ASSESSMENT OF THE COMBINED EFFECTS OF SOIL pH AND CARBONATES ON SOYBEAN YIELD AND DEVELOPMENT OF IRON DEFICIENCY CHLOROSIS

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Introduction

Soybean is extensively grown in areas of the Midwest where fields often have areas of acid to calcareous soils intermingled in complex spatial patterns. Soil pH is highly buffered by carbonates, and measured pH usually ranges from 7.5 to 8.3 depending on the concentration of CO_2 and other factors. Soybean grown on high-pH calcareous soils often shows iron (Fe) deficiency chlorosis (IDC). Symptoms of IDC include yellowing of interveinal areas of young leaves and, as the deficiency becomes severe, brown necrotic spots can appear in leaf margins and growth of affected plants can be severely limited. Although Fe is the fourth most abundant element soils, its availability to the plants depends on various soil properties. High pH and bicarbonate presence reduce the solubility of Fe compounds, Fe availability for plants, and can limit soybean yield. However, good relationships between IDC symptoms, soil pH and carbonate concentration, and yield have been difficult to establish. Possible reasons are that the effects of these factors are attenuated by soil water content, other environmental conditions that vary over time, differences between soybean varieties in tolerance Fe deficiency, similar symptoms produced by other factors, and effects of other soil properties reducing yield in calcareous soils. For example, the incidence of soybean cyst nematodes (SCN) tends to be more frequent and severe in high-pH soils (Tylka et al., 1998) and many calcareous soils in North Central Iowa are in low-laying field areas prone to excess moisture. Also, study of these relationships has been complicated by the usual intermingling of acid and calcareous soils in complex spatial patterns at a small scale. Iowa research has shown that aerial color photographs taken during the growing season reveal clear spatial patterns in soybean growth that often correspond to field areas with calcareous soil (Blackmer and Rogovska, 2000). The spatial patterns of areas with reduced growth and (or) yellow canopy color sometimes approximately coincide with units of soil survey maps, but the patterns often occur on a much finer scale and show continuous gradation rather than distinct boundaries. The objective of our research was to learn how much of the variability in soybean yield could be explained by soil pH and carbonate content by using remote sensing techniques to describe within-field variation in plant growth and canopy color and to select sampling areas.

Methodology

This study was conducted in Iowa fields located within the Des Moines Lobe landform, which extends from central Iowa into southern Minnesota and South Dakota and is characterized by fields with calcareous soils. Aerial imagery of early season soybean canopy was used to identify 12 fields with large within-field differences in early plant growth and apparent IDC symptoms. Photographs of the fields were taken from June through early September to monitor changes in spatial patterns of plant growth and color with a 35-mm camera pointed downward through a hole in the bottom of an airplane from a height of 3,000 to 3,600 ft above the ground using

Kodak Elite Chrome 200® film. Digitized soil survey maps (ICSS, 2001) indicated that dominant soil series in the fields were Clarion, Nicollet, Webster, and Canisteo while all fields had smaller areas with the series Harps and Okoboji. The series Harps always has a calcareous surface layer whereas the series Canisteo and Okoboji often have a calcareous surface layer.

Georeferenced aerial images of soybean canopy, digitized soil survey maps, and global positioning system receivers were used to identify data collection areas to include the widest possible ranges of plant height and color within each field. Ten to 28 areas approximately 30 to 75 ft^2 in size were identified within each field without prior to knowledge of soil pH or carbonate concentration. Areas 3 ft^2 in size were defined within each area at the end of the season to measure grain yield and collect soil samples. The plants were cut, dried at 140 °F, and threshed. Grain yield was expressed as yield per unit area and as relative yield by dividing the yield from each sampling area by the largest yield observed within a field and multiplying the result by 100. Use of relative yield enabled us to study relationships between yield and the soil properties across sites. Soil samples were collected immediately after grain harvest from the same small areas and from a 6-inch depth. The soil samples were analyzed for pH, percentage calcium carbonate equivalent (CCE), SCN incidence, soil-test P, K, and selected micronutrients.

