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SPATIAL VARIATION OF PROTEIN, OIL, AND STARCH IN CORN

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ABSTRACT. Significant spatial yield variations are known to exist in cornfields with different soil types, topsoil depth, and other variables. Similarly, variations might also be found among the highly valued chemical components (oil, protein, and starch) in corn kernels due to local differences in soil type, fertility, acidity/pH, organic matter, etc. This study quantified the spatial variability of protein, oil, and starch content of corn from two conventional cornfields and two high-oil cornfields. Whole ears were harvested by hand from 20 to 40 randomly selected locations within each field. A differential global positioning system (DGPS) receiver recorded the location of each collection site. Samples were also collected from hauling vehicles with a segmented probe prior to transport from the field and from the grain stream as trucks were unloaded. A NIRSystems® 6500 near-infrared reflectance instrument was used to measure the protein, oil, and starch concentration of each sample collected. Yield maps were plotted for each type of corn along with protein, oil, and starch variation. Results showed large variations between the conventional and high-oil cornfields. Slight variations were found between truck probe samples from the same field. Oil content was more variable than protein or starch. Probe samples appeared to provide the most representative results. Segregation of grain based on average values of components in hauling vehicles appeared to be feasible. The oil concentration between truck hoppers was significantly different and could be used for binning corn of different concentrations. However, segregation on the combine during harvest does not appear to be feasible due to the large variations that occurred within fields at the same location. For example, the oil concentration of individual ears varied between 1 and 7 percentage points at the same location within the field.

Keywords. Value-added, High oil, Post-harvest processing, Composition, Feed, Seed.

Many farmers worldwide have used yield monitors extensively to determine yield variability of corn and other grains within fields as the crop was harvested. Significant spatial yield variations have been found to exist for corn, soybeans, and wheat due to differences in soil fertility, acidity/pH, organic matter, soil type, etc. It has been speculated that similar variations might also be found among the highly valued chemical components of these crops (moisture, protein, oil, or fiber). For example, the development of protein in wheat depends to some extent on the availability of nitrogen at various growth stages. Hence, the application of nitrogen between tillering and heading can improve grain protein without stimulating excessive vegetative growth (Cook and Veseth, 1991).

Some research has been conducted on the variations of protein and oil content in grain. Pendleton and Dungan (1960) reported a negative correlation between grain yield and grain protein concentration. A more recent two-year study in Kansas quantified the spatial distribution of protein for corn and hard red winter wheat within one field each by measuring grain nitrogen (Eisele et al., 1998). They found

poor correlation between grain nitrogen and yield for corn but concluded that the protein content range of wheat might justify monitoring protein with a sensor on the combine.

Kravchenko and Bullock (2002) determined the spatial variability of protein and oil in soybeans related to field topographical features. They found that field topography strongly influenced the protein and oil content of soybeans, and field elevation could be used as an indicator for oil and protein variation.

The value of some specialty crops, such as high-oil corn (oil content greater than 6.0% d.b. compared to less than 4% for conventional corn — all results are presented as percent dry basis unless otherwise noted), is based on the chemical content of grain. Determining the oil content of a corn crop while it is being harvested or handled for storage would enable farmers, grain handlers, or buyers to separate incoming loads into different bins according to their physical properties and value. Segregation of corn with higher oil content could lead to increased premiums for producers. At a minimum, knowing the oil content during production or handling would allow a producer to market corn to maximize premiums based on chemical constituents.

Near-infrared (NIR) spectroscopy has been utilized as a tool to determine the protein, oil, and moisture content of numerous grains and oilseeds (Delwiche, 1998; Orman and Schumann, 1991). Value-added components of corn have been measured as part of university variety trials using near-infrared instruments from Kentucky (Pearce et al., 2002), Ohio (Minyo et al., 2003), and numerous other states. It has been shown that there are large differences in protein and oil contents between fields of the same corn variety (Ridley et al., 2002). Protein ranges between fields and plots

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located in the United States and the European Union were between 10.3% and 14.8%.

