XVII^th World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

A META-ANALYSIS OF WEATHER EFFECTS ON CORN NITROGEN FERTILIZATION REQUIREMENTS

MIN XIE[1], NICOLAS TREMBLAY[2], ZHANMIN WEI[1]

[1] M. Xie, Zhanmin Wei 1 Water Conservancy and Civil Engineering College, Inner Mongolia Agricultural University, 306 Zhaowu Da Street, Hohhot, China 010018, xiemin@live.ca
[2] N. Tremblay , Horticultural Research and Development Centre, Agriculture and Agri-Food Canada, 430 Gouin Blvd, Saint-Jean-sur-Richelieu, QC, Canada J3B 3E6, nicolas.tremblay@agr.gc.ca

CSBE100746 – Presented at Section I: Land and Water Engineering Conference

ABSTRACT Meta-analysis is an expression used to identify a set of statistical techniques developed to provide an objective comparison of research results from independent studies. A meta-analysis combines the results of several studies that address a set of related research hypotheses. In this study, a meta-analysis was performed on the relationship between the application rates of nitrogen fertilizer and the corn yield response in order to understand the effects of climate (air temperature, rain) and environmental conditions (latitude, soil surface textures). The database was constituted by publications from Africa, Europe and America published between 2000 and 2009, inclusively. The response ratios (RR) used to measure effect size indicated significant positive response of corn yield. The climate influenced nitrogen requirements. Corn grown on silt clay loams, and to a smaller extent on silt loams, was more responsive to added N. The latitudes from 39°N to 42°N were the most favourable to corn N response. During the first two months of corn growth, the effect of rain evenness on N response was larger than that of temperature or precipitation. For the mid–season period, the effect of precipitation was higher than the ones of temperature and rain evenness. For the last part of the growing season, all three factors were of equal importance for N response.

Keywords: Meta-analysis, Weather effects, Corn Nitrogen fertilization, Response ratio

INTRODUCTION Growing conditions and field management are known to influence corn yield response to nitrogen fertilization (Voss et al. 1970; Liang et al. 1991). Soil type has a significant effect on corn yield variability (Liang and MacKenzie 1991) and the yield response to nitrogen fertilization under low fertility conditions (Muchow and Sinclair 1995). The latitude is another factor involved in corn yield responses (Chang 1981; Muchow et al. 1990). Weather (rainfall and temperature) impacts on corn (*Zea mays* L.) yield and optimal nitrogen fertilization rates (Thompson 1975; Yamoah et al. 1998; Kahabka et al. 2004). A number of studies have focused on weather effects on optimal N rates in order to improve nitrogen use efficiency and reduce the N losses related to corn production (Andresen et al. 2001; Ma et al. 2005). Bondavalli and Colyer (1970) suggested that precipitation during the first half of August and temperature during the second half of May had significant effects on corn yield. Asghari and Hanson (1984) concluded that crop heat units accumulation in June promoted corn yield response to nitrogen fertilization, while precipitations had no significant influence. In July, precipitation increased, and crop heat units decreased, corn yield response to N fertilization. Teigen and Thomas (1995) and Jeutong et al. (2000) suggested that weather conditions had more importance during July and August. Reeves et al. (1993) suggested that high response to added N was related to adequate rainfall distribution.

Because they drive important soil and crop factors, temperature (impact on mineralization and crop growth) and rain (impact on mineralization, crop growth, N losses through leaching or denitrification) are often perceived as determinant in the success or failure of a fertilizer N application. For a farmer, how to manage this weather-fertilizer interaction is critical for both the profitability and the environmental impact of its corn growing operation. In-season N application is an available alternative to “all-at-sowing” N application. The former allows for considering the weather conditions that have prevailed from sowing in the decision about N dose to apply. Yet, a better understanding of weather effects on corn response to N fertilization is lacking because individual studies are each made under a limited set of weather conditions that do not warrant a comprehensive analysis of their own effects. Meta-analysis appears well suited for this matter as it is a statistical method for research synthesis where separate studies can be combined to estimate treatment effects and the causes of variability. The results of separate studies are compared and averaged on a common scale of treatment effect (i.e., effect size) (Gurevitch, Curtis et al. 2001).

