4R Meta-Analysis Project Report

Meta-analysis of phosphorus fertilizer placement and tillage interaction for corn and soybean in the US

Cristie Edwards, Dorivar Ruiz Diaz, and David Mengel, Dep. of Agronomy, Kansas State University

ABSTRACT

Phosphorus (P) placement and tillage interactions have been extensively studied for corn and soybean production in the Midwestern states of the US. A meta-analysis was conducted including publications from 1980 to the present with studies in the Midwest region to evaluate the effects of P placement and tillage interaction on corn and soybean yield. Five databases (Wiley International Science, Springer Link, Web of Science, Science Direct, and ACSESS Digital Library) were searched with standard keywords across all database. Coding criteria were set to include site identification information, background soil test, tillage practice, fertilizer P rate, placement, and source, and statistical information. Preliminary results show generally lower overall yields for no-till for the region of this study. Fertilizer placement showed a generally lower yield for band placement, however this was not statistically significant. This suggest no placement effect on yield with application rates evaluated in this study. Furthermore, band placement may provide a yield increase only if the rates are limiting (<40 lbs/acre in our study), or in soil testing very low in which the broadcast rate is very low and deficient. Perhaps in this case banding near the seeding could increase yields and additional studies with lower application rates may be required. However, the practical application of low fertilizer rates via broadcast may be questionable for the producer. Perhaps the largest overall benefit to P placement may come from reduction in runoff loses.

INTRODUCTION

Phosphorus placement and interactions with tillage has been evaluated extensively for corn and soybean in the US. Results suggest that placement of P fertilizer can play an important role in early P plant uptake and yield as well as potential P loses to surface water for some soils and tillage conditions. The rate of P uptake per unit of root in corn decreases throughout the vegetative growth phase (Mengel and Barber, 1974); and therefore early season P fertilizer applications and placement can be particularly important for optimum plant growth.

Broadcast application can result in a more uniform distribution and likely affecting more soil volume. Crops have shown a response for various levels of soil test, including low soil test P (STP) conditions (Bordoli and Mallarino, 1998) and medium to high STP (Mallarino et al., 1991). However, accumulation of P near the soil surface may result in higher lost potential with runoff; and possible decreased P availability due to increased soil-fertilizer interaction in soils with high P sorption capacity. Broadcast application may be more practical for some producers and suitable for some soils and tillage conditions. However, soils and tillage conditions and the interaction with P application methods should be evaluated with larger datasets and across different soils and environments. Potential P loses with water runoff can be affected significantly by phosphorus placement and tillage (Kimmell et al., 2001). Many studies in the US evaluated water runoff and P loses as affected by tillage and fertilizer. However studies often show

different results, which may be due to differences in soils, rainfall amounts and intensities, slope, moisture content, and infiltration rate. Evaluation and summary of the existing literature can help to identify factors contributing to potential P loses in addition to tillage and fertilizer placement.

Crop response and P loss potential can be affected by the interaction between soil and tillage factors with P fertilizer placement. Accurate evaluation of these interactions would require large dataset that comprise a variety of soils, tillage and placement combinations. Meta-analysis is considered a quantitative systematic review of published and unpublished literature/datasets with the use of statistical methods (Philibert et al., 2012; Wang and Bushman, 1999). Meta-analysis can be more powerful than simple narrative reviews of a series of studies, because it summarizes data in a quantitative manner and makes it possible to assess the between-study variability (Doré et al., 2011). However, meta-analyses should be completed following sound methods and quality control (Philibert et al., 2012).

The objectives of the study were to (1) find, analyze, and summarize published and unpublished field-based data on corn and soybean response to P placement and the interaction with tillage; (2) Complete a data review on yield response and phosphorus loses with surface runoff as affected by P placement and tillage interaction; (3) Include data review of estimated P use efficiency with placement and tillage interactions; and estimate the economic return associated with different systems.