There are a number of options for a producer to determine the oil content of corn during harvest or before binning. Currently, NIR instruments are bench-top models utilized at elevators and flour mills. However, mobile NIR analyzers are being developed for monitoring grain composition during harvest (Case Corporation, Advanced Farm Systems Group, Racine, Wis., 1999). Preliminary tests indicated that oil levels for regular field corn ranged from 1.2% to 6.0% and from 5.5% to 8.5% in high oil corn. In comparison, protein levels ranged from 5.0% to 12.0%.

Market premiums are often based on small increments of each value-added component. For example, high-oil corn producers have typically been offered a premium of \$0.39/t (\$0.01/bu) for each 0.1% of oil above a 6.0% base level (House, 1999). Hence, representative and accurate measurements are essential for both the buyer and seller. There are three potential areas where NIR instruments could be used during harvest to measure the oil, protein, and starch levels of corn. An instrument on the combine would allow for the measurement and potential segregation of corn during harvest. This would also allow for maps to be generated of the composition variability. Secondly, representative probe samples of trucks could be taken for measurement using a stationary NIR instrument. Lastly, a NIR instrument could be mounted in the receiving pit to monitor the grain and control the distributor to bin grain according to composition.

The objectives of this research were:

- to determine the spatial variation of protein, oil, and starch in two high-oil and two conventional cornfields in Kentucky,
- to obtain probe samples from trucks before unloading and measure protein, oil, and starch to determine variation within loads,
- to collect grab samples at 1-min intervals during truck unloading to determine the feasibility of using an on-line NIR sensor in the dump pit area for segregation, and
- to compare differences in the composition results from random samples collected in the field, by compartmentalized probe samples, and from grab samples during truck unloading.

MATERIALS AND METHODS

Two conventional and two high-oil cornfields were selected for harvest during the fall of 2001. The conventional fields were located in Shelby County (east of Louisville, Ky.). No-till production was practiced on the farm and both fields were planted to Pioneer 3335 (Pioneer Hi-Bred International, Johnston, Iowa) at a seeding rate of 71,660 seeds/ha (29,000 seeds/acre). The first field (SC1) was corn after corn and had relatively high damage level due to cob rot. The second field (SC2) was corn after soybeans and had a lower damage level. The exact damage level in both fields was not determined. Both fields were harvested and sampled on 18 September 2001.

One high-oil cornfield was harvested on 20 September 2001 in Hopkins County (HC) (near Madisonville, Ky.) that was replanted with Wyffels W7355 (Wyffels Hybrids Inc., Geneseo, Ill.) due to flood damage. The second high-oil cornfield was planted in McLean County (MC) (near Calhoun, Ky.) with the same variety (W7355) and harvested

on September 26, 2001. Both fields were planted to the same population density [74,129 seeds/ha (30,000 seeds/acre)] and a similar fertility program was applied. The HC field had a conventionally tilled seedbed while the MC field was planted into a no-till seedbed.

Field samples of ear corn were collected by hand in approximately 20 to 40 locations as the combine worked in the field. Between four and eight ears were harvested within three rows at each location. Harvest locations were determined using a Trimble® 132 DGPS receiver (Trimble Inc., Sunnyvale, Calif.) with satellite correction.

On all farms, corn was transferred from the combine into a grain cart, then into semi-trucks with two hopper bottoms. Each hopper was probed twice in the field with a compartmentalized probe (Seedburo, Chicago, Ill.) with sample cups 8.3 cm long and a 7-cm gap between sample cups. Samples were bagged and labeled individually after collection for further analysis. The samples from each compartment were individually analyzed and the data pooled to find the average and range of protein, oil, and starch content within the hopper.

At least three additional grab samples were taken from the flowing grain stream as each truck hopper was unloaded. Grab samples were collected at approximately 1-min intervals during unloading at all locations. This data was used to evaluate the potential of measuring the protein, oil, and starch on the pit conveyor for potential segregation.

Field, truck probe, and grab samples were transferred to the UK Grain Quality Lab the same day they were harvested and placed in a freezer for subsequent analysis. Whole ears from the conventional cornfields were shelled, blended, and analyzed as one sample from each location. In contrast, whole ears of high-oil corn were shelled and analyzed individually from each location.

Protein, oil, and starch levels were measured with a NIRsystems Model 6500 by Infratec® (Foss NIRsystems, Silver Spring, Md.) using the base equations from WinISI (Eden Prairie, Minn.). The oil calibration equations were verified with thirty samples using the University of Kentucky Regulatory Services solvent extraction method for oil content.