The purpose of this paper was primarily to assess the impact on corn yield response to N fertilizer application, of temperature and rainfall (quantity, uniformity) conditions prevailing during different periods of the seasonal growing cycle.

MATERIALS AND METHODS

Database Compilation

Suitable peer-reviewed scientific papers were identified from electronic databases, including Scopus and Google scholar. Only literature published between 2000 and 2009 was selected according to the following criteria: 1) corn yields and applied nitrogen rates are reported for each experimental year; 2) the experimental designed was randomized and included at least three replications; 3) an appropriate control (i.e. fertilizer with nitrogen rate 0 kg ha^{-1}) was present; 4) all the experiments were not irrigated and in-season fertilizer application was performed. On the basis of these criteria, 10 references representing a total of 106 trials conducted over the years 1994 to 2005 were retained (Appendix A). The necessary data were extracted from tables or from digitized figures by the Image J 1.43 software (National Institutes of Health, USA). All the information was classified and an electronic database was built using Excel®.

Meta-Analysis

In this analysis, the natural log of the response ratio (RR) was used as the effect size (Hedges et al. 1999; Gurevitch et al. 2001; Tonitto et al. 2006). The effect size for each study was calculated as follows:

$$\ln RR=\ln(Xn/ X_0) \quad (1)$$

where ln was the natural logarithm, X_n and X_0 represented response mean values for applied nitrogen fertilizer treatments and no nitrogen fertilizer treatments (i.e. control), respectively. A response ratio (RR) higher than 1 indicates an increase in yield production under nitrogen fertilization, and vice versa (Valkama et al. 2009). When studies are assembled from the published literature, the random effects model is generally of greater precision than the fixed effects model (Borenstein et al., 2009). In our study, the random effects model was used in order to increase precision of the combined estimate of effects size and to work from more balanced weights than for the fixed effect model. The total heterogeneity of effects size among studies (Q_t) was partitioned into within-group (Q_w) and between-group (Q_b) heterogeneity (Hedges and Olkin 1985). Between-group heterogeneity was attributed to the different characteristics (i.e., soil types, latitude and weather factors). If the Q_b, which follows a χ^2 distribution, was larger than a critical value and if the 95% CIs of estimates of effect size did not overlap with zero, the independent variable was considered to have a significant influence on the response ratio (Xia and Wan 2008). Statistical significance was tested at the $P < 0.05$ level. The meta-analysis was performed as suggested by Borenstein et al. (2009) using Comprehensive Meta Analysis V2 (National Institutes of Health, 2005), the mean value and variance of each studies were calculated in Excel®.

Weather Data

The weather datasets were obtained directly from the authors through email solicitations. Growing seasons, from sowing to harvest, were divided into 30-day periods as follows: 1st-30d (the first 30 days after sowing), 2nd-30d, 3rd-30d, 4th-30d and the rest of the season so as to test the effect of weather on the response ratio during each period. The effects of crop heat units (CHU) and rainfall distribution at those periods in the growing season were determined from the average daily values of CHU, precipitation (PPT) and the Shannon Diversity Index, respectively. Average daily values of CHU was calculated by using the following formula (Bootsma et al. 2005):

$$Y_{max} = 3.33\,(T_{max} - 10.0) - 0.084\,(T_{max} - 10.0)^2 \text{ (if } T_{max} < 10.0,\ Y_{max} = 0.0) \quad (2)$$

$$Y_{min} = 1.8\,(T_{min} - 4.44) \text{ (if } T_{min} < 4.44,\ Y_{min} = 0.0) \quad (3)$$

Where Y_{max} and Y_{min} were the contributions to CHU from average daily maximum (T_{max}) and minimum (T_{min}) air temperatures, respectively. Average daily CHU was computed as $(Y_{max} + Y_{min})/2$.

