**Kansas Soybean Commission Final Report of Progress**

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**Accomplished to date:**

Kansas currently uses the Mehlich 3 extractant for soil test phosphorus (ST P), with a general critical level for all crops of 20 ppm. Research conducted in the KSU Soil testing Lab in 2002 showed the Bray P1 and Mehlich 3 extractants give essentially the same values on soils with pH below 7.0. However at higher pH values, the Bray P1, a dilute acid based extractant, quickly losses its ability to extract ST P, while the Mehlich test continued to provide quality results to pH greater than 8.5 and up to 5% free lime. In the past, the problems with the Bray P1 test had been known, and on soil with pH >7, the Olson Bicarbonate test was used. Thus the switch to the Mehlich 3 allowed the use of a single test, making it easier for farmers with soils in the 6.8 to 7.2 pH range to deal with only one soil test for P.

Most Universities and soil testing labs establish a critical level, or the ST level above which no response to applied fertilizer would be expected. In states, such as Kansas, which offer Build and Maintain recommendations, the Critical Level is the beginning point of the “Optimum Soil Test Range” where no fertilizer would be required, but farmers need to apply fertilizer regularly to replace the nutrients being removed by harvested crops, and maintain the optimum soil test level. Prior to offering Build and Maintain recommendations, K-State established critical levels for each individual crop, with the expectation that farmers would apply fertilizer annually to each crop, using traditional Nutrient Sufficiency recommendations. The historical critical level for P was 15 ppm for most crops, with the exception of alfalfa, wheat and many vegetables. However, since many farmers tended to use fertilizer practices such as multiyear applications, applying all the fertilizer for a corn/soybean rotation prior to corn, similar to what is done in Iowa or Indiana, the Build and Maintain option was offered beginning in 2003, with a higher general crop rotation based critical level. The higher critical level was developed due to the high frequency of wheat in farmers rotations.

 Cropping systems in Kansas have changed dramatically in Kansas over the past decade. Wheat and alfalfa, the most P responsive crops grown in Kansas are no longer grown on every farm. A review of the limited research data available from Kansas suggests that soybeans, along with corn and milo, may not require as high a ST P level for optimum yield. By maintaining a high critical level of P in soils, above that required by the crops actually being grown, inefficiency of fertilizer use is encouraged, since nutrient removal in harvested grains and oilseed is increased per unit of production, as ST increases. By improving our understanding of the true P soil test needs of our primary crops, we can reduce P fertilizer use and minimize P runoff.

 Other universities and researchers have been asking similar questions, and found similar results and suggest a critical level for soybeans of less than 20 ppm (Table 1). When and how soybeans receive phosphorus has also been a point of contention over the years. The majority of the soybeans in Kansas are not fertilized directly, regardless of soil test level, but rather are indirectly fertilized by adding the P to preceding crops such as corn or wheat, and relying on residual effects to supply the P to the soybeans crop in rotation. Some agronomists and fertilizer distributors suggest that in these situations the use of starter fertilizer, or foliar fertilization

could be of benefit and increase soybean yields. Treatments were included in this study to look at these alternative methods of P fertilization as well.

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| **Table 1. Current soybean critical or sufficiency levels consider by north central universities and studies.**  |
| **Source** | **Term Used** | **Mehlich 3 or Bray-P1** | **Sample depth** |
|  |  | **ppm** | **inches** |
| Kansas State Univ. | Critical Level | 20 | 6 |
| North Dakota State Univ. | Critical Level | 15 | 6 |
| South Dakota State Univ. | Critical Level | 15 | 6 |
| University of Nebraska  | Critical Level | 12 | 8 |
| Dodd and Mallarino (2005) | Critical Level† | 12 | 6 |
| Borges and Mallarino (2000) | No Yield Response | 9 | 6 |
| Iowa State Univ. | Begin Optimum | 16 | 6 |
| Michigan State Univ. | Begin Maintenance Fertilizer | 15 | 8 |

†Critical level by linear plateau model.

 Plant analysis is becoming a more common tool for attempting to monitor plant nutritional status. Sufficiency levels of P in the uppermost fully developed trifoliate leaflets of soybeans at the R4 growth stage has been reported as 0.26 – 0.5 percent P (Jones, et al. 1990), and 0.31 percent P (Bell et al. 1995). Mallarino et al., (2013) did not find a good relationship between trifoliate P percent at R2-R3 and relative yield in Iowa. Establishing a good relationship between trifoliate P and STP or yield would be useful for in-season diagnoses of P deficient soybean fields, and for monitoring soil fertility programs.

