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**DRAFT**

*Methodology for meta-analysis of impact of enhanced efficiency fertilizers on corn yield in Midwest*

[Assuming there will be material already written on the database construction]

**Analysis and data**

Data on study results were taken from the database prepared during the systematic review portion of this study (Available in supplemental). All analysis was performed using the R software application (ref). All R scripts for data preparation and calculations are provided in Supplemental information.

**Calculation of effect sizes**

The meta-analysis considered the effect on corn yield of fertilizer with efficiency enhancing products (enhanced efficiency fertilizer, EEF) to the same fertilizer sources without the enhancement products (standard fertilizer, SF). Because all yield measurements were made on the same scale and were of comparable magnitude, the mean difference between EEF and non-EEF treatments was used as an effect size (need ref for these two equations):

**D = X.barEEF–X.barSF**

The variance of *D* was calculated not assuming similar variances for each result mean:

**S2D = S2EEF/nEEF + S2SF/nSF**

The database of studies in this meta-analysis recorded mean and dispersion of results at the level of the individual experimental units, and studies often reported many results representing many combinations of several experimental parameters. The effect size *D* was calculated using two different approaches:

(1) Matching yield results within each study between experiments using EEF and identical experimental conditions using SF (“matched” effect sizes);

(2) Within each study, calculating composite means and variances across all experimental conditions for each EEF versus the corresponding SF source alone (“composite” effect sizes).

Under the matched approach the means of EEF and SF results were matched across 16 experimental parameters: Total N rate, fall N rate, spring N rate, N rate at planting/emergence, N rate for side-dress post-emergence, Second split N rate, third split N rate, application timing, split N applications, fall vs. spring application, N placement, N placement (second), planting date, county, rotation, and tillage.

Composite means were weighted based on number observations in each mean, and composite variances were calculated as the pooled variance of the experimental results:

**S2pooled = Σ[(ni-1) × S2i] / Σ(ni-1)** (necessary to include the standard pooled variance equation?)

Under the matching approach any EEF or SF results reported under identical experimental conditions within each study were also combined using the same compositing approach as above.

A log response ratio was also calculated as an effect size following the two means comparison methods described above (Supplemental).

*Alternate log response ratio approach (Supplemental)*Given that the scale of the effects of EEF might have varied with overall yield levels, a parallel meta-analysis was conducted using the log response ratio (LRR) of yields as a metric of effect size. The LRR was calculated as follows:

**LRR = Log(X.barEEF/X.barSF)**

A positive LRR indicated greater proportional yield under EFF. The variance of the LRR was calculated following Hedges et al. (1999):

**S2LRR = S2EEF/(nEEF ×X.bar2EEF) + S2SF/(nSF ×X.bar2SF)**

*Yield with EEF under lower N conditions*

To specifically analyze the effect of EEF on yield under low N conditions, a separate meta-analysis was conducted using the above approaches restricted to experiments with < 150 lbs. N ac-1. This cutoff represents the approximately lower 60% of experiments recorded in this study with calculable effect sizes.

**Meta-analysis approach**

A random-effects meta-analysis was performed within each fertilizer source/efficiency product combination (ref). The variance of true effect sizes (T2) was estimated using the technique of DerSimmonian and Laird (1986). Weights of the effect size were estimated as:

**Wi\* = 1/(Si2D + T2)**

The 95% confidence interval of the summary effect of each EEF/SF category was estimated using the Z distribution (ref).

**Results**

Results of the meta-analysis using the paired effect sizes show that within each fertilizer source and EEF combination there was considerable range, with each EEF type showing both negative and positive impact on corn yield (Table 1). Urea with NBPT, NBPT+DCD, and polymer-coated urea showed summary effects significantly greater than zero (p < 0.05). However, the range of effect sizes showed that at least some experiments showed negative comparative yield with the use of these products. The urea+NBPT summary effect was based on 39 paired identical experimental observations but all of these were reported within a single study. Across all fertilizers, use of enhanced efficiency products showed both positive and negative effect sizes (i.e. there were records of increased and decreased corn yield with use of EEF in all fertilizer categories). Summary effects in general tended to be small but positive, with confidence intervals that included zero.

