Geographic Information Systems Show Impact of Field Placement on *sh2* Sweet Corn Stand Establishment

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ADDITIONAL WORDS. *Zea mays*, precision farming, GIS

SUMMARY. The objective of this study was to ascertain if stand establishment of *sh2* sweet corn (*Zea mays* L.) would benefit from variable planting depths determined by the use of geographic information systems (GIS). Spring and fall research plots were established in a field [80 × 20 m (262 × 66 ft)] containing Crosby silt loam and Kokomo silty clay loam soil series in Columbus, Ohio. Three *sh2* sweet corn cultivars (Starship, Skyline, and Confection) were planted at three depths on the two soil types in the fall study, with an additional transition soil added in the spring. Emergence counts as well as soil moisture and temperature were monitored. In the spring, sites were also sampled for nutrient levels and soil compaction. Significant variability was found within the field with respect to soil moisture, temperature, nutrient levels,

and compaction. Seedling emergence fluctuated with average soil moisture increasing in blocks with up to 24% moisture and then leveling off. Daily minimum soil temperatures impacted stand establishment. Although heat units accumulated faster on the Crosby soil, emergence was slower and less complete on these soil series than on Kokomo soil series. Further investigation determined that although temperatures of the Crosby soil were 3 to 4.5 °C (5.4 to 8.1 °F) warmer during the day than the Kokomo soil, temperatures on the Crosby soil averaged 2 °C (3.6 °F) cooler at night. Analysis of emergence patterns and field variability was performed on ArcView mapping software. Although 'Skyline' planted at 2 cm (0.8 inches) had the best emergence overall, final stand would have been increased with 'Skyline' planted variably at 2 and 4 cm (1.6 inches). Mapping the field under these different scenarios showed that although area with less than 70% stand would exist with a 2-cm uniform planting depth, the entire field would have a stand of 70% or greater with variable planting depth using a high vigor seedlot.

Location-dependent crop production techniques may improve production efficiency by raising yields and lowering amounts of chemicals such as fertilizers and pesticides (Vansichen and De Baerdemaeker, 1993). Monitoring final yields of crops within fields of the same soil type has shown as much as 40% variability (Christensen and Krause, 1995). Soil and crop management practices have traditionally been approached on a whole field basis, but recognizing within-field variability would allow for improved precision in crop production (Colvin et al., 1995). Maps of soil productivity and other variables can be produced and used to match agricultural inputs with site-specific crop needs (Cahn et al., 1994). Management decisions are usually made by taking soil samples and making a composite to get an average over a field. The larger the cell size for soil sam-

pling, the greater the possibility for losing information about field variability (Wollenhaupt et al., 1994). The use of global positioning systems (GPS) and GIS technology allows the creation of maps using a much smaller area.

Precision farming is a system that optimizes crop management on small portions of a field according to its specific characteristics (Huggins and Alderfer, 1995). The purpose of precision farming is to give maximum economic yields while using sustainable practices. High precision includes timing of planting, seed placement in the soil, choosing suitable cultivars for field conditions, timing of inputs, and other factors (Wallace, 1994). The development of GIS has been instrumental to precision farming as it provides a way to store and analyze geographic information. A GIS is a tool for combining data layers into useful information about production and profitability by taking into account static (soils, slope, elevation, etc.) and dynamic (e.g., precipitation, crop cover) data (Griffith, 1995).

The GPS is a space-based triangu-

Fig. 1. Diagram of field layout for spring study. There are six replications of each treatment per soil type with cultivar remaining the same across row and depth varying by row segment. The plus (+) represents sets of 20 planted seeds; 1–6 refers to blocks and Xs mark locations of data loggers. Dimensions of the field are 80 × 20 m (262 × 66 ft).

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Table 1. Summary of indices used for field study analysis.

Index	Season used	Description
Maximum emergence	Fall 1996 and Spring 1997	Peak number of seedlings observed in a plot
Total numbers	Fall 1996 and Spring 1997	Total number of seedlings observed in a plot throughout study
Seedling weight	Fall 1996 and Spring 1997	Average weight of a seedling in corresponding plot at three- to four-leaf stage
Final count	Spring 1997	Number of seedlings observed on day harvested for seedling weight

lation system using satellites and computers to measure positions on earth. Developed as a defense system by the United States Department of Defense, it is referred to as the Navigation Satellite Timing and Ranging Global Positioning System or NAVSTAR GPS (Stafford and Ambler, 1994). The uniqueness of this navigational system is that it avoids the limitations of other land-based systems such as limited geographic coverage, lack of continuous 24-h coverage, and the limited accuracy of other related navigational instruments.

