A16-7 1992

Nutrient Status of Irrigated Forage Alfalfa

R.C. McKenzie[1], D.J. Heaney[2] and L.M. Kryzanowski[2]

Southern Alberta has about 130,000 ha of irrigated forage alfalfa and about 26,000 ha of cereal crops underseeded to alfalfa. This represents about 30% of the total area irrigated. Export and Canadian sales of processed alfalfa from southern Alberta amount to $32 million/yr. There are markets for more export sales if more high quality alfalfa would be available. Alfalfa is also an important forage for the cow calf industry in southern Alberta. Farmers grow alfalfa as a reliable cash crop and to provide feed to overwintering beef cows. Alfalfa is also grown to control annual weeds and because it is recognized as a crop which improves soil tilth and fertility. Farmers apply little or no nitrogen to cereal crops grown in the first one or two years after alfalfa.

OBJECTIVES

In 1989, the Alberta Special Crops and Horticulture Research Centre, in cooperation with the Alberta Agriculture Soils and Animal Nutrition Lab commenced a research program to collect the background data necessary to develop Diagnostic Recommendation Integrated System (DRIS) standards for silage and grain corn, greenhouse cucumbers and forage alfalfa. DRIS is a method of diagnosing nutrient deficiencies based on plant tissue nutrient ratios rather than nutrient concentrations in the soil. Tissue nutrient concentrations vary due to the time of sampling. Tissue nutrient ratios are less sensitive to this variation. DRIS was developed and used first in south Africa and later in the southern and east central USA. It is applicable to high value crops where the costs of tissue testing and supplemental fertilization can be justified by high profit margins or to long lasting crops where there is time to adjust nutrient levels.

A second objective of the research program was to survey the three crops and determine the current status of plant nutrition for these crops. This paper will only report on alfalfa.

METHODS

The number of alfalfa fields sampled were 22, 11, 23, 44 in 1989 to 1992, respectively. Fields were in the Rolling Hills, Brooks and Rosemary areas in 1989 and 1990. In 1991 and 1992, fields from Bow Island and Hays, areas were also sampled. Fields were sampled over about a two and one half week period in June starting with first flowering. Sampling commenced each year in the south and moved north to minimize differences in maturity.

Fields were selected randomly. Information about previous applications of fertilizer, age of the stand, variety and irrigation practices were obtained from the farmer. Three samples of 1.14 sq m were cut to determine crop yield. Soil samples to 1.20 m were taken and soil moisture, texture and nutrient analysis were determined. A tissue sample of the 0.15 m apical segments of stems was also collected and analyzed for macro and micro nutrient content.

---

[1]Alberta Agric., ASCHRC, Brooks, AB; [2]Alberta Agric., Soils and Crop Protection Br., Edmonton, AB.

Soil data from the 0-30 cm depth were compared to Alberta Agriculture soil test guidelines for determining deficiency. Plant tissue analyses were compared to tissue standards of the Alfalfa Management Guide published by the American Society of Agronomy (ASA) guidelines (Undersander et al 1991) and to DRIS standards for midwest USA (Wallworth et al, 1986).

RESULTS

Most of the fields sampled were less than 5 years old (Figure 1). Five years is the normal life of an irrigated alfalfa field. Only a few high yielding fields were kept beyond six years.

Fertilizer applied

Fertilizer applications are illustrated in Figure 2. Nitrogen other than that provided by monoammonium phosphate (11-51-0) was used by 34% of farmers at the time of seeding. In subsequent years, 9% of the fields received N at rates up to 50 lbs/acre. More than 50 lbs/acre N was applied to 2% of fields tested. Nitrogen is generally not recommended for alfalfa. Many farmers and some agronomists believe it is useful to apply nitrogen to older stands.

Phosphorus fertilizer was not applied on 28% of fields and minimal or below 50 lb/acre of P_2O_5 on 27% of the fields. Another 13% applied more than 50 lbs/acre P at the time of seeding. A small proportion of fields (25%) received phosphorus during the life span of the alfalfa. About 29% of farmers add sufficient phosphorus to supply one year's phosphorus (> 50 lbs acre P_20_5 either at seeding or in subsequent years for the crop). Another 7% used manure as a fertilizer prior to seeding the crop. Yield on fields which had received more than 50 kg/acre P_20_5 averaged 5.1 t/ha as compared to 4.4 t/ha on fields that received no fertilizer or manure and 4.0 t/ha on fields that had less than 50 lb/acre P_20_5. Manured fields yielded 5.0 t/ha which was more than most other fields.

Potassium fertilizer was applied to 15% of the fields, however only 2% received more than 50 lb/acre. Fields receiving more than 50 lbs/ac K yielded 6.4 t/ac as compared to 4.6 t/ac on fields receiving less than 50 lbs/ac K and 4.3 t/ac with no K. A typical crop of 4 T/acre would remove about 200 lb/acre/year of potassium. This compares to 23 lb/acre/year of K removed by 70 bu/acre of wheat when the straw is left on the field.

Micro nutrients were not usually applied to the alfalfa fields tested. The only example was boron which was applied on 1% of fields.

Soil Test and Tissue Nitrogen Phosphorus and Potassium

Soil test nitrogen was low by Alberta Agriculture standards on 96% of fields and marginal on 2% of fields. Tissue nitrogen, however, was low on only 1% of fields by ASA standards (Fig. 3). Tissue nitrogen was usually higher than midwest USA DRIS values. This adequate level of tissue nitrogen, despite low levels of soil nitrogen, suggests alfalfa is obtaining sufficient nitrogen from dinitrogen fixation.

Soil test phosphorus was deficient on 70% of fields and marginal on 11% of fields. Tissue phosphorus was low on 43% of fields. This discrepancy exists in part because the Miller Axley test for soil phosphorus does not effectively measure mineral phosphorus left from fertilizer

Figure 1. Age and yield of alfalfa fields.

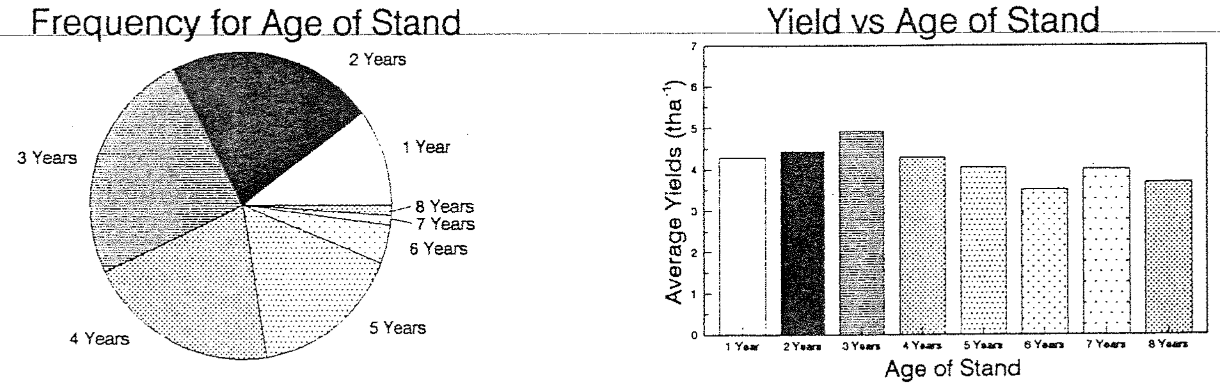


Figure 2. Fertilizer applications and relationship to yield.

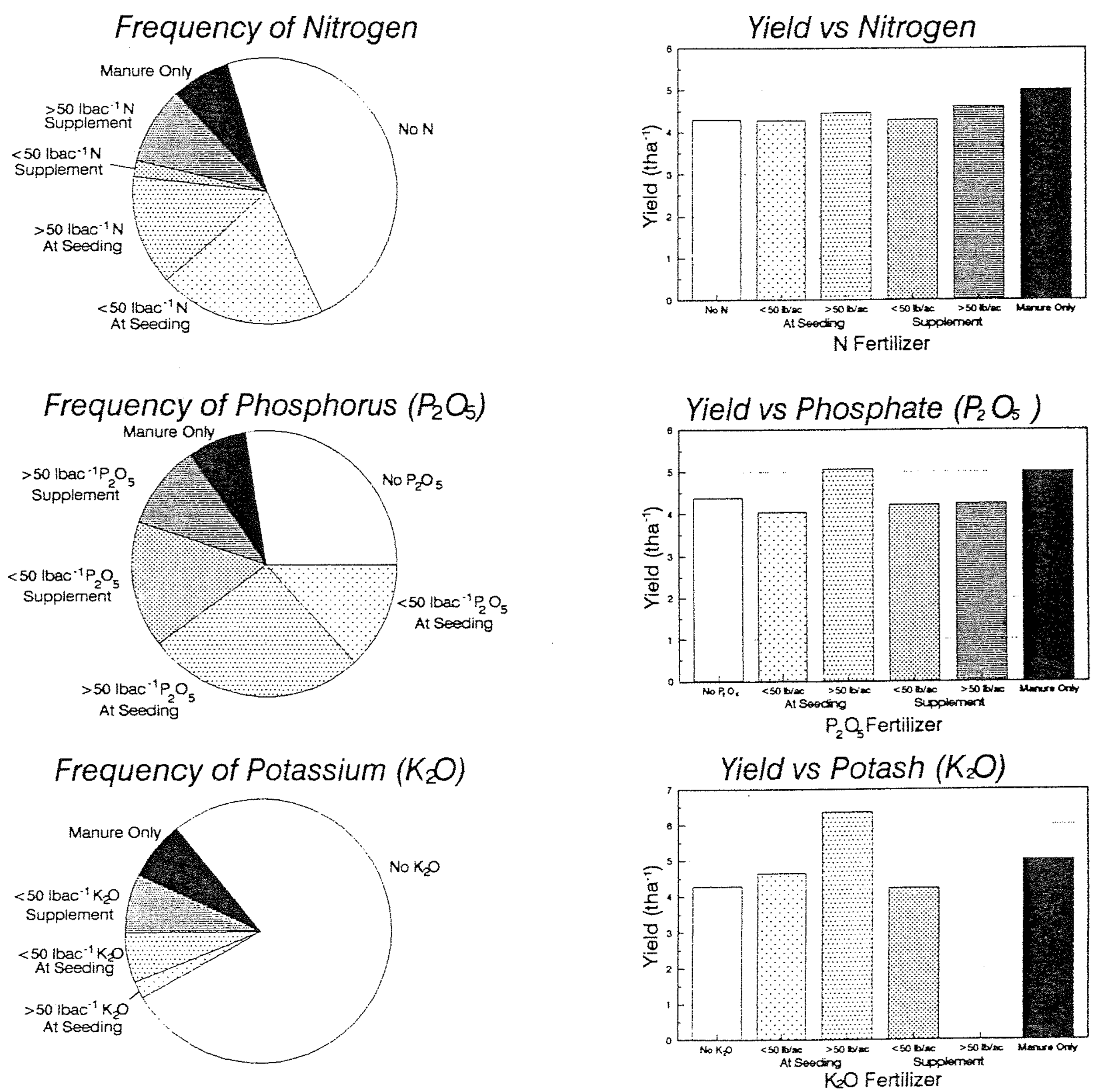
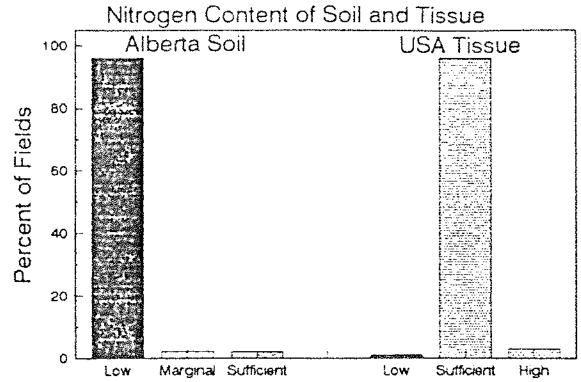
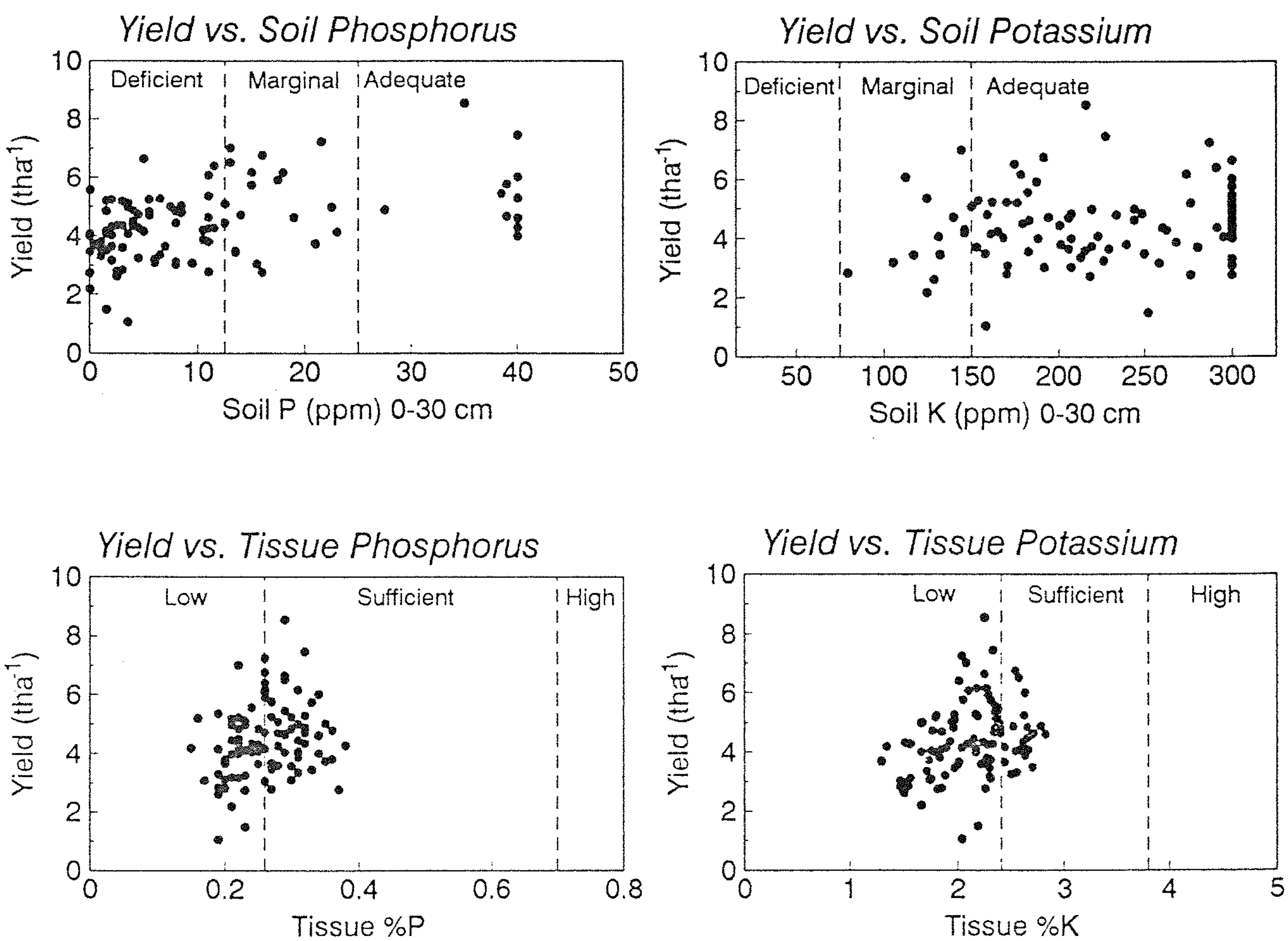


Figure 3. Soil and tissue nitrogen values compared to Alberta soil and USA tissue standards.