Farmers are constantly receiving information on the need for secondary and micronutrient fertilizers for high yield soybean production from many sources. Much of this information is based on research conducted in other regions on different soils and genetic materials. In Kansas, past work has shown response to both iron and zinc on soybeans. No research to date has shown any response to manganese, copper or boron on soybeans in Kansas, all commonly recommended based on soil test, and common ingredients in micronutrient mixes. Recent efforts to remove sulfur from P fertilizers and from air emissions has reduced the S deposition across the US dramatically. In many parts of eastern Kansas, wheat, bromegrass and corn S deficiencies are becoming common, and are routinely corrected with the addition of S fertilizers. To date no confirmed S deficiencies have been diagnosed in soybeans in Kansas.

This study’s objectives were to:

* Use both historical and current field research to determine the ST P levels required to produce economically optimum soybean yields and establish a current ST P correlation and critical level;
* Determine if soybeans, regardless of ST P level, will respond to the use of band applied P at planting or foliar applications of P fertilizers.
* Observe what relationships exist between trifoliate P content and ST P levels and yield; and
* Determine if soybeans will respond to applications of sulfur, iron, zinc, manganese and boron.

**MATERIALS AND METHODS**

This study, a verification of currently considered ST P critical levels for soybeans, began in 2011. Funds to support this work were provided primarily from the Kansas Soybean Commission, and the Kansas Fertilizer Check-off program. To date a total of 22 field trials have been completed on cooperating farmer’s production fields and university experiment stations. Mehlich-3 colorimetric STP levels at these locations varied from 3 to 56 ppm, with the majority of the sites having soil test P levels from 8 to 25 ppm. In 2011 and 2012, 0-6 inch soil samples for P were taken by block to determine initial STP levels at each location. However, having observed considerable variation in soil test levels between blocks at several locations, along with high coefficient of variability in yield and leaf P content across the area, beginning in 2013 soil sampling was intensified to each individual plot. A randomized complete block design was employed with four replications, at all locations. Individual plots sizes were 10 or 15 feet (4 or 6-30 inch rows) x 40 feet minimum, depending on the cooperating farmers planting equipment to avoid “guess” rows within the harvested plot areas. In 2011, two sites were conducted using broadcast P rates of 0, 20, 40, 60 and 80 pounds P2O5 per acre. In 2012, 2013 and 2014, 7 experiments were conducted each year with a sixth treatment of 100 pounds P2O5 per acre added. Broadcast P treatments were applied as granular monoammonium phosphate (MAP, 11-52-0) immediately after the field was planted.

In addition to the broadcast treatments, a set of combination broadcast and band treatments with 20 pounds P2O5 banded and the balance broadcast was also applied in all three years. Banded fertilizer was applied at all P rates. In addition, treatments receiving 60 pounds P2O5 broadcast, plus 20 pounds sulfur as sulfate, and 20 pounds S plus zinc, iron, manganese and boron were also added, for a total of 13 treatments at each site. Beginning in 2013, foliar fertilization treatments were also added.

Early season growth was evaluated by measuring dry weight per plant and N, P, K, S and micronutrient content of 30 plants at the V-2/3 growth stage. Leaf nutrient content was determined from 30 trifoliates, collected without petiole, at R-4, early pod set. Yield was determined by combine harvesting the two middle rows of each plot. Seed moisture was measured and yield adjusted to 13 percent moisture. Relative trifoliate P percent and yield were calculated for each block’s check plot and measured against the block’s ST P in 2011 and 2012, and the check plot’s ST P in 2013 and 2014.. Statistical analysis was performed using Proc Glimmix (SAS 9.2; Cary, NC) with blocks as random effects. Most data from 2012 is not presented as severe heat and drought limited yield at most sites.