Although *sh2* sweet corn cultivars are highly desirable especially for the long distance shipping market, poor seed vigor and sporadic seedling disease have limited their acceptance by growers (Wilson et al. 1992). Seeds with the *sh2* gene have high sugar endosperm and exhibit a higher risk of preemergence failure than traditional sweet corn (*su*) hybrids. Achieving successful stand establishment of supersweet corn, especially in cold soils, remains a challenge to growers and researchers.

Seeds are particularly vulnerable to stress between planting and germination (Carter and Chesson, 1996). It is important to plant in conditions that favor quick emergence (Price and Gaultney, 1993). Some seedling diseases are more likely to develop in cool, overly moist soil (Carter and Chesson, 1996). Rapid corn germination and seedling growth are promoted by favorable soil temperature, which varies with soil depth, color, moisture, and cover (Willis et al., 1957). Growth activity for most crops is practically suspended at soil temperatures below 4.5 °C (40.1 °F) (Willis et al., 1957). In the midwestern U.S., optimum soil temperatures are not observed until later in the season when the benefit of early market price has been missed. Assuming that *sh2* sweet corn seed will be planted before optimal temperatures are reached, placing the seed in the best possible environment becomes critical.

Having narrow windows for planting and the desire to get sweet corn harvests as early as possible may also mean that soils have not dried adequately before planting in the field. Not only does this introduce seeds into a possibly cold and wet environment, but vehicle traffic particularly when used on wet soils is the most common cause of soil compaction (Hakansson et al., 1988). Slower seedling growth in compacted plots prolongs the period when plants are most susceptible to disease, insects, and competition from weeds (Wolfe et al., 1995). Restricted root distribution due to compacted soil may also lead to reduced shoot growth and yield by limiting water and nutrient availability to the plant (Hakansson et al., 1988). The Crosby soil series used in this study is more likely to crust after heavy rains than the Kokomo. The Kokomo soil series typically has higher clay content and organic matter and is wetter than the Crosby soil. Incorporating the differences of soils into management practices could increase stand establishment. The primary objective of this study was to define field conditions using GIS for optimum stand establishment of *sh2* sweet corn.

Materials and methods

The study compared nine treatments consisting of three cultivars planted at each of the following depths: 1.3, 2.5, and 5.1 cm (0.5, 1, and 2 inches) in Expts. 1 and 2, 4, and 6 cm (0.8, 1.6, and 2.4 inches) in Expt. 2. A randomized split block design was used with the nine treatments planted in six replications in each soil type (a transition between the Kokomo and Crosby soils was also planted in Expt. 2). Rows were divided into three segments with 20 seeds planted in each segment. Cultivar remained the same across an entire row with depth varying by segment. Gaps of 3 m (10 ft) were left between row segments to assure separation of the treatments in sampling (Fig. 1). Conventional tillage was used to prepare the seed bed.

EXPERIMENT 1, 1996. Seedling counts were taken daily until emergence had occurred in all nine treatments on both soil types at 12 d after planting (DAP). Counts were then taken once every 3 d until frost killed the entire stand on 5 November 1996. On 15 October (27 DAP) when most of the seedlings were at the three to four leaf stage, five seedlings were harvested for each of the 108 plots. Seedlings were chosen as the five closest to the plot but in the 3 m buffer zone so that germination records could be continued until frost. These seedlings were dried at 57 °C (135 °F) for 48 h for biomass determination.

Soil moisture and temperature were measured on the day of planting at all 108 sites at the corresponding depth to the treatment at that site. Soil moisture at seed level was taken with about 1.3-cm increments of soil for wet weight and dry weight determinations after drying for 24 h at 60 °C (140 °F). Soil moisture was calculated using the equation: (wet weight – dry weight)/dry weight. Soil temperature was measured with a thermocouple at the tip of a copper stake that could be pushed into the ground at the appropriate depth.

Three indices were created to measure emergence for the fall study (Table 1). Maximum emergence was the peak number of seedlings that emerged in a plot during the study. This was used instead of a final stand count because, this being a fall study, the stands eventually died off due to cold weather. The total numbers index is a sum of emergence counts for every day of the study. This index takes into account both the quickness and uniformity of emergence, as well as seedling die-off later in the season. The seedling weight index is the average dry weight for the five seedlings harvested from the various treatment plots at 27 DAP.

EXPERIMENT 2, 1997. Seedling counts were again taken daily until all nine treatments had initial emergence (18 DAP). Thereafter, sampling was

every 3 d until the seedlings were harvested on 5 June 1998. The same procedure used in the fall study for taking dry weight samples was followed in spring study except that the entire row of seedlings used for emergence counts was harvested.

