oats, barley and winter wheat (Crooke and Knight, 1971). Similarly, an increase in pH from 4.5 to 6.5 decreased exchangeable Mn by a factor of 20 to 50 (Christensen et al., 1950).

Microbial Activity. The fact that soil organisms could oxidize Mn was first observed by Beijerinck (1913). It was shown that the rhizosphere of a variety of oats highly susceptible to Mn deficiency contained 5 to 13 times as many oxidizing bacteria as the rhizosphere of a resistant variety (Timonin, 1946). Fumigation treatments decreased the amount of bacteria, and the oat growth was increased.

Microorganisms appear to be able to oxidize Mn^{++} at pH values above 5.5 (Mulder and Gerretsen, 1952), while chemical oxidation of Mn^{++} in the test tubes takes place at pH values above 8 (Sohngen, 1914).

Certain microorganisms can reduce manganic oxides to manganous salts (Sohngen, 1914). Whether manganous salts will be converted to manganic oxides or the reverse reaction will take place largely depends on the pH of the medium.

Organic Matter. Addition of organic matter to soils is known to decrease the amount of water-soluble Mn, but this probably is not a result of oxidation. Heintze (1957) reported that higher oxides of Mn do not commonly occur in organic soils. It was shown by Kozakiewicz (unpublished data, Michigan State University, as reported by Brown et al., 1972) that extraction of Mn from organic soils can be accomplished more effectively by using $CuSO_4$ and $NH_4C_2H_3O_2$ than by the latter alone. This shows that a considerable portion of the Mn was organically bound and not precipitated.

It is also possible that under certain conditions addition of easily decomposable organic matter can increase the amount of exchangeable Mn (Hurwitz, 1948). It was explained by the author that rapid breakdown of organic matter resulted in O_2 depletion and hence reduction of manganic oxides.

Effects of Aeration. Mulder and Gerretsen (1952) observed that flooding temporarily corrected Mn deficiency. It was also found

that availability of soil Mn increased as the water table approached the soil surface (Lal and Taylor, 1970). These studies show that as drainage becomes impeded and the oxidation potential is lowered, oxides of Mn can be reduced to available forms.

Seasonal Changes. Water-soluble Mn is generally higher during the summer than the winter months in areas with low winter rainfall (McCool, 1934; Dorph-Petersen, 1950). Recently, Takkar (1969) showed that water soluble and exchangeable Mn levels increased considerably with increasing temperature in presence of organic matter.

On the other hand, the presence of a rising water table and the resulting reducing conditions increases solubility of Mn in winter months in areas with high winter rainfall (Sherman and Harmer, 1942).

Fertilizer Salts. Fertilizer salt treatments were reported to increase the level of extractable soil Mn. Westermann et al., (1971) found that K salts increased extractable soil Mn in the order of KBr > KCl>KNO_3>K_2SO_4. Soil acidity changes were the main reason for the treatment effects when KNO_3 or K_2SO_4 was applied. But KBr and KCl did not cause a significant change in soil pH and yet they increased the extractable Mn. The authors explained this effect on the basis of certain oxidation reduction reactions in which halide ions play a functional role.

Similarly, NaCl (York et al., 1954) and $CaCl_2$ (Foy, 1964) were found to increase the Mn uptake by oats.

Plant Factors

Plants differ in their susceptibility to Mn deficiency. Munns et al. (1963) found that six oat varieties contained widely different amounts of Mn when grown in similar nutrient solutions. This might be due to differential requirements or differential capacities to utilize soil Mn.

Some organic compounds in the root exudates of plants can promote microbial activity in the rhizosphere (Rovira, 1962), resulting in oxidation of manganese. A manganese-sensitive oat variety was shown to have a larger amount of manganese oxidizing bacteria in the rhizosphere than less sensitive varieties (Timonin, 1946). This might be due to differences in composition of root exudates. Bromfield (1958) found that plant roots release substances that can readily dissolve MnO_2, but oats were less able to use MnO_2 as a manganese source than was vetch.

Munns et al. (1963) also found that shoots of different oat varieties were affected equally by Mn concentration, temperature, and changes in soil acidity, but roots were affected quite differently. They separated the portion of manganese in the roots that was replaceable by cation exchange into labile and nonlabile fraction.

Labile fraction was the source for Mn movement to shoots. The labile fraction was affected by changes in temperature and acidity in the same manner for each variety as was the Mn content of shoots. On the other hand, Ouellette and Desseraux (1958) attributed the differential tolerances of alfalfa clones to Mn toxicity to their differential capacity to translocate Mn to shoots. They also found that Ca restricted Mn translocation to shoots and that differences between tolerances were associated with differential Ca-absorption capacities of the clones.

Plants may differ in the degree to which a given ion may interfere with the uptake of another ion. Lohnis (1960) found that the depressing effect of Mg on Mn uptake was quite different from plant to plant. Also, adding Ca decreased Mn accumulation in alfalfa but increased it in flax.

Interaction with Other Ions

1. Mg. Maas et al. (1969) reported that Mg decreased Mn absorption by barley roots. Hannay et al. (1959) found the same interaction for tomatoes. This may be due to competition between the two elements for reactive sites on enzymes (Hewitt, 1958) or to the mutual interference in uptake (Jackson, 1967).

2. Ca. In an experiment with barley roots Ca did not interfere with Mn absorption when applied alone, but when Ca and Mg were

both present, increasing Ca sharply reduced Mn absorption (Maas et al., 1969). On the other hand, Mn uptake by isolated tobacco leaf cells was shown to be inhibited by Ca alone (Kannan, 1969). Bowen (1969) reported that Mn uptake by sugarcane leaf tissue was greater in absence of Ca. According to the author, this might be due to the loss of integrity of the membrane, because of lack of Ca, and a subsequent large influx of Mn.

3. NO_3^- vs. NH_4^+. Oxidation of NH_4^+ ions to NO_3^- ions increases soil acidity by adding free H^+ ions to the medium; also, the solubility of soil manganese increases with decreasing soil pH. Accordingly, it was shown that application of $(NH_4)_2SO_4$ increased Mn uptake by oat plants (Hudig, 1911). However, Millikan (1950) reported that toxic effects of Mn on flax were not as pronounced when NH_4 instead of NO_3 form of N was used. This controversy can be explained by the direct and indirect effects of NH_4^+ ions on Mn uptake. The indirect effect is a decrease in soil pH due to nitrification of NH_4^+ ions and the direct effect is the inhibitory action of NH_4^+ ions on Mn uptake. Similarly, Vlamis and Williams (1962) showed in their experiments in which acidity was carefully controlled that NH_4^+ ions exerted a direct inhibitory effect on Mn uptake by barley.

4. P and K. Jackson et al. (1964) found that P enhanced Mn absorption by barley and wheat grown in solution. He also found that translocation of Mn, previously accumulated in the root tissue, to the

shoots was quite low in P deficient wheat but increased by resupplying P in the external solution.

Potassium reduced the uptake of Mn from nutrient solution by excised barley roots (Maas, 1967). On the other hand, Swanback (1939) reported that increasing K supply resulted in higher Mn concentration in both roots and shoots of tobacco.

Functions of Manganese in Plants

In an experiment with detached oat leaves, Mn deficiency decreased photosynthesis per unit area under conditions where chlorophyll content was not much different in high and low Mn treatments (Gerretsen, 1949).

Manganese was also reported to increase the redox potential of oat leaves when the leaves were illuminated, but there was no effect of Mn upon redox potential in the dark (Gerretsen, 1950). McHargue (1926) found that sugar and starch contents of Mn deficient oat leaves were lower than those of healthy plants. Mulder and Gerretsen (1952) concluded this was a result of reduced photosynthesis.

Manganese also plays an important role in Hill reaction (Spencer and Possingham, 1960) and in O_2 evolution (Spencer and Possingham, 1961). The addition of Mn was found to increase the rate of H_2O_2 formation and it was concluded that Mn increased O_2 evolution and O_2 acted as an electron acceptor in formation of H_2O_2 (Haberman, 1960).

Manganese has an important role in some enzyme systems. Von Euler et al. (1939) found that isocitric dehydrogenase system did not work in the absence of Mn.

Activity of Mn is important in nitrogen metabolism of plants. An accumulation of nitrite was found on soybean roots when no manganese was added to the culture solution (Jones et al., 1949). Presence of large quantities of nitrates in the leaves of manganese deficient oat plants was also observed (Leeper, 1941).

Manganese Nutrition of Small Grains

Cereal species differ in their susceptibility to Mn deficiency. Loneragan et al. (1970, personal communication as referred to by Brown et al., 1972) found that rye and oats took up more Mn from soils and both were better adapted to low Mn soils than barley or wheat. However, on a soil containing 1 ppm extractable Mn, barley was found to be most effective in utilizing soil Mn, oats were the most susceptible to Mn deficiency, wheat was intermediate (Nyborg, 1970).

Under non-deficient conditions, concentrations of Mn in barley, oats and wheat were similar (Crooke and Knight, 1971).

The susceptibility of oats to Mn deficiency was attributed to low accumulation capacity (Lohnis, 1951). It also might be due to increased activity of oxidizing microorganisms in the rhizosphere.

Gerretsen (1937) succeeded in growing healthy oat plants in sterilized medium very low in available manganese. Values as low as 5 to 10 ppm were found in these plants. In another soil low in available Mn, oat leaves had 7 ppm Mn and showed pronounced deficiency symptoms (Nicholas, 1949). Samuel and Piper (1928) grew oat plants in pots and analyzed them when they were 11 weeks old. The plants showed deficiency symptoms and had less than 10 ppm Mn in the whole plant. Optimum range for Mn concentration in above ground parts of oats, wheat and barley at booting stage of growth was given as 25 to 100 ppm by Ward, Whitney and Westfall (1972). Leeper (1935) found 14 to 15 ppm Mn in the whole plant at the flowering stage to be the lowest value in healthy cereals.

Goodall (1949) reported no response from Mn when older leaf blades of wheat plants contained more than 34 ppm Mn at the beginning of shooting. Winter wheat having 20.3 and 22.5 ppm manganese in tops in early spring was reported to be Mn deficient (Coic and Coppenet, 1949). Nicholas (1949) reported that barley and wheat leaves showed deficiency symptoms when they contained 12 and 14 ppm manganese, respectively. The critical level was reported to be 15 ppm for the tops of wheat at the seedling stage of growth (Nicholas, 1949).

Rye was found to be healthy when containing only 10 to 11 ppm Mn in the whole plant (Samuel and Piper, 1929).

Plant Analysis of Cereal Crops as an Aid in Diagnosing Manganese Deficiency

Stage of Growth

Williams and Moore (1952) reported Mn concentration increased in various parts of oat plants throughout the growing season, but the rate of increase was much less after flowering. During grain filling Mn content continued to increase in the leaves but decreased in stems. These data were obtained with plants which had a continual source of Mn in the root environment. Similarly, Mn content of the tops of the oat plants were in the range of 5 to 57 ppm at flowering (Piper, 1931), and 6 to 111 ppm after flowering (Samuel and Piper, 1929). On the other hand, Schrenk (1955) reported that the Mn content of the whole wheat plants were 92 ppm on the average and decreased as plants approached maturity, these plants had an adequate supply of Mn throughout their growth.