Table 1: Results of meta-analysis on paired effect sizes (mean difference). Figures include number of studies and effect sizes obtained for each analysis category, Effect size (D) and Variance (S2D), T2 (estimated true variance in effect sizes), I2 (% variation due to variance in true effect size), Q (observed variation : within-study error), p value and confidence interval for summary effects, and observed range of effect sizes. Summary effect significantly different from 0 (p < 0.05) labeled with \*.

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Fertilizer/EEF** |  | |  | |  | |  | |  | |  | |  | | **95% CI** | | | **ES Range** | | |
| **# effects (studies)** | **Summary effect (D)** | | **S2D** | | **T2** | | **I2** | | **Q** | | **p(Z ≠ 0)** | | **Low** | | **High** | **Low** | | **High** |
| **Urea** |  |  | |  | |  | |  | |  | |  | |  | |  |  | |  |
| *PCF* | 100 (18) | \*0.144 | | 0.005 | | 0.160 | | 37.2% | | 157.5 | | 0.047 | | 0.002 | | 0.287 | -1.927 | | 1.834 |
| *nitrapyrin* | 31 (5) | 0.054 | | 0.006 | | 0.061 | | 37.2% | | 47.8 | | 0.480 | | -0.097 | | 0.205 | -0.750 | | 1.200 |
| *NBPT* | 39 (1) | \*0.319 | | 0.010 | | 0 | | 0% | | 32.9 | | 0.001 | | 0.123 | | 0.515 | -1.180 | | 1.620 |
| *NBPT+DCD* | 62 (8) | \*0.226 | | 0.009 | | 0.084 | | 16.5% | | 73.1 | | 0.017 | | 0.041 | | 0.411 | -1.785 | | 1.730 |
| *S.R.* | 14 (5) | 0.206 | | 0.020 | | 0 | | 0% | | 11.8 | | 0.140 | | -0.067 | | 0.480 | -0.450 | | 2.620 |
| **UAN** |  |  | |  | |  | |  | |  | |  | |  | |  |  | |  |
| *nitrapyrin* | 14 (3) | -0.030 | | 0.018 | | 0 | | 0% | | 8.9 | | 0.823 | | -0.295 | | 0.235 | -0.535 | | 0.880 |
| *NBPT* | 53 (2) | 0.097 | | 0.005 | | 0 | | 0% | | 30.4 | | 0.156 | | -0.037 | | 0.232 | -1.670 | | 2.000 |
| *NBPT+DCD* | 46 (4) | 0.072 | | 0.015 | | 0.265 | | 42.9% | | 78.8 | | 0.564 | | -0.172 | | 0.315 | -1.310 | | 1.320 |
| *S.R.* | 2 (1) | -0.084 | | 0.164 | | 0.103 | | 30.0% | | 1.4 | | 0.836 | | -0.877 | | 0.710 | -0.590 | | 0.240 |
| *thiosulfate* | 39 (1) | -0.132 | | 0.012 | | 0.103 | | 23.6% | | 49.7 | | 0.233 | | -0.348 | | 0.085 | -1.130 | | 1.400 |
| **AA** |  |  | |  | |  | |  | |  | |  | |  | |  |  | |  |
| *nitrapyrin* | 21 (14) | 0.150 | | 0.007 | | 0.015 | | 11.5% | | 22.6 | | 0.066 | | -0.010 | | 0.311 | -0.500 | | 1.300 |

A examination of the meta-analysis results using the composite effect sizes showed less extreme summary effects in urea compared to the summaries of the paired effects, but somewhat more extreme summary effects in AA and UAN (Figures 1-3). The summary effects using the composite effect sizes were not significantly different from zero in any category. The difference in significance between summary effects calculated from paired and composite effect sizes likely reflects the larger number of experiment pairs and effect sizes obtained using the paired approach as well as the potentially more sensitive measures of effect possible when results were compared only with similar experimental conditions within studies.