Data loggers (Hobo XT temperature logger; Onset Computer Corp. Pocasset, Mass.) were placed at six sites in the field and set to record temperature every 30 min throughout the study. The six sites were chosen so that each soil type had two sampling sites and each of these sites would be in the middle of the northern and southern halves of each soil type. The areas containing these six sites will be referred to as blocks throughout this paper (Fig. 1). Three data loggers were buried at each site so that each of the 2, 4, and 6 cm depths had a corresponding logger. Soil moisture at seed level was taken at the same six sites with about 2-cm increments of soil that were weighed for wet weight and then dry weight after oven drying for 24 h at 60 °C. Soil moisture determinations were taken at the time of planting as in the fall study.

On 20 May 1997 (14 DAP) the soil was tested for compaction differences using a neutron probe (3400-B series surface moisture-density gauge; Troxler Electronic Laboratories, Research Triangle Park, N.C.). The probe measured wet and dry soil density. Soil moisture was taken at the same time with this probe. Before emergence, all 162 sites were sampled for soil nutrient analysis. Soil was drawn in 15-cm (6-inch) increments from the sites with soil borers and sent to the Agronomic Service Lab (Washington Court House, Ohio) for determinations of phosphorus, calcium, magnesium, and potassium levels. A GPS receiver (Trimble Pro-XL; Trimble Navigation, Sunnyvale, Calif.) in a backpack was used to record latitude and longitude coordinates from the perimeter of the field and at the 162 sample points. Differential correction was obtained through a Raycal Landstar receiver (Raycal Survey USA, Inc., Houston, Texas). These coordinates were later put into the GIS, ArcView (Environmental Systems Research Institute, Redlands, Calif.) for analysis of seedling emergence and soil moisture, temperature and nutrient variability.

In the spring study, indices used to measure seedling emergence were

maximum emergence, total numbers, seedling weight and final count (Table 1). Total numbers and maximum emergence indices were calculated by the same methods as the fall study. Final count was total number of seedlings counted and harvested for any given treatment at 30 DAP. These seedlings were then weighed and averaged by the count for the seedling weight index.

STATISTICAL ANALYSIS. Tests for significance were done using Systat 6.0 for Windows (SPSS Inc., Chicago, Ill.). Analysis of variance was conducted for the indices relating to the effects of soil type, cultivar, and planting depth and the combinations of those factors. For tests that were significant at $P < 0.05$, pairwise comparisons were done with the Bonferroni adjustment. (LSD method showed same trend.) Analysis was also conducted to test for statistically significant differences in soil moisture, temperature, compaction, and

nutrients. This analysis checked to see if within field differences occurred, and whether differences were related to soil type or depth. These factors were also checked against emergence data to determine correlation with emergence patterns. Heat units were calculated for each planting depth in the blocks. Maximum and minimum daily temperatures were acquired from data loggers and used in the following equation: (maximum °C + minimum °C)/2 to 10 °C. The resulting calculation gave heat units which were totaled over the course of the spring study (6 May to 5 June) and were compared with emergence data.

ARCVIEW ANALYSIS. Once data were

Fig. 2. Average emergence on (A) Crosby and (B) Kokomo soil during Expt. 1. Star = 'Starship', Sky = 'Skyline', Conf = 'Confection'; 1.3, 2.5, and 5.1 = planting depths in cm (0.5, 1, and 2 inches).

Table 2. Means of indices used in Expt. 1.^z

Soil type	Cultivar	Depth (cm)	Maximum emergence (%)	Total emergence (no.)	Avg seedling wt (mg)
Crosby	Starship	1.3	59	136	31
		2.5	89	229	37
		5.1	78	176	32
	Skyline	1.3	35	65	24
		2.5	46	87	29
		5.1	42	64	29
	Confection	1.3	88	232	32
		2.5	104	258	27
		5.1	89	202	33
Kokomo	Starship	1.3	31	71	26
		2.5	79	199	52
		5.1	80	196	62
	Skyline	1.3	37	71	30
		2.5	53	108	38
		5.1	41	79	39
	Confection	1.3	61	155	38
		2.5	74	186	68
		5.1	98	256	49

^z2.5 cm = 1 inch, 28,350 mg = 1.0 oz.

brought into ArcView, the data table was queried to include only 'Skyline' data, as 'Skyline' had produced the highest emergence of the *sh2* cultivars. The final count index for 'Skyline' was made into two themes, one with 2 cm and the other with 4 cm planting depth. The themes were interpolated using inverse distance weight (IDW) to map emergence over the entire area. IDW was used because it assumes that the points closer to any given area have more in common with that area than points that are further away. To make planting recommendations, calculations were used to find areas where 'Skyline' planted at the 2-cm depth would result in higher final stand counts than 'Skyline' planted at 4 cm. Through

the use of the map calculator, percent emergence of 'Skyline' at variable depths was forecasted.