In making comparisons among species, it is necessary to analyze specific plant parts at progressive stages of growth (Jackson, 1967). The differences between two species that affect their uptake of Mn may be overcome later in the season (Lee, 1960).

Small grains have been typically sampled at tillering (stage 3), boot (stage 10), or heading (stage 10. 3). Samples taken at the later stages of growth have the advantage of reflecting nutrient levels after

most of the growth has taken place. The majority of the nutrient uptake and growth usually proceeds most rapidly between tillering and heading (Ward et al., 1972).

Plant Part

Generally, more Mn is found in leaves than in stems and petioles (Millikan, 1950) with the Mn content in leaves being more stable (Bolle-Jones, 1955). Williams and Moore (1952) reported that, in oats, half of the total Mn was found in the laves. Similarly, Mn content in tops of deficient wheat plants were 15 ppm (Nicholas, 1949), while 4 to 10 ppm was found in deficient whole wheat plants by Gallagher and Walsh (1943).

When sampling cereal crops at tillering (stage 3) the entire above ground portion of the plant, which is essentially leaf tissue, is most commonly sampled. At heading (stage 10.3), either whole above ground parts or upper leaves are the most common parts taken. The entire above ground portion of the plant just as the head is emerging from the boot is recommended for wheat, oats and barley by Ward et al. (1972). However, Jones et al. (1971) recommended taking all leaf material at the seedling stage or the four uppermost leaves just before heading for the analysis of small grains.

Correction of Manganese Deficiency by Soil Application of Manganese Sulfate

Sjollema and Hudig (1909) found that application of 50 kg/ha of of Mn SO_4 corrected grey speck symptoms of oats which has since been identified as Mn deficiency.

Manganese sulfate was found to be more effective than all other Mn sources on experiments with onions (Shepherd et al., 1960), beans (Fitts, et al., 1967) and tomatoes (Fiskell and Mourkedes, 1955). Soil application of Mn SO_4 on alkaline soils gave poor control of Mn deficiency on oats (MacLahlan, 1941) and wheat (Younts and Patterson, 1964).

In general, amounts from 50 to 100 kg per hectare of $MnSO_4$ are being recommended, although on alkaline peat soils larger amounts may be required for good plant growth (Mulder and Gerretsen, 1952) with band application of Mn being superior to broadcast application. Randall and Schulte (1971) found that 5.6 kg/ha of banded Mn as $MnSO_4$ was approximately equivalent to 67.2 kg/ha of broadcast Mn.

Wain et al. (1943) found that Mn added to calcareous soils was converted to completely unavailable forms within 7 days. Addition of $MnSO_4$ together with $(NH_4)_2SO_4$ increased the solubility of Mn and produced healthy oat crops (Hudig, 1911). It was also found that Mn uptake of plants increased by combining banded $MnSO_4$ with NPK

fertilizers (Mederski et al., 1960). Hammes and Berger (1960) reported incorporation of $MnSO_4$ with an acid-fertilizer carrier was superior to a neutral-fertilizer carrier, when fertilizer $MnSO_4$ mixture was applied with a grain drill on oats. On the other hand, it was also reported that uptake of Mn by plants was related to the acidity of the entire soil rather than to the Mn dissolved by the acid solution diffusing from the fertilizer band (White et al., 1970).

MATERIALS AND METHODS

Experimental Area

The experiment was conducted on a Warden soil, an alkaline histosol with an organic matter content of 70-80 percent, located 3 miles north of the Warden Station in Klamath County. Spring barley has been produced most of the time since 1940 in this area. Soil test values for the experimental area before the experiment was planted are presented in Table 1.

Spring discing was used for general seedbed preparation. A broadcast application of superphosphate and potassium chloride to supply 40 and 90 lbs of P_2O_5 and K_2O per acre respectively was applied before discing. Eighty lbs of N per acre as anhydrous ammonia was injected after spring discing. The N and Mn treatments that were broadcast plus all Cu treatments were incorporated into the soil by rototilling and subsequent packing. Banded N and Mn were applied with the double-disc opener of the grain drill at planting time.

A seeding depth of 1.5 to 2 inches and a seeding rate of 70 to 80 lbs of seed per acre was used for all species. The area was irrigated by flooding during the winter followed by subirrigation in the summer. Broad leaf weeds were controlled with a spray application of 2, 4-D.

Table 1. Soil test values* for the experimental area.

pH	Nutrients					Na	Salts
	Mn	Cu	Zn	P	K		
	ppm					meg/ 100 gm	mmhos/ cm
8.5	7.9	2.3	5.6	27	553	4.7	1.12

*As measured by Ore. State University Soil Analyses Laboratory

Table 2. The fertilizer treatments used for barley, oats, wheat, and triticale.

Plant species	Treatment no.	Treatments				
		N (banded)	N (br)	Mn (banded)	Mn (br)	Cu*
		lb/A				
Barley	1	30	--	--	--	10
	2	30	--	5	--	10
	3	30	--	10	--	10
	4	30	--	10	--	--
	5	30	--	10	--	5
	6	30	--	20	--	10
	7	--	30	5	--	10
	8	--	30	10	--	10
	9	--	30	--	5	10
	10	--	30	--	10	10
	11	--	30	--	--	10
	12	--	--	--	10	10
Oats	1	30	--	--	--	10
	2	30	--	5	--	10
	3	30	--	10	--	10
	4	30	--	10	--	--
Wheat	1	30	--	--	--	10
	2	30	--	5	--	10
	3	30	--	10	--	10
	4	30	--	10	--	--
Triticale	1	30	--	--	--	10
	2	30	--	5	--	10
	3	30	--	10	--	10
	4	30	--	10	--	--

*Cu treatments were broadcast.

Plot Design

Experimental layout was a randomized complete block design. The plot area for each crop was divided into five replications with the treatments randomized within each replication. Twelve treatments were applied on barley and four treatments on oats, wheat and triticale. Each treatment plot was 30 ft. long and 5 ft. wide with individual rows seven inches apart.

Treatments

Ammonium sulfate treatments at 30 lbs. N per acre were banded with the seed or broadcast before rototilling. Manganese sulfate was banded on both the broadcast and banded ammonium sulfate treatments, and broadcast with the broadcast ammonium sulfate treatments. This combination of broadcast and banded N and Mn treatments made it possible to evaluate the effects of a banded acidifying ammonium sulfate treatment on the uptake of micronutrients by barley in a situation where N was not limiting. Manganese rates of 5, 10, and 20 lbs. Mn per acre and Cu rates of 5 and 10 lbs. per acre were applied.

Nitrogen and manganese treatments were banded on wheat, oats, and triticale. Table 2 shows the combination of treatments established for the four species.

Sampling

Plant samples were taken from each species to evaluate 1) the seasonal changes in concentrations of Mn, Cu, Zn, Ca, Mg, K and P, 2) the effects of fertilizer treatments on changes in nutrient composition, and 3) the relationship between nutrient composition and response from fertilizers.

The first samples were taken when the plants were in an early seedling stage of growth, the above ground plant parts were sampled; the second sample was taken at the tillering stage and was limited to leaf material. The third and fourth samples were taken at the boot and flowering stages of growth with flag leaves being sampled.

Analytical Procedure

Plant samples were oven dried at 70°C for approximately 48 hours and ground through a stainless-steel Wiley mill. One gm of each sample was weighed and digested by HNO_3-$HClO_4$ technique. A Perkin-Elmer model 306 atomic absorption spectrometer was used to analyze the samples for Mn, Cu, Zn, Ca, Mg and K, and instrument parameters established by the Perkin-Elmer corporation were followed. The Vanadate-molybdate colorimetric method (Jackson, 1958) was used to measure P.

Statistical Analysis

Results from each treatment were tested for significance at the 1 and 5 percent levels using F tests and LSD values in the analysis of variance (Steel and Torrie, 1960). LSD values were calculated for individual treatment comparisons and subsets of treatments when two or three treatment means could be combined.

RESULTS AND DISCUSSIONS

Barley Experiment

The plant nutrient concentrations at the seedling, tillering, boot and flowering stages of growth and the plant yield data for the barley experiment are presented in Tables 3 through 6.

Plant Yield

The yield was increased an average of 290 lbs/A from the band application vs. broadcast application of ammonium sulfate. While the maximum yield increase of 410 lbs/A was obtained at the Mn_{10} level, there were no significant yield difference associated with the different rates of Mn applied or methods of Mn application.

The broadcast application of N did not significantly affect yields when these treatments were compared with the zero N treatment having comparable levels of Cu and Mn. This was anticipated since 80 lbs of N/A had been applied over the plot area before final seedbed preparation.

Manganese Concentrations

Banding ammonium sulfate increased the Mn concentration of barley an average of 2.9, 2.0, 2.2 and 2.0 ppm at the seedling, tillering, boot and flowering stages of growth, respectively. These

Table 3. The effect of N, Mn and Cu treatments on the grain yield and nutrient concentrations of barley leaves at the seedling stage of growth.

Treatments			Grain yield	Nutrient concentrations						
N	Mn	Cu		Mn	Cu	Zn	Ca	Mg	K	P
lb/A				ppm			%			
30	0	10	3320	17.7	5.1	31	0.29	0.31	6.3	0.28
30	5	10	3300	16.6	5.5	32	0.33	0.34	5.5	0.29
30	10	10	3480	17.0	5.6	27	0.31	0.32	5.5	0.31
30	10	0	3420	16.8	5.3	29	0.34	0.33	6.0	0.33
30	10	5	3290	18.4	5.8	29	0.37	0.32	5.2	0.33
30	20	10	3300	19.1	5.3	30	0.35	0.33	6.2	0.29
30_{br}*	5	10	3100	13.8	5.3	32	0.30	0.32	6.0	0.31
30_{br}	10	10	3070	13.6	5.3	31	0.29	0.31	5.8	0.32
30_{br}	5_{br}	10	3070	12.6	4.8	30	0.31	0.31	5.9	0.30
30_{br}	10_{br}	10	2960	13.7	5.6	36	0.30	0.36	6.4	0.34
30_{br}	0	10	3060	15.2	5.1	29	0.32	0.33	6.4	0.32
0	10_{br}	10	2880	13.8	5.6	35	0.28	0.32	6.0	0.36

*br: broadcast

Table 4. The effect of N, Mn and Cu treatments on the nutrient concentrations of barley leaves at the tillering stage of growth.

Treatments			Nutrient concentrations					
N	Mn	Cu	Mn	Zn	Ca	Mg	K	P
lb/A			ppm		%			
30	0	10	14.6	38	0.27	0.29	4.2	0.52
30	5	10	15.0	39	0.30	0.30	4.3	0.49
30	10	10	14.9	34	0.29	0.30	4.8	0.49
30	10	0	14.5	37	0.30	0.30	4.4	0.49
30	10	5	14.1	32	0.26	0.29	4.6	0.49
30	20	10	15.9	35	0.23	0.31	4.5	0.44
30_{br}*	5	10	12.6	40	0.30	0.33	4.6	0.50
30_{br}	10	10	13.2	38	0.32	0.33	5.6	0.49
30_{br}	5_{br}	10	13.4	36	0.31	0.31	4.9	0.50
30_{br}	10_{br}	10	12.8	39	0.31	0.34	5.8	0.50
30_{br}	0	10	12.7	32	0.29	0.31	5.0	0.49
0	10_{br}	10	12.9	33	0.28	0.31	5.4	0.53

*br: broadcast

Table 5. The effect of N, Mn and Cu treatments on the nutrient concentrations of barley leaves at the boot stage of growth.