EXPERIMENTAL DESIGN

Average values of oil, protein, and starch content were calculated from random grab samples from each field. Yield data from each field was obtained from yield monitors and transferred to a geographic information system (GIS) spreadsheet (Arcmap, 8.3, ESRI, Redlands, Calif.) where average values were computed and maps generated. Variations in values found within each field and by each collection method were statistically analyzed and reported to quantify observed differences.

RESULTS

The average yield for SC1, SC2, HC, and MC was 4.25, 5.27, 4.02, and 7.86 dry t/ha (80, 100, 75, and 147 dry bu/acre), respectively. The average grain moisture contents from each field was 19.7%, 25.3%, 21.2%, and 16.4%, respectively. Field sizes were 7.1, 6.4, 34.2, and 33.6 ha (17.6, 15.7, 84.5, and 83.0 acre), respectively.

Table 1. Average values (and standard deviations, dry basis) for protein, oil, and starch content of corn samples collected randomly before harvest during the fall of 2001.^[a]

Field Location	Protein (%)	Oil (%)	Starch (%)	No. of Locations
Shelby 1 (SC1)	7.3b (1.31)	2.1d (0.60)	75.3a (1.85)	24 ^[b]
Shelby 2 (SC2)	7.2b (1.05)	2.5c (0.52)	75.6a (2.02)	22 ^[b]
Hopkins (HC)	7.2b (0.78)	6.4b (0.79)	69.8b (2.26)	41 ^[b]
McClellan (MC)	8.8a (1.33)	7.0a (0.83)	69.8b (1.66)	39 ^[b]
LSD (0.05)	0.58	0.39	1.0	

^[a] Results with the same letter are not significantly different at the 95% significance level.

^[b] A total of 67, 76, 279, and 213 ears were analyzed for SC1, SC2, HC, and MC, respectively.

RANDOM FIELD SAMPLES

Whole ears from each field were shelled and analyzed separately with averages calculated. Table 1 summarizes the average and standard deviation of the protein, oil, and starch content for the four fields sampled at harvest. The average protein content was 7.3%, 7.2%, 7.2%, and 8.8% dry basis for fields SC1, SC2, HC, and MC, respectively with a least significant difference (LSD) of 0.58% (SAS, 2000). Thus, at a significance level of 95% the average protein content measurements at the random locations in each field were equal for SC1, SC2, and HC. In contrast, grain from high-oil

cornfield MC had a significantly higher protein content than the other fields sampled.

Oil content was significantly different between all fields. The average oil content in the MC field samples was 7.0%, and was 0.6 points lower in field HC. Fields SC1 and SC2 had the lowest oil concentrations (less than 3%), which was expected. The standard deviations for oil content were greater in the two high-oil cornfields (MC and HC) than in the conventional cornfields.

Starch content levels were significantly higher in SC1 and SC2 fields than in HC and MC, however differences in starch content between SC1 and SC2 fields or between HC and MC fields were not significant. The concentration of starch was inversely proportional to the sum of protein and oil contents.

Maps showing sample location and protein, oil, starch, and yield levels for each field are shown in figure 1 (SC1 and SC2 fields), figure 2 (HC field), and figure 3 (MC field). Legend values in each figure were selected based on the median value of each variable.

PROBE SAMPLES FROM TRUCKS IN FIELDS

Table 2 shows the average and standard deviation of the protein, oil, and starch content of samples collected with the compartmentalized probe from all trucks used in each of the four fields of study. All trucks held approximately 23 tonnes