Results and discussion

EXPERIMENT 1, 1996. Emergence during the fall study generally began around 6 d after planting (DAP) on both soils, but reached higher levels on the Crosby (Fig. 2A and B). The shallowest planting depth (1.3 cm) had poor emergence for all cultivars across both soil types. In all cases, the 1.3 cm planting depth was slower to emerge than other treatments and never reached levels above 60% (Fig. 2A and B) 'Confection' tended to outperform 'Starship' on the Crosby soil but most treatments of both cultivars suffered at

least a 15% loss of maximum emergence levels on Kokomo soil. 'Skyline' had the lowest emergence on both soil series, averaging 30% to 45% emergence on Crosby and 40% to 50% emergence on Kokomo soil (Fig. 2A and B).

Maximum emergence ranged from 5% to 100%, and average seedling weight per plot ranged from 10 to 105 mg (0.00035 to 0.0037 oz). Significantly higher maximum emergence was found on Crosby than on the Kokomo soil series, but the average seedling weight was higher on the Kokomo than the Crosby soil (Table 2). Cultivar rankings from highest to lowest emergence were 'Confection' > 'Starship' > 'Skyline' for all three indices. Cold tests had given the same cultivar ranking in a previous lab study (Barr, 1998). The 2.5- and 5.1-cm planting depths emerged significantly better than the 1.3-cm depth according to all indices. There were no significant effects of soil and cultivar interactions. There was a significant soil and depth interaction as the shallow 1.3-cm depth had higher maximum emergence and total numbers on the Crosby than on Kokomo. The 2.5-cm depth had higher total numbers on Crosby, but average seedling weight at this planting depth was significantly higher on Kokomo (Tables 2 and 3). The deepest planting depth of 5.1 cm showed significantly higher total numbers and seedling weight on Kokomo soil. Although there was no significance in the cultivar and depth interaction according to the seedling weight index, both maximum emergence and total numbers showed that 'Starship' no longer outperformed 'Skyline' at

Table 3. Analysis of variance for indices used in Expt. 1.

Index	Maximum emergence	Total no.	Seedling wt
Soil treatment (S)	Crosby>Kokomo*	NS	Kokomo>Crosby**
Cultivar (C)	Confection>Starship>Skyline**	Confection>Starship>Skyline**	Confection and Starship>Skyline*
Depth (D)	2.5 and 5.1>1.3 cm**	2.5 and 5.1>1.3 cm**	2.5 and 5.1>1.3 cm**
S × C	NS	NS	NS
S × D	1.3 cm: Crosby>Kokomo* 2.5 and 5.1 cm: No difference	5.1 cm: Kokomo>Crosby** 2.5 and 1.3 cm: Crosby>Kokomo**	2.5 and 5.1 cm: Kokomo>Crosby* 1.3 cm: No difference
C × D	Starship: 2.5 and 5.1>1.3 cm* Confection and Skyline: No difference	Starship: 2.5 and 5.1>1.3 cm** Confection and Skyline: No difference	NS

NS,*,**Nonsignificant or significant at $P < 0.05$ or 0.01 , respectively.

Fig. 3. Average emergence on (A) Crosby, (B) transition, and (C) Kokomo soil during Expt. 2. Sky = 'Skyline', Star = 'Starship', Conf = 'Confection'. 2, 4, and 6 = planting depths in cm (0.8, 1.6, and 2.4 inches).

the shallow 1.3-cm planting depth (Table 3).

Soil moisture and temperature data taken at the time of planting were both significantly affected by depth, with the 1.3-cm depth being warmer and drier than the 2.5-cm depth, which were significantly warmer and drier than the 5.1 cm depths. Soil temperature was warm for the beginning of the study ranging from 17.5 to 23.1 °C (63.5 to 73.6 °F). Soil moisture at seed level ranged from 11% to 31%. Al-

though the average soil moisture levels were slightly higher on Kokomo (21%) than on Crosby (20%) soil type did not show any significance with respect to soil temperature. Maximum emergence did not show a significant correlation with soil moisture or temperature at planting (data not shown).