(McKenzie et al 1989). Furthermore, alfalfa has an effective rooting depth of 2 to 4 meters which means it can take up phosphorus at depths that are not available to annual crops. However, (Fig. 4) neither soil phosphorus ($r^2=0.19$) or tissue phosphorus ($r^2=0.05$) are closely correlated to yield.

Figure 4. Soil and tissue phosphorus and potassium and relationship to yield and to Alberta Agriculture soil and USA tissue standards.



Other Nutrients

Sulphur values (Figure 5) were sometimes low in surface (0-30 cm) but were high in subsurface layers. Calcium values were adequate for all tissue samples and were not determined for soil samples. Twenty percent of tissue samples were low in magnesium. Magnesium was not determined on soil samples.

Zinc was low on 8% of soil samples and deficient on 8% of plant samples. There was no match between fields testing low in soil zinc and low in tissue zinc. Manganese was deficient on 13% of plant samples. Boron was deficient on 9% of soil samples but was not deficient on any plant samples. No soil samples and 2% of tissue samples tested deficient in copper.

CONCLUSIONS

This survey of soil analysis plant tissue analysis and yields will provide a start for establishing DRIS standards for irrigated alfalfa in southern Alberta. To complete the project, field experiments will be needed with nutrients which appear to be a problem. These are phosphorus, potassium, magnesium, zinc, manganese and boron.

One third of farmers have added nitrogen to the fields tested but this does not appear to be necessary. The most serious deficiency is phosphorus but a combination of soil and tissue analysis is required to identify it. Fields that tested deficient in tissue phosphorus were also deficient in soil phosphorus.

The discrepancy between soil and tissue potassium requires research. Fields which produced alfalfa for many years and have not received large applications of manure or potassium fertilizer may be deficient in potassium. More needs to be done with testing soils and tissue samples and combining this with fertilizer trials on fields testing low in zinc, magnesium or manganese to determine if there are economic benefits to fertilization with these nutrients.

Manure is high in phosphorus, has a moderate supply of potassium which alfalfa require and it is relatively low in nitrogen for most other crop requirements. Manure is also a slow release fertilizer and when applied before planting will release nutrients over 3-5 years. The large and increasing cattle population in feedlots means that large amounts of manure are available in some areas. These characteristics make manure an ideal fertilizer for irrigated alfalfa.

ACKNOWLEDGEMENTS

Support was received from Potash and Phosphate Institute of Canada and Lakeside Research.

REFERENCES

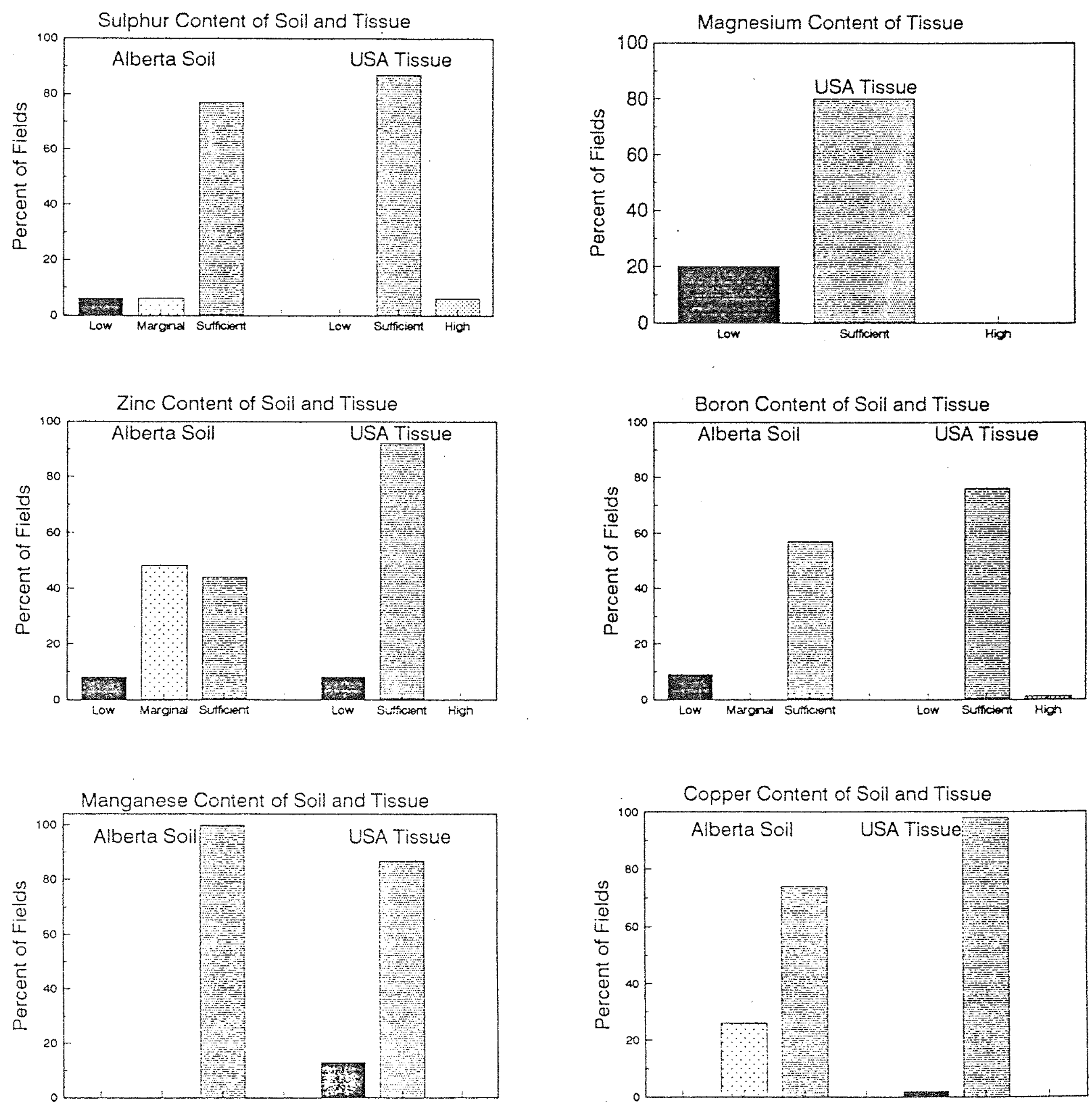
McKenzie, R.H.; Dormar, J.F. and J.W. Stewart 1989. The Weak Link in Soil Phosphorus testing and Fertilizer Recommendations. *In Proc.* 26 Ann. AB Soil Sc. Workshop. pp 166-177.

Undersander, D.; Martin, N.; Cosgrave, D.; Kelling, K.; Schmitt, M.; Wedburg, J.; Becker, R.; Grau, C. and Doll, J. 1991. Alfalfa Management Guide. Pub. by Am. Soc. of Agronomy. 14 p.

Walworth, J.L.; Sumner, M.E.; Isaac, R.A. and Plank, C.O. 1986. Preliminary DRIS Norms for Alfalfa in the Southeastern United States and a Comparison with Midwestern Norms. Agron. J. 78 pp. 1046-1052.

Soil potassium was not deficient on any fields and was marginal on 12% of fields (Figure 4). Tissue potassium was low on 79% of fields. This means there is a discrepancy between soil potassium and tissue potassium values. Tissue potassium values were also low when compared to midwest USA DRIS norms. Low potassium levels may in Alberta be associated with cool weather during the growing season or high levels of soil calcium or magnesium. A field program is needed to measure if there is a response to potassium fertilizer on these soils which test low in tissue potassium. In the Eastern Irrigation District near Brooks, alfalfa has been an important crop for 60 or more years. If a field has grown alfalfa for 30 years without manure or potassium fertilizer, this could represent removal of 6000 lb/acre of potassium. However, no fields tested deficient in soil potassium using current guidelines.

Figure 5. Soil and tissue values compared to Alberta Agriculture soil and USA tissue standards.



DRIS SYSTEMS

R.C. McKenzie, J.A. Butt, D. Heaney and L.M. Kryzanowski
Alberta Special Crops and Horticultural Research Center
Brooks, Alberta

There is increasing interest among agronomists in using tissue testing in the diagnosis of nutrient deficiencies and the optimization of fertilizer applications. Tissue testing holds the most promise for high value crops that receive large applications of fertilizer and for long lasting crops where more fertilizer can be added.

Most tissue testing techniques are interpreted using a sufficiency level approach, i.e. nutrient concentration above a threshold value signifies that sufficient quantities of that nutrient are present. The threshold values are usually specified for a particular part of the plant at a certain stage of growth. As a result, the window of opportunity for diagnosis and correction is narrow. The sufficiency approach to tissue testing also tends to consider each nutrient in isolation and ignore interactions.

An alternative to the sufficiency approach is the Diagnostic Recommendation Integrated System or DRIS. First developed in South Africa by Beaufils (1973) for use on rubber trees and corn, DRIS has since been refined mainly by Sumner and others (Wallworth and Sumner 1987) at Atlanta Georgia and applied to corn, alfalfa, soybeans, sunflowers, wheat and numerous other crops.

Advantages in using DRIS come from the use of nutrient ratios in plant tissue rather than nutrient concentration in diagnosing the nutrient status of plants. Nutrient ratios are less dependent upon crop growth stage and can be based on whole plant analysis which simplifies sampling procedures.

In the DRIS system, interpretation of nutrient ratios is performed by comparing them to regional averages or DRIS norms. Developing DRIS norms is not a trivial exercise. A database must be assembled, factors affecting crop yield defined and relationships between factors these expressed mathematically. This usually involves measuring yield and taking tissue and soil samples from a number of different fields in a region over a period of several years before the norms can be generated.

In 1989, a project was initiated aimed at developing DRIS norms for alfalfa and greenhouse cucumbers. In 1990 corn was added to the list. The objectives also were to survey the current status of plant nutrition of these crops in Alberta and compare this to conventional nutritional standards.

There were numerous reasons for choosing alfalfa. Alfalfa is an important crop in the irrigated areas of Alberta but it has not received as much nutrient monitoring or research as the cereal crops. Alfalfa stands normally last 5-8 years, it is therefore possible for nutrient deficiencies to develop and these can appreciably lower crop yield. There is also a possibility for connection of nutrient deficiencies within the lifespan of the crop. The DRIS data developed in Alberta could also be compared with norms developed in the Midwest United States.

The reasons for working with greenhouse cucumbers were also numerous. It is a high value crop \$600,000 ha^{-1} (\$250,000 ac^{-1}, 35 acres in Alberta) grown under intensive management within a narrowly defined and carefully controlled environment. Alberta growers are already making use of tissue sampling. They regularly sample nutrient solutions, growing media and leaf tissue and adjust fertilizer programs accordingly. A recent switch to substrate media, such as sawdust and rockwool, has forced growers to carefully monitor nutrient solutions and adjust nutrient concentrations depending on stage of growth, plant vigor and light conditions. For example, it is a common practice to feed a higher concentration of calcium, iron and boron in the early stages of growth. Once plants begin to set a heavy fruit load, the calcium, iron and boron concentrations are often reduced and potassium concentration is increased. However, they use the same range of acceptable tissue nutrient considerations regardless of crop growth stage and environmental conditions. Although nutrient solution analysis is common when substrates are used, many cucumber growers continue to use tissue analysis as a guideline for adjusting fertilizer programs.

Furthermore, Alberta greenhouses are subjected to more intense light than most greenhouses at comparable latitudes in areas such as Eastern Canada the United Kingdom and the Netherlands. Nutritional requirements for optimum cucumber growth in Alberta may be different from these other regions where most of the nutritional information has been developed.

Corn is a crop that is heavily fertilized. Corn producers often apply fertilizer during the season by means of fertigation and some use tissue testing. DRIS standards for corn are available from several areas of the USA. Data collected in southern Alberta will be compared to DRIS standards developed in the midwest USA.

If workable DRIS norms can be developed, the next step would be to package the database in a user friendly format for personal computers and make the software available to producers. That is still a year or two away. In 1991 the DRIS program received funding from the Alberta Corn Committee.

Methods

Alfalfa

The number of alfalfa fields sampled in 1989, 1990 and 1991 respectively were 23, 11 and 22. In 1989 and 1990 the fields sampled were in the eastern irrigation district and in 1991 the sampling area was extended 60 km further south to include the Bow Island area.

Forage samples consisted of three 1.14 m^2 squares. They were taken in the early blossom stages, oven dried at 40-60°C and weighed to determine yield. Tissue subsamples were analyzed to determine macro- and micronutrient content. Eight soil samples were taken to a depth of 1.20 m with a king tube and analyzed for soil moisture, particle size, EC, pH, NO_3-N, NH_4-N and other macro- and micronutrients. Data on the variety, age of the stand, previous fertilizer applications and irrigation practices were recorded.

Grain and Forage Corn

In 1990 and 1991 respectively, 9 and 11 grain corn fields, 10 and 17 forage corn fields were sampled. The fields were in the Bow Island, Taber, Vauxhall, Hays, Brooks and Jenner areas. Tissue nutrient levels are compared to midwest USA DRIS norms. Soil nutrient values are compared to Alberta Agriculture adequate, marginal and deficient limits.

Tissue and soil samples were collected when labor was available. In 1990 the forage corn was sampled from July 13-17 and the grain corn from August 3-8. In 1991, tissue and soil samples were collected from forage corn from August 1-14 and the grain corn from August 2-14. Analysis on leaf tissue and soils was similar to that performed on alfalfa. Information on previous cropping and fertilizer applications was collected for each field.

In September the same portion each of the field was sampled to determine yields. A 5 m portion of row of forage corn wer harvested and weighed and a subsample was dried to determine forage yield. For grain corn, cobs from a 10 m portion of row were harvested, dried and threshed to determine grain yield.

Cucumbers

Crops of long English seedless cucumbers from 18 greenhouses in the Medicine Hat and Redcliff areas were sampled in both 1990 and 1991. Leaf tissue samples were collected every 2 weeks from mid-March until July and soil or nutrient solution samples were taken every 4 weeks. Yields from each greenhouse were determined throughout the season from the growers marketing records and the greenhouse size.

Results and Discussion

Graphs were developed for yields, macro- and micronutrients, soil EC, available soil moisture, age of the stand and a number of nutrient ratios. A sample of graphs for alfalfa (Fig. 1-10) and corn (Fig. 11-23) is included in this report. Tissue analyses from alfalfa for 1989 and 1990 and corn for 1990 and 1991 were compared with yields to DRIS standards for the mid-west USA. Alfalfa tissue nutrient levels from 1991 were compared to nutrient sufficiency standards established for alfalfa by the American Society of Agonomy (USA). Soil analysis for alfalfa and corn were compared to Alberta Agriculture soil test adequate, marginal and deficiency limits. In the figures, fields are ranked according to yields (left hand y axis) that are shown by a bar graph. Soil and tissue nutrient values (right hand y-axis) are shown on the figures by an asterisk (*).