Treatments			Nutrient concentration						
N	Mn	Cu	Mn	Cu	Zn	Ca	Mg	K	P
	lb/A			ppm			%		
30	0	10	11.7	9.0	34	0.49	0.26	2.1	0.39
30	5	10	12.2	8.6	33	0.52	0.28	2.2	0.38
30	10	10	11.0	8.0	33	0.60	0.27	2.0	0.43
30	10	0	11.1	7.7	32	0.46	0.25	2.0	0.36
30	10	5	10.8	8.6	35	0.50	0.27	2.0	0.38
30	20	10	11.9	8.7	36	0.56	0.29	2.0	0.35
30_{br}*	5	10	9.1	8.8	35	0.44	0.25	2.3	0.42
30_{br}	10	10	9.0	8.8	37	0.43	0.25	2.5	0.36
30_{br}	5_{br}	10	9.2	8.8	33	0.44	0.24	2.2	0.42
30_{br}	10_{br}	10	9.3	8.9	39	0.46	0.26	2.4	0.40
30_{br}	0	10	10.0	8.2	38	0.54	0.27	2.3	0.46
0	10_{br}	10	10.0	8.8	33	0.46	0.26	2.1	0.35

*br: broadcast

Table 6. The effect of N, Mn and Cu treatments on the nutrient concentrations of barley leaves at the flowering stage of growth.

Treatments			Nutrient concentrations						
N	Mn	Cu	Mn	Cu	Zn	Ca	Mg	K	P
	lb/A			ppm			%		
30	0	10	10.5	9.9	24	0.78	0.32	2.0	0.25
30	5	10	9.3	9.8	24	0.75	0.32	2.2	0.31
30	10	10	9.6	9.6	25	0.68	0.31	2.3	0.26
30	10	0	10.7	9.7	26	0.77	0.31	2.1	0.33
30	10	5	9.7	9.6	26	0.77	0.32	2.2	0.27
30	20	10	11.1	9.8	23	0.84	0.33	2.0	0.23
30_{br}*	5	10	7.9	9.1	32	0.73	0.32	2.4	0.33
30_{br}	10	10	7.4	9.6	30	0.71	0.28	2.7	0.33
30_{br}	5_{br}	10	7.6	10.4	32	0.73	0.29	2.5	0.31
30_{br}	10_{br}	10	7.4	10.1	28	0.72	0.30	2.5	0.30
30_{br}	0	10	8.0	10.4	26	0.74	0.29	2.4	0.30
0	10_{br}	10	8.9	10.5	29	0.73	0.31	2.5	0.30

*br: broadcast

increases in Mn concentration were significant for each stage of growth. This might be explained by the increased solubility of Mn associated with the acidifying effect of banded ammonium sulfate. Apparently, when ammonium sulfate is banded, the localized acidifying effect resulting from the oxidation of NH_4^+ ions and subsequent increase in H^+ ion concentration dissolves Mn near the band. When ammonium sulfate was broadcast, the increase in H^+ ions was not localized and thus was not effective in increasing the Mn solubility.

Broadcast application of ammonium sulfate tended to give a lower Mn concentration than the zero N treatment, but the difference was not significant except at the flowering stage of growth. This difference could have been due to some dilution effect or possibly an effect of the NH_4^+ ions involved.

The only treatment where application of Mn increased the Mn content of barley leaves was when 20 lbs. of Mn per acre was combined with banded ammonium sulfate and the samples were collected at flowering time. This single significant difference might be expected by chance. None of the Mn treatments increased the Mn content of plant samples when Mn was broadcast before planting.

Copper Concentrations

The application of N did not affect the Cu concentration of barley leaves. However, band application of Mn resulted in significantly

lower level of Cu at the flowering stage of growth than the broadcast application of Mn. Copper treatments had a tendency to increase the Cu concentration but these increases were not statistically significant.

Concentrations of Other Nutrients

The differences in plant levels of other nutrients among treatments were not statistically significant. However, banding ammonium sulfate tended to increase Zn and decrease Ca concentrations of barley leaves when no Mn was applied and vice versa when Mn was applied. When Mn was not applied, Ca content of the leaves at the boot stage of growth were 0.49 and 0.54 percent for the banded and broadcast N treatments, respectively. In presence of applied Mn, boot stage leaf Ca concentrations were increased from 0.44 percent for the broadcast N treatments to 0.56 percent for the banded N treatments. Zinc concentrations at the tillering stage of growth were 38 and 32 ppm when no Mn was applied, and 37 and 39 ppm when Mn was applied for the banded and broadcast N treatments, respectively. The band application of ammonium sulfate could increase the solubility of Zn. However, when Mn was added, the Mn applied could compete with the uptake of Zn. There was a trend toward decreasing K and P concentrations of barley at all stages of growth associated with the band application of ammonium sulfate; this could be a dilution effect due to yield increases from banding N.

Oats, Wheat and Triticale Experiments

The plant nutrient concentrations at the seedling, tillering, boot, and flowering stages of growth and the plant yield data for the oat, wheat, and triticale experiments are presented in Tables 7 and 10.

Plant Yield

Manganese and Cu treatments did not have a significant effect on yield for any of these three species. However, N was banded at planting on all of these comparisons.

Chemical Composition

There were no significant differences in Mn, Cu and other nutrient concentrations among treatments. However, Mn levels tended to decrease with application of Mn. There was a trend towards higher plant K levels with Mn application. These increases might be associated with lower yield and Mn concentrations.

Seasonal Changes in Nutrient Concentrations

Manganese

Manganese concentrations of all species decreased throughout the season (Figure 1). Treatments with band application of Mn and N averaged 17.0, 14.9, 11.0 and 9.6 ppm Mn for barley; 15.0, 12.2,

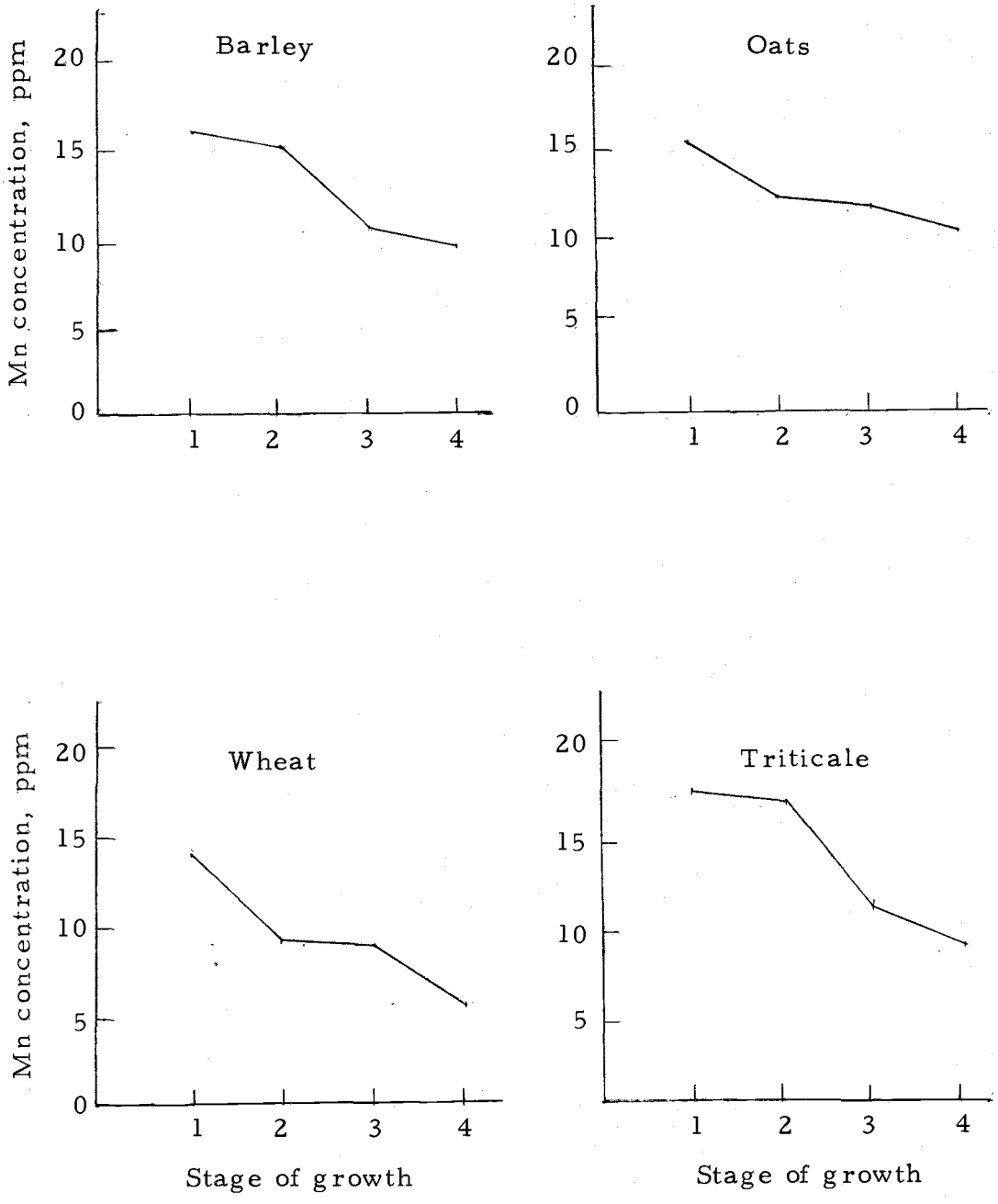

Figure 1. Changes in Mn concentrations of barley, oats, wheat and triticale leaf material from (1) seedling through (2) tillering, (3) boot and (4) flowering stage of growth.

11.5 and 9.6 ppm Mn for oats; 13.6, 9.4, 9.1 and 6.4 ppm Mn for wheat; and 17.4, 17.0, 11.2 and 8.9 ppm for triticale at the seedling, tillering, boot and flowering stages of growth, respectively.

In barley and triticale, the greatest decrease occurred between the tillering and the boot stages. But Mn concentration of oats and wheat sharply decreased between the seedling and the tillering stages.

Copper

In barley and oats, Cu concentrations increased from 5.6 to 9.6 ppm and from 3.6 to 7.2 ppm throughout the season, respectively. In wheat and triticale, however, plant Cu levels increased from 5.4 and 5.5 ppm for the seedling stage of growth to 8.0 and 8.3 ppm for the boot stage, respectively and then decreased or remained the same (Figure 2).

In barley and oats, the rate of increase in Cu levels was much less after the boot stage of growth.