Relationships between Soybean Grain Yield and Soil pH or Carbonate Content

Relationships between soil pH and relative soybean yield within individual sites indicated that yield decreased with increasing pH in all sites (data not shown), although linear trends were not statistically significant ($P < 0.05$) at three of the 12 sites. The r^2 values of significant linear models ranged from 0.22 to 0.59. Data pooled across sites (Fig. 1) indicate that a linear regression of yield on pH explained 30% of the yield variability whereas a curvilinear model (not shown) explained only a slightly higher proportion (33%). Very high yield variability at pH > 7.5 weakened the strength of the relationship across the entire pH range. Mean relative yield for 0.5 pH-unit intervals shown in Fig. 2 indicate that the frequency of low yield was much higher at pH > 6.0, although in high-pH areas sometimes yield was as high as in acid areas. The fact that high yield was more consistent for slightly acid soils (as low as pH 5.6) is consistent with previous observations in fields of the Des Moines Lobe. Liming research in Iowa (Bianchini and Mallarino, 2002) and Minnesota (Vetsch and Randall, 2004) showed high soybean yield and little or no response to lime application in similarly acidic soils of the region having calcareous subsoil. Iowa liming guidelines (Sawyer et al., 2002) recognize this trend by recommending no lime application for corn or soybean for pH > 5.9 in soil associations with calcareous subsoil compared with pH > 6.4 in other associations.

Very large yield variability at pH approximately > 7.5, where yield often ranged from 0 to 100%, can be partly explained by large variation in soil CCE. The correlation between CCE and yield within each site was negative and statistically significant ($P < 0.05$) at 11 of the 12 sites (data not shown). The r^2 of significant linear models ranged from 0.51 to 0.82. Data pooled across all sites (Fig. 2) also showed that yield decreased as soil CCE increased, and a linear model explained 41% of variability in yield. Although the large yield variation across almost the entire CCE range weakened the linear relationship, mean yields for CCE intervals shown in Fig. 2

indicate that yield decreased with increasing CCE.

The relationships in Figs. 1 and 2 indicate that soil pH and CCE accounted for a major proportion of soybean yield variability in these fields and that these soil properties have interacting effects on yield. Figure 3 shows the relationship between soil pH and CCE. The data show high pH variation when there were no carbonates and little pH variation when carbonates were present. Calculations using the statistical Cate-Nelson model (Cate and Nelson, 1971) indicated a change point at pH 7.7 and 2.5% CCE. At higher values, pH varied only from 7.7 to 8.2 while CCE varied from 2.5 to 30%. Such a large variation in CCE for pH = 7.7 can explain an almost vertical distribution of relative yield values ranging from 0 to 100% at that pH range in Fig. 1. Aerial images and field observations indicated large variation in leaf chlorosis within that pH range, which suggested different degrees of IDC. However, factors other than Fe deficiency could be responsible for leaf chlorosis and yield variation. Previous Iowa research (Tylka et al, 1998; Tylka and Mallarino, unpublished) showed higher incidence of SCN in high pH soils with varying CCE levels. Measurements in this study indicated a weak relationship between SCN incidence and soil pH (an increase from approximately 1,100 to 3,500 eggs/100 g soil as pH increased) but not with CCE. In spite of these potential additional factors, a multiple regression model estimating relative yield as a function of pH and CCE (not shown) indicated that 47% of yield variability across sites was explained by those two factors simultaneously. Therefore, these results suggest the usefulness of an index that accounts for both factors at the same time.

Development of an Alkalinity Stress Index

Study of relationships between relative soybean yield and soil pH across sites showed that class means for yield decreased by 22% for each unit increase in soil pH (Fig. 1). A similar study for CCE showed that class means for yield decreased by 3% for each unit increase in soil CCE (Fig. 2). The average effect of a CCE unit on yield was 0.14 times the effect of each pH unit. Therefore, we developed an alkalinity stress index (ASI) that weighed the effects of these measurements on yield: ASI = pH + 0.14CCE. In this equation, units of CCE are adjusted to have an average effect on plants equal to the average effect of one pH unit as observed in this study. The relationship between ASI and yield within each site was continuous (without the dichotomy shown for the relationship between yield and pH or CCE), negative linear models were significant ($P < 0.05$) at 11 of the 12 sites, and r^2 of significant models ranged from 0.47 to 0.89 (data not shown). Figure 4 shows a significant linear and negative relationship between relative yield and SI across sites that explained 45% of the yield variability. The unexplained variability for the relationship between yield and ASI was less than for relationships between yield and soil pH or CCE and approximately similar for the entire range of observations.