**RESULTS AND DISCUSSION**

Impact of Broadcast P Fertilization on Soybean Yield

Historical data. The historical soybean P response data found from the Kansas Fertilizer Research Reports is summarized in Table 1. Statistical analysis of the individual sites was not always performed, and an analysis could not be done since the reports only included treatment means. However, based on the information given one can estimate that due to the very limited response observed at most locations, only 5 of the 25 experiments showed any minimal yield response to P fertilizer. A correlation was made of soybean control plot relative/percent yield data to the soil test P levels at the site the experiment was conducted. A Linear Plateau model was used to fit the data and determine the joint point, an estimate of the Critical Level, that point where the model changes from a positive linear increase/response to increasing P soil test, to a flat plateau with no additional increase in yield with higher soil test levels ( Figure 1). The model has a relatively poor fit (p=0.26) raising additional questions if soybeans respond to increasing ST P. But using this model suggests that the current critical value of 20 ppm is substantially too high for soybeans. The Joint Point of the linear-linear model, the point where the two linear lines change from a positive slope indicating a response to no slope indicating no response, occurs at a soil test of 6.8 ppm P. The joint point is a good estimate of the Critical Level. Thus, one has to question if the original Soil Test P critical level of 15 ppm was not a significant over statement of fertility needs for soybeans, and that the increase of the critical level made in 2003 was not a bigger mistake, if one was to use traditional Nutrient Sufficiency fertilizer recommendations. If Kansas had used a Build and Maintain approach to making fertilizer recommendations historically, one could argue that a generalized cropping system approach to maintaining P soil tests above 20 ppm to meet the needs of all crops likely grown would have been a reasonable approach.

A review of similar historic data for grain sorghum (data not shown) also suggests a similar over statement of P fertilizer needs. One interesting difference between the sorghum and soybean data sets however is the limited response to P fertilizer seen at low soil test levels by soybeans, but a much greater and more consistent response to P fertilizer at low ST levels by grain sorghum. For a number of years Agronomists have argued that soybeans respond to soil fertility, ie. increased soil test levels, rather than fertilizer. This argument strongly supports the use of Build and Maintain fertilizer recommendations by soybean growers, and the need for current, updated crop specific critical levels. The historical soybean P response data available supports that argument.

Table 1. Historical Soybean P response data found in the Kansas Fertilizer Research Reports, 1964 to 1988.

 P Applied, lb P2O5 per acre

Site Year Soil Test P 0 15 30-40 40-60 60 to 80 80 to 100 >100

 ppm ---------------------Soybean Yield, bu/acre------------------------

\*Parsons 1978 6 22 24 26 27

Powhattan 1966 7 41 38 39

\*Powhattan 1967 8 38 39 39 41 39

Powhattan 1969 8 37 35 36 35 36

Columbus 1969 8 26 26 25 29

\*Parsons 1966 9 25 26 29 26 27

Parsons 1981 9 40 40 40

Newton 1966 10 19 19 17 16 17

Ottawa 1966 12 49 50 49 52 48

\*Ottawa 1967 12 23 25 26 26 25

Ottawa 1969 12 34 34 35 32

Cherokee 1970 12 28 29

Columbus 1964 13 17 18 17

\*Pawnee 1974 13 29 32 32 31

Cherokee 1978 13 19 18 19 20

Cherokee 1988 13 24 24 24

Cherokee 1980 14 11 11 12

Columbus 1978 17 30 28 30 30

Unknown 1970 19 30 31 31

McPherson 1970 19 33 32 33

Cherokee 1988 20 37 38 38

Gardner 1970 23 17 18

St. John 1969 35 48 43 44

Desoto 1971 37 31 33

St. John 1970 41 55 52 50

\* Research sites where minimal P response was observed



Figure 1. Linear-Linear Plateau model used to determine the Bray-Kurtz P-1 Soil Test Critical Level for soybean yield using historical Kanasas P fertilizer trials with soybeans from 1964 to 1988 published in the Kansas Fertilizer Research Reports..

 Experimental results from the 2012-1014 project. The soybean yield response to P data obtained in this project is summarized in Table 2. Data is listed in order of increasing soil test levels. As with the historic data, only a limited number of sites, three, gave a statistically significant response to P fertilization, though 3-4 others also showed similar trends not considered significant due to variability levels. All of the responsive sites had soil test P levels below 11 ppm.

Table 2. Observed Yield Response of Soybeans at 22 experiments in Kansas to Broadcast applications of P, 2011-2014.