Other Nutrients

Zinc concentrations were 27, 31 and 22 ppm for barley, oats and wheat, respectively, at the seedling stage of growth and increased until the tillering stage of growth, then decreased. In barley, the greatest decrease in Zn concentration occurred after the boot stage

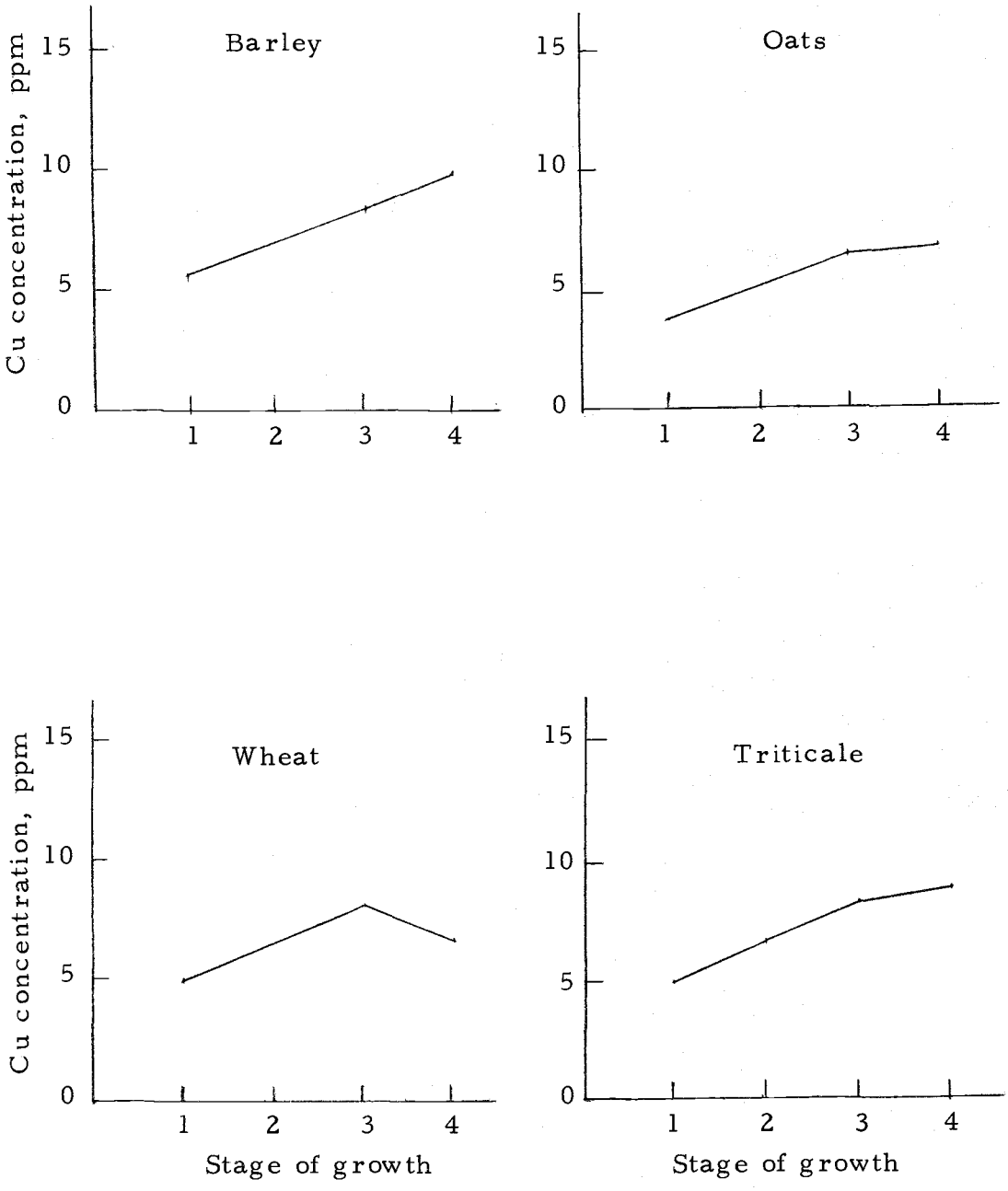

Figure 2. Changes in Cu concentrations of barley, oats, wheat and triticale leaf material from (1) seedling through (2) tillering, (3) boot and (4) flowering stages of growth.

of growth while in oats and wheat it occurred between the tillering and the boot stages (Figure 3).

Calcium concentrations started at 0.31, 0.27, 0.25 and 0.44 percent for barley, oats, wheat and triticale, respectively, for the seedling stage of growth and decreased until the tillering stage of growth, then increased (Figure 4). Magnesium concentrations were 0.32, 0.35, 0.34, and 0.32 percent for barley, oats, wheat and triticale, respectively, at the seedling stage of growth and decreased until the tillering stage (Figure 5). Phosphorus concentrations started at 0.31, 0.37, 0.39 and 0.33 percent for barley, oats, wheat and triticale, respectively, for the seedling stage of growth and increased until the tillering stage of growth, then decreased (Figure 6). Plant K levels decreased until the boot stage of growth, then remained more or less the same. The greatest decrease in K concentrations occurred between the tillering and the boot stages for all species (Figure 7).

Species Comparisons

Nutrient concentrations of the species at the four stages of growth are presented in Tables 7 through 10.

In making comparisons, the mean of the 4 treatments was taken for oats, wheat and triticale, and the mean of the first 4 treatments was taken for barley.

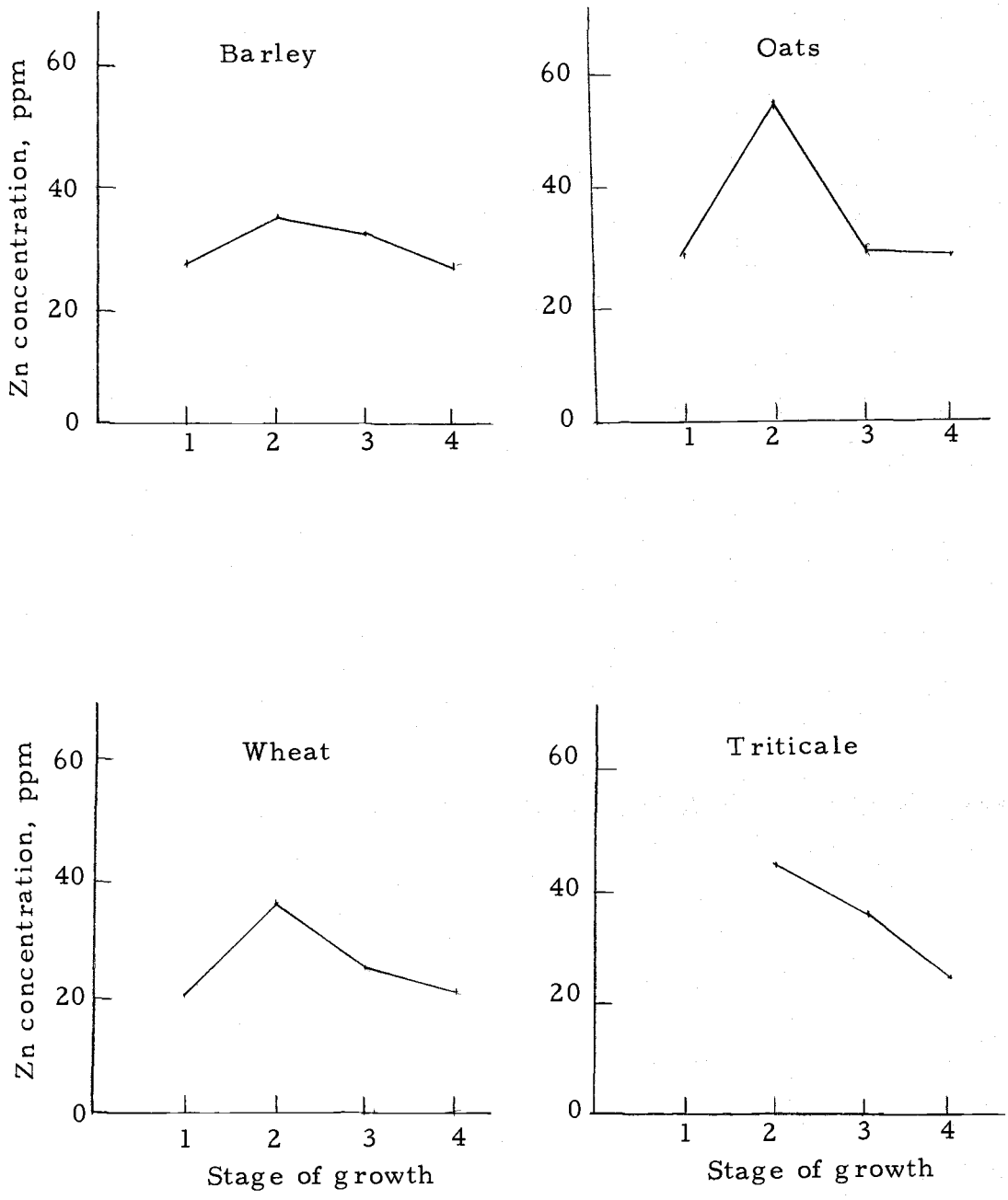

Figure 3. Changes in Zn concentrations of barley, oats, wheat and triticale leaf material from (1) seedling through (2) tillering, (3) boot and (4) flowering stage of growth.

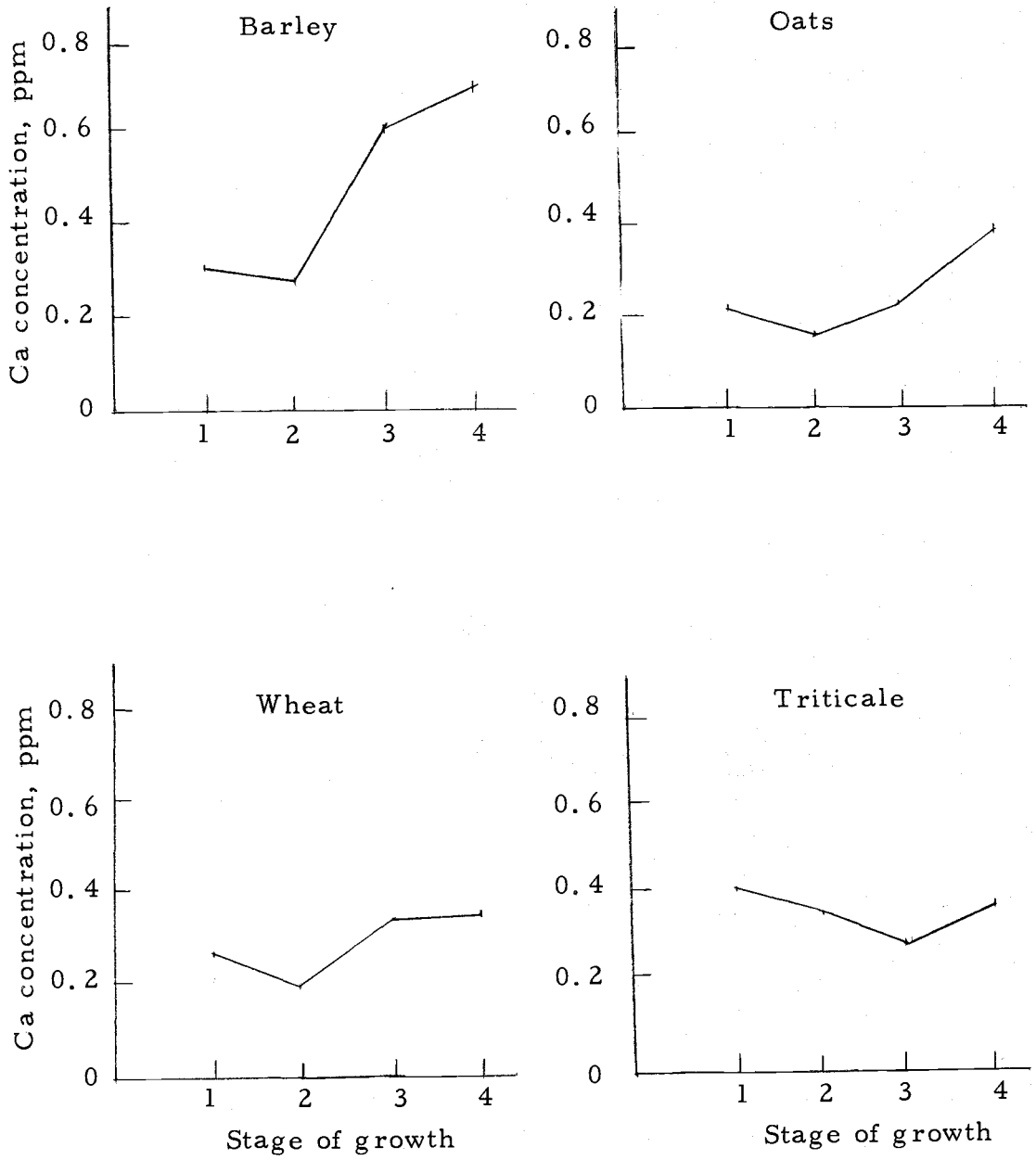

Figure 4. Changes in Ca concentrations of barley, oats, wheat and triticale leaf material from (1) seedling through (2) tillering, (3) boot and (4) flowering stage of growth.