MATERIALS AND METHODS

Some key components of meta-analyses suggested by several authors include: (1) Correct description of the bibliographic search procedures; (2) Listing of the references of the selected individual studies used in the meta-analysis; (3) Analysis of the variability of the results of individual studies, including estimation of variability between the selected individual studies and, when relevant, investigation of the sources of between-study variability; (4) Analysis of the sensitivity of the conclusions to any change in the dataset and/or in the statistical method used to analyze the data; (5) Assessment of the publication bias; (6) Data weighting. When the results reported in the individual studies differ in their levels of accuracy; (7) Availability of the dataset; and (8) Availability of the program used for statistical analysis (Borenstein et al., 2011; Gates, 2002; Roberts et al., 2006; Sutton et al., 2000; Wang and Bushman, 1999).

This meta-analysis was developed using the steps described by Philibert et al., 2012, and with especial attention to the quality of the meta-analysis procedure. A database search for all publications that included yield data for corn and soybean was conducted within Wiley International Science, Springer Link, Web of Science, Science Direct, and ACSESS Digital Library databases. The primary search criteria was set to include publications from 1980 to the present and studies conducted in the Midwest or Great Plains region of the US (Colorado, Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Montana, Nebraska, North Dakota, Ohio, Oklahoma, South Dakota, and Wisconsin).

Published articles were selected based on key criteria for quality of information and relevance. Coding parameters were set to include site information (location and study year), background soil (soil series, classification, soil test method, soil sampling depth, STP, and soil test potassium), management practice (tillage type, P fertilizer rate, application method, and P source), crop information (corn hybrid, soybean cultivar, crop yield), and statistics (number of replications, means, standard error (SE), coefficient of variation (CV)). Soybean data was categorized as “residual” when fertilizer was applied before corn in a corn-soybean rotation with

no additional fertilizer applied to soybeans or "fertilized" when fertilizer was applied before soybean planting. Double cropped soybeans were not include in the analysis. Studies involving manure applications that contained an inorganic fertilizer and control treatments were included in the analysis.

The response ratio was estimated based on the ratio between the response variables (yield or P loses) from plots with contrasting treatments (i.e. band placement vs broadcast), and used to evaluate the effect of P fertilizer application under different tillage systems (Hedges et al., 1999). The response ratio was presented primarily as relative responses ([treatment-control)/control] × 100). Statistical analysis was completed using MetaWin and SAS (Rosenberg et al., 2000; SAS Institute, 2010), and following methods described by (Wang and Bushman, 1999).

RESULTS AND DISCUSSION

The number of studies selected at various stages is shown in the flow diagram in Fig 1. The number of publications included in the meta-analysis was 247. This included both "gray literature" and peer-reviewed publications, and additional selection criteria may include separating these categories. In recent years several review papers have summarized "unpublished" datasets, showing the value of this information with proper assessment of the quality of the data (Tremblay et al., 2012). However, the use of only peer-reviewed publications may provide additional assurance regarding the quality of the studies and the data included.