Alfalfa

The average age of the alfalfa fields was 4.0, 2.1 and 2.2 years in 1989, 1990 and 1991, respectively (Fig. 1). The reason the average age declined is likely due to winterkilling of older fields and declining hay prices in 1990 and 1991 which made it less attractive to keep older alfalfa fields.

Tissue nutrient standards in the 1991 figures were compared to American Society of Agronomy (USA) nutrient sufficiency standards for alfalfa. In 1989 and 1990 they were compared to midwest USA alfalfa DRIS norms. Soil nutrient values were compared to Alberta Agriculture adequate, marginal and deficient limits.

Tissue nitrogen was normal or above normal on all alfalfa fields (Fig. 2). Soil nitrogen was deficient on 98% of fields. This indicates nitrogen deficiency is not a problem and that the crops must be obtaining adequate nitrogen by dinitrogen fixation since soil nitrogen is low. This may also indicate southern Alberta irrigated alfalfa fields have a higher protein content than alfalfa produced in the USA. More analysis of forage samples in addition to tissue samples needs to be done to confirm if this is so.

Tissue phosphorus by USA sufficiency limits was low on 32% of fields sampled over 3 years (Fig. 3). Soil phosphorus was deficient on 67% and marginal on 22% of fields sampled. Alfalfa fields usually receive phosphorus fertilizer only at the time of seeding. The soil phosphorus test used in Alberta does not do a good job of recognizing fertilizer phosphate remaining in the soil. This may explain why more than twice as many fields tested deficient in soil phosphorus than low in tissue phosphorus. All fields that tested low in tissue phosphorus also tested deficient in soil phosphorus. More work is needed to confirm why the soil phosphorus test is frequently indicating a deficiency which is not present.

Tissue potassium was low by USA sufficiency limits on 71% of all alfalfa fields (Fig.4). When tissue potassium was compared to midwest -USA DRIS norms, 34% of fields are more than 1 standard deviation below and no fields are more than one standard deviation above these norms. Soil potassium by Alberta Agriculture standards was marginal on 7% of fields and adequate on 93%. Potassium fertilizer trials need to be done on these fields with marginal soil potassium and the many fields that test adequate in soil potassium and deficient in tissue potassium.

Tissue zinc tested low on 9% (5 fields) of alfalfa fields by USA sufficiency standards but was not low on any fields when compared to DRIS norms (Fig 8). Of the 5 fields that tested low 2 were the highest yielding fields in 1990 and 1991. By Alberta soil test standards 45% of fields test marginal and 11% (6 fields) test deficient in zinc. There is only one field that tests deficient in both tissue and soil zinc. Agreement is poor between tissue and soil zinc tests but there does not appear to be a major problem with zinc deficiency.

Tissue copper is low on 4% of fields tested by USA sufficiency limits and Georgia DRIS norms (Fig. 9). All of the fields tested had adequate amounts of soil copper. In 1990 and 1991 tissue boron was normal by both USA sufficiency limits and by midwest USA DRIS norms (Fig. 10). Soil manganese is adequate by Alberta Agriculture standards on all fields in 1990 and 1991.

Grain and Forage Corn

Soil nitrate nitrogen was deficient on 93% of all corn fields in 1991 and 21% of all corn fields in 1990 (Fig. 11). Tissue nitrogen was below the midwest DRIS norms on 100% of forage and 82% of the grain corn fields in 1991. This was similar to 1990 results (Fig. 12). July rainfall was above normal in 1991 which would have caused leaching of soil nitrogen and reduced the opportunity of farmers to add nitrogen through their irrigation systems. Total soil nitrogen (nitrate + ammonium N) from 0-60 cm is adequate or above 15 ppm on 29% of fields. Two fields which have 96 ppm and 70 ppm total N are excessively high and liable to appreciable losses of N by leaching.

Soil phosphorus was deficient on 36% and marginal on 32% of corn fields in 1991 (Fig. 13). Soil phosphorus was similarly low in 1990. Tissue phosphorus was more than 0.5% below the midwest USA DRIS norms on 75% of corn fields in 1991 and 89% of corn fields in 1990. There is little relationship between tissue phosphorus and soil phosphorus. High soil phosphorus frequently occurs on corn fields with lower than average yields. High tissue phosphorus usually occurs on corn fields with above average yields.

Tissue potassium was more than 0.5% lower than midwest USA DRIS norms on 18% of grain corn fields and 94% of forage corn fields in 1991 (Fig 14). In 1990 most of the corn fields were more than 0.5% lower in potassium than midwest USA DRIS norms. By Alberta Agriculture standards soil potassium was never deficient but was marginal on 25% of corn fields in 1991 and 21% of corn fields in 1990.

References

Beaufils, E.R. 1973. Diagnosis and Recommendation Integrated System (DRIS). A general scheme of experimentation based on principles developed from research in plant nutrition. Soil Sci. Bull. 1. Univ. of Natal Pietermaritzburg, South Africa.

McKenzie, R.C. 1991. DRIS Systems in Soilutions 1:#4. pp. 4-5.

McKenzie, R.C., Butt, J.A., Kryzanowski, L.M., and Heaney, D.J. 1991. DRIS Analysis of Forage Alfalfa, Grain Corn, Silage Corn and Greenhouse Cucumbers. *In* ASCHRC Pamphlet 91-16. Soil and Water Program 1990. pp. 33-45.

Walworth, J.L. and Sumner, M.E. 1987. The Diagnosis and Recommendation Integrated System. Adv. Soil Sc. 6:149-188.

Figure 1. Age of stand and soil EC vs. yield of alfalfa.

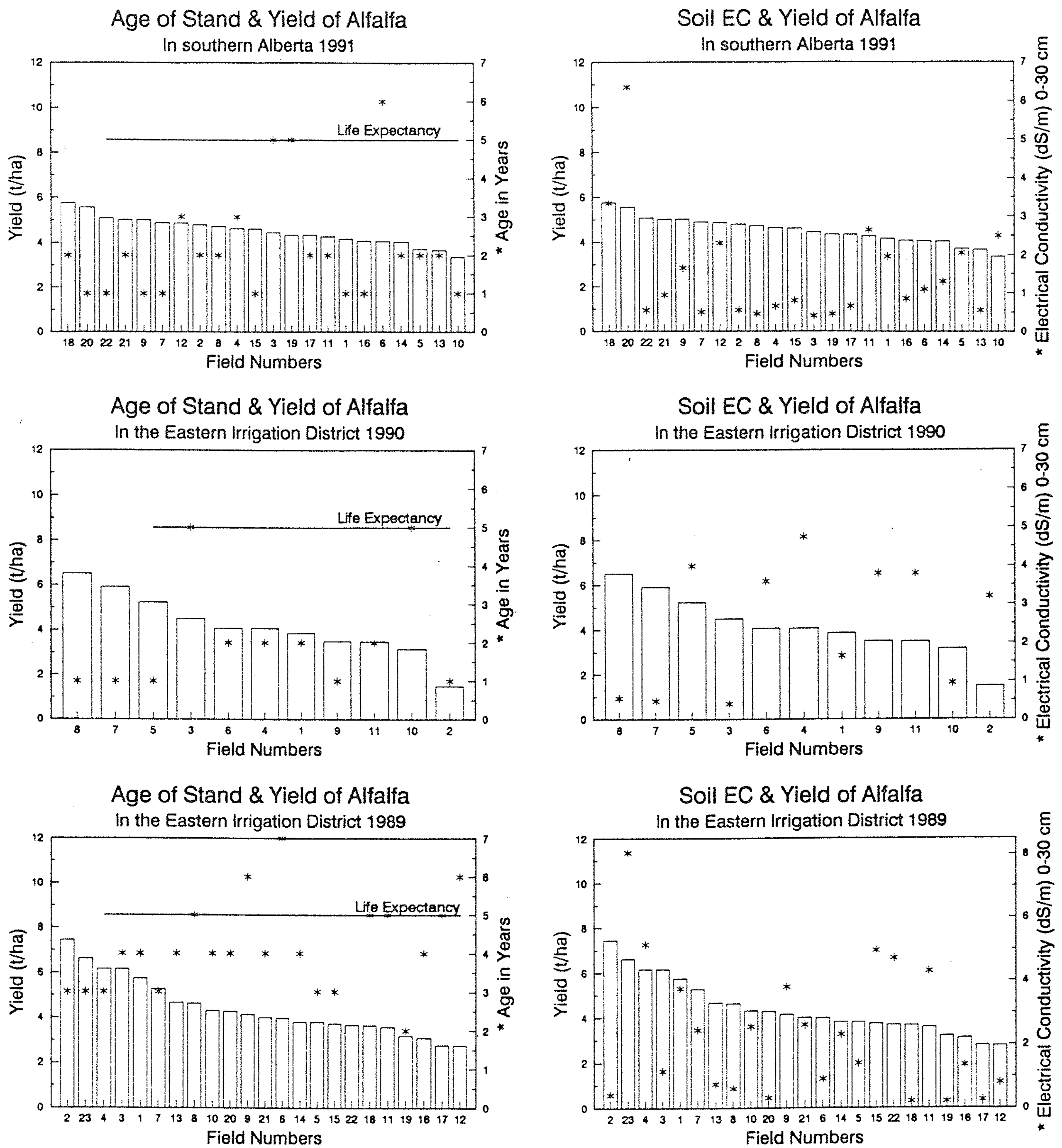


Figure 3. Tissue phosphorus and soil phosphorus vs. yield of alfalfa.

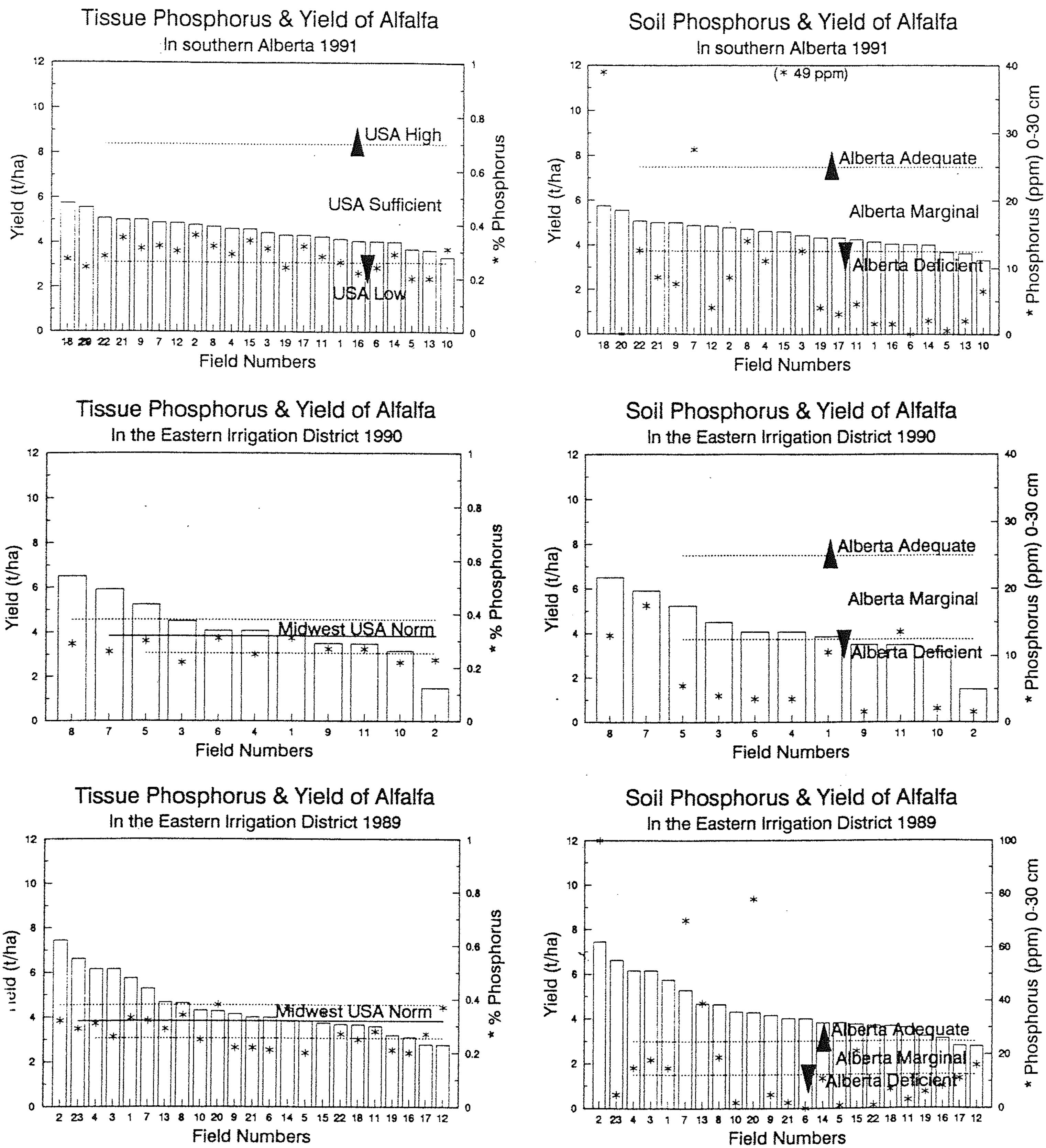


Figure 2. Tissue nitrogen and soil nitrate vs. yield of alfalfa.

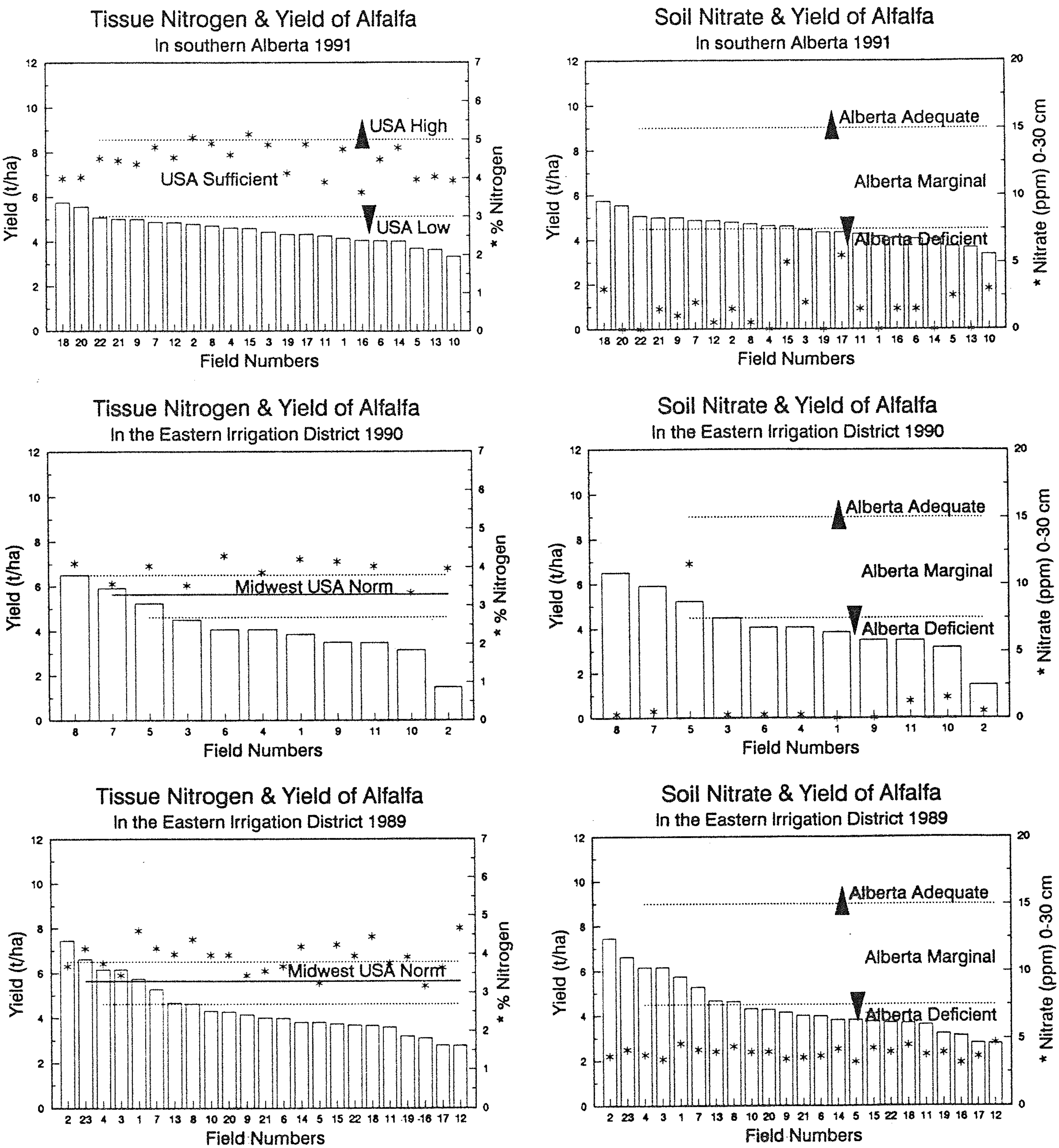


Figure 4. Tissue potassium and soil potassium vs. yield of alfalfa.