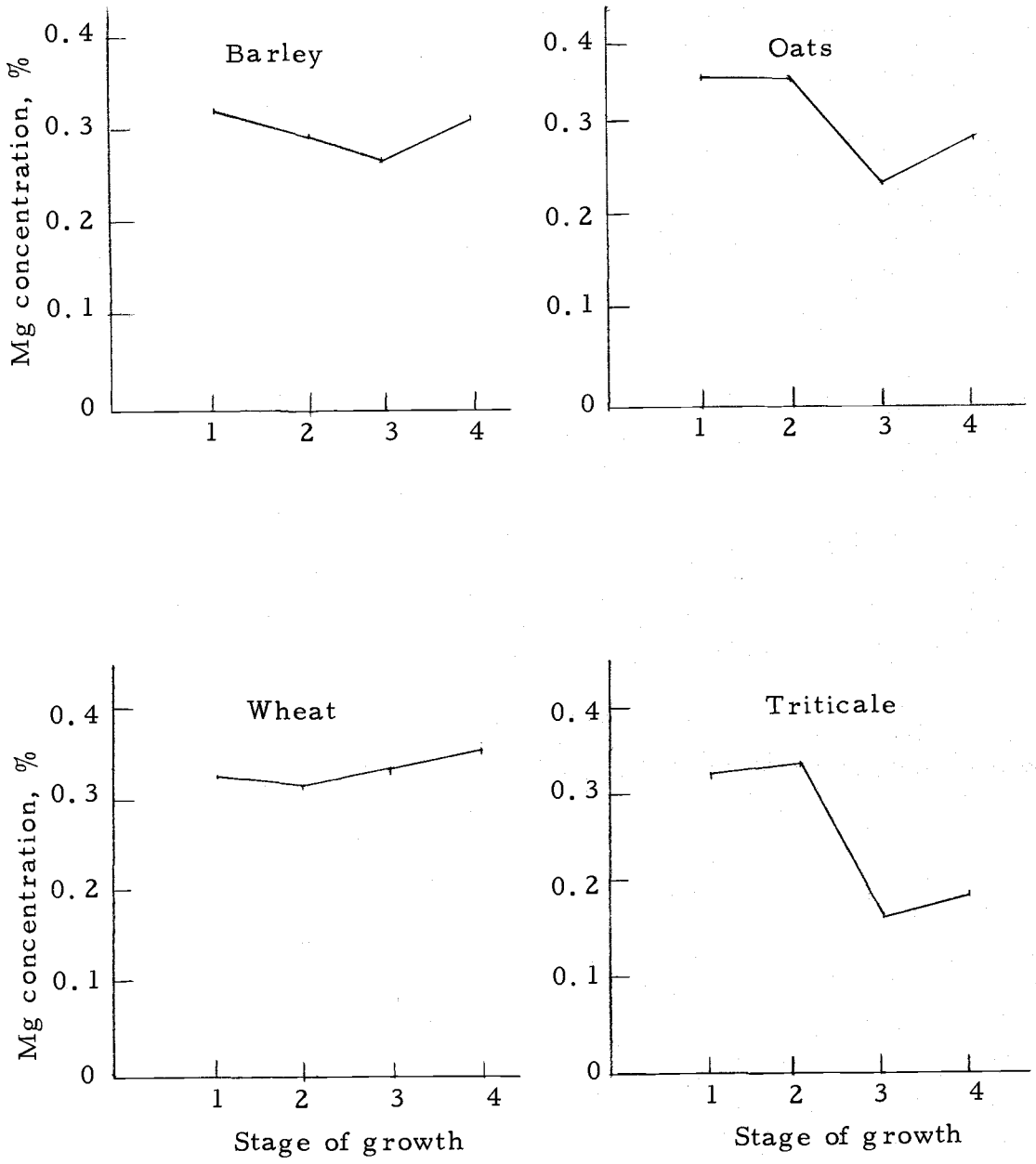

Figure 5. Changes in Mg concentrations of barley, oats, wheat and triticale leaf material from (1) seedling through (2) tillering, (3) boot and (4) flowering stages of growth.

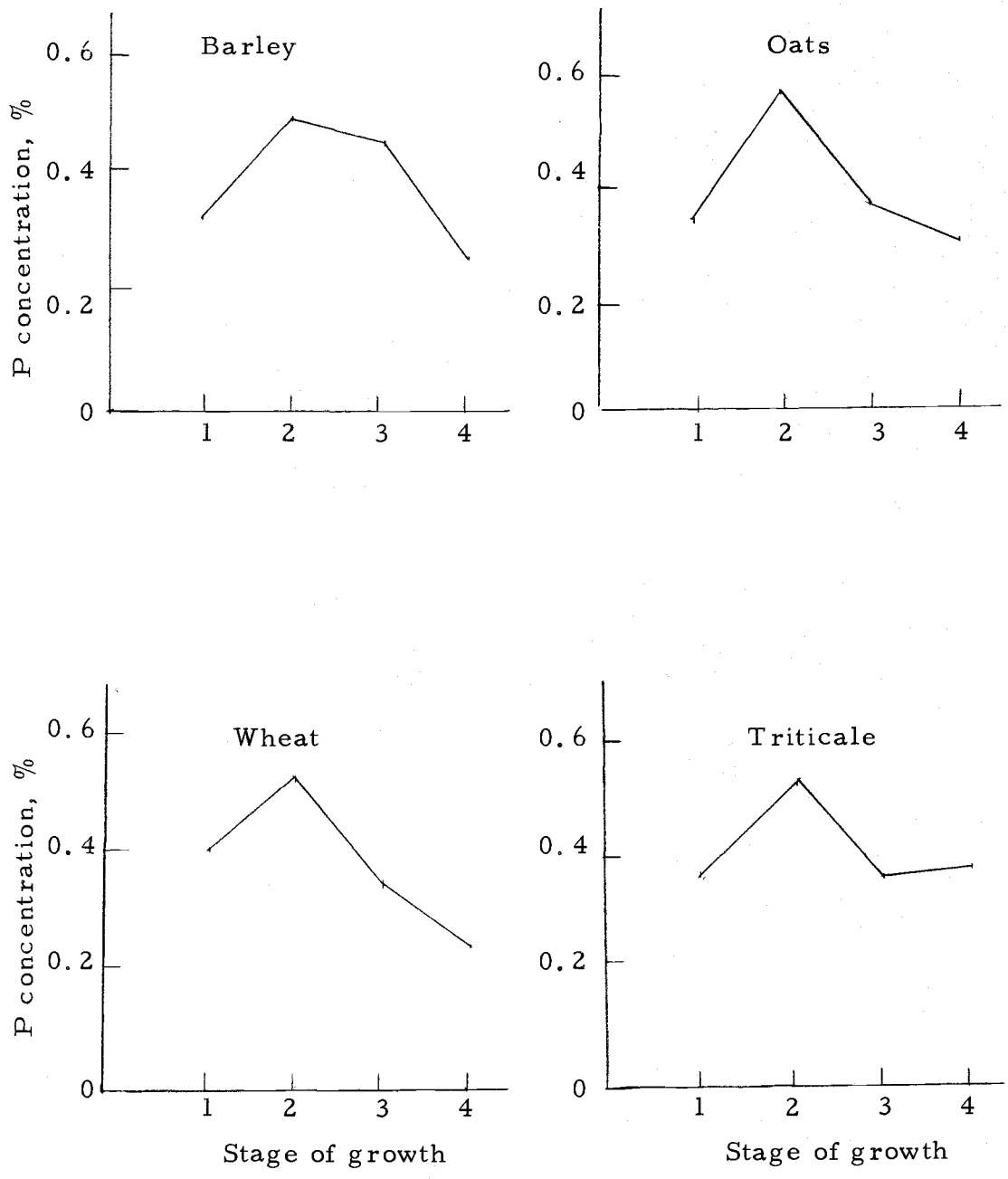

Figure 6. Changes in P concentrations of barley, oats, wheat and triticale leaf material from (1) seedling through (2) tillering, (3) boot and (4) flowering stage of growth.