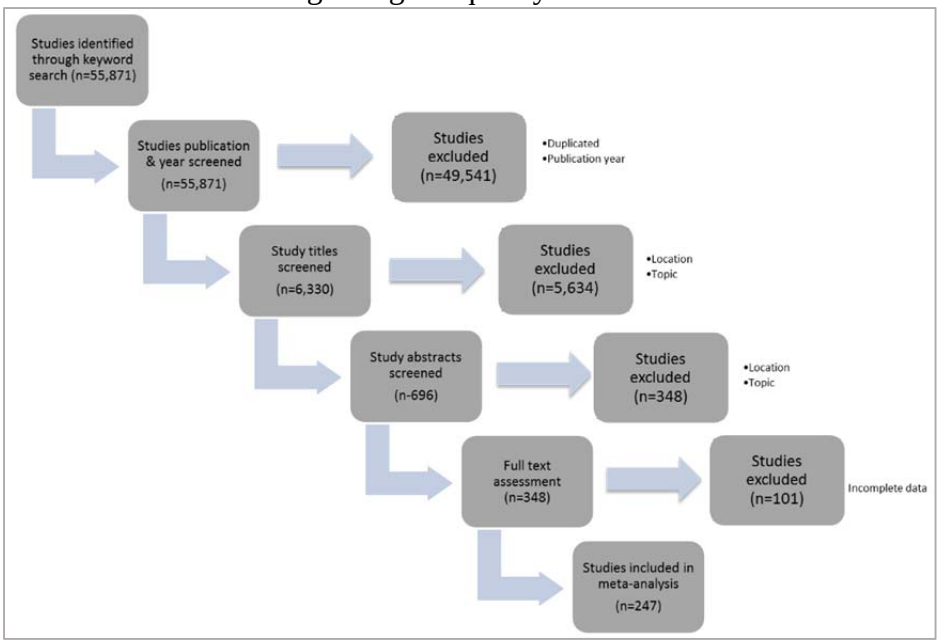
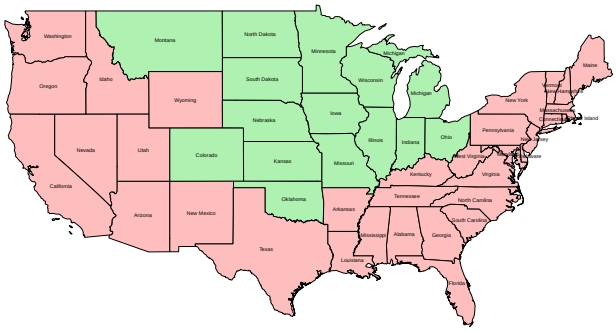


Figure 1. Selection of studies for inclusion in the meta-analysis

The selection criteria for this meta-analysis required studies from 15 US states. A total of 11 states were include (Colorado, Illinois, Indiana, Iowa, Kansas, Minnesota, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin); and 4 states did not met the criteria (Michigan, Montana, North Dakota, and Oklahoma) (Fig 2).

US states considered as seletcion critaria (15)



US states that met the selction criteria (11)

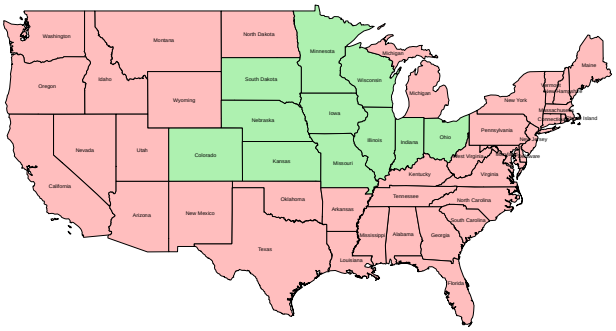


Figure 2. US states included in the selection criteria and states that met the criteria

The dataset developed with this search were analyzed using different categories. For tillage, the studies were categorized in two (no-till and conventional tillage). The conventional tillage included strip-till and minimum tillage. Phosphorus placement categories were defined as broadcast and band; the band category included different types of subsurface and surface band placement and data shown here only include fertilizer rates with 40 lbs P2O5/acre or more.

Response ratio of tillage showed overall lower yields with no-till (Fig 3). These results agree with previous studies, and no-till systems seems to provide relatively higher yields under arid conditions. Previous studies showed that yields can be lower under humid conditions such as the area for this study in the USA (Brouder and Gomez-Macpherson, 2014; Pittelkow et al., 2015a; Pittelkow et al., 2015b). However, is also possible that the current body of literature comparing no-till versus conventional tillage is not providing a “fair” evaluation of both tillage systems. Some researchers suggest that no-till “system” comprise many factors that are essential for no-till, and just the lack of tillage cannot be considered no-till system (Derpsch et al., 2014). This may require some revision of the methodology used for current tillage system research.