Figure 1-3 – forest plots and interpretation of lumped results here

Results of meta-analysis using the paired effect sizes calculated as LRR were in most respects similar to the results using the mean difference (Table S1, supplemental). The significance of the summary effect for Urea+PCF was slightly higher than in the mean difference results and non-significant (p > 0.06). The summary effect for AA+nitrapyrin was very nearly significant (p > 0.05) as opposed to slightly below the significance threshold in the mean difference results (p > 0.06). As in the mean difference results, the summary effect for Urea+NBPT and Urea+NBPT+DCD were positive and significantly different from zero. In agreement with the mean difference results, the range of effect sizes and 95% confidence interval of the summary effects (as Response Ratio) generally spanned either side of 1 (both positive and negative impacts on yield were measured relative to non-EEF).

Table : Table 3: Results of meta-analysis on paired effect sizes using log response ratio (LRR) Figures include number of studies and effect sizes obtained for each analysis category, Effect size (LRR) and Variance (S2LRR), T2 (estimated true variance in effect sizes), I2 (% variation due to variance in true effect size), Q (observed variation : within-study error), p value and confidence interval for summary effects, and observed range of effect sizes (expressed as Response Ratios (RR) for ease of interpretation). Summary effect significantly different from 0 (p < 0.05) labeled with \*.

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Fertilizer/EEF** |  |  |  |  |  |  |  | **RR 95% CI** | | **RR range** | |
| **# effects (studies)** | **Summary effect**  **(LRR x 10-2)** | **S2LRR (x 10-4)** | **T2**  **(x 10-4)** | **I2** | **Q** | **p(Z ≠ 0)** | **Low** | **High** | **Low** | **High** |
| **Urea** |  |  |  |  |  |  |  |  |  |  |  |
| *PCF* | 100 (18) | 1.193 | 0.406 | 12.120 | 37% | 157.2 | 0.061 | 0.999 | 1.025 | 0.862 | 1.175 |
| *nitrapyrin* | 31 (5) | 0.495 | 0.421 | 4.419 | 38% | 48.3 | 0.446 | 0.992 | 1.018 | 0.934 | 1.087 |
| *NBPT* | 39 (1) | \*2.774 | 0.882 | 0 | 0% | 33.3 | 0.003 | 1.009 | 1.047 | 0.904 | 1.120 |
| *NBPT+DCD* | 62 (8) | \*1.979 | 0.704 | 7.270 | 18% | 74.6 | 0.018 | 1.003 | 1.037 | 0.817 | 1.139 |
| *S.R* | 14 (5) | 1.567 | 1.235 | 0 | 0% | 12.1 | 0.159 | 0.994 | 1.038 | 0.969 | 1.218 |
| **UAN** |  |  |  |  |  |  |  |  |  |  |  |
| *NBPT* | 53 (2) | 1.132 | 0.449 | 0 | 0% | 29.7 | 0.091 | 0.998 | 1.025 | 0.865 | 1.279 |
| *NBPT+DCD* | 46 (4) | 0.554 | 1.343 | 22.056 | 41% | 76.7 | 0.632 | 0.983 | 1.029 | 0.874 | 1.145 |
| *thiosulfate* | 39 (1) | -1.538 | 1.151 | 9.613 | 23% | 49.4 | 0.152 | 0.964 | 1.006 | 0.880 | 1.194 |
| *S.R* | 2 (1) | -0.734 | 7.384 | 4.203 | 28% | 1.4 | 0.787 | 0.941 | 1.047 | 0.965 | 1.019 |
| *nitrapyrin* | 14 (3) | -0.254 | 1.340 | 0 | 0% | 9.0 | 0.826 | 0.975 | 1.020 | 0.954 | 1.094 |
| **AA** |  |  |  |  |  |  |  |  |  |  |  |
| *nitrapyrin* | 21 (14) | 1.240 | 0.409 | 0.766 | 9% | 22.1 | 0.053 | 1.000 | 1.025 | 0.955 | 1.103 |

N-limited results:

Funnel Plot results:

Hedges, L.V., Gurevich, J. and P.S. Curtis. 1999. Ecology 80(4):1150-1156.

DerSimmonian, R. & N. Liard. 1986. Controlled Clinical Trials 7(3): 177-188.