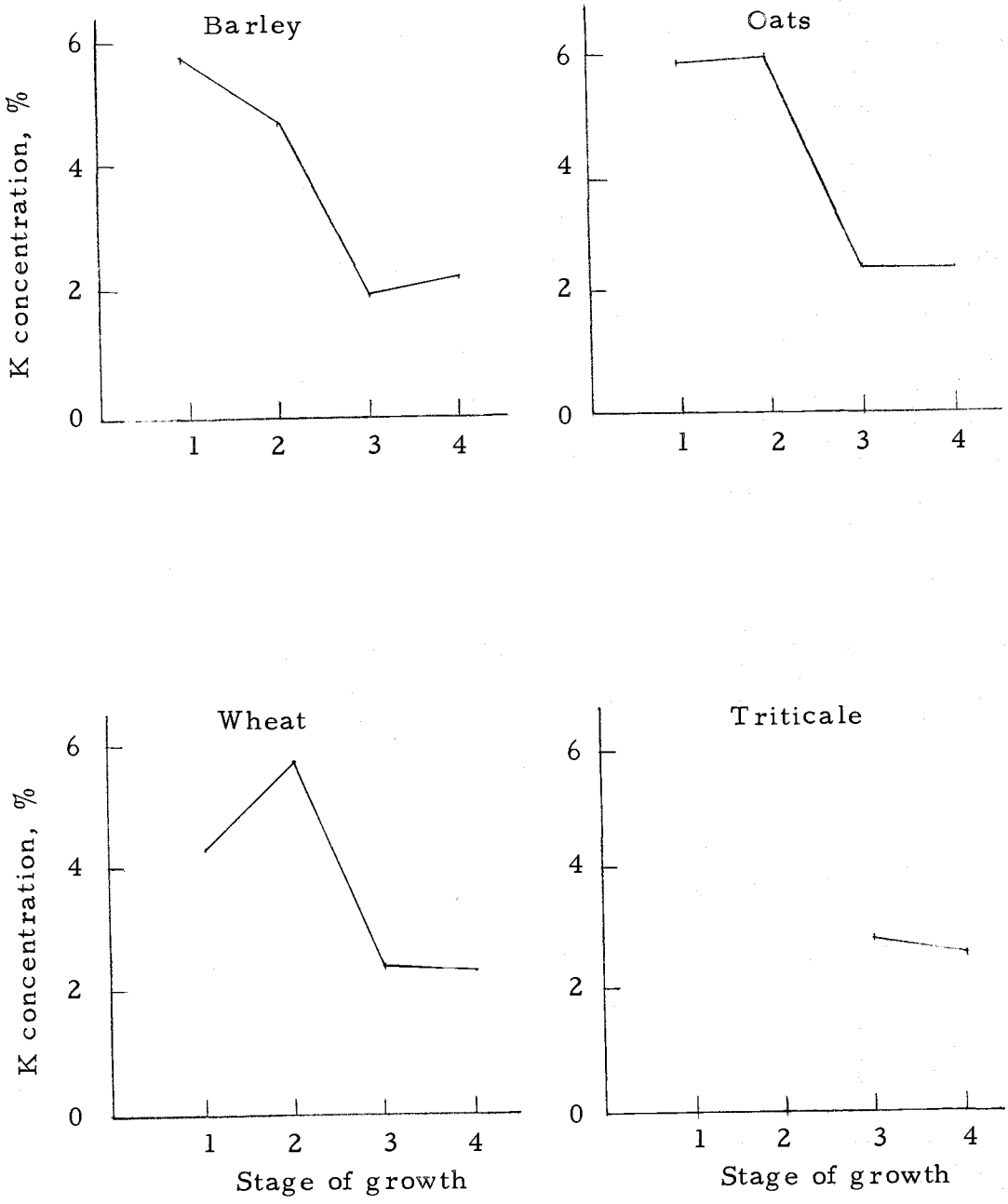

Figure 7. Changes in K concentrations of barley, oats, wheat and triticale leaf material from (1) seedling through (2) tillering, (3) boot and (4) flowering stages of growth.

Table 7. The effect of Mn and Cu treatments on the grain yields and the nutrient concentrations of barley, oats, wheat and triticale leaves at the seedling stage of growth.

Plant species	Treatments*		Grain yield	Nutrient concentrations						
	Mn	Cu		Mn	Cu	Zn	Ca	Mg	K	P
	lb/A			ppm			%			
Barley	0	10	3320	17.7	5.1	31	.29	0.31	6.3	0.28
	5	10	3300	16.6	5.5	32	0.33	0.34	5.5	0.29
	10	10	3480	17.0	5.6	27	0.11	0.32	5.5	0.31
	10	0	3420	16.8	5.3	29	0.34	0.33	6.0	0.33
Oats	0	10	610	17.3	4.4	25	0.26	0.31	4.1	0.32
	5	10	540	12.2	4.8	38	0.25	0.32	5.2	0.28
	10	10	580	15.0	3.6	31	0.27	0.35	5.5	0.37
	10	0	620	13.0	4.3	35	0.25	0.33	5.9	0.32
Wheat	0	10	2450	14.2	5.6	32	0.28	0.38	4.7	0.39
	5	10	2330	12.3	5.4	25	0.25	0.34	5.3	0.40
	10	10	2360	13.6	5.4	22	0.25	0.33	4.3	0.39
	10	0	2230	13.0	5.5	27	0.24	0.33	4.3	0.38
Triticale	0	10	2740	17.8	5.4	--	0.35	0.32	--	0.33
	5	10	2840	23.0	5.4	--	0.42	0.36	--	0.31
	10	10	2500	17.4	5.5	--	0.44	0.32	--	0.33
	10	0	2810	19.6	4.8	--	0.39	0.34	--	0.31

*N was banded at 30 lb/A at planting.

Table 8. The effect of Mn and Cu treatments on the nutrient concentrations of barley, oats, wheat and triticale leaves at the tillering stage of growth.

Plant Species	Treatments*		Nutrient concentrations					
	Mn	Cu	Mn	Zn	Ca	Mg	K	P
	lb/A		ppm		%			
Barley	0	10	14.6	38	0.27	0.29	4.2	0.52
	5	10	15.0	39	0.30	0.30	4.3	0.49
	10	10	14.9	34	0.29	0.30	4.8	0.49
	10	0	14.5	37	0.30	0.30	4.4	0.49
Oats	0	10	13.4	46	0.20	0.36	5.1	0.52
	5	10	11.6	52	0.20	0.35	5.4	0.53
	10	10	12.2	55	0.19	0.35	5.6	0.55
	10	0	11.8	48	0.19	0.36	5.4	0.57
Wheat	0	10	10.4	42	0.21	0.30	4.7	0.52
	5	10	10.0	70	0.21	0.30	4.9	0.52
	10	10	9.4	37	0.21	0.32	5.8	0.53
	10	0	9.5	39	0.21	0.31	5.1	0.53
Triticale	0	10	17.8	41	0.35	0.31	--	0.50
	5	10	17.2	47	0.36	0.30	--	0.47
	10	10	17.0	45	0.33	0.33	--	0.49
	10	0	18.5	46	0.31	0.30	--	0.50

*N was banded at 30 lb/A at planting.

Table 9. The effect of Mn and Cu treatments on the nutrient concentrations of barley, oats, wheat and triticale leaves at the boot stage of growth.

Plant species	Treatments*		Nutrient concentrations						
	Mn	Cu	Mn	Cu	Zn	Ca	Mg	K	P
	lb/A		ppm			%			
Barley	0	10	11.7	9.0	34	0.49	0.26	2.1	0.39
	5	10	12.2	8.6	33	0.52	0.28	2.2	0.38
	10	10	11.0	8.0	33	0.60	0.27	2.0	0.43
	10	0	11.1	7.7	32	0.46	0.25	2.0	0.36
Oats	0	10	11.6	6.9	33	0.26	0.26	2.0	0.34
	5	10	11.0	6.3	31	0.24	0.26	2.7	0.40
	10	10	11.5	6.1	32	0.25	0.24	2.3	0.34
	10	0	11.6	6.0	30	0.30	0.25	2.3	0.35
Wheat	0	10	9.6	8.8	28	0.32	0.31	1.9	0.34
	5	10	10.4	9.0	30	0.36	0.31	2.3	0.38
	10	10	9.1	8.0	27	0.35	0.34	2.1	0.35
	10	0	8.4	7.9	25	0.27	0.30	2.1	0.36
Triticale	0	10	12.2	8.2	37	0.29	0.19	2.2	0.33
	5	10	11.8	8.4	37	0.28	0.16	2.3	0.31
	10	10	11.2	8.3	36	0.29	0.16	2.7	0.33
	10	0	11.8	8.7	36	0.26	0.14	2.3	0.31

*N was banded at 30 lb/A at planting.

Table 10. The effect of Mn and Cu treatments on the nutrient concentrations of barley, oats, wheat and triticale at the flowering stage of growth.

Plant species	Treatments*		Nutrient concentrations						
	Mn	Cu	Mn	Cu	Zn	Ca	Mg	K	P
	lb/A		ppm			%			
Barley	0	10	10.5	9.9	24	0.78	0.32	2.0	0.25
	5	10	9.3	9.8	24	0.75	0.32	2.2	0.31
	10	10	9.6	9.6	25	0.68	0.31	2.3	0.26
	10	0	10.7	9.7	26	0.77	0.31	2.1	0.33
Oats	0	10	8.9	7.9	32	0.36	0.28	2.1	0.28
	5	10	9.6	7.6	29	0.36	0.27	2.4	0.27
	10	10	9.6	7.2	31	0.38	0.28	2.3	0.28
	10	0	9.0	8.2	32	0.34	0.28	2.6	0.33
Wheat	0	10	6.2	6.2	22	0.33	0.37	2.2	0.26
	5	10	6.6	7.2	21	0.32	0.35	2.2	0.23
	10	10	6.4	7.2	21	0.34	0.35	2.3	0.26
	10	0	6.3	6.6	23	0.35	0.38	2.1	0.27
Triticale	0	10	8.6	8.1	27	0.36	0.19	2.2	0.33
	5	10	9.7	7.6	29	0.37	0.17	2.2	0.34
	10	10	8.9	9.0	28	0.37	0.18	2.6	0.35
	10	0	8.9	8.4	28	0.36	0.18	2.3	0.35

*N was banded at 30 lb/A at planting.

Generally, barley and triticale had higher Mn concentrations than oats and wheat. Manganese concentrations at the seedling stage of growth were 19.5, 17.0, 14.4 and 13.3 ppm for triticale, barley, oats and wheat, respectively. Species were different in the rate at which the decrease in Mn concentrations with maturity occurred. Triticale had the greatest decrease of Mn level and oats had the least. Therefore, while triticale had much more Mn than oats at the seedling stage of growth, the difference was nil and in favor of oats at the flowering stage.

Copper concentrations of barley, oats, wheat and triticale were 5.4, 4.3, 5.5 and 5.3 ppm, respectively, at the seedling stage of growth. Until the flowering stage of growth, oats had the lowest copper content and the other species had the same Cu level; but Cu concentration of wheat was as low as that of oats at the flowering stage of growth.

Differences in Zn concentrations among species were variable. Oats appeared to have the highest Zn concentrations and wheat to have the lowest at all stages of growth except for the boot stage. Zinc concentrations ranged from 27 ppm for wheat to 30 ppm for barley, and to 32 ppm for oats, at the seedling stage of growth. Since there is no literature showing wheat response to Zn fertilization, this low accumulation of Zn by wheat may reflect a low requirement for Zn.

Barley and triticale had higher Ca levels than oats and wheat. The fact that the same plants had higher concentrations of both Mn and Ca might show the similarity in the uptake of these two cations.

Differences in plant Mg levels among species were quite variable. There were no important differences in K and P levels.

SUMMARY AND CONCLUSIONS

Experiments were established on a Warden soil on Lower Klamath Lake area to evaluate the effect of Mn and Cu, and band applications of ammonium sulfate on the uptake of micronutrients and response from Mn and Cu applied for the production of small grain crops. Concentrations of Mn, Cu, Zn, Ca, Mg, K and P present in leaf tissue were measured for barley, oats, wheat, and triticale at seedling, tillering, boot, and flowering stages of growth.

Band application of ammonium sulfate increased yield and concentration of Mn found in plant samples while broadcast application of ammonium sulfate before planting did not increase yield or Mn concentration of plant samples. Since an application of N as anhydrous ammonia had been applied on all plots, it was assumed that the major difference between the broadcast and band application of ammonium sulfate was to increase uptake of Mn.

Mn and Cu applications did not increase yields or Mn concentrations found in the leaves.

Band application of ammonium sulfate increased Mn concentration of the barley leaves on average of 2.89, 2.02, 2.28, and 2.02 ppm at seedling, tillering, boot, and flowering stages of growth, respectively. The levels of Mn in leaf material of these crops decreased as the crops matured. For example, Mn content of barley

leaves with broadcast application of ammonium sulfate decreased from 13.7 to 12.8, 9.3 and 7.6 ppm for seedling, tillering, boot and flowering stages of growth respectively. These values are lower than critical levels for barley suggested by Ward et al. (1972). Furthermore, Mn concentrations of plant leaves with optimum levels of Mn generally increases as the plant matures (Williams and Moore, 1952). This illustrates that the critical level of a deficient plant probably changes with maturity and must be established for each stage of growth and in a situation where response from the nutrient in question is being measured. While the Mn concentrations of treatments receiving band applications of ammonium sulfate were 2 to 3 ppm higher than treatments receiving broadcast ammonium sulfate, these concentrations were still below suggested critical levels. Also, the Mn content of leaves from these treatments decreased as the plants matured.