 **Pounds P2O5 per acre**

**Location/ Mehlich 3 0 20 40 60 80 100 P Value**

**County and Year Soil Test ----------------Yield, bu/acre ------------------**

 **ppm**

Nemaha, 12 3 22 19 19 17 20 20 0.25

Woodson, 11 5 32 B 38A 37A 37A 37A ----- 0.07

Woodson, Lynx, 12 7 47 49 50 51 49 48 0.47

Woodson, pasture, 14 7 29 28 32 30 32 30 0.24

Lyon, 13 (Flooded) 8 17 17 18 17 19 18 0.57

Lyon 14 (delayed) 9 10 11 14 12 12 12 0.24

Atchison, 13 11 48B 41C 50B 48B 53B 58A 0.01

Douglas, 13 11 43 43 41 43 46 45 0.90

Riley, Randolph 14 11 26C 30B 29B 31AB 31B 33A 0.01

Woodson, Meadow, 14 11 32 29 35 32 29 28 0.35

Osage, 14 15 46 46 46 46 48 49 0.79

Woodson, Meadow, 12 15 27 32 24 29 31 33 0.14

Cherokee, 11 16 28 26 28 29 29 ----- 0.66

Woodson, low, 13 16 60 61 61 61 60 61 0.76

Woodson, upland,13 16 32 36 37 34 33 34 0.42

Riley, Leonardville, 12 18 19 17 13 12 14 6 0.43

Riley, N Farm, 13 21 53 51 54 53 51 56 0.65

Clay, 14 22 37 36 38 39 36 39 0.94

Riley, Randolph 13 23 56 59 57 59 58 62 0.32

Jackson, 14 34 68 71 62 69 67 67 0.41

Saline, Dryland, 12 43 15 17 13 12 14 12 0.43

Saline, Irrigated, 12 56 35 34 35 37 34 37 0.98

2012 sites, with the exception of Woodson County, impacted by severe drought.

Letters signify statistical differences at alpha=0.10 level.

 The relative yield of the control, unfertilized plots, versus soil test P levels is shown in Figure 2. A linear-linear model is again used to show the soil test level above which no increase in yield is found. The data shown in this figure is the 2011, 2013 and 2014 data only. No 2012 data is presented due to general drought conditions limiting soybean yield and fertilizer response in 2012.

The linear-linear model provided a good explanation of the data as indicated by the high P-value, 0.001. The intercept value of 72 indicates that at very low soil test levels, <1, the expected yield of unfertilized soybeans would be roughly 72% of those grown at soil test levels above 12 ppm. The joint value of 11.6 is again the estimate of the Critical Value from these 16 experiments.

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Figure 2 Realtive yield of control plots compared to STP level of experiments conducted in this project in 2011, 2013 and 2014.

The Use of Alternative P Application Systems.

 Band Application . Research with wheat and corn, has shown a consistent response to placing a small quantity of P fertilizer in a band close to the seed, or a smaller quantity directly with the seed at planting. The use of starter or row placement of P fertilizer at low P soil test levels is an accepted practice among corn and wheat growers throughout many parts of the world. However similar practices have not shown the same consistent responses with soybeans. Borges and Mallarino (2000) only found that two out of 20 field experiments gave a significant banding response with soybeans in Iowa. In this study only 1 site of 20 showed a significant yield response to banding vs broadcasting. At that location a significant 1 bushel yield response was observed.

 There are a number of potential reasons why corn might respond to band applications of P at planting while soybeans may not. Earlier planting of corn into cold soils which limit early root growth is a likely reason. Soybeans are normally planted at least 2-3 weeks later that corn, and sometimes even later, in Kansas. A second important difference between the two crops is the P concentration in the seed. Corn has approximately 0.3 pounds of P2O5 in one bushel of seed, while soybeans contain over twice that quantity at 0.7 pounds P2O5 per bushel. Thus the soybean seed can provide substantially more P to the developing seedling than a corn seed.

 The results from this and other studies in the Midwest strongly suggest that band applications of P fertilizer, while an important management tool with corn and wheat, are not likely to provide economic benefits to Kansas soybean farmers, especially at ST levels above the Critical Level..

 Foliar Fertilization. Another alternative placement technique often recommended to farmers is the use of foliar fertilizer application. Beginning in 2013, a N, P, K and S foliar fertilizer was applied to five of the seven research sites at the R-4 growth stage (early pod set). In 2014 this was expanded to include all seven sites, with applications made at V-4 and at both V-4 and R-4. These treatments were applied to plots which had also received 60 pounds of P2O5 as MAP immediately after planting.