Figure 5 describes how soil pH and CCE are expressed in different ranges of ASI values and how pH or CCE can correlate with the intensity of stress (by recognizing that ASI correlates with yield) but the effect of each variable becomes clear only when the soils are studied separately based on CCE. The Cate-Nelson model (not shown) identified a change point at pH 7.7 for the relationship between pH and ASI (Fig. 5A) above which CCE was the major factor affecting ASI. Calculation of a change point for the relationship in Fig. 5B indicated that soil pH is the major factor affecting ASI below 2.5% CCE. These results are consistent with the well-known buffering effect of carbonates on pH. Soil pH does not increase with an increase in carbonate concentration after concentrations are high enough to saturate the soil solution. The main advantage of using ASI over a model considering both pH and CCE, therefore, is that it expresses a wide range of pH and CCE values as a single index with common units.

Summary and Conclusions

Study of relationships across all fields showed that soybean yield decreased with increasing pH and CCE, that each measurement explained 30 and 41% of the yield variability, respectively. An alkalinity stress index (ASI = pH + 0.14CCE) developed based on relationships between pH and CCE with yield was continuously and linearly correlated with yield across the entire range of observations and explained 45% of the yield variability. This index is a useful tool because both soil pH and carbonate concentration need to be considered when trying to quantify the degree of potential plant stress in fields with calcareous and non-calcareous soils. The proportion of yield variability explained by the ASI was surprisingly high since yield variability can also be attributed to variation in many other growth factors (i.e. soil moisture, nutrients, weeds, insects, diseases, etc.). Use of remote sensing imagery facilitated the identification of fields and parts of fields that encompassed a wide range of soil characteristics and plant stress symptoms. The technique was particularly useful to account for very high variability in plant stress within a few square feet and with highly irregular patterns. The underlying problem avoided by using this technique and small areas to measure yield and relevant soil properties was that, as noted by Cline (1944), a soil sample composed of cores collected within a highly variable area is not representative of the area. Therefore, an important byproduct of this study was that it demonstrated the value of remote sensing of soybean canopy to guide soil sampling in fields with complex patterns of acid and calcareous soils that are not described at an appropriate scale by soil survey maps.