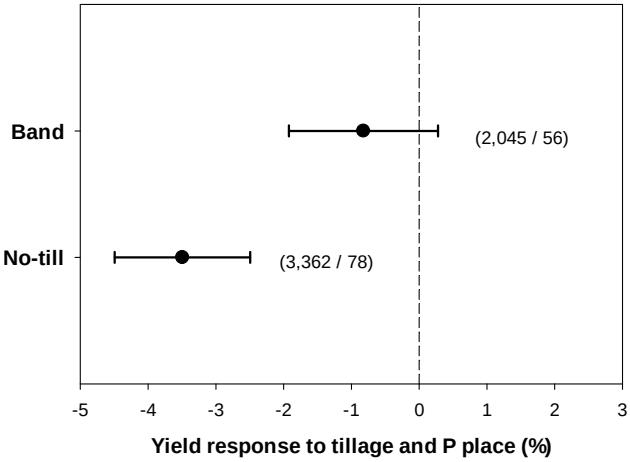


Figure 3. Overall response ratio to tillage and P fertilizer placement.

Yield response to band phosphorus fertilizer application showed a generally lower yields when compared to broadcast application, however this was only statistically significant for no-till system (Fig 3 and 4). Is important to emphasize that this analysis was completed for

phosphorus application rates above 40 lbs P2O5/acre. Is possible that lower fertilizer application rates would show higher efficiency (higher yields) with band application compared to broadcast. Relatively higher yield for broadcast under NT system may be due to relatively higher surface moisture and therefore root activity under NT compared to conventional tillage (Farmaha et al., 2012).

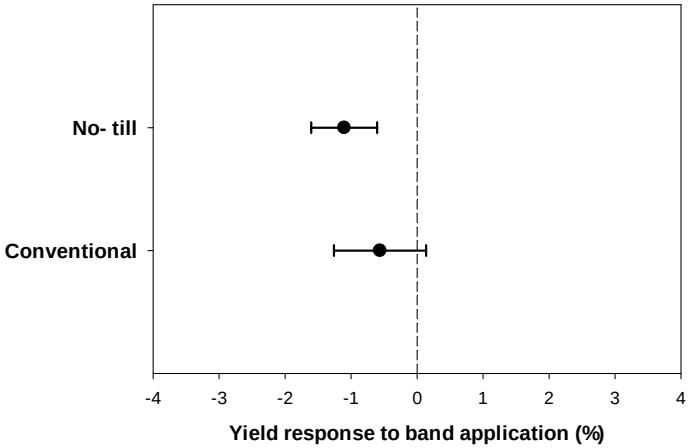


Figure 4. Response ratio to band versus broadcast fertilizer application for two tillage categories. Fertilizer application rates were at 40 lbs P2O5/acre or higher.

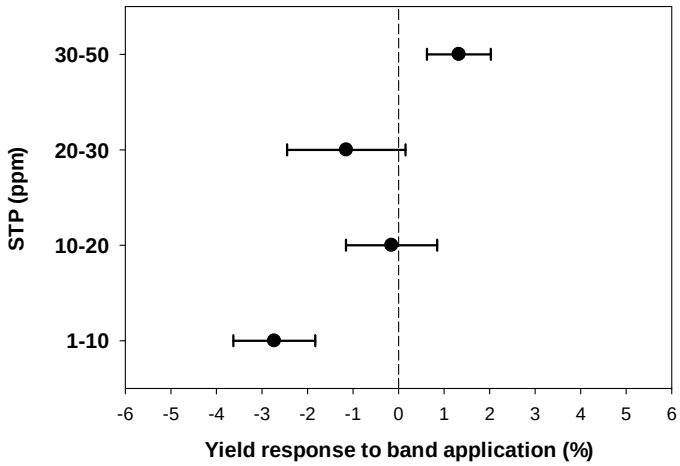


Figure 5. Response ratio to band versus broadcast fertilizer application across tillage categories, for four soil test categories. Fertilizer application rates were at 40 lbs P2O5/acre or higher.

The preliminary analysis for different soil test categories showed generally higher yields for broadcast application at lower soil test P levels (Fig 5 and 6). These results may require additional evaluations and verify that other confounding factors such as fertilizer application rates are not affecting these values creating a possible bias in the results. Accurate evaluation of these soil test categories may require the inclusion of more studies, likely from outside the original criteria for geographic region.