 To analyze the impact of these foliar application treatments, a separate analysis of variance was done looking at four specific treatments: the unfertilized control plots; plots which received 60 pounds of P2O5 broadcast; plots which received the broadcast phosphate plus an application of foliar fertilizer following company suggestions at V-4; and plots which received the broadcast phosphate plus foliar fertilizer at V-4 and R-4. At no sites did foliar fertilization increase yield significantly over the use of broadcast phosphate alone. Leaf analysis at the R-4 growth stage taken shortly after foliar application did show that the use of foliar fertilizer application in single or multiple applications did increase the leaf P levels at several locations, especially those with lower soil test P levels. The results from the 2014 foliar applications are summarized in Tables 3 and 4.

Table 3. Impact of P fertilization, both soil and foliar applied, on soybean yield. 2014 sites only.

 Treatments

Location ST No P 60 lb P2O5 Soil P + Soil P +

ppmControl Soil only V-4 Foliar V-4 and R-4

------------------------ Yield, bu/acre ------------------------ P-Value

Woodson, pasture 7 30 30 33 28 0.53

Lyon County 8 10 12 13 12 0.22

Riley, Randolph 11 26B 31A 31A 25B 0.01

Osage County 15 46 46 48 44 0.76

Woodson, meadow 15 32 31 29 29 0.88

Clay County 23 37 39 36 33 0.50

Jackson County 34 68 69 68 68 0.99

Table 4. Impact of P fertilization, both soil and foliar applied, on soybean leaf P content. 2014 sites only.

 Treatments

Location ST No P 60 lb P2O5 Soil P + Soil P +

ppmControl Soil only V-4 Foliar V-4 and R-4

-------------------- percent P in leaf ------------------------ P-Value

Woodson, pasture 7 0.28 0.28 0.28 0.28 0.96

Lyon County 8 0.19B 023A 0.24A 0.24A 0.02

Riley, Randolph 11 0.25B 0.29B 0.32A 0.26B 0.03

Osage County 15 0.19 0.21 0.20 0.21 0.64

Woodson, meadow 15 0.24C 0.27B 0.28AB 0.29A 0.01

Clay County 23 0.30 0.29 0.30 0.29 0.77

Jackson County 34 0.37 0.36 0.36 0.35 0.67

 Soybean Plant Analysis. Only a limited amount of plant analysis data is available on soybeans in recent years in the US. The high cost of sample analysis to obtain this data and lack of funding to support these efforts is one of the primary reasons this type work is not widely done today. The availability of large data sets which show small plant and leaf nutrient levels across a range of soil test levels, general yield levels and in both nutrient deficient and sufficient ranges is very limited. This data, together with data collected in a previous similar project on potassium sponsored by the Soybean Commission will allow development of useful diagnostic standards for soybean leaf data collected at early pod set, a standard growth stage for plant nutrient monitoring for N, P, K and S. Data on other nutrients will still be somewhat limited since ranges in soil pH for example of iron availability available in this data are limited.

The data given on leaf P content in Table 4 is an example of the type of data which will be very useful. With the exception of the Woodson pasture site a clear trend can be seen that as soil test P levels increase, P levels in the leaf increase. The pasture site can be explained as an outlier as this location was recently broken out of a long-term grass sod, and the decomposing grass residue is likely releasing significant amounts of organic P. Studies in Iowa have shown that in high organic matter soils, or where a pasture or hay field has recently been converted to crop land, up to 50% of the P entering the plant was supplied by the mineralization of organic P.

At this point only limited time has been available to mine this data for useful insights into relationships between nutrient levels in the plant and yield. Hopefully over the next year or two this will be possible.

Response of Soybeans to Micronutrient Fertilization.

 Yield response, 2013 and 2014. The response by site to the addition of sulfur fertilizers, or sulfur plus the micronutrients iron, zinc, manganese and boron in 2013 and 2014 is presented in Table 5. No positive yield responses to the addition of sulfur (S) or S plus micronutrients, compared to treatments where P was applied were observed in 2013 or 2014. At four sites, the, a negative response to the addition of the S plus micronutrients was observed as compared to the sulfur alone. Hopefully something in the plant analysis data can help us sort this trend out.