It is interesting that Kokomo provided a 50% increase in average mean seedling mass over the Crosby soil, although maximum emergence averaged 8.5% higher on the Crosby than the Kokomo soil. This could be partly due to there being a higher organic matter content in the Kokomo soil. The seedlings on the Crosby soil reached maximum emergence early and then began to decline soon after (Fig. 2A). The decline was not seen as soon

(and was less severe) for the Kokomo soil (Fig. 2B). The plots were harvested for seedling weight measurements on 15 Oct. (27 DAP) when seedlings on the Kokomo soil were still at high emergence levels. It is possible that extra cold stress had been placed on the Crosby seedlings accounting for the different seedling mass.

When planted at the shallowest depth, some of the seed was not completely covered by the soil. This may explain why the 1.3-cm depths consistently ranked poorly in all three fall emergence indices. To correct for this the planting depth was shifted from 1.3, 2.5, and 5.1 cm to 2, 4, and 6 cm in the spring.

EXPERIMENT 2, 1997. Emergence during the spring study was generally higher on the dark Kokomo soil than on the Crosby. On 5 June 1997 (30 DAP) when all emerged seedlings had reached the three- to four-leaf stage, they were harvested from sample plots. Emergence ranged from 45% to 78% on Crosby (Fig. 3A), 58% to 85% on the transition soil (Fig. 3B), and 60% to 93% on Kokomo (Fig. 3C). Unlike the fall results, 'Skyline' had the highest emergence on all soil types. Earliest emergence occurred at the 2-cm planting depth on all three soils. Seeds planted at 6 cm took longer to emerge and had less final stand than other depths on the transition and Kokomo soils (Fig. 3B and C).

The Kokomo and transition soil produced significantly higher emergence levels than the Crosby according to all four indices used in Expt. 2 (Tables 4 and 5). Cultivars were all significantly different from each other using the maximum emergence index with 'Skyline' > 'Confection' > 'Starship'. Cold tests again ranked cultivars similarly as did the accelerated aging test when a saturated NaCl solution was used instead of water in previous laboratory studies (Barr, 1998). 'Skyline' was also the top performer in the other indices and ranked significantly higher than 'Starship' in all cases (Table 5). The 2-cm planting depth produced higher emergence levels than the 6 cm depth according to all indices as did the 4-cm depth in the total numbers and seedling weight indices (Tables 4 and 5). As in Expt. 1, there were no significant effects of soil and cultivar interactions. There were no significant interactions among soil, cultivar, or depth factors relating to

Table 4. Means of indices used in Expt. 2.^z

Soil type	Cultivar	Depth (cm)	Maximum emergence (%)	Total no.	Seedling wt (mg)	Final count (%)
Crosby	Starship	2	74	51	102	74
		4	49	34	92	48
		6	59	48	138	54
	Skyline	2	79	95	252	78
		4	74	60	184	72
		6	70	57	173	68
	Confection	2	69	84	189	68
		4	69	77	200	64
		6	69	67	163	66
Transition	Starship	2	79	87	154	77
		4	69	79	193	67
		6	64	59	149	64
	Skyline	2	86	124	291	86
		4	87	124	413	84
		6	76	67	176	74
	Confection	2	74	111	364	70
		4	68	88	211	65
		6	63	74	227	59
Kokomo	Starship	2	69	96	190	69
		4	82	107	211	79
		6	66	71	154	60
	Skyline	2	91	134	351	91
		4	91	134	381	89
		6	83	103	307	79
	Confection	2	75	117	335	73
		4	76	123	313	73
		6	70	95	296	60

^z2.5 cm = 1 inch, 28,350 mg = 1.0 oz.

the maximum emergence or final count indices. According to total numbers and seedling weight indices, there was no difference in emergence at varying planting depths within the Crosby soil, but the 6-cm planting depth under performed the shallower planting depths within Kokomo and transition soils. According to the seedling weight index, there was no difference in 'Starship' seedling weight due to planting depth but the other cultivars had higher seedling weight at the shallower

planting depths (Table 5).

Soil moisture at planting ranged from 15% to 27%. Seeding depth was not a significant factor in soil moisture differences, but soil type and location within soil types were. When soil moisture was analyzed by block, a coefficient of determination value (r^2) of 0.80 resulted. Figure 4A shows moisture differences by blocks. Interestingly, the total numbers index when plotted by block (Fig. 4B) has a strikingly similar appearance to Fig. 4A.

Thus planting *sh2* sweet corn at a soil moisture level up to 24% may prove beneficial to stand establishment while no observed benefit would come from wetter conditions.