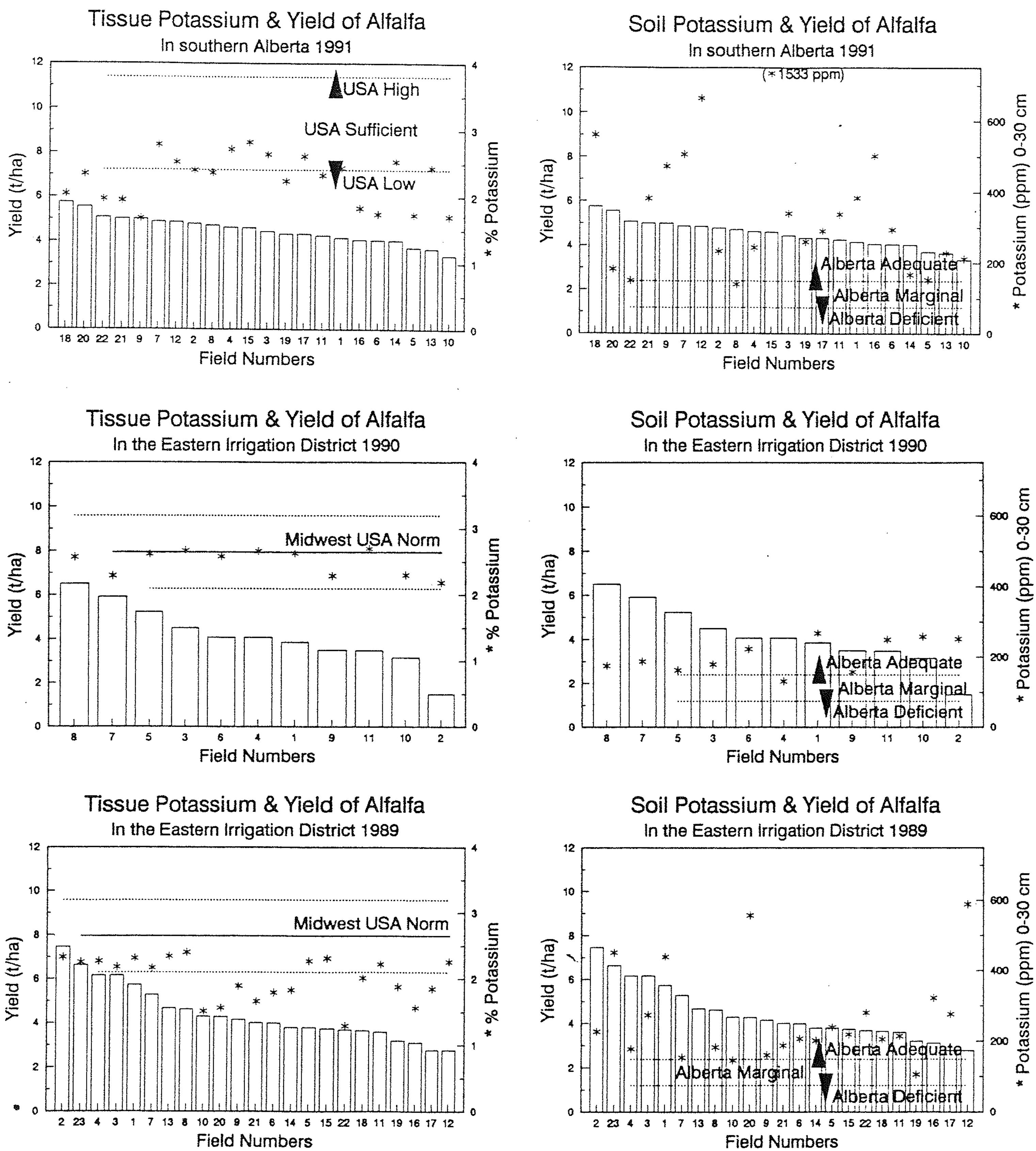


Figure 5. Tissue nitrogen to phosphorus and nitrogen to potassium ratios vs. yield of alfalfa.

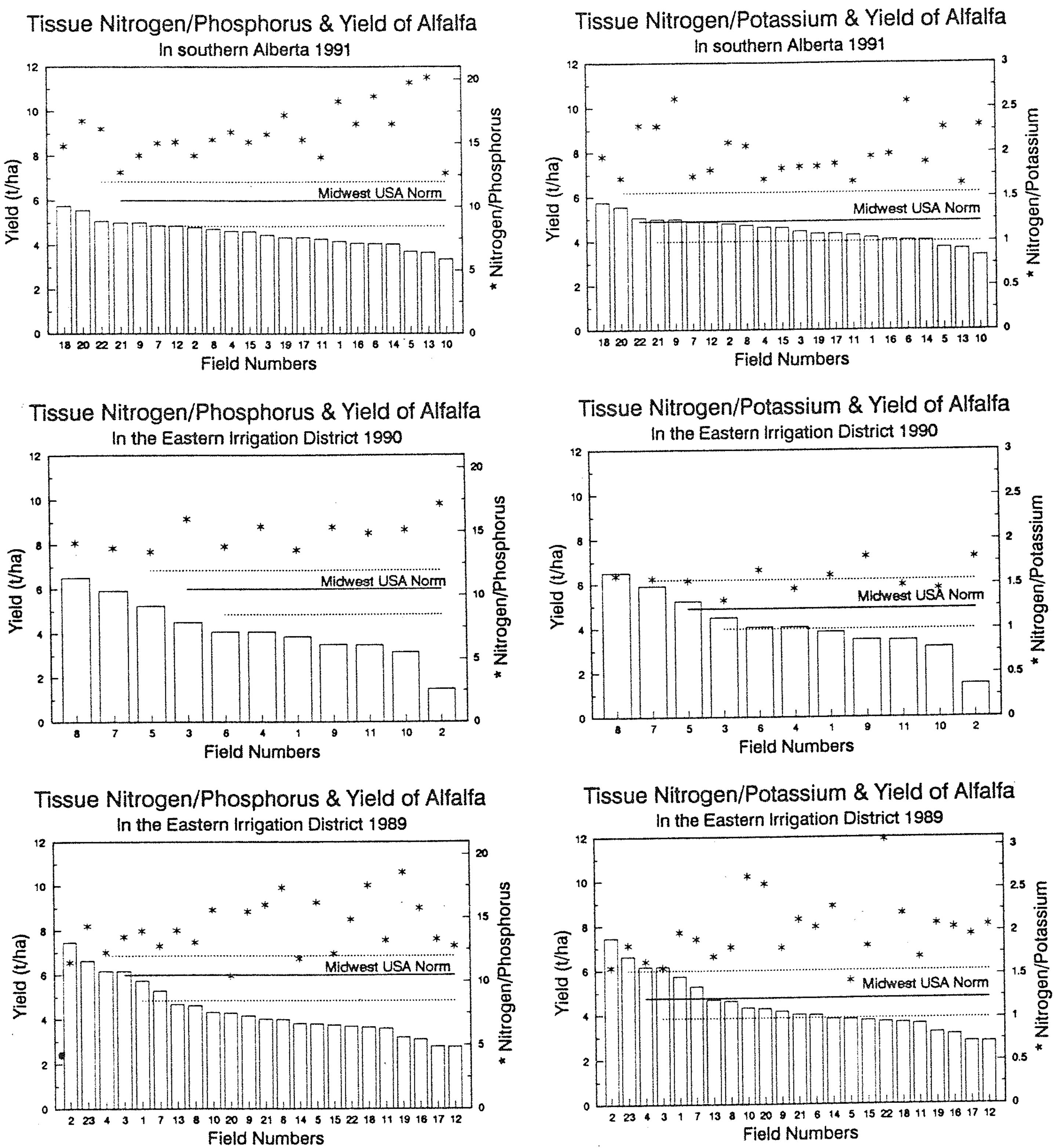


Figure 6. Tissue zinc to phosphorus and phosphorus to potassium ratios for alfalfa.

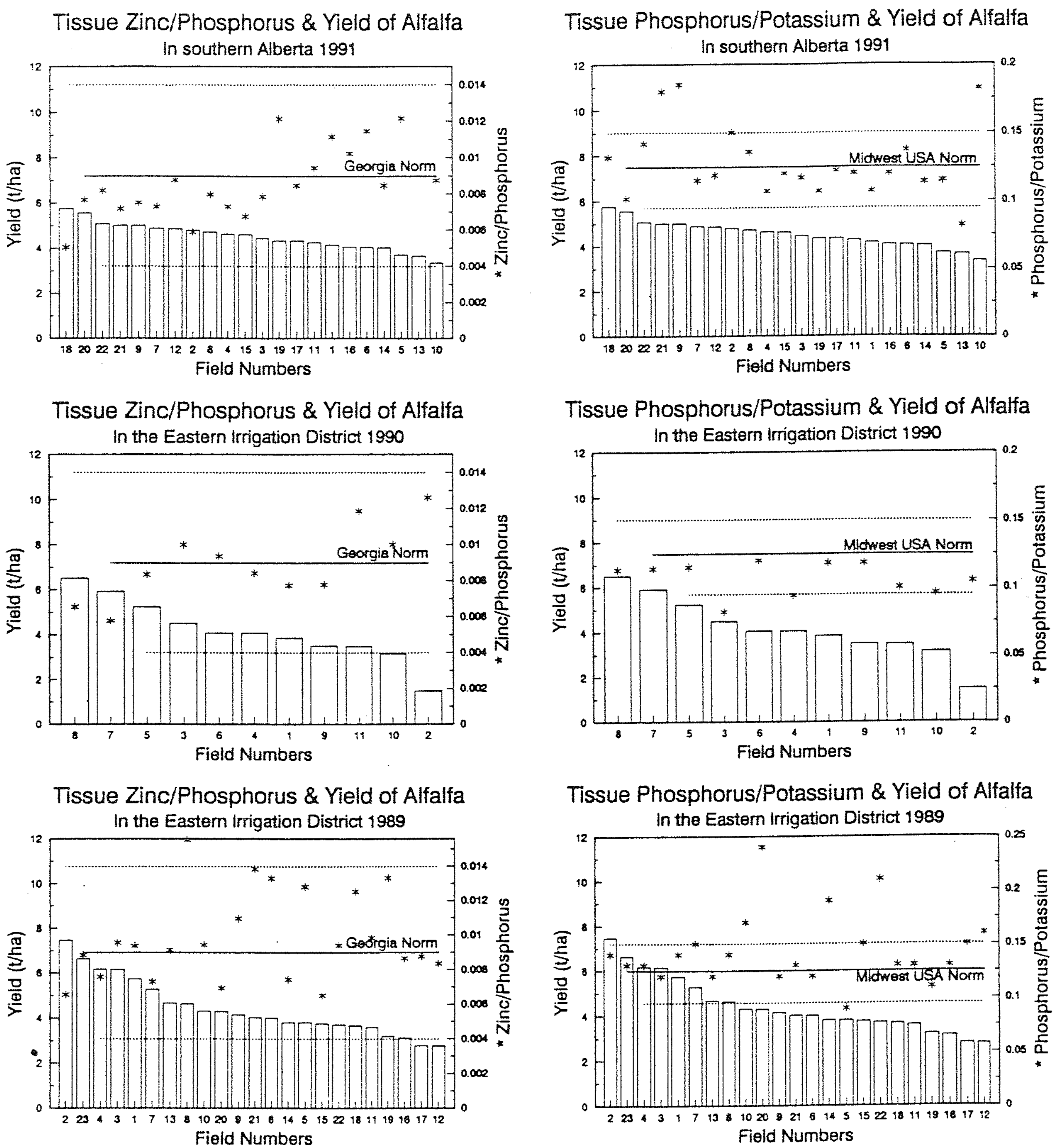


Figure 7. Tissue calcium and soil sodium vs. yield of alfalfa.