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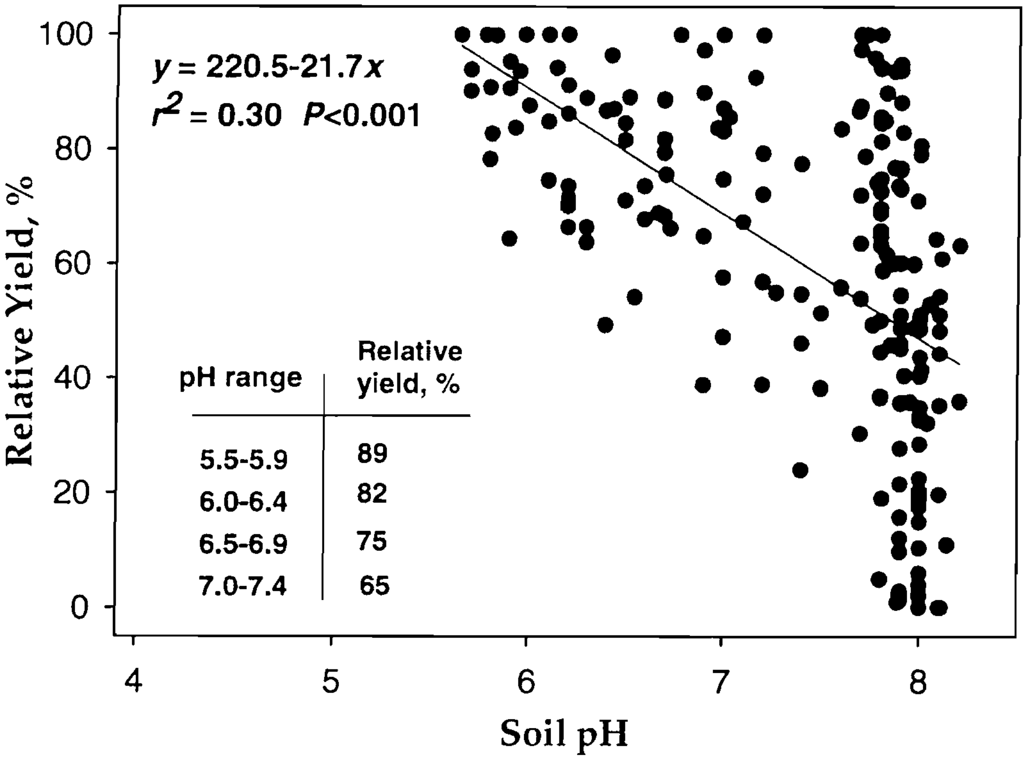
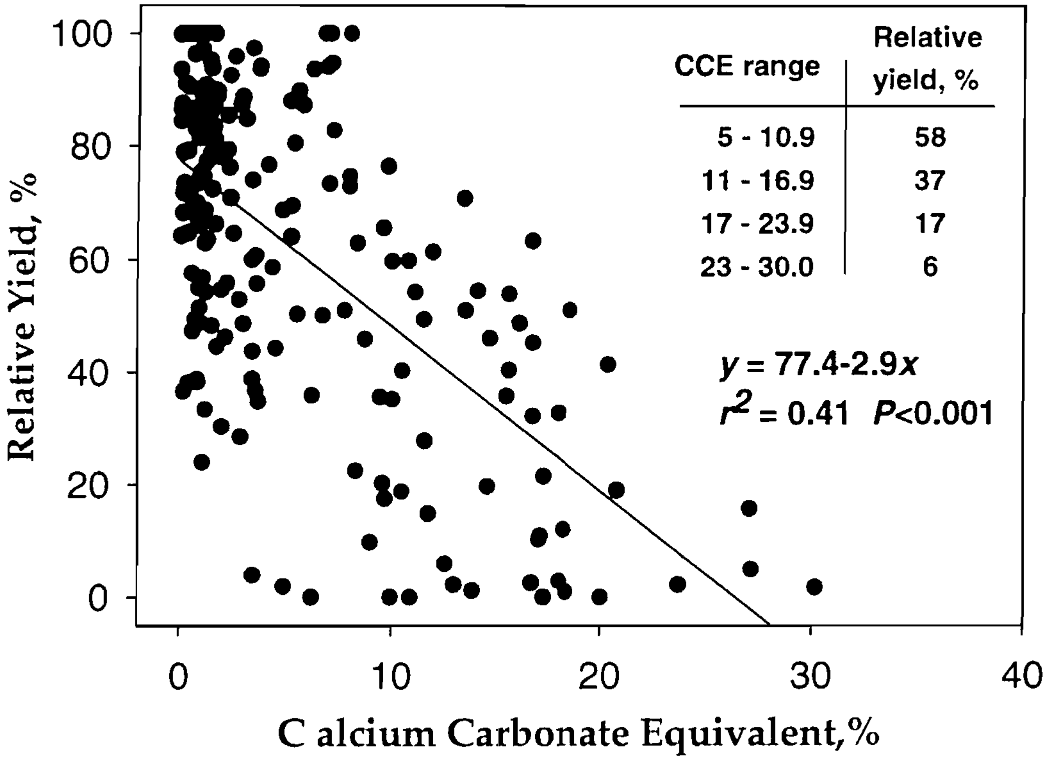


pH range	Relative yield, %
5.5-5.9	89
6.0-6.4	82
6.5-6.9	75
7.0-7.4	65

Fig. 1. Relationship between soybean yield and soil pH for sampling areas across 12 fields.



CCE range	Relative yield, %
5 - 10.9	58
11 - 16.9	37
17 - 23.9	17
23 - 30.0	6

Fig. 2. Relationship between soybean yield and soil calcium carbonate equivalent for sampling areas across 12 fields.