Soil temperatures were much cooler in the beginning of the study and grew warmer as the season progressed. This added more stress at the time of germination and emergence. Also, the decline in seedlings due to harsh weather towards the end of the study was not seen as in Expt. 1. Average soil temperatures for the first 10 d were about 12 °C (53.6 °F) with the shallower planting depths dropping to 2 to 3 °C (3.6 to 5.4 °F) at times. The 6 cm planting depth had a low of about 5 °C (41 °F) early on but also did not warm up as much as the shallower depths during the day.

Data loggers provided more accurate readings of the temperature than could be done with thermocouples and gave extra information, such as minimum night time temperatures, that were not available with the daily afternoon readings. The lack of correlation of temperatures to emergence patterns in the fall study was explained using logger temperature data. When temperatures were averaged over the time of the study for each of the six sites, the averages were significantly different from each other but not in any apparent way related to germination. In fact, if the two blocks in each soil type were averaged together the three soils seemed to be almost the exact same temperature with no significant differences.

Minimum soil temperature was a more useful predictor of seedling emergence showing an almost linear relationship between blocks with the light Crosby (blocks 1 and 2) soil reaching cooler temperatures than the dark Kokomo (blocks 5 and 6; Fig. 4 C).

Table 5. Analysis of variance for indices used in Expt. 2.^z

Index	Maximum emergence	Total no.	Seedling wt	Final count
Soil treatment (S)	Kokomo and Tran>Crosby**	Kokomo>Tran>Crosby**	Kokomo and Tran>Crosby**	Kokomo and Tran>Crosby**
Cultivar (C)	Skyline>Confection>Starship**	Skyline and Confection>Starship**	Skyline and Confection>Starship**	Skyline>Confection and Starship**
Depth (D)	2>6 cm**	2 and 4>6 cm**	2 and 4>6 cm**	2>6 cm**
S × C	NS	NS	NS	NS
S × D	NS	Kokomo: 2 and 4>6 cm** Crosby: No difference	Kokomo: 2 and 4>6 cm* Crosby: No difference	NS
C × D	NS	NS	Skyline and Confection: 2 and 4>6 cm** Starship: No difference	NS

^z2.5 cm = 1 inch.NS, *, ** Nonsignificant or significant at $P < 0.05$ or 0.01 , respectively.

A

B

C

Fig. 4. (A) Mean percent soil moisture, (B) total seedling numbers emerged, and (C) mean minimum daily temperature with standard error bars for each of the six blocks in Expt. 2; °F = 1.8 (°C) + 32.

The average minimum temperature in block 1 to that in block 6 ranged from 2.5 to 4.7 °C (36.5 to 40.7 °F), which could have been a major influence on the establishment of the sweet corn. These minimum temperatures corresponded well not only with the total numbers index, but also with the average weight index showing that blocks that did not reach the lower temperatures grew more plants at a higher average weight than blocks that reached the coldest temperatures.

It was suspected that the darker Kokomo soil would warm faster thus accumulating heat units more quickly than the Crosby and transition soils. This would have supported data showing earlier and more rapid emergence on the Kokomo soil. However, heat units actually accumulated faster on the lighter colored Crosby soil, counter to the hypothesis. To investigate further, maximum and minimum temperatures were averaged for the Crosby soil. These results were then plotted by date showing the daily average maximum and minimum temperatures for each of the planting depths in the Crosby soil. The same procedure was carried out for the Kokomo soil. Results show that, typically, soil temperatures were about 2 °C (3.6 °F) cooler in the evening on the Crosby soil but also reached maximum temperature 3 to 4.5 °C (5.4 to 8.1 °F) warmer than the Kokomo soil (data not shown). These results were consistent throughout the study period, explaining why heat units accumulated faster on the Crosby soil series.

Kokomo soil had higher moisture levels than the Crosby when tested with the neutron probe. The extra water in the soil may have acted as a buffer against temperature fluctuations that kept the Kokomo soil from reaching the same extremes as the Crosby. Perhaps smaller temperature fluctuation provided a better environment for germination, or small differences in nightly minimum temperatures reached on the Crosby soil may have been enough to inhibit *sh2* sweet corn germination. In either case, it may prove more beneficial to consider the length of time that soil remains at critical temperatures. With data loggers this type of analysis becomes possible, instead of relying solely on maximum and minimum temperatures.

There were significant differences in soil dry density running north to

Table 6. Soil dry density and percent moisture for spring study at 14 d after planting.