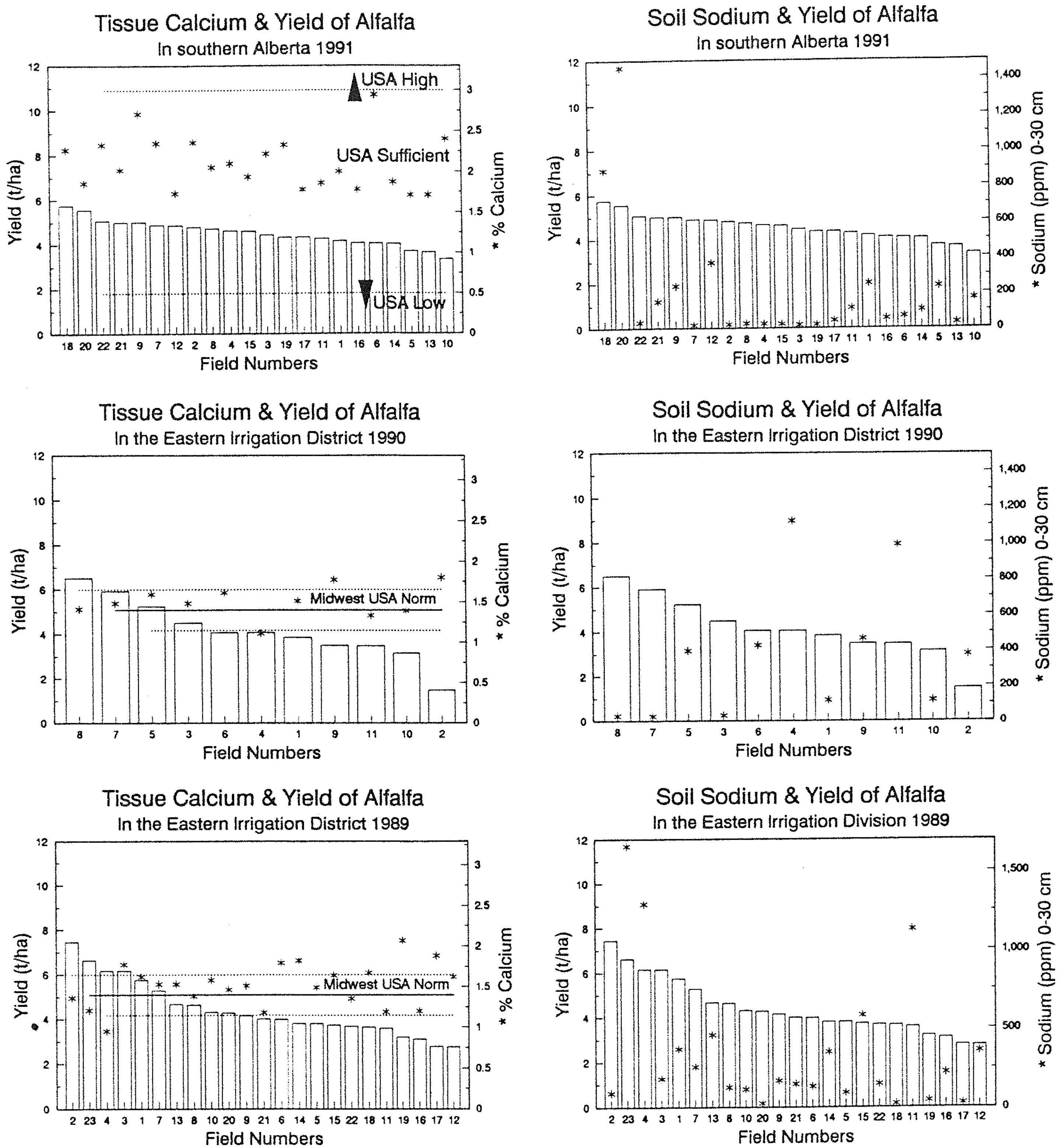


Figure 8. Tissue zinc and soil zinc vs. yield of alfalfa.

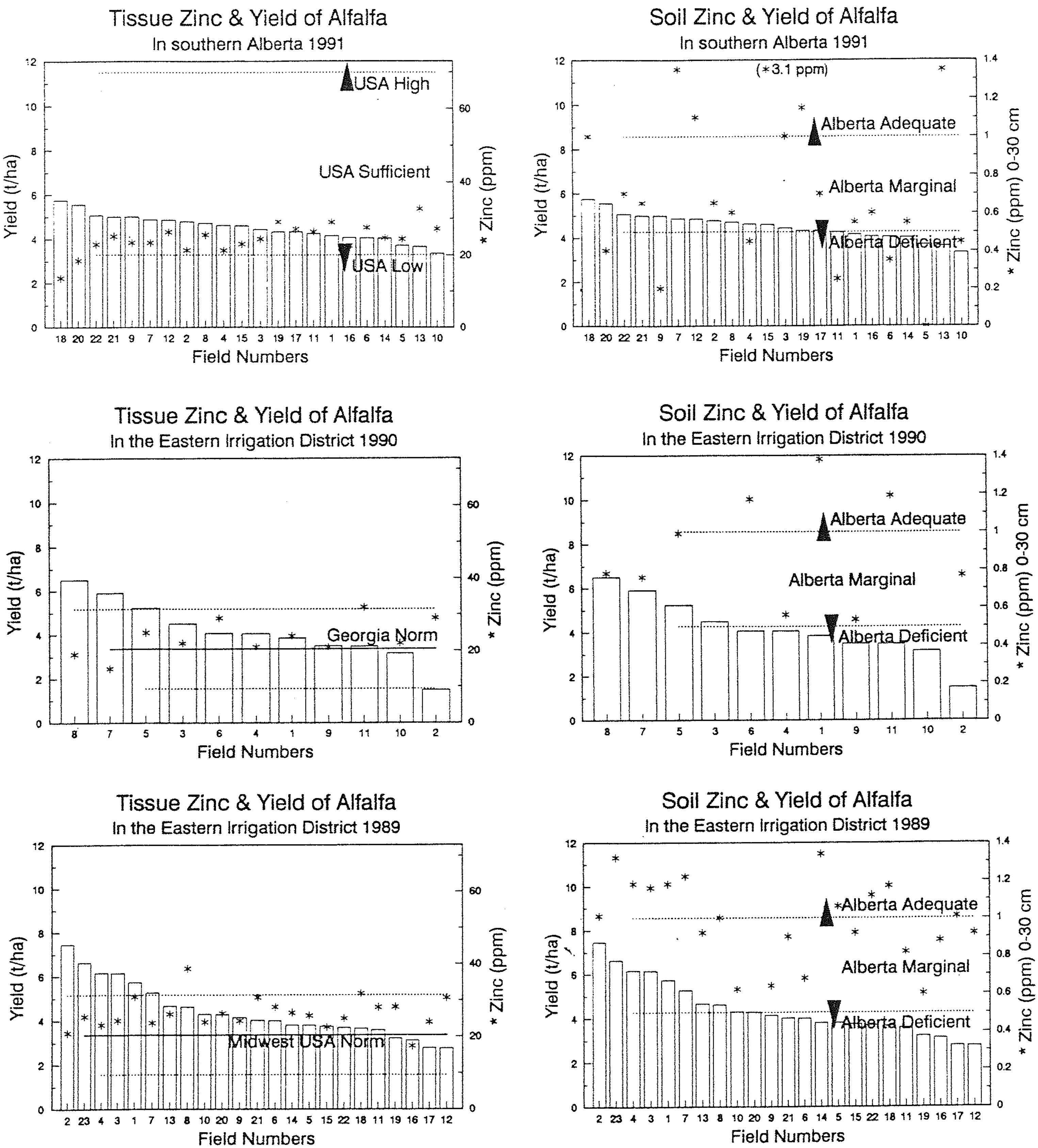


Figure 9. Tissue copper and soil copper vs. yield of alfalfa.

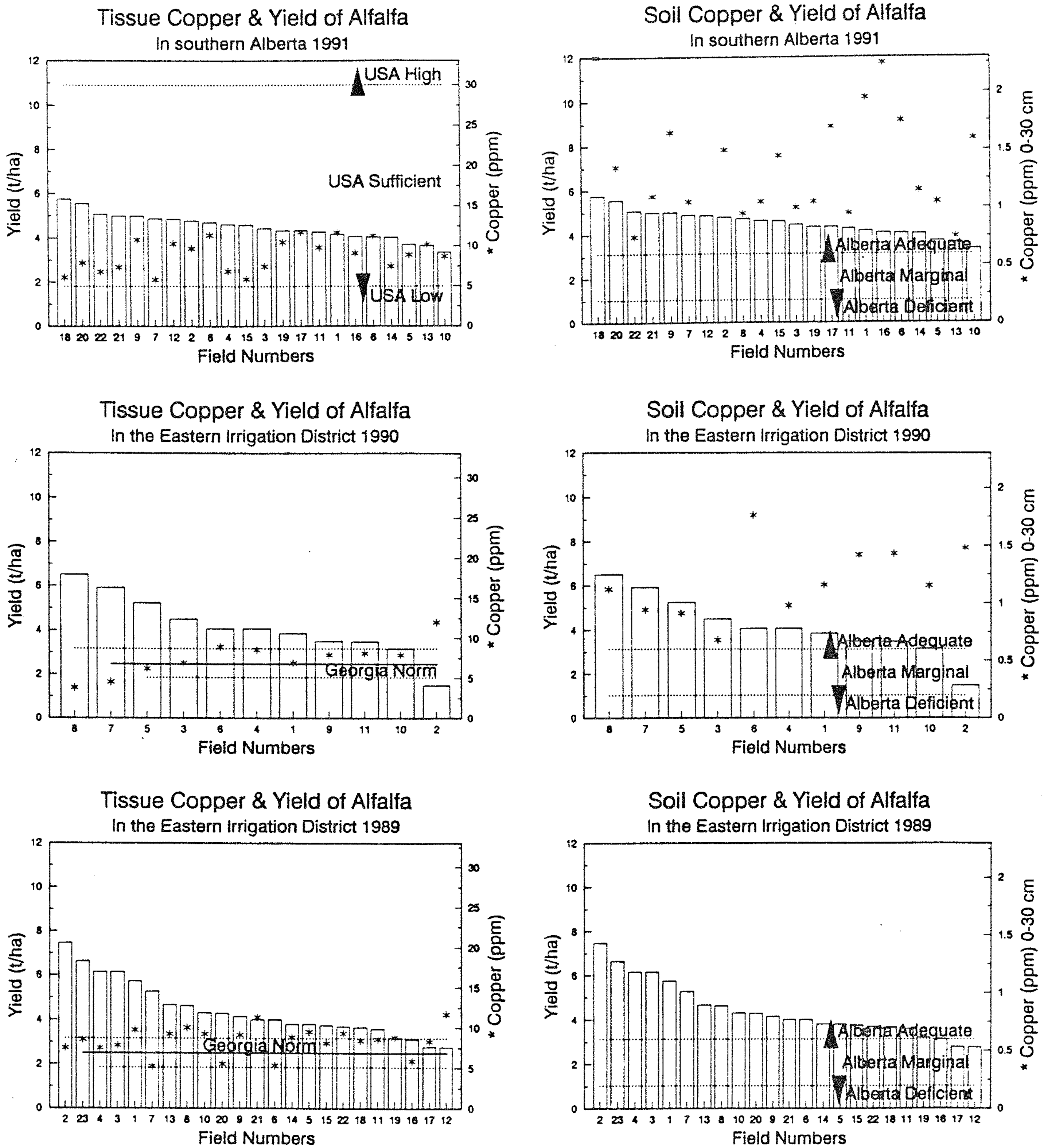


Figure 10. Tissue boron and soil manganese vs. yield of alfalfa.

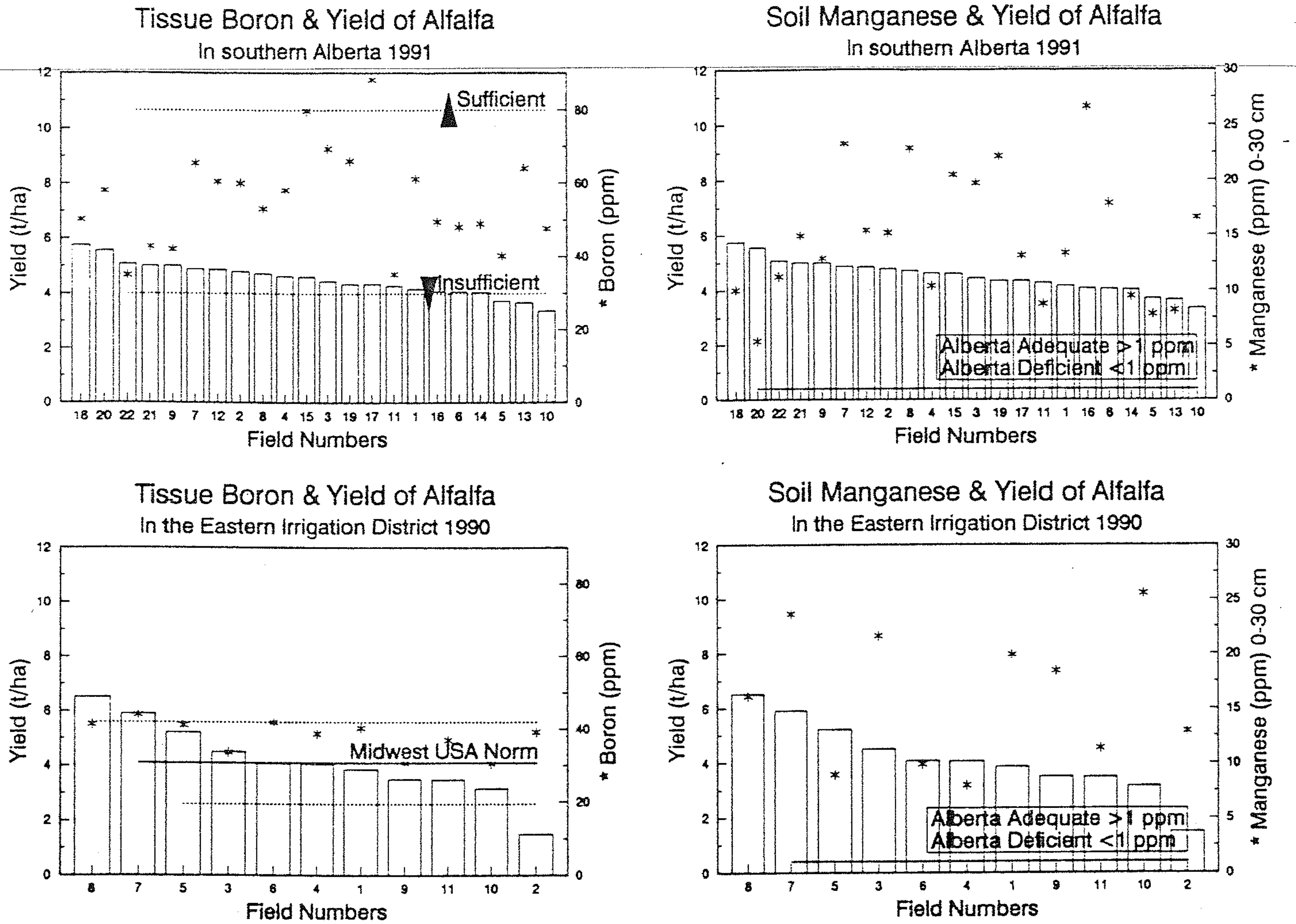


Figure 11. Soil EC and soil nitrate vs. the yield of grain and forage corn.