Concentrations of other nutrients were not significantly affected by the fertilizer treatments applied.

Concentrations of all nutrients measured changed as the crops matured. Copper concentrations increased throughout the season; Cu concentrations of barley leaves averaged 5.3 and 9.9 ppm at the seedling and the flowering stages of growth, respectively. Concentrations of Zn and P increased until the tillering stage of growth, than decreased. Zinc concentrations of barley leaves were 31, 36, and 27

ppm, and P concentrations were 0.32, 0.49, and 0.29 percent at the seedling, tillering and the flowering stages of growth, respectively. Calcium decreased until the tillering, and Mg decreased until the boot stages of growth, then both nutrients increased. Calcium concentrations of barley leaves were 0.31, 0.29, 0.49, and 0.75 percent, and Mg concentrations were 0.33, 0.31, 0.26, and 0.31 percent at the seedling, tillering, boot, and the flowering stages of growth, respectively. Potassium levels decreased until the boot stage then remained more or less the same; K concentration of barley leaves decreased from 6.1 percent at the seedling stage to 2.2 percent at the boot stage. The same general trend for changes in nutrient concentrations were present for wheat, oats, and triticale.

Barley and triticale took up more manganese from these soils than oats and wheat. This does not necessarily mean that barley and triticale were better adapted to these soils. Higher Mn concentrations might be associated with higher Mn requirements and critical levels. For example, Mn concentrations of the plant leaves at the seedling stage of growth were 19.5, 17.0, 14.4 and 13.3 ppm for triticale, barley, oats, and wheat, respectively. Similarly, Nyborg (1970) reported that barley had a higher concentration of manganese than wheat and oats grown on a manganese deficient soil. However, Loneragen, Gladstone and Simmons (1970, personal communication, as reported by Browns et al., 1972) found rye and oats took up more

Mn than barley and wheat and were better adapted to the Mn deficient soil. Copper concentrations of oats were lower than those of the other species. At the seedling stage of growth, Cu contents of leaves were 5.4, 4.3, 5.5 and 5.3 ppm for barley, oats, wheat and triticale respectively. At the flowering stage of growth, however, wheat leaves had the lowest Cu level with 6.7 ppm and barley, oats and triticale leaves had 9.8, 7.7 and 9.0 ppm Cu, respectively.

Differences in Zn and Mg concentrations among species were variable from stage to stage. Barley and triticale generally had higher Ca concentrations in their leaf material. There were no real differences in K and P contents among species.

Foliar applications or higher rates of Mn banded with an acidifying fertilizer material should be applied to obtain a better definition of a Mn response curve and Mn critical levels. Levels of other nutrients were adequate for normal plant nutrition.

BIBLIOGRAPHY

Beijerinck, M. W. 1913. Oxidation of manganous carbonate by microbes. K. Akad. Wetensch. Amsterdam, Versl. Wis en Natuurk. Afdeel., 22:415-420; (Chem. Abs., 8:2211).

Bolle-Jones, E. W. 1955. The effect of varied nutrient levels on the concentration and distribution of manganese within the potato plant. Plant and Soil. 6:45-60.

Bowen, J. E. 1969. Absorption of copper, zinc, and manganese by sugar cane tissue. Plant Physiol. 44:254-261.

Bromfield, S. M. 1958. The solution of MnO_2 by substances released from the soil and from roots of oats and vetch in relation to manganese availability. Plant and Soil. 10:147-160.

Brown, J. C., J. E. Ambler, R. L. Chaney, and C. D. Foy. 1972. Differential responses of plant genotypes to micronutrients. p. 389-418. In: J. J. Mortvedt, P. M. Giardano, and W. L. Lindsay (Ed.). Micronutrients in agriculture. SSSA Pub. Madison, Wisconsin.

Christensen, P. D., S. J. Toth, and F. E. Bear. 1950. The status of soil manganese as influenced by moisture, organic matter, and pH. Soil Sci. Soc. Amer. Proc. 15:279-282.

Coic, Y., and M. Coppenet. 1949. Manganese and growth of wheat. Compt. Rend. 228:1379-1381. (Soils and fert., 17:293)

Coppenet, M. and S. Voix. 1951. Delayed action of manganese fertilizers and soil manganese reducible with hydroquinone. Compt. Rend. Acad. Agr. France. 37:67-69. (Chem. Abs., 47:809)

Crooke, W. M. and A. H. Knight. 1971. Crop composition in relation to soil pH and root cation exchange capacity. J. Sci. Food Agr. 22:235-241.

Dorph-Petersen, K. 1950. Variations in the acidity and the content of available phosphate, potassium, and manganese in a sandy soil during four years. Tids. Plantaeavl. 53:650-677. (Chem. Abs., 45:4346)

Fiskell, J. G. A. and G. A. Mourkedes. 1955. A comparison of manganese sources using tomato plants grown on marl, peat, and sand soils. Plant and Soil 6:313-331.

Fitts, J. B., N. Gammon, Jr., and R. B. Forbes. 1967. Relative availability of manganese from several sources. Proc. Soil Crop Sci. Soc. Fla. 27:243-251.

Foy, C. D. 1964. Toxic factors in acid soils of the southeastern United States as related to the response of alfalfa to lime. USDA Prod. Res. Rep. No. 80. 25 p.

Gallagher, P. H. and T. Walsh. 1943. Influence of manganese on the growth of cereals. Proc. Roy. Irish Acad. 49 B, 187-200. (Chem. Abs., 38:825)

Geering, H. R., J. F. Hodgson, and C. Sdano. 1969. Micronutrient cation complexes in soil solution. IV. The chemical state of manganese in soil solution. Soil Sci. Soc. Amer. Proc. 33: 81-85.

Gerretsen, F. C. 1937. Manganese deficiency of oats and its relation to soil bacteria. Ann. Bot. 1:207-230.

_____ 1949. Manganese in relation to photosynthesis. I. Carbon dioxide assimilation and the typical symptoms of manganese deficiency in oats. Plant and Soil. 1 :347-358.

_____ 1950. Manganese in relation to photosynthesis. II. Reduction-oxidation potentials of illuminated crude chloroplast suspensions. Plant and Soil 2:159-193.

Goodall, D. W. 1949. Diagnosis of mineral deficiency. V. Manganese deficiency in wheat. Ann. Applied. Biol. 36:26-39.

Habermann, H. M. 1960. Light dependent oxygen metabolism of chloroplast preparations. Plant Physiol. 35:307-312.

Hammes, J. K. and K. C. Berger. 1960. Manganese deficiency in oats and correlation of plant manganese with various soil tests. Soil Sci. 60:239-244.

Hannay, J. W., B. L. Fletcher, and H. E. Street. 1959. Studies on the growth of excised roots. IX. The effects of other nutrient ions upon the growth of excised tomato roots supplied with various nitrogen sources. New Phytol. 58:142-154.

Heintze, S. G. 1957. Studies on soil manganese. J. Soil Sci. 8:287-300.

Hewitt, E. J. 1958. The role of mineral elements in the activity of plant enzymes systems. In "Handbuch der Pflanzenphysiology-Encyclopedia of plant physiology." Vol. 4, pp. 427-481. Springer, Berlin.

Hudig, J. 1911. Landw. Jahrb. 40:613-644.

Hurwitz, C. 1948. Effect of incubation of amended soil on exchangeable manganese. Soil Sci. 66:267-272.

Jackson, M L. 1958. Soil chemical analysis. Prentice Hall. Englewood Cliffs, N. J. 495 p.

Jackson, W. A. 1967. Physiological effects of soil acidity. In: R. W. Pearson and F. Adams (Ed.). Soil Acidity and Liming. ASA Pub. Madison, Wisconsin. pp. 43-124.

Jackson, W. A., D. L. Craig, P. N. Laudencia, and E. W. Carson, Jr. 1964. Effects of phosphorus nutrition on manganese uptake by wheat seedlings. Int. Congr. Soil Sci., Trans. 8th Bucharest)

Jones, J. B., Jr., R. L. Large, D. B. Pfleiderer, and H. S. Klosky. 1971. How to properly sample for plant analysis. Crops Soils 23(8):15-18.

Jones, L. H. P., W. B. Shepardson, and C.A. Peters. 1949. Plant Physiol. 24:300-306.

Kannan, S. 1969. Factors related to iron absorption by enzymically isolated leaf cells. Plant Physiol. 44:1457-1460.

Lal, R. and G. S. Taylor. 1970. Drainage and nutrient effects in a field lysimeter study: II. Mineral uptake by corn. Soil Sci. Soc. Amer. Proc. 34:245-248.

Lee, J. A. 1960. A study of plant composition in relation to development. Evolution 14:18-29.

Leeper, G. W. 1935. Soils and manganese deficiency. J. Australian Inst. Agr. Sci. 1:161-163.

_____ 1941. Manganese deficiency and accumulation of nitrates in plants. J. Australian Inst. Agr. Sci. 7:161-162.

Lohnis, M. P. 1951. Manganese toxicity in field and market crops. Plant and Soil 3:193-222.

_____ 1960. Effect of magnesium and calcium supply on the uptake of manganese by various crop plants. Plant and Soil 12:339-376.

Maas, E. V. 1967. Manganese absorption by barley roots. Ph. D. Thesis, Oregon State University.

Maas, E. V., D. P. Moore, and B. J. Mason. 1968. Manganese absorption by excised barley roots. Plant Physiol. 43:527-530.

_____ 1969. Influence of calcium and magnesium on manganese absorption. Plant Physiol. 44:796-800.

MacLahlan, J. D. 1941. Manganese deficiency in crops and soils. I. Control in oats by spraying; studies of the role of microorganisms. Sci. Agr. 22:201-207.

McCool, M. M. 1934. Effect of various factors on the soluble manganese in soils. Contrib. Boyce Thompson Inst. 6 No. 2 pp. 147-164. (Exp. Sta. Rec., USDA, 71:594-595).

McHargue, J. S. 1926. Manganese and plant growth. J. Industrial and Engineering Chem., 18:172-175.

Mederski, H. J., D. J. Hoff, and J. H. Wilson. 1960. Manganese oxide and manganese sulfate as fertilizer sources for correcting manganese deficiency in soybeans. Agron. J. 52:667.

Millikan, C. R. 1950. Relation between nitrogen source and the effects on the flax of an excess of manganese or molybdenum in the nutrient solution. Australian J. Sci. Res. B3:450-473.

Mulder, E. G. and F. C. Gerretsen. 1952. Soil manganese in relation to plant growth. Adv. Agron. 4:221-277.

Munns, D. N., C. M. Johnson, and L. Jacobson. 1963. Uptake and distribution of manganese. III. An analysis of biotic and environmental effects. Plant and Soil 19:285-295.

Nicholas, D. J. D. 1949. The manganese and iron contents of crop plants as determined by chemical methods. J. Hort. Sci. 25:60-77.

Nyborg, M. 1970. Sensitivity to manganese deficiency of different cultivars of wheat, oats, and barley. Can. J. Plant Sci. 50:198-200.