The Shannon Diversity Index (SDI) gives an indication of the evenness of precipitation events. An index equal to one implies complete evenness (i.e., equivalent amounts of rain in each day of the period) and an index equal to zero implies complete unevenness (i.e., all rain in 1 day). SDI was found by Bronikowski and Webb (1996) as the best index in terms of spread and sensitivity under different rainfall regimes. It is computed as follows:

$$\text{SDI} = \frac{-\sum pi \ln(pi)}{\ln(N)} \quad (4)$$

where SDI is rainfall diversity index during the period, *pi* is the fraction of rainfall relative to the total rainfall in a given period and N is the number of days in the period.

RESULTS AND DISCUSSION

For the whole database, the test of homogeneity was significant (Q_t = 472.7 df = 105, P < 0.0001) so there was sufficient variability in the whole data to warrant further analysis by the introduction of categorical variability. The dataset was analyzed for CHU, precipitation, Shannon Index, soil classification, and latitude effects as follows. Between-group homogeneity was evaluated (Table 1) and some main effects were considered significant for CHU (1st-30d, 2nd-30d, 3rd-30d and rest of the season), PPT (1st-30d, 2nd-30d, 3rd-30d, 4th-30d,and rest of the season), SDI (1st-30d, 2nd-30d, 3rd-30d, rest of the season, in the whole growing season), soil classification, and latitude. However, some tests of homogeneity were not significant for CHU (4th-30d and whole growing season) PPT (whole growing season), and SDI (4th-30d). No further analyses were conducted for these non-significant results.

Table 1. Between-group homogeneity analysis (Q_t) for all the categorical variables of N response in the review

Categorical variable	Q_t	df	*P*-value
CHU in 1st-30d	11.92	4	0.018
CHU in 2nd-30d	52.73	3	<0.0001
CHU in 3rd-30d	9.54	2	0.008
CHU in 4th-30d	0.01	2	0.917
CHU in Rest	72.31	4	<0.0001
CHU in the whole growing season	4.63	3	0.201
PPT in 1st-30d	12.79	4	0.012
PPT in 2nd-30d	27.32	4	<0.0001
PPT in 3rd-30d	35.77	5	<0.0001
PPT in 4th-30d	12.36	3	0.006
PPT in Rest	18.55	2	<0.0001
PPT in the whole growing season	1.68	3	0.642
SDI in 1st-30d	41.12	6	<0.0001
SDI in 2nd-30d	53.72	5	<0.0001
SDI in 3rd-30d	18.24	5	0.003
SDI in 4th-30d	9.18	6	0.164
SDI in Rest	69.48	6	<0.0001
SDI in the whole growing season	10.30	3	0.016
Soil classification	21.57	3	<0.0001
Latitude	31.47	3	<0.0001

The effects of soil type and latitude

Silt clay loams, and to smaller extent silt loams, impacted on N responses despite considerable variability in response ratios (Fig. 1a). Loams (few studies represented) and sandy loams were less conducive to N responses.