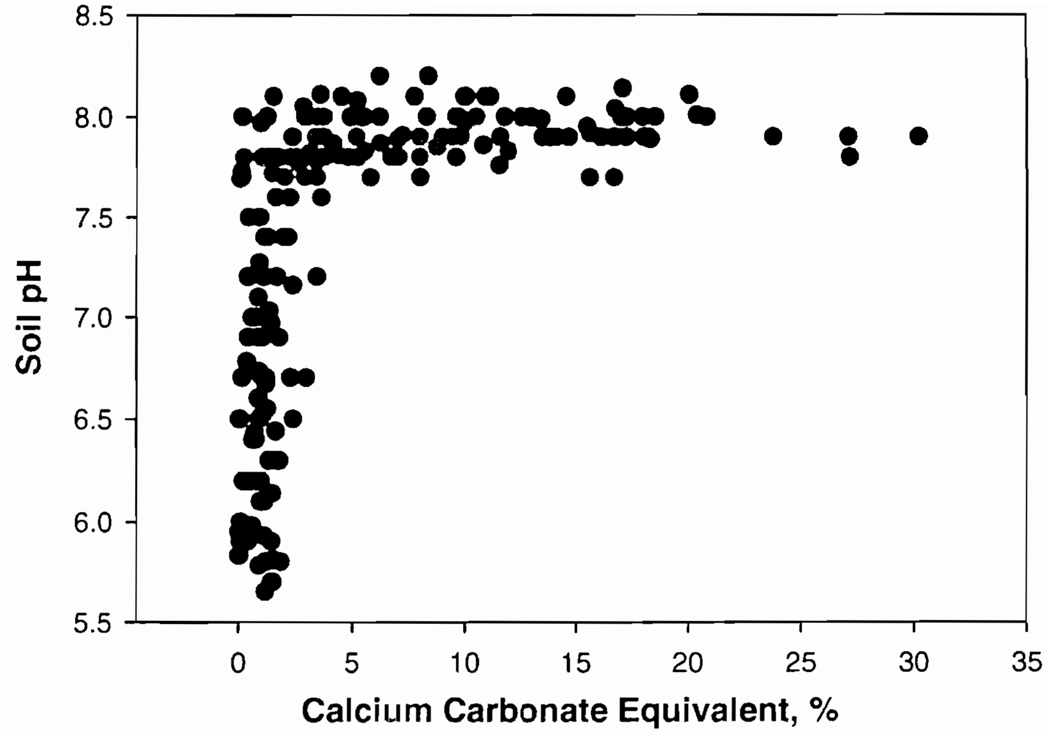


Fig. 3. Relationship between soil pH and calcium carbonate equivalent for sampling areas across 12 fields.

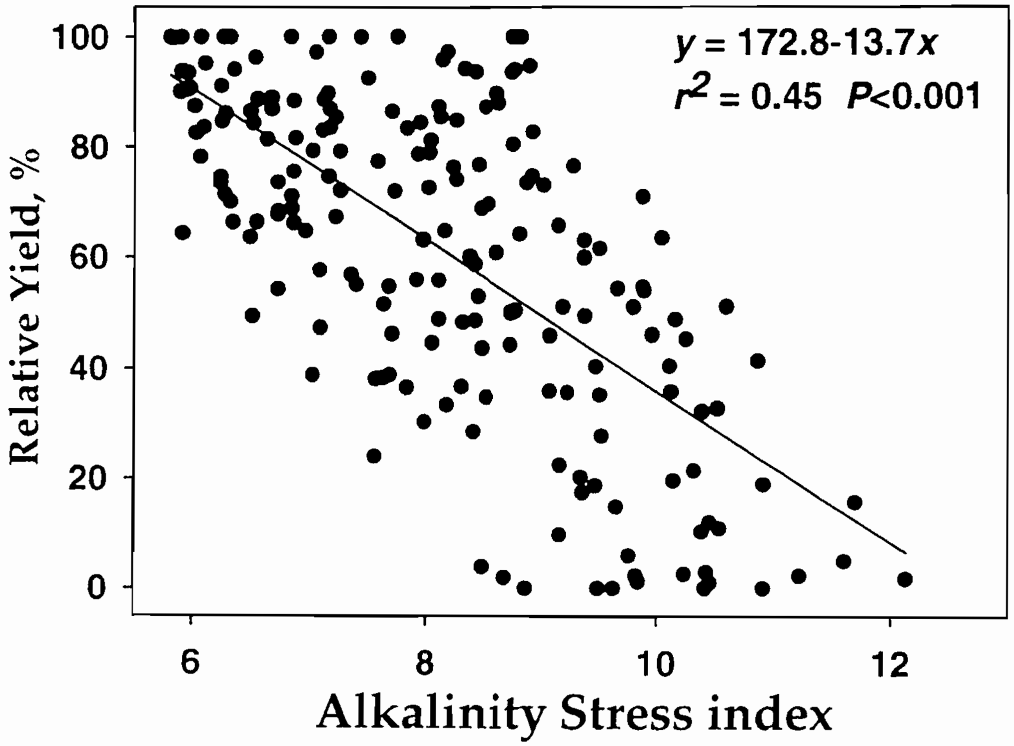


Fig. 4. Relationship between an alkalinity stress index and soybean yield across sampling areas in 12 fields.