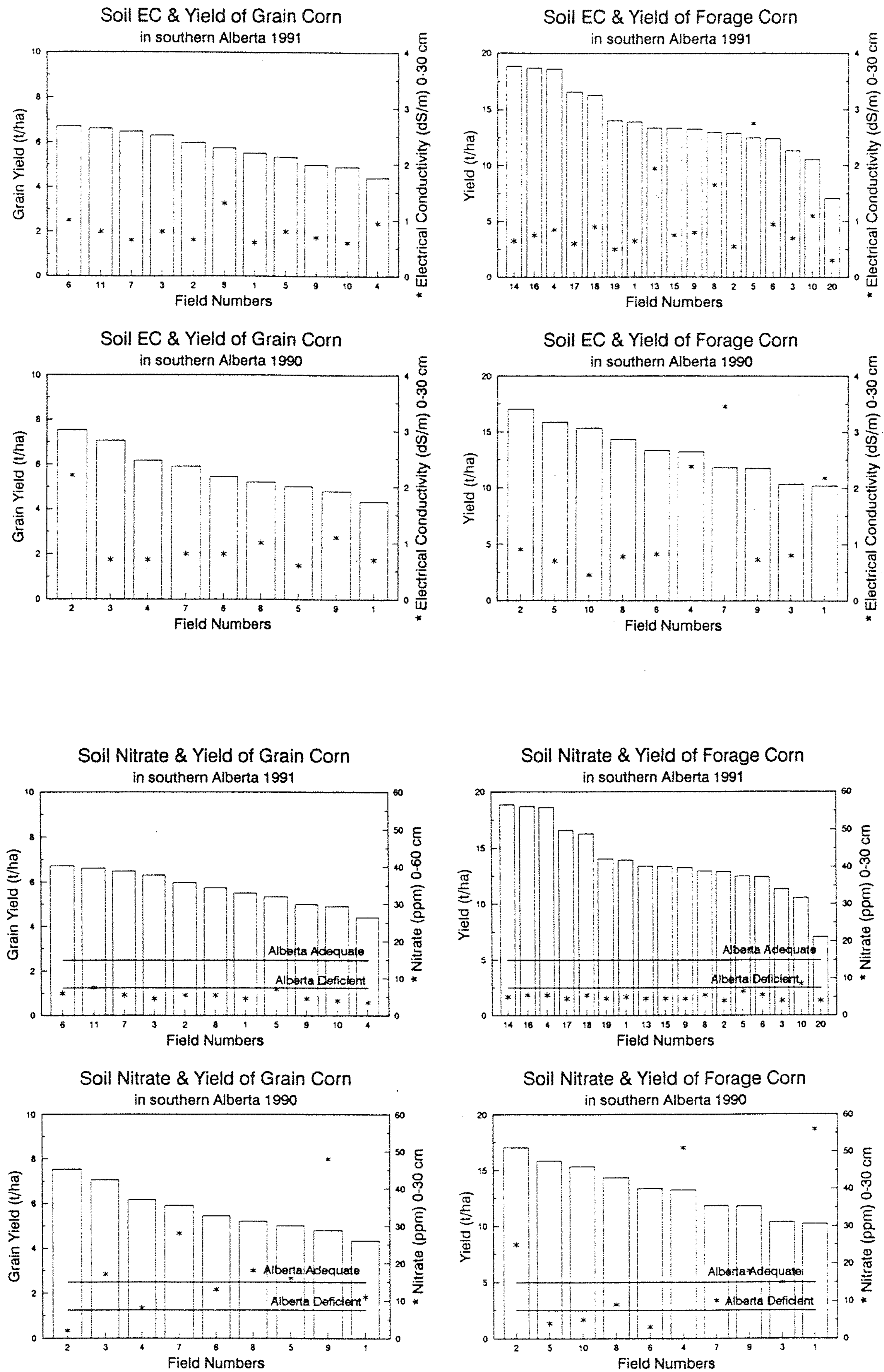


Figure 12. Tissue nitrogen and soil nitrate and ammonium nitrogen vs. the yield of grain and forage corn.

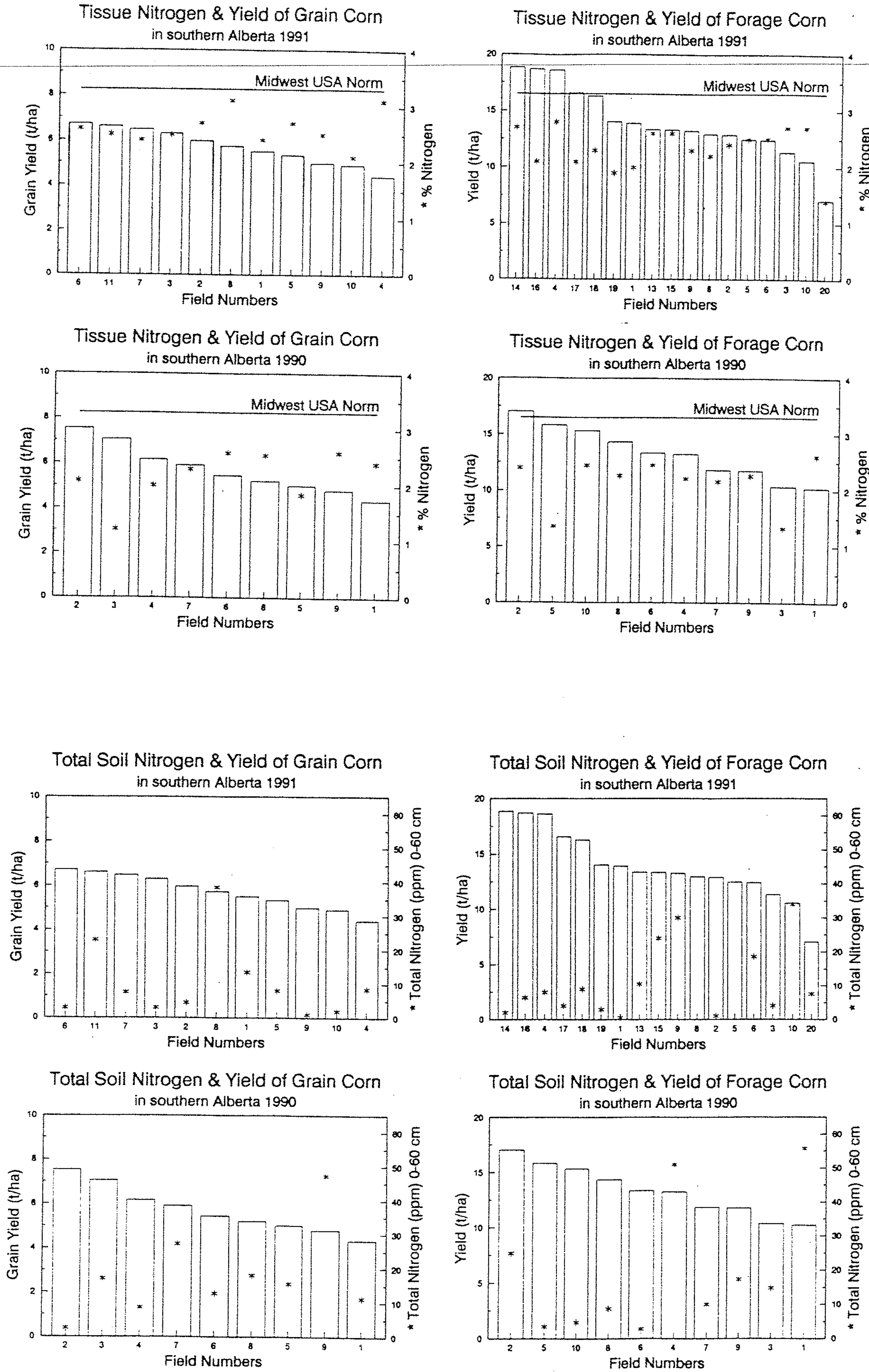


Figure 13. Tissue phosphorus and soil phosphorus vs. the yield of grain and forage corn.

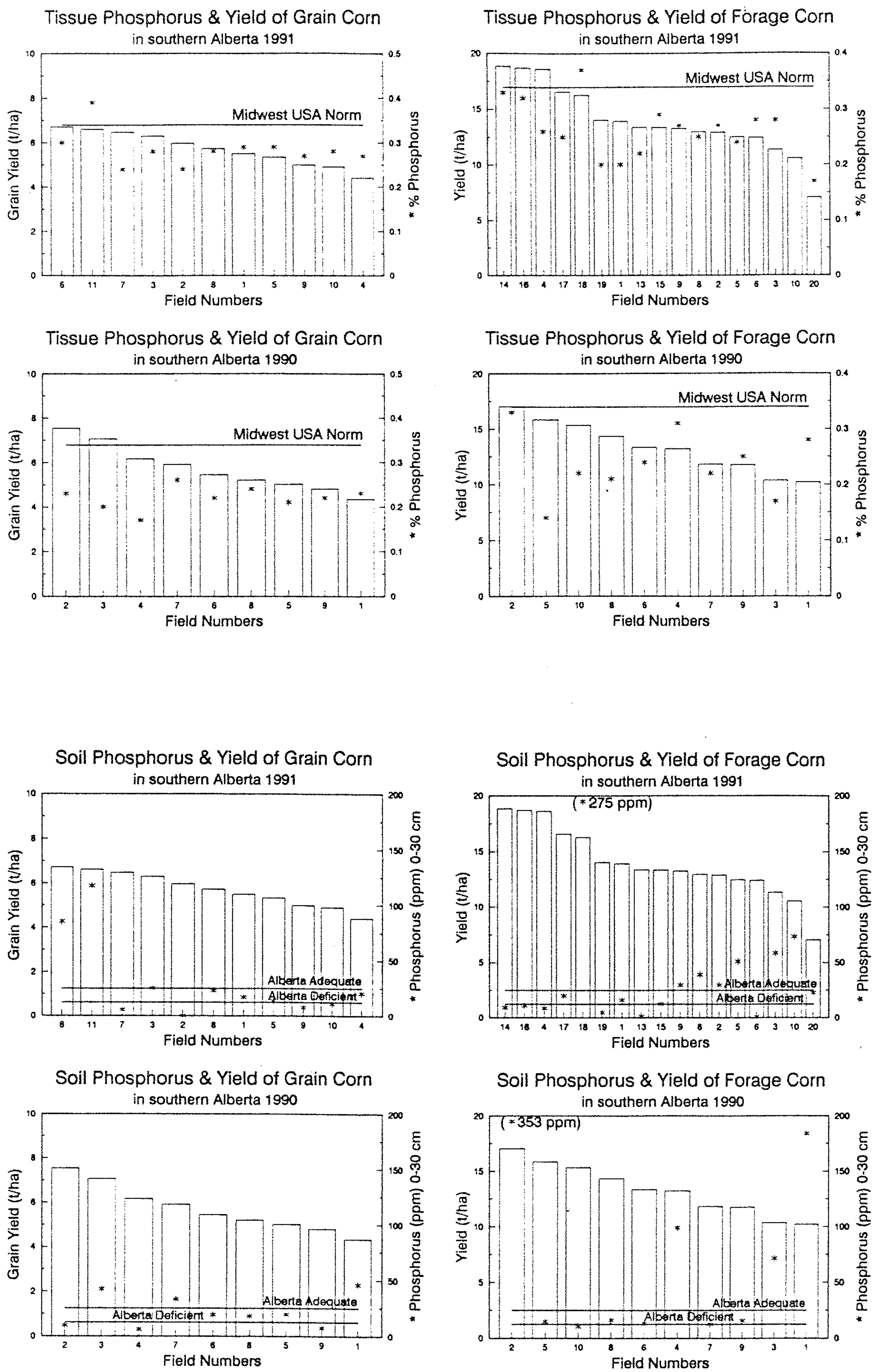


Figure 14. Tissue potassium and soil potassium vs. the yield of grain and forage corn.

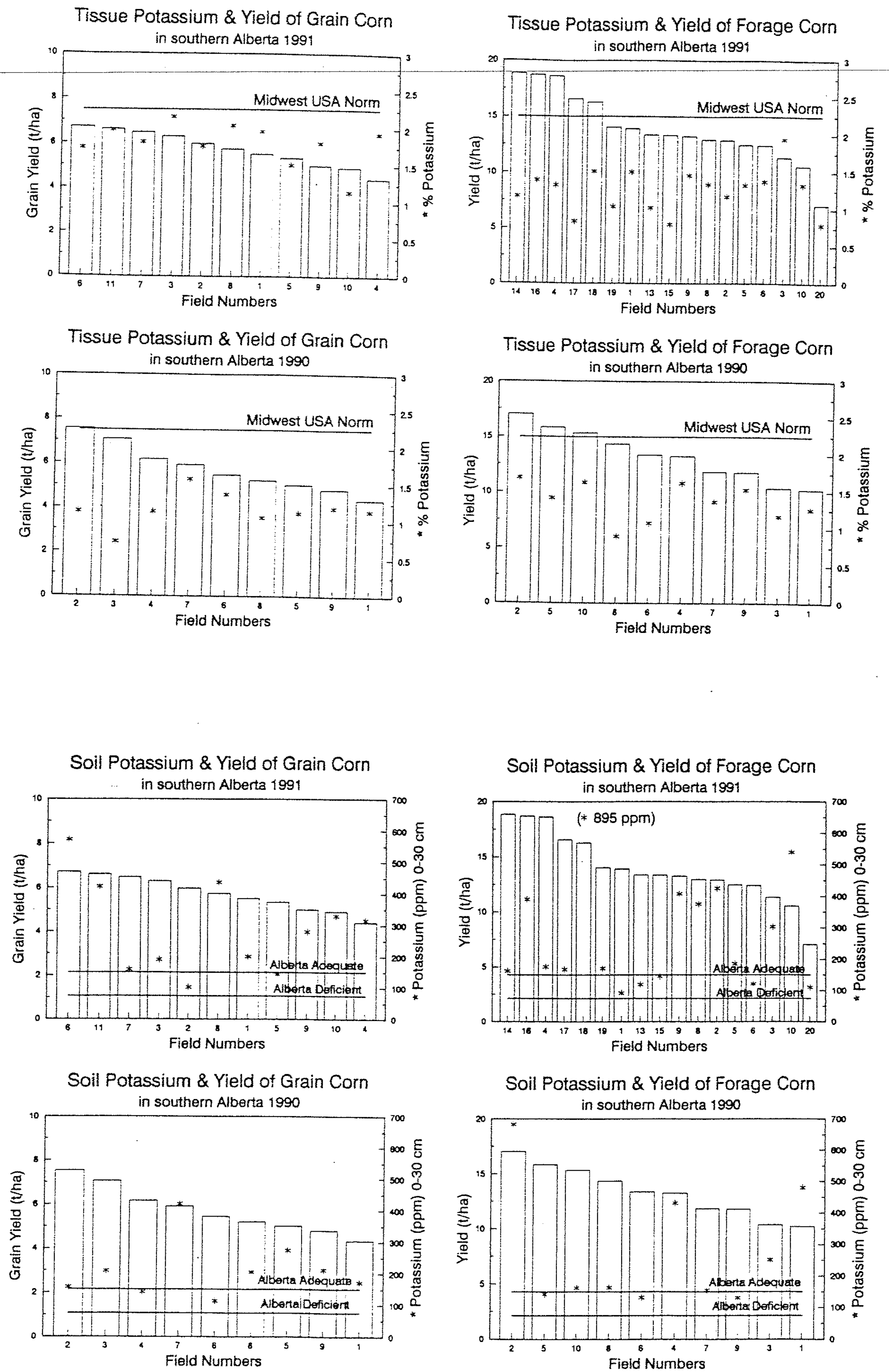


Figure 15. Tissue sulphur and soil sulphate sulphur vs. the yield of grain and forage corn.