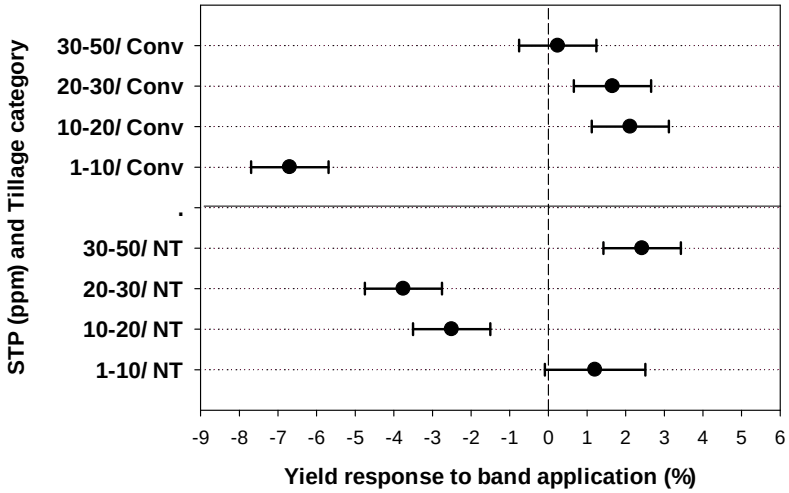


Figure 6. Response ratio to band versus broadcast fertilizer application by tillage and soil test categories. Fertilizer application rates were at 40 lbs P2O5/acre or higher.

SUMMARY

The work focusing on the evaluation of phosphorus loss with different tillage and P placement interactions is relatively limited, especially comparing to work evaluating agronomic aspects. The majority of the previous work on P loss focus on P from manure source, and a large amount of work was completed in the East and North East region of the U.S. leaving limited number of papers meeting our selection criteria for the P loss component. Therefore we are currently expanding the geographic area covered for this meta-analysis, and including the entire US.

During the literate search, many issues were identified as related to data presentation/availability in peer-reviewed papers, including differences and inconsistences among journals and papers within journals (i.e. background soil information, soil sampling methods and limited detail on fertilizer sources used). Future improvements in data stewardship are clearly needed to increase access and improve the use of published data on this topic. This literature search show that some database (i.e. The Digital Library) are better suited for an effective meta-analysis search. Very limited amount of work is available on the long-term effect of specific management systems used by producers for tillage and/or placement on potential P loses to surface water. Furthermore, some specific states in the US have limited amount of published data on the overall topic of tillage by P placement interaction for both agronomic and environmental implications.

Two manuscripts on this topic are currently under preparation, the component on environmental P loss required additional literature search, and the criteria of geographic area was expanded to include the entire US. These manuscripts will be included as thesis chapter for Cristie Edwards, the graduate student working on this project. Results of this study will be presented at the American Society of Agronomy international meeting in 2015.

REFERENCES

Boomsma, C., M. Cánepa, T. Vyn. 2007 Factors affecting the relative benefit of deep-banding versus broadcast application of phosphorus and potassium for corn and soybean, North Central Extension-Industry Soil Fertility Conference Proceedings. pp. 55-63.

Bordoli, J.M., A.P. Mallarino. 1998 Deep and shallow banding of phosphorus and potassium as alternatives to broadcast fertilization for no-till corn. Agron. J. 90:27-33.

Borenstein, M., L.V. Hedges, J.P. Higgins, H.R. Rothstein. 2011 Introduction to meta-analysis Wiley. com.

Brouder, S.M., H. Gomez-Macpherson. 2014 The impact of conservation agriculture on smallholder agricultural yields: A scoping review of the evidence. Agriculture, Ecosystems & Environment 187:11-32.

Derpsch, R., A. Franzluebbers, S. Duiker, D. Reicosky, K. Koeller, T. Friedrich, W. Sturny, J. Sá, K. Weiss. 2014 Why do we need to standardize no-tillage research? Soil and Tillage Research 137:16-22.

Doré, T., D. Makowski, E. Malézieux, N. Munier-Jolain, M. Tchamitchian, P. Tittonell. 2011 Facing up to the paradigm of ecological intensification in agronomy: Revisiting methods, concepts and knowledge. European J. of Agron. 34:197-210.