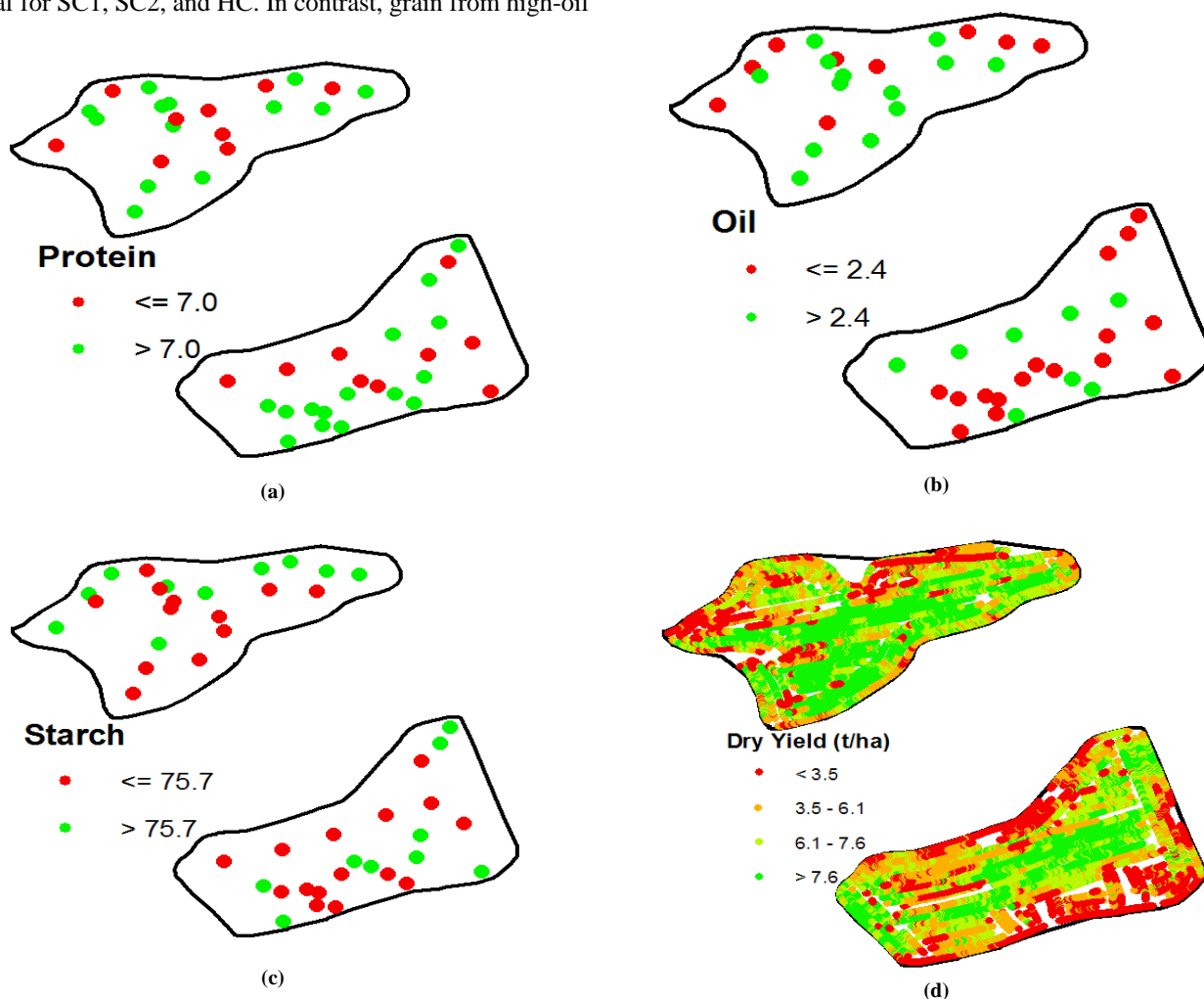


Figure 1. Concentration of protein, oil, starch (% dry basis), and yield (dry t/ha) in two fields of conventional corn [Fields SC1 (bottom) and SC2 (top)].