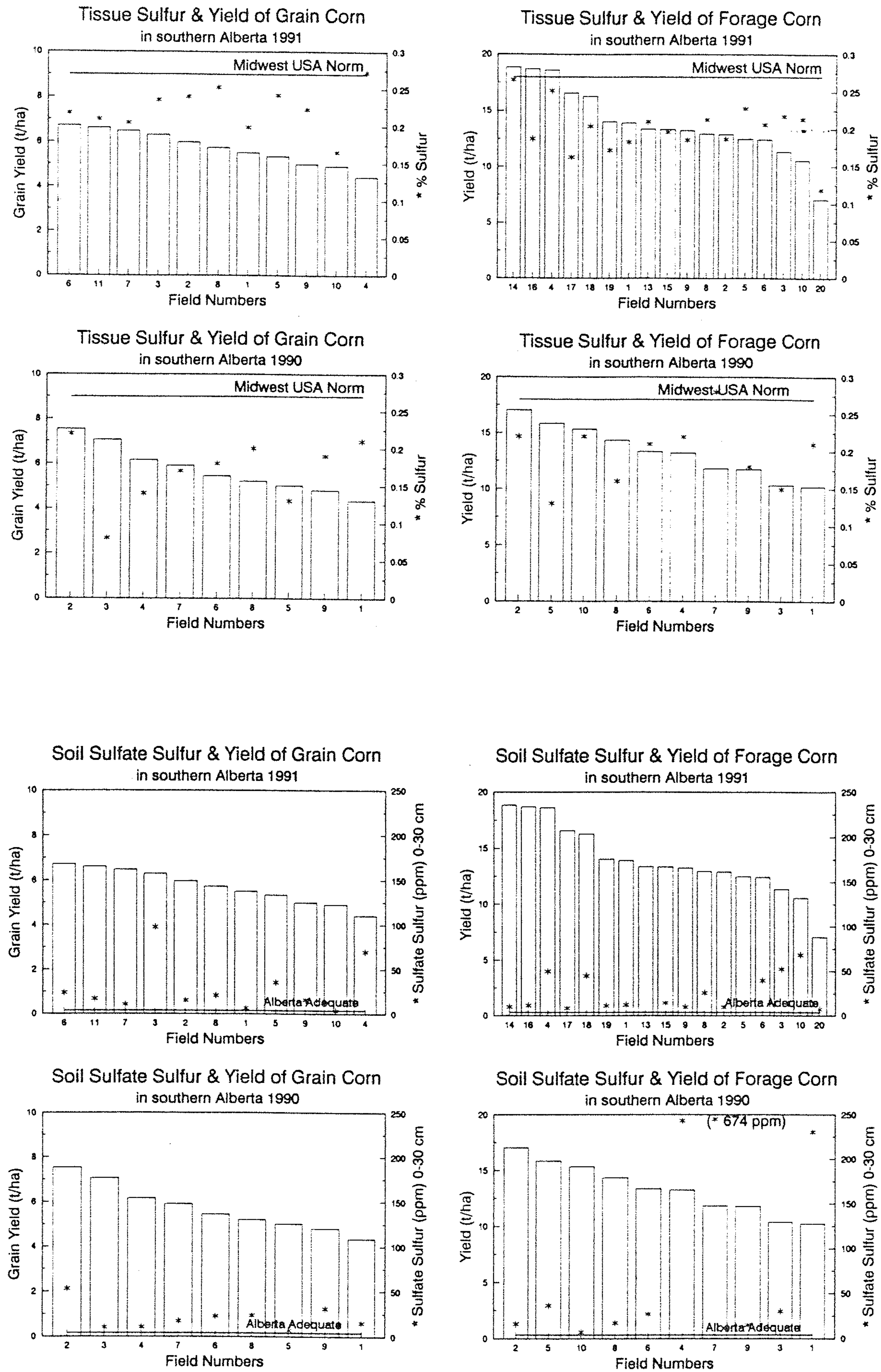


Figure 16. Tissue calcium and soil calcium vs. the yield of grain and forage corn.

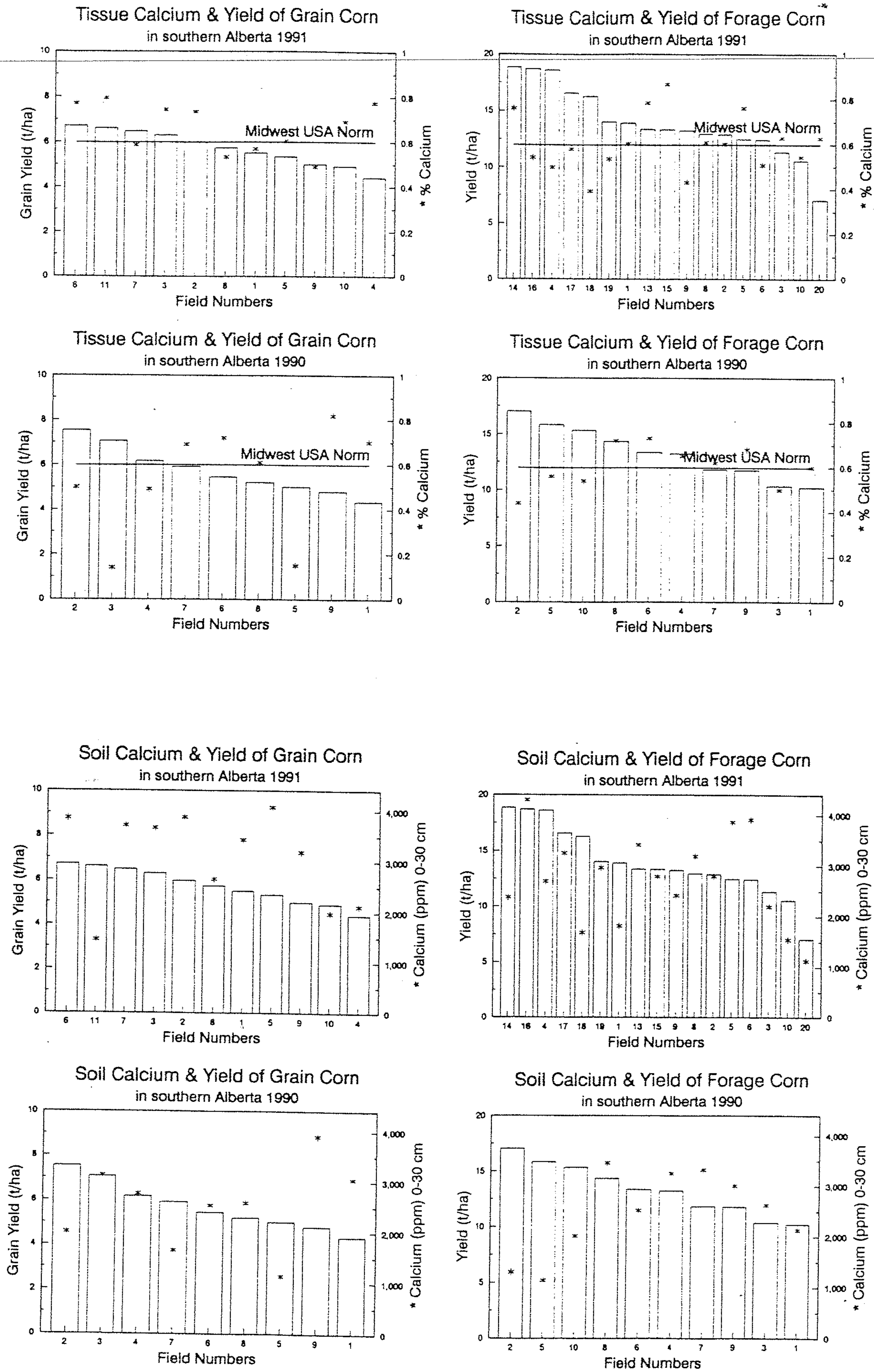


Figure 17. Tissue magnesium and soil magnesium vs. the yield of grain and forage corn.

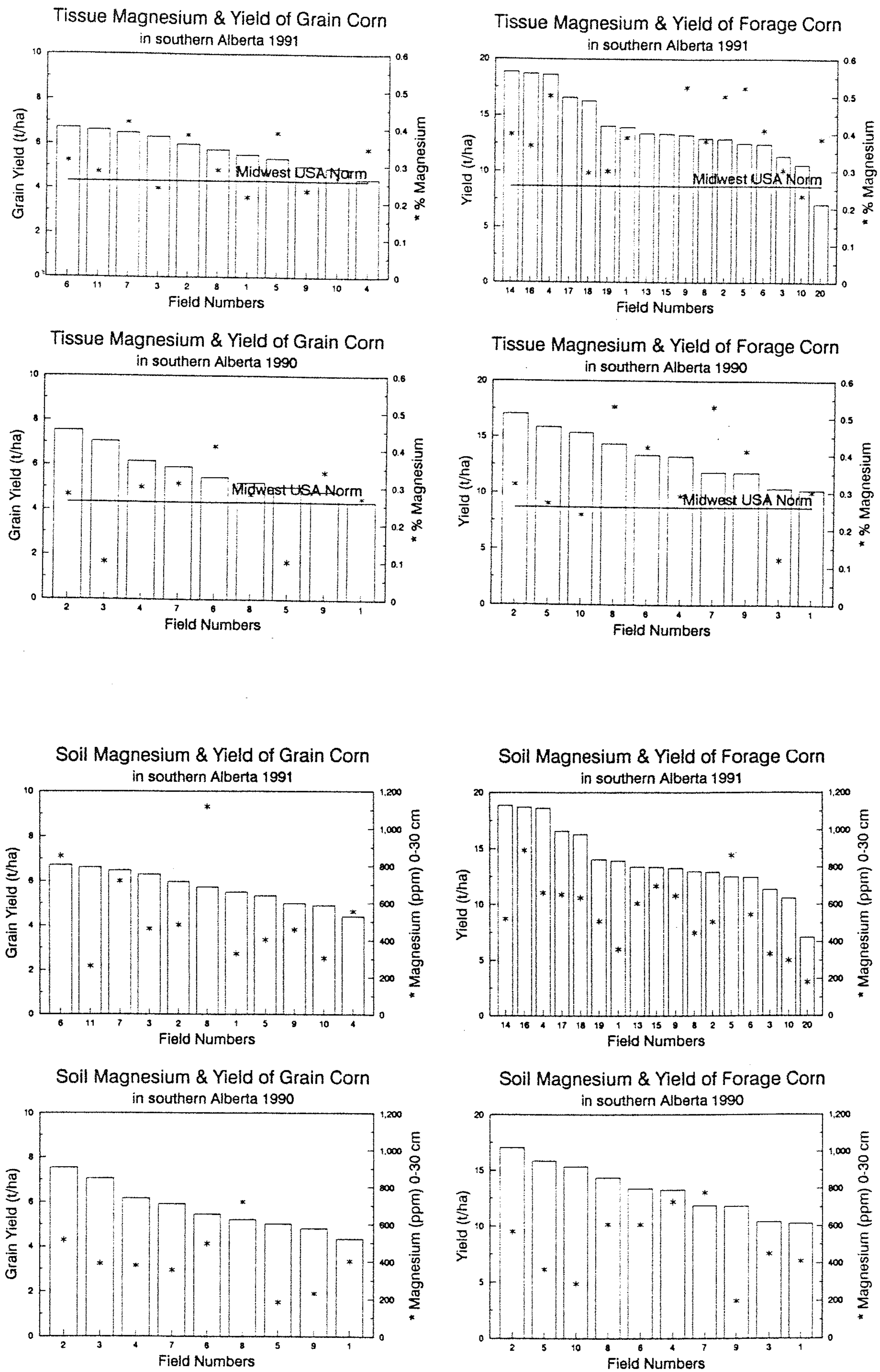


Figure 18. Tissue zinc and soil zinc vs. the yield of grain and forage corn.

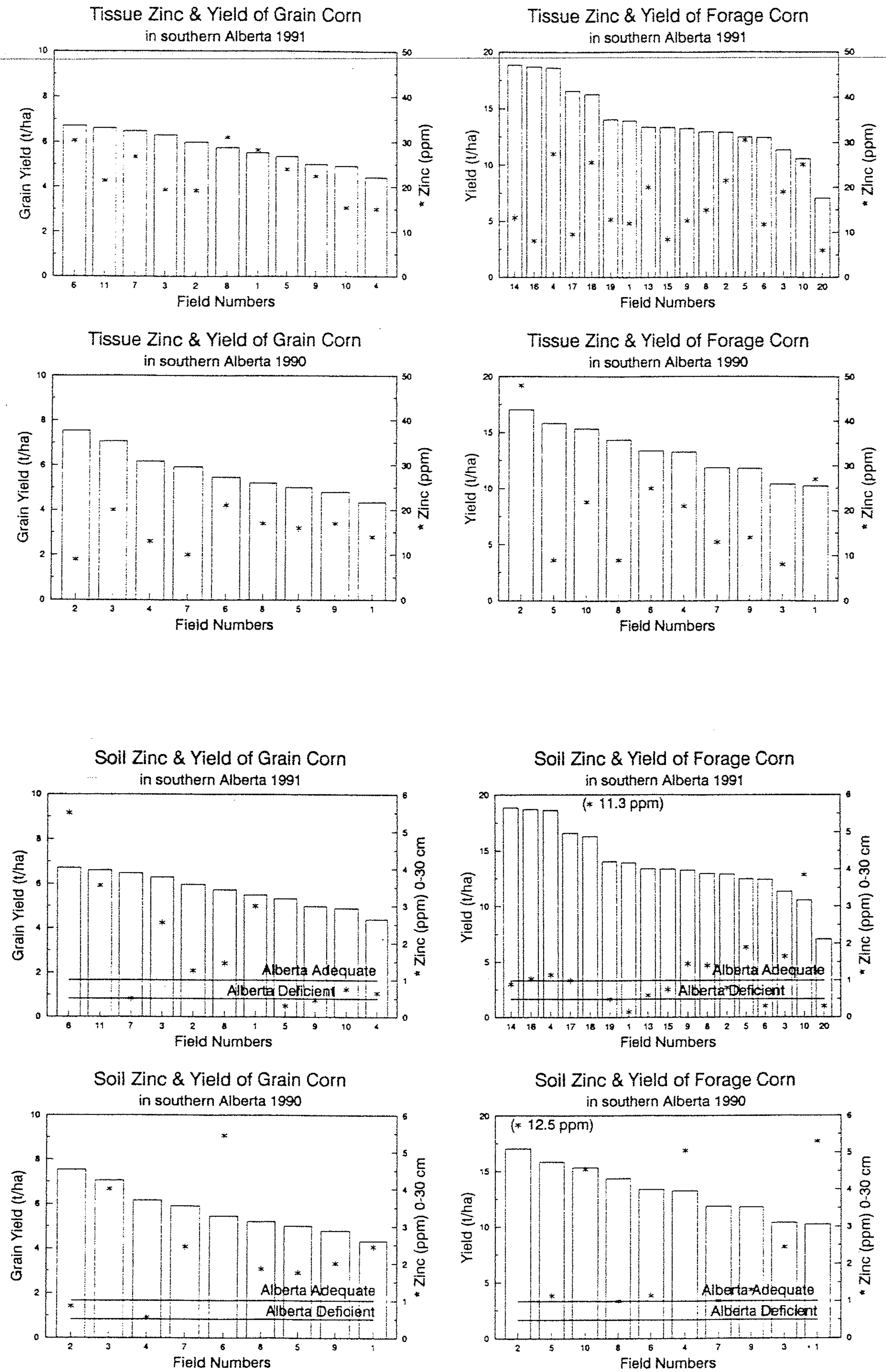


Figure 19. Tissue copper and soil copper vs. the yield of grain and forage corn.