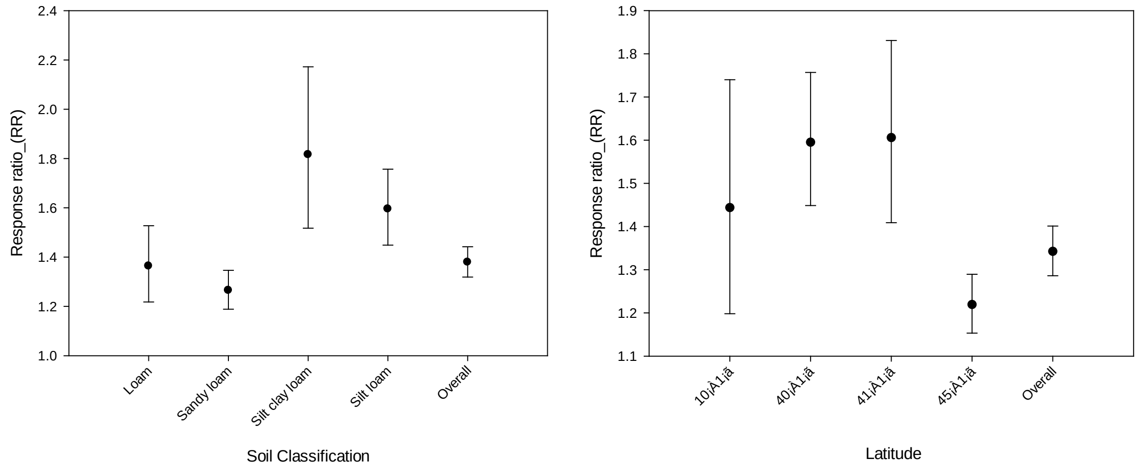

Figure 1. Response ratio and 95% confidence interval a) for the four types of soils and; b) for the latitude.

The test of between group homogeneity for the latitude levels was significant (Q_t = 31.4, df = 3, P < 0.0001). The N dosage was effective in increasing corn yield at all latitude levels compared to the no-nitrogen control but the degree of variability was also considerable. Latitudes from 39°N to 42°N which include the USA Corn Belt were the most favourable to corn N response (Fig. 1b).

Table 2 Response ratio (RR) and 95% confidence intervals (C.I. in parentheses) at five periods during the season of the influence of corn heat units (CHU) levels on yield response to fertilizer N doses.

Period	Corn heat units (CHU) levels and corresponding RR and (C.I.)					
	< 400	400~599	600~799	800~999	> 1000	Overall
1st – 30 d	1.5	1.3	1.6	1.6	1.2	1.4
	(1.2;1.7)	(1.2;1.4)	(1.4;1.8)	(1.4;1.8)	(1.0;1.4)	(1.3;1.5)
		600~799	800~999	1000~1500	> 1500	Overall
2nd – 30 d		1.5	1.6	1.2	1.0	1.4
		(1.4;1.6)	(1.5;1.7)	(1.0;1.4)	(0.9;1.1)	(1.3;1.4)
			600~799	800~999	> 1000	Overall
3rd – 30 d			1.3	1.6	1.2	1.4
			(1.3;1.5)	(1.4;1.7)	(1.0;1.4)	(1.3;1.5)
			600~699	700~799	800~999	Overall
4th – 30 d			1.4	1.5	1.5	1.4
			(1.3;1.5)	(1.4;1.6)	(1.2;1.8)	(1.4;1.5)
	< 400	400~599	600~799	800~999	> 1000	Overall
Rest	1.6	1.2	1.5	2.2	1.3	1.4
	(1.5;1.8)	(1.1;1.3)	(1.4;1.6)	(1.8;2.7)	(1.1;1.6)	(1.3;1.4)
		<3000	3000~3499	3500~3999	4000~4499	Overall
Whole		1.4	1.4	1.5	1.9	1.4
		(1.3;1.6)	(1.3;1.5)	(1.3;1.6)	(1.4;2.6)	(1.4;1.5)

The effects of Corn Heat Unit

High N responses were obtained in the range 600~999 CHU in the first three periods which represents neither low, now high CHU accumulation. Yield responses to added N were affected by CHU except at CHU > 1500 in the 2^{nd}-30d period (Table 2). The highest N response in the 3^{rd}-30d period was obtained at CHU from 800 to 999 with a mean response ratio of 1.6. Thus, medium CHU in that period would increase the effect of N fertilization. At later periods (4^{th} – 30 d and rest of season), relatively high CHU accumulations were generally conducive to N response. For the whole growing season, CHU in the range 4000 - 4499 resulted in average corn yield response about 46% greater than at any lower CHU accumulation. The largest response ratio in the periods “rest of season” and “whole season” were also characterized by the largest confidence intervals. Hence, other factors such as rainfall and soil type may also determine the importance of the response ratio in any particular situation.