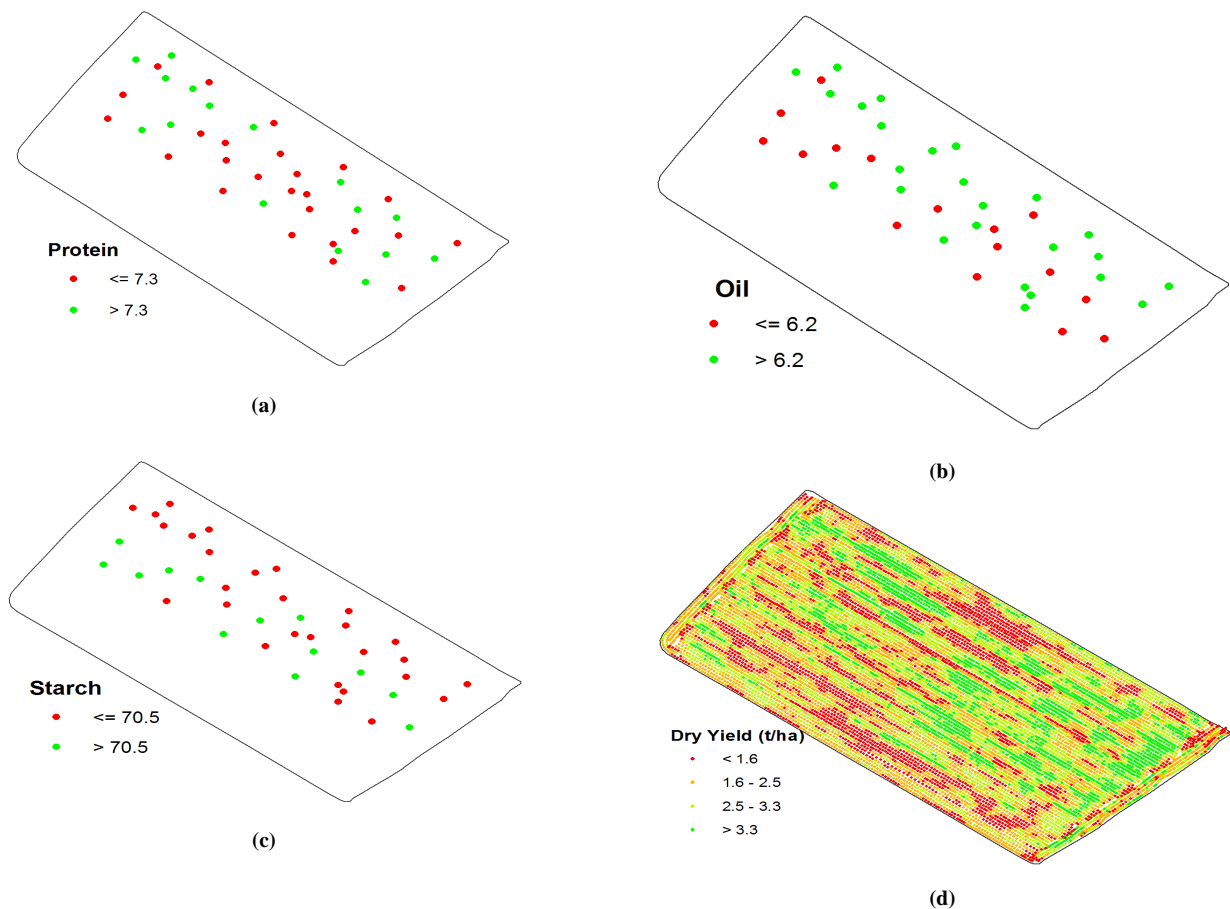


Figure 2. Concentration of protein, oil, starch (% dry basis), and yield (dry t/ha) in the high oil cornfield in Hopkins County (HC).

(900 bushels) in two hopper-bottom sections. Two compartmentalized probe samples were collected from each hopper (with eleven individual compartments for each probe) for a total of 44 grain samples per truck. The protein, oil, and starch content were determined for each compartmentalized sample. The average protein content was 7.2%, 7.3%, 6.7%, and 9.0% in SC1, SC2, HC, and MC fields, respectively.

The average oil content was 8.0% in field MC and was 11%, 66%, and 74% lower in HC, SC2, and SC1 fields, respectively. Oil concentrations between all fields were significantly different. Starch content levels were essentially equal in both SC fields and significantly lower in the high-oil cornfields (HC and MC). It was observed that the sum of average protein and oil values was inversely proportional to the average starch content.

Average values and the standard deviation of the oil by truck number and hopper location for field MC is shown in figure 4. The average value for a hopper was defined as the average oil content of the 22 probe samples taken in each hopper. The average oil content for the field was 8.0% (table 2), yet this value varied between 7.5% and 8.8% for the composite probe samples collected from each hopper. Columns with different letters are significantly different.