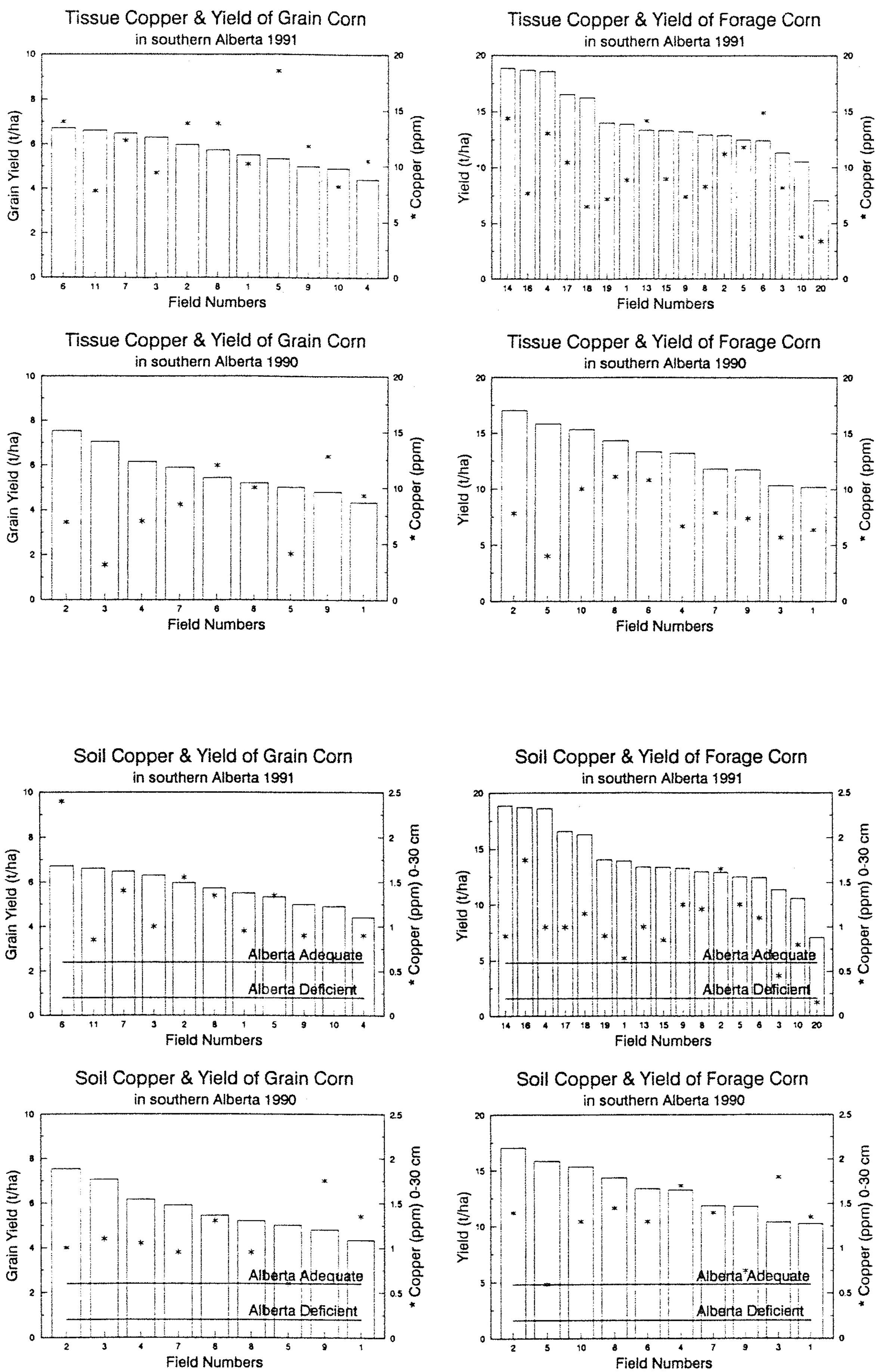


Figure 20. Tissue boron and soil boron vs. the yield of grain corn and forage corn.

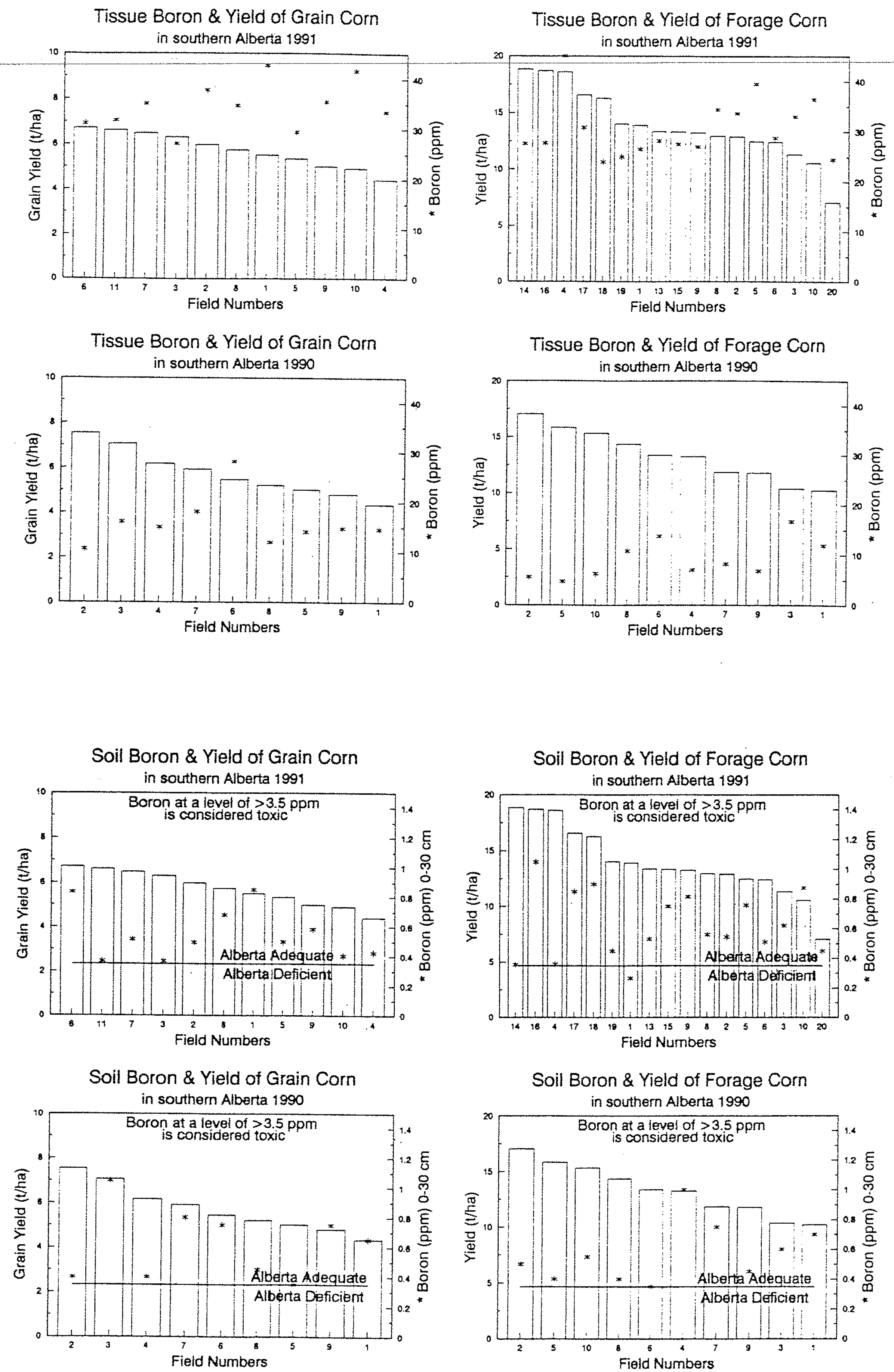


Figure 21. Tissue manganese and soil manganese vs. the yield of grain corn and forage corn.

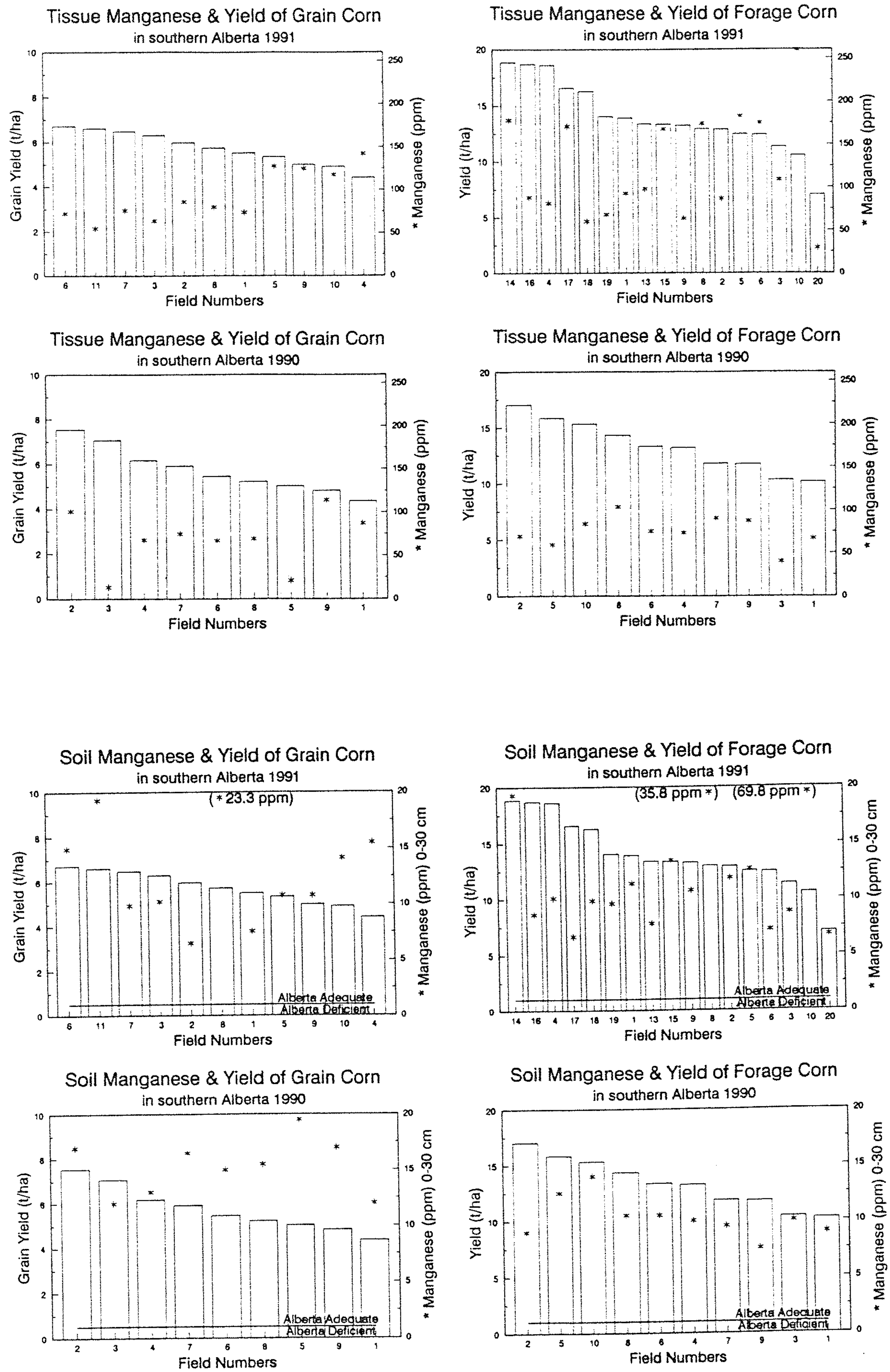


Figure 22. Tissue zinc to phosphorus and copper to phosphorus ratios vs. the yield of grain corn and forage corn.

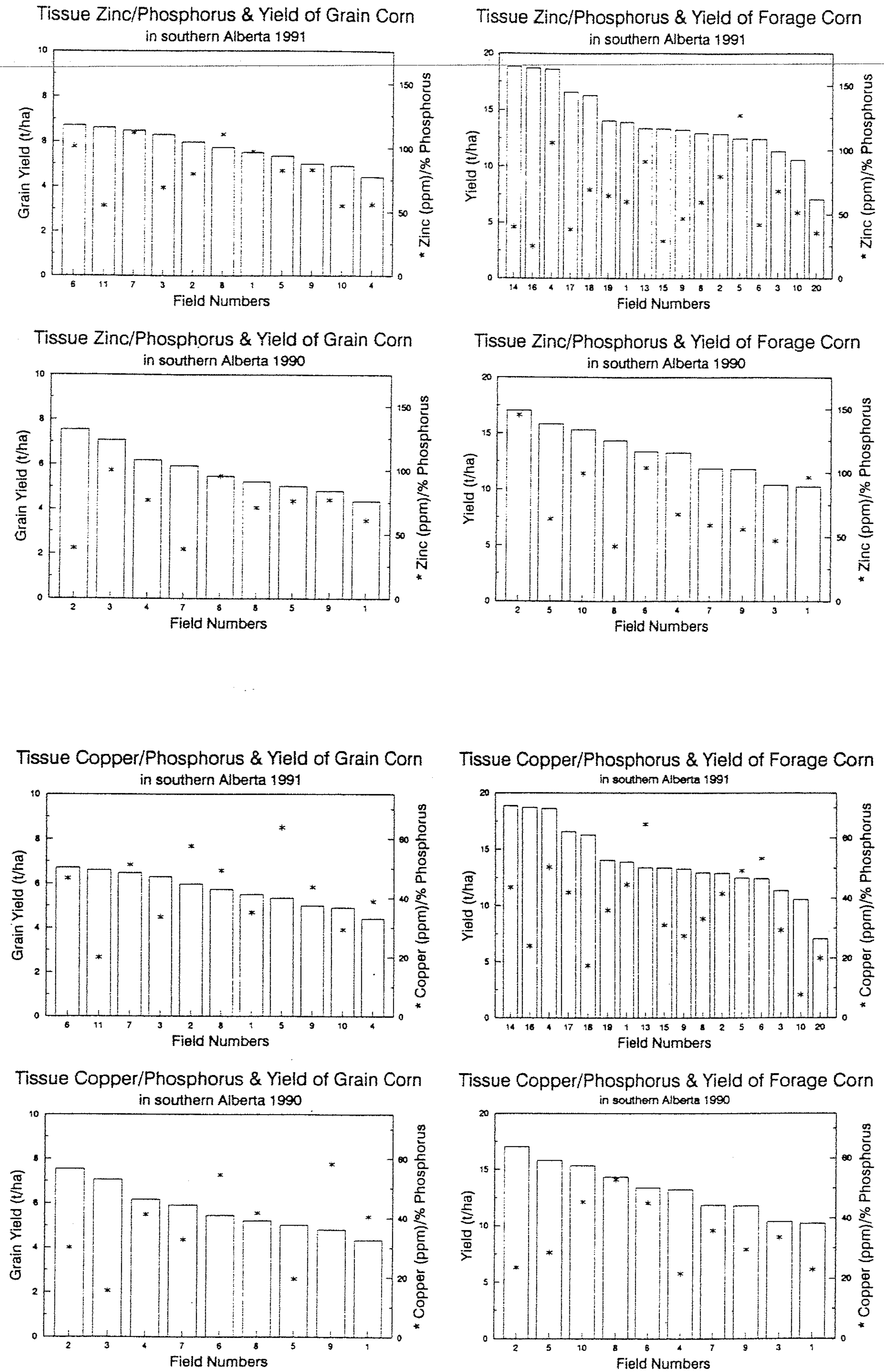


Figure 23. Tissue nitrogen to phosphorus and nitrogen to potassium ratios vs. the yield of grain and forage corn.