Olsen, C. 1934. Absorption of manganese by plants. Biochem. Ztschr. 269:329-348.

Ouellette, G. J. and L. Desseraux. 1958. Chemical composition of alfalfa as related to degree of tolerance to manganese and aluminum. Can. J. Plant Sci. 38:206-214.

Piper, C. S. 1931. The availability of manganese in the soil. J. Agr. Sci. 21:762-779.

Randall, G. W. and E. E. Schulte. 1971. Manganese fertilization of soybeans in Wisconsin. Proc. Wis. Fert. and Aglime Conf. 10:4-10.

Rovira, A. D. 1962. Plant-root exudates in relation to the rhizosphere microflora. Soils Fertilizers. 25:167-172.

Samuel, G. and C. S. Piper. 1928. Grey speck disease of oats. J. S. Australia Dept. Agr. 31:696-705, 789-799.

_____ 1929. Manganese as an essential element for plant growth. Ann. Appl. Biol. 16:494-524.

Schrenk, W. G. 1955. Chemical composition of Kansas wheat. Kansas Agr. Exp. sta. Tech. Bull. 79.

Shepherd, L. W., K. Lawton, and J. F. Davis. 1960. The effectiveness of various manganese materials in supplying manganese to crops. Soil Sci, Soc. Amer. Proc. 24:218-221.

Sherman, G. D. and P. M. Harmer. 1943. The manganous-manganic equilibrium of soils. Soil Sci. Soc. Amer. Proc. 7:398-405.

Sjollema, B. and J. Hudig. 1909. Inquiry into the causes of the decrease in fertility of some soils in the Graningen and Drenthe moor colonies. Verslag. Landouwk. Onderzoek. Rijkslandbouwproefstat. (Netherlands). No. 5, pp. 29-157. (Exp. Sta. Rep., USDA, 21:115).

Sohngen, N. L. 1914. Zentr. Bakt. II. 40:545-554.

Spencer, D. and J. V. Possingham. 1960. The effect of nutrient deficiencies on the Hill reaction of isolated chloroplasts from tomato. Australian J. Biol. Sci. 13:441-455.

_____ 1961. The effect of manganese deficiency on phosphorylation and the oxygen evolution sequence in spinach chloroplasts. Biochem. Biophys. Acta. 52:379-381.

Steel, R. G. D. and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill, N. Y. Sci. (Gr. Brit.). Tech. Common. No. 48.

Swanback, T. R. 1939. Studies on the antagonistic phenomena and cation absorption in tobacco in the presence and absence of manganese and boron. Plant Physiol. 14:423-446.

Takkar, P. M. 1969. Effect of organic matter on soil iron and manganese. Soil Sci. 108:108-112.

Timonin, M. I. 1946. Microflora of the rhizosphere in relation to the manganese deficiency of oats. Soil Sci. Soc. Amer. Proc. 11:284-292.

Vlamis, J. and D. E. Williams. 1962. Ion competition in manganese uptake by barley plants. Plant Physiol. 37:650-655.

Wain, R. I., B. J. Silk, and B. C. Willis. 1943. The fate of manganese sulfate in alkaline soils. J. Agr. Sci. 33:18-22.

Ward, R. C., D. A. Whitney, and D. G. Westfall. 1972. Plant analysis as an aid in fertilizing small grains. In Soil and Plant Analysis. SSSA Pub. Madison, Wisconsin.

Westermann, D. T., T. L. Jackson, and D. P. Moore. 1971. Effect of potassium salts on extractable soil manganese. Soil Sci. Soc. Amer. Proc. 35:43-46.

White, R. P., E. C. Doll, and J. R. Melton. 1970. Growth and manganese uptake by potatoes as related to liming and acidity of fertilizer bands. Soil Sci. Soc. Amer. Proc. 34:268-271.

Williams, C. H. and C. W. E. Moore. 1952. The effect of stage of growth on the copper, zinc, manganese and molybdenum contents of Algerian oats grown on thirteen soils. Australian J. Agr. Res. 3:343-361.

York, E. T., Jr., R. Bradfield, and M. Peech. 1954. Influence of lime and potassium on yield and chemical composition of plants. Soil Sci. 77:53-63.

Younts, S. E. and R. P. Patterson. 1964. Copper-lime interactions in field experiments with wheat: yield and chemical composition. Agron. J. 56:229-232.

APPENDIX

APPENDIX

LSD values at the 0.05 and 0.01 significance levels from analysis of variance for grain yield and Mn and Cu concentrations of plant leaves at the seedling, tillering, boot, and flowering stages of growth.

Barley Experiment

1. Grain yield (lb/A)

Individual treatments	:	$LSD_{.05} = 361$	
		$LSD_{.01} = 483$	
N treatments	:	$LSD_{.05} = 210$	for means of 3 trts.
		$LSD_{.01} = 282$	
Mn treatments	:	$LSD_{.05} = 258$	for means of 2 trts.
		$LSD_{.01} = 346$	

2. Mn concentration at the seedling stage of growth (ppm)

Individual treatments	:	$LSD_{.05} = 3.36$	
		$LSD_{.01} = 4.48$	
N treatments	:	$LSD_{.05} = 1.94$	for means of 3 trts.
		$LSD_{.01} = 2.59$	
Mn treatments	:	$LSD_{.05} = 2.37$	for means of 2 trts.
		$LSD_{.01} = 3.17$	

3. Mn concentration at the tillering stage of growth (ppm)

Individual treatments	:	$LSD_{.05} = 1.21$	
		$LSD_{.01} = 1.62$	
N treatments	:	$LSD_{.05} = 0.70$	for means of 3 trts.
		$LSD_{.01} = 0.93$	
Mn treatments	:	$LSD_{.05} = 0.86$	for means of 2 trts.
		$LSD_{.01} = 1.14$	

4. Mn concentration at the boot stage of growth (ppm)

Individual treatments	:	$LSD_{.05} = 1.77$	
		$LSD_{.01} = 2.36$	
N treatments	:	$LSD_{.05} = 1.02$	

		$LSD_{.01}$ = 1.36	for means of 3 trts.
Mn treatments	:	$LSD_{.05}$ = 1.25	for means of 2 trts.
		$LSD_{.01}$ = 1.67	

5. Mn concentration of the flowering stage of growth (ppm)

Individual treatments	:	$LSD_{.05}$ = 1.14	
		$LSD_{.01}$ = 1.52	
N treatments	:	$LSD_{.05}$ = 0.66	for means of 3 trts.
		$LSD_{.01}$ = 0.88	
Mn treatments	:	$LSD_{.05}$ = 0.81	for means of 2 trts.
		$LSD_{.01}$ = 1.08	

6. Cu concentration at the seedling stage of growth (ppm)

Individual treatments	:	$LSD_{.05}$ = 0.74	
		$LSD_{.01}$ = 1.05	
N treatments	:	$LSD_{.05}$ = 0.65	for means of 3 trts.
		$LSD_{.01}$ = 0.61	
Mn treatments		$LSD_{.05}$ = 0.56	for means of 2 trts.
		$LSD_{.01}$ = 0.74	

7. Cu concentration at the boot stage of growth (ppm)

Individual treatments	:	$LSD_{.05}$ = 1.06	
		$LSD_{.01}$ = 1.62	
N treatments	:	$LSD_{.05}$ = 0.61	for means of 3 trts.
		$LSD_{.01}$ = 0.82	
Mn treatments	:	$LSD_{.05}$ = 0.75	for means of 2 trts.
		$LSD_{.01}$ = 1.00	

8. Cu concentration at the flowering stage of growth (ppm)

Individual treatments	:	$LSD_{.05}$ = 1.12	
		$LSD_{.01}$ = 1.50	
N treatments	:	$LSD_{.05}$ = 0.65	for means of 3 trts.
		$LSD_{.01}$ = 0.86	
Mn treatments	:	$LSD_{.05}$ = 0.79	for means of 2 trts.
		$LSD_{.01}$ = 1.06	

Oat Experiment

1. Grain yield (lb/A)
   $LSD_{.05} = 210$
   $LSD_{.01} = 293$
2. Mn concentration at the seedling stage of growth (ppm)
   $LSD_{.05} = 5.45$
   $LSD_{.01} = 7.64$
3. Mn concentration at the tillering stage of growth (ppm)
   $LSD_{.05} = 2.57$
   $LSD_{.01} = 3.60$
4. Mn concentration at the boot stage of growth (ppm)
   $LSD_{.05} = 1.77$
   $LSD_{.01} = 2.68$
5. Mn concentration at the flowering stage of growth (ppm)
   $LSD_{.05} = 1.19$
   $LSD_{.01} = 1.66$
6. Cu concentration at the seedling stage of growth (ppm)
   $LSD_{.05} = 1.83$
   $LSD_{.01} = 2.57$
7. Cu concentration at the boot stage of growth (ppm)
   $LSD_{.05} = 1.44$
   $LSD_{.01} = 2.02$
8. Cu concentration at the flowering stage of growth (ppm)
   $LSD_{.05} = 1.28$
   $LSD_{.01} = 1.79$

Wheat Experiment

1. Grain yield (lb/A)
   $LSD_{.05} = 1062$
   $LSD_{.01} = 1490$
2. Mu concentration at the seedling stage of growth (ppm)
   $LSD_{.05} = 2.11$
   $LSD_{.01} = 2.96$
3. Mn concentration at the tillering stage of growth (ppm)
   $LSD_{.05} = 1.33$
   $LSD_{.01} = 1.87$
4. Mn concentration at the boot stage of growth (ppm)
   $LSD_{.05} = 1.74$
   $LSD_{.01} = 2.45$
5. Mn concentration at the flowering stage of growth (ppm)
   $LSD_{.05} = 1.46$
   $LSD_{.01} = 2.05$
6. Cu concentration at the seedling stage of growth (ppm)
   $LSD_{.05} = 0.79$
   $LSD_{.01} = 1.10$
7. Cu concentration at the boot stage of growth (ppm)
   $LSD_{.05} = 1.36$
   $LSD_{.01} = 1.91$
8. Cu concentration at the flowering stage of growth (ppm)
   $LSD_{.05} = 0.96$
   $LSD_{.01} = 1.35$

Triticale Experiment

1. Grain yield (lb/A)
   $LSD_{.05}$ = 350
   $LSD_{.01}$ = 490
2. Mn concentration at the seedling stage of growth (ppm)
   $LSD_{.05}$ = 4.82
   $LSD_{.01}$ = 6.75
3. Mn concentration at the tillering stage of growth (ppm)
   $LSD_{.05}$ = 2.61
   $LSD_{.01}$ = 3.67
4. Mn concentration at the boot stage of growth (ppm)
   $LSD_{.05}$ = 2.17
   $LSD_{.01}$ = 3.04
5. Mn concentration at the flowering stage of growth (ppm)
   $LSD_{.05}$ = 1.23
   $LSD_{.01}$ = 1.72
6. Cu concentration at the seedling stage of growth (ppm)
   $LSD_{.05}$ = 0.87
   $LSD_{.01}$ = 1.22
7. Cu concentration at the boot stage of growth (ppm)
   $LSD_{.05}$ = 1.49
   $LSD_{.01}$ = 2.09
8. Cu concentration at the flowering stage of growth (ppm)
   $LSD_{.05}$ = 0.98
   $LSD_{.01}$ = 1.37