The effects of precipitation (PPT)

The test of between-group homogeneity for PPT effects on N response was significant for every 30 d-period, except for the whole growing season (Table 1). High N responses were obtained for medium PPT at the 1st, 2nd, and 3rd-30 d periods, and for higher PPT at later periods (Table 3). When PPT at the 3^{rd}-30d period was in the 150 to 199 mm range, corn yield response to N was 2.6 times greater than that of the control (no nitrogen). This period of 3^{rd}-30 d appears as a critical one. For each additional 200 mm of precipitations, yield response to N increased by ~25% for the “rest of season” period.

Table 3. Response ratio (RR) and 95% confidence intervals (C.I., in parentheses) at five periods during the season of the influence of precipitation (PPT) levels on yield response to fertilizer N doses.

Period	Precipitation mm (PPT) levels and corresponding RR and (C.I.)					
	<50	50~99	100~149	150~199	250~299	Overall
1^{st} – 30 d	1.5	1.3	1.6	1.4	1.2	1.4
	(1.41;1.71)	(1.3;1.4)	(1.4;1.8)	(1.2;1.6)	(1.0;1.4)	(1.3;1.5)
	<50	50~99	100~149	150~199	200~249	Overall
2^{nd} – 30 d	1.6	1.3	1.5	1.6	1.2	1.4
	(1.5;1.9)	(1.1;1.4)	(1.4;1.6)	(1.4;1.8)	(1.1;1.3)	(1.4;1.5)
	<50	50~99	100~149	150~199	200~249	Overall
3^{rd} – 30 d	1.3	1.5	1.4	2.6	1.7	1.4
	(1.2;1.3)	(1.4;1.6)	(1.3;1.6)	(1.9;3.5)	(1.3;2.2)	(1.3;1.5)
		<50	50~99	100~149	150~199	Overall
4^{th} – 30 d		1.3	1.6	1.5	1.6	1.5
		(1.2;1.4)	(1.4;1.7)	(1.2;1.9)	(1.4;1.7)	(1.4;1.5)
			<200	200~399	400~600	Overall
Rest			1.2	1.6	2.0	1.4
			(1.1;1.4)	(1.4;1.7)	(1.6;2.5)	(1.3;1.5)
		<200	200~399	400~600	> 1000	Overall
Whole		1.4	1.4	1.4	1.7	1.4
		(1.2;1.6)	(1.3;1.5)	(1.3;1.5)	(1.3;2.1)	(1.4;1.5)

The effects of Shannon Diversity Index

The Shannon Diversity Index was an important determinant of N response, especially during 1^{st}-30d, 2^{nd}-30d and the rest or the season periods (Table 4) with RR up to 2.2, 2.2

and 2.5, respectively. The effects of SDI at the 3rd-30 d period on crop response to added N are likely affected by other factors since all mean RR showed wide confidence intervals. For that particular period, increases of SDI generally corresponded to increases of corn yield response to added N. At the 4th-30 d period, crop responses were better when SDI was neither very low, nor very high. For the whole growing season, the largest mean RR was found for SDI 0.600 ~ 0.649 (Table 4). At most stages, the SDI most likely stimulated response to N dose in the range of 0.45 to 0.65. This suggests that an equal number of days with rain and days without rain produced the highest corn response to added N.

Table 4 Response ratio (RR) and 95% confidence intervals (C.I., in parentheses) at five periods during the season using the Shannon Diversity Index (SDI)