Block	Mean dry density [kg·m ⁻³] (lb/ft ³)	Avg moisture (%)
1	1.29 (0.296)	17.8
2	1.29 (0.296)	17.6
3	1.29 (0.296)	19.1
4	1.29 (0.296)	19.8
5	1.19 (0.273)	24.8
6	1.24 (0.284)	24.0
	SE = 0.02	SE = 0.72

Table 7. Soil nutrient levels for spring study sampling sites.

Level	P	K [mg·g ⁻¹ (ppm)]	Ca	Mg
Minimum	35	133	1440	225
Maximum	75	276	3000	383
Mean	59	195	2200	297
SD	7	35	420	43

south through the field, with $P=0.006$ between blocks with blocks 5 and 6

having significantly lower dry density than the others (Table 6). Blocks 5 and

Fig. 5. Planting depth recommendations for 'Skyline' using Arcview; 2 cm = 0.8 inches, 4 cm = 1.6 inches, 20 m = 66 ft, 80 m = 262 ft.

6 were contained in the Kokomo soil series showing that it was less compact than the other soil types (data not shown). Dry density testing showed an inverse relationship in soil compaction and moisture. In general, the more moisture the soil held at the time of sampling, the less compact the soil was. The fact that the emergence indices show higher germination in the darker soils may suggest that the less compact soil favored germination. The same conclusion would not be drawn from the moisture data. Although blocks 5 and 6 had the highest percent moisture and ranked high in emergence indices, there is definitely a limit to desirable percent moisture. Planting *sh2* seed in overly wet conditions (>24% soil moisture) led to a poor stand as the total numbers index showed fewer seedlings in the stand at the 6-cm depth for all three cultivars. The 6-cm depth also had the lowest average seedling weight for all cultivars and the greatest number of seedlings that died after emergence. In both years, moisture was directly related to depth as all soil types held more moisture the deeper they were sampled.

According to the soil test report, all positions tested had good or excessive levels of nutrients. Although there were significant differences in all nutrients tested between blocks, even the lowest levels should not hinder the germination and growth of these *sh2* sweet corn cultivars (Table 7).

There were no significant differences seen in soil compaction over east or west directions (data not shown) and soil nutrient levels had been more than adequate over the entire field. Soil moisture and minimum temperature were more related to final stand than any of the other tested parameters. There were only six sites where soil moisture and temperature were tested which were in the middle of each block (Fig. 1). If more points had been sampled, a trend in emergence patterns with smaller pockets of soil moisture and temperature fluctuation could be discussed.

Although the 2-cm depth would typically produce higher emergence in the final stand of 'Skyline' than the other planting depths, there were areas scattered in the northern and central field and the southwest corner that would have greatest stand establishment at the 4-cm planting depth (Fig.

Fig. 6. Projected stand establishment if 'Skyline' planted at (A) 2 cm (0.8 inches) over entire field and (B) 2 and 4 cm (0.8 and 1.6 inches) variable depth; 20 m = 66 ft, 80 m = 262 ft.

5) according to ArcView analysis. Areas that were not planted between soil types show the 2-cm planting depth recommendation (Fig. 5) but these areas are not as certain since IDW was used to interpolate the surface of these maps. Nearly half of the Kokomo soil series that was actually planted in the study has a planting depth recommen-

dation of 4 cm (Figs. 1 and 5). Corresponding latitude and longitude points could be programmed into planting equipment so that planting depth could be varied between 2 and 4 cm over the field. 'Skyline' planted at 2 cm over the entire field would have resulted in some northern areas with less than 70% emergence, and areas in the south-

ern end of the field with less than 80% emergence (Fig. 6A). When the variable planting depth scenario was used, there was no area in the field with less than 70% emergence and the southern half of the field had final stands of 80% emergence or higher (Fig. 6B).

Because 'Skyline' planted at the 2-cm depth emerged more quickly (in the spring study) on the Crosby soil than the other planting depths, the 2-cm planting depth should be used exclusively on the Crosby soil series. Since blocks in the Crosby soil had significantly cooler soil temperatures than the central and southern blocks (Fig. 4C), it may be advantageous to plant blocks in the Crosby soil at a later planting date than the Kokomo soil series.

Conclusions

Significant variability was found within the 80 × 20 m field with respect to soil moisture, temperature, nutrient levels, and compaction. Soil moisture seemed to correspond to emergence levels but actual differences were probably due to soil series changes. Low temperatures were detrimental to good stand establishment in the Crosby soil and a recommendation was made to postpone the planting date on the Crosby soil series. It was determined that the Crosby soil series was 3 to 4.5 °C warmer than the Kokomo soil series during the day, but averaged 2 °C cooler minimum temperatures than the Kokomo at night. Thus, heat units accrued faster on the Crosby soil but because seedling emergence was slower and less complete on the Crosby soil during the spring study, minimum temperatures from the early spring planting date hindered stand establishment. Although variability existed for soil nutrients, all levels though out the field were at good or excess levels so that nutrient levels did not affect emergence. Blocks in the Kokomo soil series had lower dry density than blocks in Crosby and transition soils.