GRAB SAMPLES AS TRUCKS UNLOADED

Table 3 shows the average and standard deviation of protein, oil, and starch content for grab samples taken as trucks were unloaded. At least three samples were collected from the grain stream at approximately 1-min intervals as

Table 2. Average values (and standard deviations, dry basis) of protein, oil, and starch content of corn collected with a compartmentalized probe from loaded trucks in each field^[a].

Field Location	Protein (%)	Oil (%)	Starch (%)	No. of Samples
SC1	7.2b (0.53)	2.1d (0.66)	76.1a (2.43)	103
SC2	7.3b (0.66)	2.7c (1.10)	75.8a (3.16)	118
HC	6.7c (0.79)	7.1b (0.95)	71.5b (3.43)	190
MC	8.9a (0.60)	8.0a (0.75)	66.5c (1.58)	240
LSD (0.05)	0.15	0.20	0.61	

^[a] Results with the same letter are not significantly different at the 95% significance level.

each hopper was emptied. The average protein content was 7.6%, 7.8%, 7.0%, and 8.7% for SC1, SC2, HC, and MC fields, respectively. The average oil and starch contents were

Table 3. Average values (and standard deviations, dry basis) for protein, oil, and starch content for collective grab samples of corn from trucks used at each location^[a].

Field Location	Protein (%)	Oil (%)	Starch (%)	No. of Samples
SC1	7.6b (0.40)	3.2b (0.70)	73.0a (1.20)	25
SC2	7.8b (0.46)	3.2b (0.49)	72.4a (1.21)	20
HC	7.0c (0.38)	7.2a (0.59)	69.9b (1.70)	18
MC	8.7a (0.44)	7.3a (0.56)	67.0b (1.34)	24
LSD (0.05)	0.26	0.35	0.82	

^[a] Results with the same letter are not significantly different at the 95% significance level.

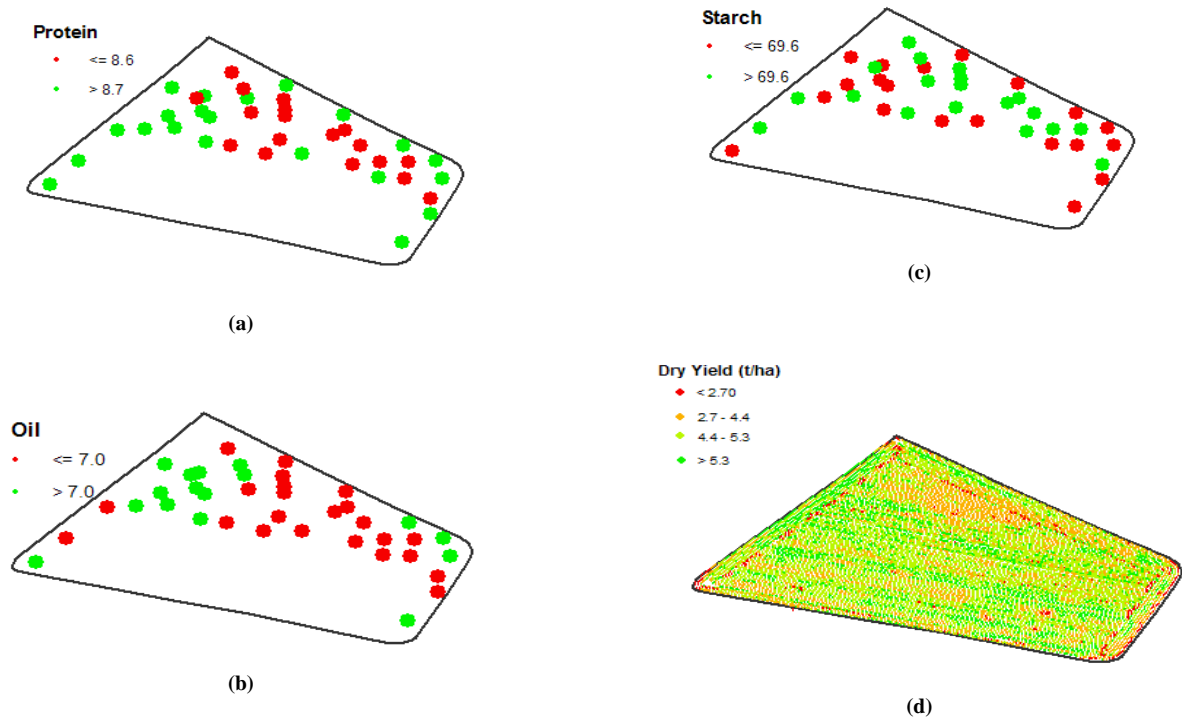


Figure 3. Concentration of protein, oil, starch (% dry basis), and yield (dry t/ha) in the high oil cornfield in McLean County (MC).