Period	Shannon Diversity Index (SDI) levels and corresponding RR and (C.I.)							
	<0.4	0.4~0.45	0.45~0.5	0.5~0.55	0.55~0.6	0.6~0.65	0.65~0.69	Overall
1st-30d	1.9	1.5	2.2	1.3	1.6	1.5	1.2	1.4
	(1.6;2.3)	(1.2;1.7)	(1.7;2.9)	(1.2;1.4)	(1.4;1.9)	(1.3;1.6)	(1.1;1.3)	(1.3;1.5)
		<0.4	0.45~0.5	0.5~0.55	0.55~0.6	0.6~0.65	0.65~0.69	Overall
2nd-30d		1.4	1.1	2.2	1.5	1.4	1.4	1.4
		(1.2;1.6)	(1.0;1.2)	(1.8;2.7)	(1.3;1.7)	(1.3;1.5)	(1.3;1.5)	(1.3;1.4)
		<0.4	0.4~0.45	0.45~0.5	0.5~0.55	0.55~0.59	0.6~0.65	Overall
3rd-30d		1.2	1.4	1.4	1.6	1.7	1.6	1.4
		(1.1;1.4)	(1.3;1.4)	(1.2;1.5)	(1.4;1.8)	(1.5;1.9)	(1.4;1.9)	(1.4;1.5)
	<0.4	0.4~0.45	0.45~0.45	0.5~0.55	0.55~0.6	0.6~0.65	>0.70	Overall
4th-30d	1.3	1.5	1.5	1.6	1.3	1.5	1.3	1.5
	(1.1;1.5)	(1.3;1.7)	(1.4;1.6)	(1.4;1.8)	(1.1;1.6)	(1.4;1.7)	(1.0;1.5)	(1.4;1.5)
	<0.4	0.4~0.45	0.45~0.5	0.5~0.55	0.55~0.6	0.6~0.65	0.65~0.69	Overall
Rest	1.7	1.4	1.2	2.5	1.3	1.4	1.3	1.4
	(1.6;1.8)	(1.3;1.6)	(1.1;1.2)	(1.8;3.3)	(1.1;1.5)	(1.3;1.6)	(1.2;1.5)	(1.3;1.5)
				0.55~0.6	0.6~0.65	0.65~0.69	0.7~0.75	Overall
Whole				1.5	1.6	1.3	1.4	1.4
				(1.3;1.7)	(1.4;1.8)	(1.2;1.4)	(1.3;1.6)	(1.4;1.5)

CONCLUSION

The meta-analysis of selected corn response to added N using literature data showed that: 1) weather effects had a great influence on corn yield response to added N; 2) the largest response ratios were associated with the widest confidence intervals, suggesting interactions with other factors; 3) during the first 60 days, effects of SDI on crop response was larger compared to CHU and PPT; for the mid–season period (3rd-30d), the effects of PPT and SDI were more important than the one of CHU. During that period, even and moderate rain events stimulate the effects of N fertilization. For the rest of the growing season, those three factors were equally important; for the season as a whole, CHU had the largest effect; 4) soil types and latitude impacted on the probability of response. The mid-season period appeared critical since this is the most active period for corn growth.

Acknowledgements

We would like to thank all the authors who shared the detailed information of weather with us, and to Yacine Bouroubi and Carl Bélec for their critical comments on this manuscript.

REFERENCES

Andresen J.A., Alagarswamy G., Rotz C.A., Ritchie J.T., LeBaron A.W. 2001. Weather impacts on maize, soybean, and alfalfa production in the Great Lakes region, 1895-1996. Agronomy Journal 93:1059-1070.

Asghari M., Hanson R.G. 1984. Nitrogen, Climate, and Previous Crop Effect on Corn Yield and Grain N. Agronomy Journal 76:536-542.

Bondavalli B., Colyer D., Kroth E.M. 1970. Effects of weather, Nitrogen and Population on Corn Yield Response. Agronomy Journal 62:669~672.

Bootsma A., Gameda S., McKenney D.W. 2005. Potential impacts of climate change on corn, soybeans and barley yields in Atlantic Canada. Canadian Journal of Soil Science 85:345-357.

Borenstein M., Hedges L.V., Higgins J.P.T., Rothstein H.R. 2009. Introduction to Meta-Analysis John Wiley & Sons.

Bronikowski A., Webb C. 1996. Appendix: A critical examination of rainfall variability measures used in behavioral ecology studies. Behavioral Ecology and Sociobiology 39:27-30.

Chang J.H. 1981. Corn yield in relation to photoperiod, night temperature, and solar radiation. Agricultural Meteorology 24:253-262.