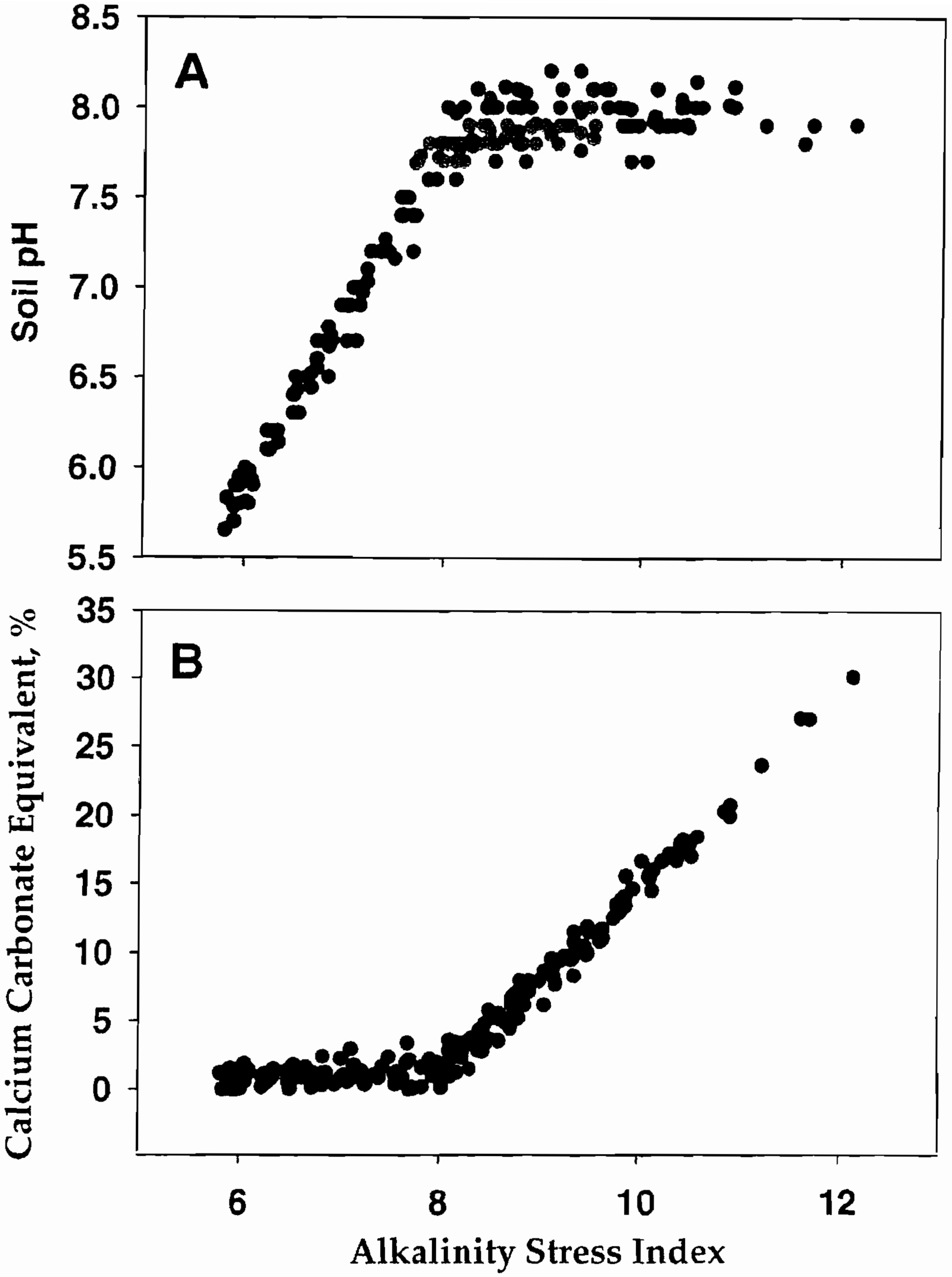


Fig. 5. Partitioning of the alkalinity stress index into its components soil pH (A) and soil carbonate concentration (B) for sampling areas across 12 fields.

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