essentially equal for corn from fields SC1 and SC2 as well as for loads from the two high-oil cornfields (HC and MC). Average oil values were significantly lower from SC1 and SC2 fields compared to high-oil cornfields HC and MC, which was expected. Conversely, average starch values were significantly higher in fields SC1 and SC2.

Figure 4 includes a line graph that represents the average oil content of three grab samples taken from each hopper during unloading from the MC field. Across loads, the average oil content from grab samples was generally lower than the compartmentalized probe samples for the MC field.

In contrast, corresponding average values were virtually the same for the HC field and slightly higher in SC1 and SC2 fields.

DISCUSSION

DIFFERENCES BETWEEN FIELDS

Based on data presented in table 2 the oil content in field SC2 was significantly higher than in field SC1. Field SC1 was planted to a corn-after-corn crop rotation and had a

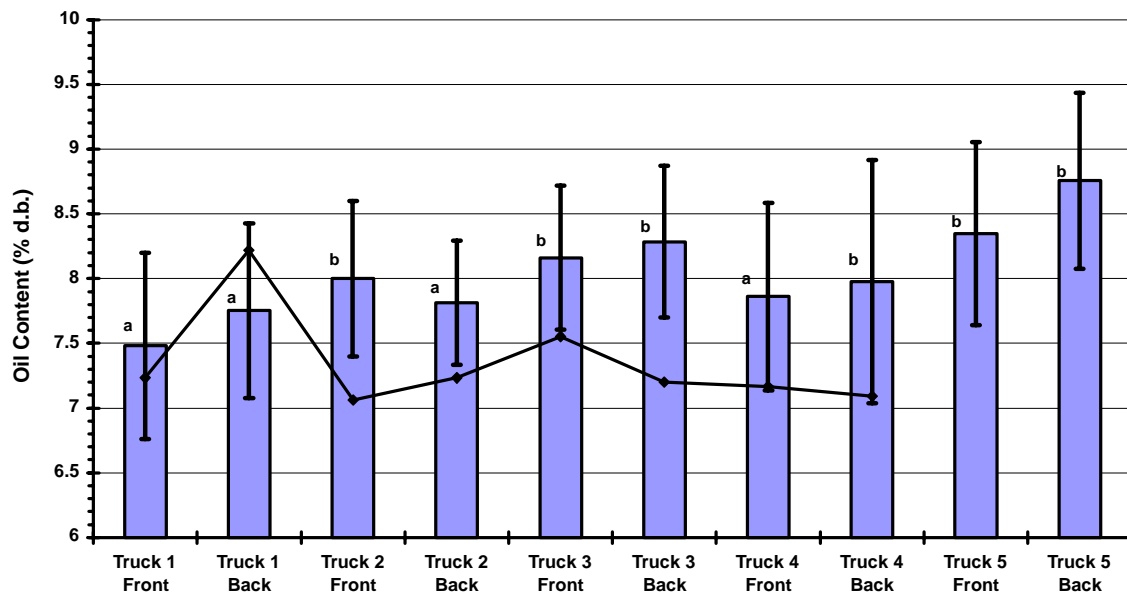


Figure 4. Average oil concentration and standard deviation of individual hoppers in field MC using the compartmentalized probe. Line graph is average of three random grab samples taken during unloading from each hopper. (Error bars are the standard deviation and hoppers with the same letter are not significantly different).

significant amount of cob rot damage. The SC2 field was in a corn-soybean rotation and had a lower level of damage. No significant differences in protein and starch content levels were found between these fields regardless of the sampling method. However, the measured oil content was found to be different with field and probe samples but not with grab samples.