Gurevitch J., Curtis P.S., Jones M.H. 2001. Meta-analysis in ecology, Advances in Ecological Research. pp. 199-247.

Hedges L.V., Olkin I. 1985. Statistical methods for meta-analysis Academic Press, New York.

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

Jeutong F., Eskridge K.M., Waltman W.J., Smith O.S. 2000. Comparison of bioclimatic indices for prediction of maize yields. Crop Science 40:1612-1617.

Kahabka J.E., Van Es H.M., McClenahan E.J., Cox W.J. 2004. Spatial analysis of maize response to nitrogen fertilizer in Central New York. Precision Agriculture 5:463-476.

Liang B.C., MacKenzie A.F., Kirby P.C., Remillard M. 1991. Corn Production in Relation to Water Inputs and Heat Units. Agronomy Journal 83:794-799.

Ma B.L., Subedi K.D., Costa C. 2005. Comparison of crop-based indicators with soil nitrate test for corn nitrogen requirement. Agronomy Journal 97:462-471.

Muchow R.C., Sinclair T.R. 1995. Effect of nitrogen supply on maize yield: II. Field and model analysis. Agronomy Journal 87:642-648.

Muchow R.C., Sinclair T.R., Bennett J.M. 1990. Temperature and Solar Radiation Effects on Potential Maize Yield across Locations. Agronomy Journal 82:338-343.

Reeves D.W., Wood C.W., Touchton J.T. 1993. Timing Nitrogen Applications for Corn in a Winter Legume Conservation-Tillage System. Agronomy Journal 85:98-106.

Teigen L.D., Thomas M. 1995. Weather and yield, 1950-94 relationships, distributions, and data, Staff Paper No.9527, Commercial Agriculture Division, Economic Research Service.

Thompson L.M. 1975. Weather variability, climatic change, and grain production. Science 188:535-541.

Tonitto C., David M.B., Drinkwater L.E. 2006. Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics. Agriculture, Ecosystems and Environment 112:58-72.

Valkama E., Uusitalo R., Ylivainio K., VirkajÃ¤rvi P., Turtola E. 2009. Phosphorus fertilization: A meta-analysis of 80 years of research in Finland. Agriculture,

Ecosystems and Environment 130:75-85.
Voss R., E;, Hanway J.J., Fuller W.A. 1970. Influence of Soil, Management, and Climatic Factors on the Yield Response by Corn (Zea mays L.) to N, P, and K Fertilizer. Agronomy Journal 62:736~740.
Xia J., Wan S. 2008. Global response patterns of terrestrial plant species to nitrogen addition. New Phytologist 179:428-439.
Yamoah C.F., Varvel G.E., Francis C.A., Waltman W.J. 1998. Weather and management impact on crop yield variability in rotations. Journal of Production Agriculture 11:219-225.

APPENDIX A

Table 1, Publication, years covered by trials, bibliographical source of the studies included in the meta-analysis database

Publication	Year	Source	Numbers of trials
Ma, Dwyer et al. 2003	1997~2000	Canadian Journal of Plant Science 83 (2): 241-247	21
Ma, Subedi et al. 2005	2000~2002	Agronomy Journal 97(2): 462-471	8
Chen, Kost et al, 2008	2002~2005	Soil Science Society of America Journal 72 (5): 1464-1470	24
Dellinger, Schmidt et al. 2008	2005	Agronomy Journal 100(6):1546-1552	5
Izsaki,ki,Z 2007	2004~2005	Cereal Research Communications 35(4):1701-1711	6
Loecke, Liebman et al. 2004	2000~2001	Agronomy Journal 96(1):214-223	6
Miao, Mulla et al. 2006	2000~2001	Agronomy Journal 98(1): 129-140	8
Viswakumar, Mullen et al. 2008	2002~2005	Journal of Plant Nutrition 31(11): 1963-1974.	8
Gungula, Togun et al. 2005	1996, 1998	World J. Agric. Sci 1: 1-5.	8
Stevens, Hoeft et al. 2005	1994~1996	Agronomy Journal 97(4): 1046-1053	12