Farmaha, B.S., F.G. Fernández, E.D. Nafziger. 2012 Distribution of soybean roots, soil water, phosphorus and potassium concentrations with broadcast and subsurface-band fertilization. Soil Science Society of America Journal 76:1079-1089.

Gates, S. 2002 Review of methodology of quantitative reviews using meta-analysis in ecology. J. of Animal Ecology 71:547-557.

Hedges, L.V., J. Gurevitch, P.S. Curtis. 1999 The meta-analysis of response ratios in experimental ecology. Ecology 80:1150-1156.

Kimmell, R., G. Pierzynski, K. Janssen, P. Barnes. 2001 Effects of tillage and phosphorus placement on phosphorus runoff losses in a grain sorghum–soybean rotation. J. of Envir. Qual. 30:1324-1330.

Klausner, S.D., R.W. Guest. 1981 Influence of NH_3 conservation from dairy manure on the yield of corn. Agron. J. 73:720-723.

Littell, R.C., G.A. Milliken, W.W. Stroup, R. Wolfinger. 2006 SAS for Mixed Models. 2nd ed. SAS Institute Inc., Cary, NC.

Mallarino, A., J. Webb, A. Blackmer. 1991 Soil test values and grain yields during 14 years of potassium fertilization of corn and soybean. J. of Prod. Agric. 4:560-567.

Mengel, D., S. Barber. 1974 Rate of nutrient uptake per unit of corn root under field conditions. Agron. J. 66:399-402.

Philibert, A., C. Loyce, D. Makowski. 2012 Assessment of the quality of meta-analysis in agronomy. Agriculture, Ecosystems & Environment 148:72-82.

Pinheiro, J., D. Bates, S. DebRoy, D. Sarkar. the R Core team (2007) nlme: linear and nonlinear mixed effects models. R package version 3:1–83.

Pittelkow, C.M., B.A. Linquist, M.E. Lundy, X. Liang, K.J. van Groenigen, J. Lee, N. van Gestel, J. Six, R.T. Venterea, C. van Kessel. 2015a When does no-till yield more? A global meta-analysis. Field Crops Research 183:156-168.

Pittelkow, C.M., X. Liang, B.A. Linquist, K.J. Van Groenigen, J. Lee, M.E. Lundy, N. van Gestel, J. Six, R.T. Venterea, C. van Kessel. 2015b Productivity limits and potentials of the principles of conservation agriculture. Nature 517:365-368.

Roberts, P.D., G.B. Stewart, A.S. Pullin. 2006 Are review articles a reliable source of evidence to support conservation and environmental management? A comparison with medicine. Biological Conservation 132:409-423.

Rosenberg, M.S., D.C. Adams, J. Gurevitch. 2000 MetaWin: statistical software for meta-analysis Sinauer Associates Sunderland, Massachusetts, USA.

Ruiz Diaz, D.A., D.B. Mengel, R.E. Lamond, S.R. Duncan, D.A. Whitney, T.M. Maxwell. 2012 Meta-analysis of winter wheat response to chloride fertilization in Kansas. Commun. in Soil Sci. and Plant Anal. 43:2437-2447.

SAS Institute. 2010 The SAS system for Windows. Release 9.3.1, SAS Institute,, SAS Inst., Cary, NC.

Sutton, A.J., K.R. Abrams, D.R. Jones, T.A. Sheldon, F. Song. 2000 Methods for meta-analysis in medical research J. Wiley.

Tremblay, N., Y.M. Bouroubi, C. Bélec, R.W. Mullen, N.R. Kitchen, W.E. Thomason, S. Ebelhar, D.B. Mengel, W.R. Raun, D.D. Francis, E.D. Vories, I. Ortiz-Monasterio. 2012 Corn Response to Nitrogen is Influenced by Soil Texture and Weather. Agronomy Journal 104:1658-1671.

Wang, M.C., B.J. Bushman. 1999 Integrating results through meta-analytic review using SAS software SAS Publishing, Cary, NC.