Significant effects were seen for seedling emergence outside of cultivar vigor differences. Soil type and planting depth along with various interactions had significant impact on *sh2* sweet corn emergence under field conditions. There was a near linear relationship, with the 2-cm depth having less die off than the 4-cm and especially the 6-cm planting depths. Cooler and wetter conditions are generally

found at deeper plantings. These conditions may have led to disease or possibly the extra distance that the plant had to travel to reach the surface was the difference that caused it to deplete its energy source. ArcView proved to be a powerful tool for analysis of stand establishment of sweet corn. Using the cultivar, Skyline, variable planting depth recommendations were made to improve stand establishment over uniform planting depth. The ability to map factors affecting seedling establishment may guide precision seeding to obtain plant population targets in the future.

Literature cited

- Barr, A. 1998. Precision planting for *sh2* sweet corn (*Zea mays* L.) stand establishment. MS thesis. Ohio State Univ., Columbus.
- Cahn, M.D., J.W. Hummel, and B.H. Brouer. 1994. Spatial analysis of soil fertility for site-specific crop management. *Soil Sci. Soc. Amer. J.* 58:1240-1248.
- Carter, L.M. and J.H. Chesson. 1996. Two USDA researchers develop a moisture-seeking attachment for crop seeders that is designed to help growers plant seed in soil sufficiently moist for germination. *Seed World* (March):14-15.
- Christensen and Krause. 1995. Precision farming: Harnessing technology. *Agr. Outlook*. (May):18-19.
- Colvin, T.S., D.L. Karlen, J.R. Ambuel, and F. Perez-Munoz. 1995. Yield monitoring for mapping, p. 5-14. In: P.C. Robert, R.H. Rust, and W.E. Larson (eds.). *Site-specific management for agricultural systems*. ASA-CSA-SSSA, Madison, Wis.
- Griffith, D. 1995. Incorporating economic analysis into on-farm GIS, p. 723-729. In: P.C. Robert, R.H. Rust, and W.E. Larson (eds.). *Site-specific management for agricultural systems*. ASA-CSA-SSSA, Madison, Wis.
- Hakansson, I., W.B. Voorhees, and H. Riley. 1988. Vehicle and wheel factors influencing soil compaction and crop response in different traffic regimes. *Soil Till. Res.* 11:239-282.
- Huggins, D.R. and R.D. Alderfer. 1995. Yield variability within a long-term corn management study: Implications for precision farming, p. 417-426. In: P.C. Robert, R.H. Rust, and W.E. Larson (eds.). *Site-specific management for agricultural systems*. ASA-CSA-SSSA, Madison, Wis.
- Price, R.R. and L.D. Gaultney. 1993. Soil moisture sensor for predicting seed planting depth. *Trans. Amer. Soc. Agr. Eng.* 36(6):1703-1711.
- Stafford, J.V. and B. Ambler. 1994. In-field location using GPS for spatially variable field operations. *Computers Electronics Agr.* 11:23-26.
- Vansichen, R. and J. De Baerdemaeker. 1993. A measurement technique for yield mapping of corn silage. *J. Agr. Eng. Res.* 55:1-10.
- Wallace, A. 1994. High-precision agriculture is an excellent tool for conservation of natural resources. *Commun. Soil Sci. Plant Anal.* 25(1&2):45-49.
- Willis, W.O., W.E. Larson, and D. Kirkham. 1957. Corn growth as affected by soil temperature and mulch. *Agron. J.* 49:323-328.
- Wilson, D.O. Jr., J.C. Alleyne, B. Shafii, and S.K. Mohan. 1992. Combining vigor test results for prediction of final stand of *shrunk-2* sweet corn seed. *Crop Sci.* 32:1496-1502.
- Wolfe, D.W., D.T. Topoleski, N.A. Gundersheim, and B.A. Ingall. 1995. Growth and yield sensitivity of four vegetable crops to soil compaction. *J. Amer. Soc. Hort. Sci.* 120:956-963.
- Wollenhaupt, N.C., R.P. Wolkowski, and M.K. Clayton. 1994. Nutrient management mapping soil test phosphorus and potassium for variable-rate fertilizer application. *J. Prod. Agr.* 7(4):441-447.