Oil levels were significantly higher in the high-oil cornfields than the conventional cornfields, as expected. Oil levels were significantly higher in the MC field for field and probe samples but not for grab samples. The HC field was replanted due to flood damage relatively late in the growing season that may have reduced the oil content relative to the MC field. Between the two high-oil cornfields, all three sampling methods showed that the MC location had a significantly higher percentage of protein. Starch levels were not significantly different between field and grab samples but were significantly lower with probe samples in the HC field.

DIFFERENCES WITHIN FIELDS

The protein and oil distribution within each field appeared to be random, thus segregating grain based on these traits during harvest would probably be difficult (figs. 1, 2, and 3). No relationship was found between grain moisture, yield, or maximum potential yield (using neighbor analysis with the potential yield being the maximum value within 20 m (60 ft) of the sampling point).

There was a significant variation in the protein and oil concentration between ears at the same location within the field. Ear samples were analyzed separately then combined and analyzed to obtain an average value. The variation in average oil content between ear samples at the same location varied between 1 and 7 percentage points. The average standard deviation in oil content between the ears of field SC1 at individual locations was 0.6 percentage points. However, the standard deviation of the oil concentration in field MC was 0.85 percentage points. This large variation in composition of individual ears at each location would indicate that segregation by components during harvest would probably not be practical.

DIFFERENCES BETWEEN SAMPLING METHODS

Ideally all three sampling methods should result in the same protein, oil, and starch content. However, all three components varied considerably according to the sampling method. The probe results (table 2) would be expected to give the most representative samples. Each hopper of the truck was probed twice using a compartmentalized grain trier with 11 divisions. This provided the most representative sample because grain was mixed by the combine during harvest, by transport into a grain cart, and by a second transport into the truck.

Considering field MC, the average oil content of all probe samples was 8.0%. Based on random field and grab samples during unloading, the average oil content was 7.0% and 7.3%, respectively. Thus in this case, obtaining misrepresentative samples resulted in values that were significantly lower than the probe sample. Proper sampling techniques have been identified for measuring moisture content and would appear to be more critical with more valuable yet highly variable components, such as oil or protein.

As with hand-harvested samples, protein levels in probe samples from SC1 and SC2 fields were essentially equal, significantly higher than in the HC field and significantly lower than the MC field. Figure 4 would indicate that segregation according to average oil content by hopper could be feasible. The average oil content of the 10 hoppers was 8.0%. However, if the hoppers that were significantly lower than the average were binned separately, two lots of corn with an average oil content of 7.8% and 8.4% could be produced. This assumes that extra bins would be available and that a sufficient premium could be generated to pay for an NIR instrument and the extra labor required for sampling.

CONCLUSION

Protein, oil, and starch content of two high-oil and two conventional cornfields were measured during the fall of 2001 along with grain moisture and yield. The spatial variation of each chemical component within each field and the variation within truck loads were measured to determine the feasibility of segregation based on chemical properties. The following conclusions were found:

- Variations existed between fields due to genetic traits (high-oil vs. conventional corn) and weather conditions. The average oil content in the replanted high-oil cornfield was 7.1% compared to 8.0% in the field that was not replanted. The oil content of conventional corn varieties was 2.1% and 2.7% in fields that had a high and low level of grain damage, respectively.
- Significant differences were found between individual ears in the high-oil cornfields that would limit the feasibility of segregation during harvest. Average oil contents of individual ear samples in the same location varied by up to 6 percentage points and had an average standard deviation of 1 percentage point.
- Variations found between hoppers of semi-trucks could provide motivation for grain segregation. Obtaining representative samples from individual hoppers could be used to determine the average oil content and to bin high-oil corn separately, assuming that it was economically desirable.
- Corn protein and oil content were found to be highly variable in random grab samples in the field and from the unloading grain stream and did not compare well to probe samples from each truck/hopper. Thus, numerous field and/or unloading samples would be required to obtain comparable results.
- Some differences in protein, oil, and starch were found between the fields selected in this study. More work is needed to determine whether there might be an economic incentive to segregate grain loads as they are delivered from the field. Such a system would need to be designed to minimize the amount of time required to sample and analyze each load so that the hauling vehicle could return to the field quickly enough to maintain high harvest efficiency. Otherwise, additional hauling vehicles or wet grain holding bins may be needed in the operation.

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