 Treatments

Location ST No P 60 lb P2O5 Soil P + Soil P +

ppmControl Soil only Sulfur S + Micros

------------------------ Yield, bu/acre ------------------------ P-Value

Lyon County, 13 8 18B 18B 23A 18B

Atchison Co, 13 11 48AB 48AB 52A 46B

Douglas Co, 13 11 44 45 45 46

Woodson, Low, 13 16 60A 62A 60A 55B

Woodson, Upland, 13 16 32 34 33 33

Riley, N Farm, 13 21 54 53 53 50

Riley, Randolph, 13 23 56 60 57 54

Woodson, pasture 7 30 30 33 28 0.53

Lyon County 8 10 12 13 12 0.22

Riley, Randolph 11 26B 31A 31A 25B 0.01

Osage County 15 46 46 48 44 0.76

Woodson, meadow 15 32 31 29 29 0.88

Clay County 23 37 39 36 33 0.50

Jackson County 34 68 69 68 68 0.99

**CONCLUSIONS**

The results of this extensive multi-year study provide some valuable information to farmers, but also leaves several questions that still need answers.

 First, it is clear that soybeans do not respond to fertilizer application well, but do respond to increasing soil test levels. However the current soil test critical level of 20 ppm clearly over estimates the need for P fertilization for soybeans in Kansas. No significant response to P fertilization was seen in the historical data published in the Kansas Fertilizer Research Reports, or in the 22 field experiments conducted in this project, at soil test P levels above 11 ppm. The linear-linear model used to fit the data from the recently completed project, suggests a critical soil test P level of 12 ppm is probably more appropriate.

 This is important for farmers to know. Most Kansas farmers realize that soybeans are not as responsive to P fertilizer as corn or wheat, crops commonly grown in rotation with soybeans. If the critical soil test level for P was truly 20 ppm, then the use of multi-year fertilizer application programs which applied all the P in a rotation to wheat or corn, a common practice in Kansas, would be inappropriate, and would result in yield reductions on over half the soybean acres annually (based on a mean P soil test in Kansas of 18 ppm as reported by surveys of commercial soil testing labs conducted by the International Plant Nutrition Institute). The fact that the critical value for P is closer to 12 ppm, indicates that this routine practice of multi-year fertilization with P is an appropriate practice that farmers can use to save time and application costs in these tight economic times.

 Second, the fact that little or no response to band applications of P at planting was observed in this study is also significant to farmers. This finding supports previous work that has only seen starter P responses in soybeans when soil tests are very low, < 5 or 6 ppm. Again, by not having to apply fertilizer, broadcast or band, to soybeans, equipment costs and time can be saved, leading to greater production efficiency.

 Similarly, the fact that no response to foliar fertilizer was seen in these studies, should remove that question from many growers minds. Many products designed for foliar application are actively marketed in Kansas and surrounding states. The results from this study show that while foliar application of fertilizer may increase the P level in the leaf, no advantage over regular P soil applied P was observed in yield. This supports findings made over past decades by researchers at Land Grant Universities thoughout the Midwest.

 Last, no need for micronutrients and sulfur were found in this study. This is an important point since sulfur deficiencies in corn and wheat especially, have been increasing in recent years, as efforts to improve air quality have reduced sulfur deposition throughout the US. In Kansas, confirmed S deficiencies in both corn and wheat are increasing. There were some interesting trends observed at these sites however. Sulfur nutrition of all crops, including soybeans, is going to need to be watched closely as efforts to protect the environment will continue to reduce the S deposition in Kansas and gradually deplete soil S in many parts of the state.

**A Personal Note**

 Finally, I would like to thank the Kansas Soybean Commission and the Kansas soybean producers they represent, for their continued support of my research over the past decade. The Soybean Commission helped me make the transition from Department Head back to Agronomist easy, and I greatly appreciate that. The level of trust which was displayed a number of times at Commission meetings and the Soy Expo was greatly appreciated. As this portion of my career comes to a close, I want to thank current and past Commission members and staff for the support and respect they have given me over the past 17 years I have been in Kansas. Your support has allowed me to train some excellent students who are active in your industry, and hopefully provided you with some information you can use in your business. Thank You.