Journal of Agriculture, Biology and Applied Statistics
Vol. 5, Nos. 1-2, 2026, pp. 41-52
© ARF India. All Right Reserved
URL: www.arfjournals.com
https://doi.org/10.47509/JABAS.2026.v05i01-02.04

Assessing the Impact of Fertilizer Consumption on Crop Yield using Canonical Correlation Analysis

S.R. Krishna Priya[1], K. Gowthami[2] and L. Rubashree[3]
[1,2,3]Department of Statistics, PSG College of Arts & Science, Coimbatore

To Cite this Article

S.R. Krishna Priya, K. Gowthami & L. Rubashree (2026). Assessing the Impact of Fertilizer Consumption on Crop Yield using Canonical Correlation Analysis. *Journal of Agriculture, Biology and Applied Statistics,* 5: 1-2, pp. 41-52.

Abstract: Agriculture plays vital role in India's economy, contributing significantly to national GDP and employment while continuing to face challenges such as soil degradation and regional yield disparities. Optimizing fertilizer use is therefore essential to meet growing food demands sustainably. This study examines the relationship between fertilizer consumption and agricultural yield using Canonical Correlation Analysis (CCA) on secondary data spanning 1950 to 2022. The independent variable set included Nitrogen (N), Phosphorus (P_2O_5), and Potassium (K_2O) consumption, while the dependent variable set included the yields of Jute, Potato, and Groundnut. The results reveal a very strong and statistically significant relationship between fertilizer consumption and crop yield, with the first canonical function returning a canonical correlation of 0.990, explaining 95.6% of the variance in fertilizer consumption and 76.0% of the variance in crop yield. Nitrogen emerged as the most dominant fertilizer influencing yield, followed closely by phosphorus, while potassium contributed a comparatively smaller but still meaningful role. Among the three crops, Potato yield showed the strongest dependence on fertilizer application, with a cross-loading of 0.975, followed by Jute (0.878) and Groundnut (0.716). These findings indicate that balanced, fertilizer -specific fertilizer strategies, rather than uniform application, offer the most effective path to improving crop productivity. The study provides practical insights for policymakers and agricultural planners seeking to enhance fertilizer efficiency, support targeted fertilizer management, and minimize the environmental impact of excessive fertilizer use.

Keywords: Canonical Correlation Analysis; fertilizer consumption; crop yield; fertilizer management; sustainable agriculture

Received : 20 May 2026 • **Revised :** 23 June 2026 • **Accepted :** 30 June 2026 • **Published :** 19 October 2026

1. INTRODUCTION

Agriculture remains central to global food security, and among the many inputs that determine crop productivity, fertilizers stand out as one of the most influential. Balanced application of Nitrogen (N), Phosphorus (P_2O_5), and Potassium (K_2O) has repeatedly been shown to shape yield outcomes across major crops, since each fertilizer governs a distinct physiological function that ranges from vegetative growth and root development to disease resistance and stress tolerance. Research on nitrogen's interaction with phosphorus and potassium has shown that P and K availability directly affects how efficiently a crop can use applied nitrogen, influencing root development, dry matter production, and overall yield (Usherwood & Segars, 2001).

For Jute, nitrogen is central to protein and amino-acid synthesis needed for fiber-bearing biomass, while potassium contributes to the plant's electron-transport and photosynthate-supply processes (Islam et al., 2010). Combined NPK and organic-manure treatments have also been shown to raise Jute fibre yield and fertilizer uptake compared with recommended-dose fertilizer alone (Majumdar et al., 2014). For Potato, long-term factorial trials found that nitrogen, phosphorus, and potassium each significantly affect tuber yield, while rising potassium rates in particular depress tuber starch content (Black & White, 1973). More recent work confirms that nitrogen and potassium levels significantly influence tuber growth and quality traits (Li et al., 2022). For Groundnut, nitrogen and phosphorus have been found to dominate vegetative growth, pod number, and harvest index (Hasan et al., 2021). Phosphorus application specifically raises pod yield and fertilizer uptake (Shiva Kumar et al., 2014), and potassium application has been shown to significantly improve canopy growth and pod yield (Khan et al., 2023).

Despite this well-documented role of balanced fertilization, excessive or imbalanced fertilizer application has raised concerns about soil degradation, fertilizer runoff, and long-term productivity decline. This makes the identification of optimal fertilizer combinations, rather than simple input maximization, a priority for sustainable agricultural planning.

Canonical Correlation Analysis (CCA) has become a widely used tool wherever researchers need to understand how one set of variables jointly relates to another, and its applications span well beyond agriculture. Iman et al. (2023) examined face-to-face and online business education using CCA among students at Al-Balqa Applied University. Alamgir et al. (2014) applied to birth size measurements and maternal factors among women in rural Northwest Bangladesh. Ebenezer et al. (2012) used

to study the relationship between poverty and literacy levels in Ekiti State, Nigeria. Balkaya et al. (2011) applied to relate plant characters to yield components in winter squash populations from Turkey's Black Sea Region. Cankaya et al. (2010) used to link plant characters with yield components across red pepper populations. Zuffo et al. (2022) used to study how agricultural production area, corn cultivar, and nitrogen application rate jointly related to corn agronomic traits. Heinilä et al. (2024) applied penalized to relate temperament traits to brain oscillation patterns during mind-wandering tasks. Jiang et al. (2023) used sparse multiple CCA to integrate proteomic and methylomic data across two cohort studies for multi-omics health research. Song et al. (2026) applied CCA to examine the relationship between microbial community composition and water-quality parameters in an industrial coastal river basin.

While CCA has been applied to yield relationships in individual crops such as squash and pepper, and to fertilizer rate and trait relationships in maize, comparatively little work has used CCA to jointly examine how N, P_2O_5, and K_2O consumption relates to yield and quality outcomes across multiple economically important crops. Jute, Potato, and Groundnut, in particular, have not been studied together within a single unified CCA framework, despite each crop depending on the same three fertilizer s for distinct physiological functions. This study aims to analyze the relationship between different fertilizer types and crop yields, identify the most effective fertilizer combinations for maximizing productivity, and explore optimization strategies for efficient, sustainable application.

2. MATERIALS AND METHODS

2.1. Data description

This study examines the relationship between fertilizer consumption and crop yield in India using secondary data from 1950 to 2022. Fertilizer consumption data for Nitrogen (N), Phosphorus (P_2O_5), and Potassium (K_2O), measured in '000 tonnes, were obtained from the Fertilizer Association of India. Crop yield data for Jute, Potato, and Groundnut, measured in kilograms per hectare (kg/ha), were obtained from India Stat. All analyses were carried out using IBM SPSS Statistics 26.

2.2. Canonical Correlation Analysis

Canonical Correlation Analysis (CCA), first introduced by Hotelling (1936), is a multivariate statistical technique used to examine the relationship between two sets of variables. It extends traditional bivariate correlation by identifying linear combinations

of independent variables (X-set) and dependent variables (Y-set) that produce the highest possible correlation between the two sets. In this study, CCA was used to examine the relationship between fertilizer consumptions (Nitrogen, Phosphorus, and Potassium) as the X-set and crop yields (Jute, Potato, and Groundnut) as the Y-set.

Canonical Variables and Canonical Correlation

Canonical variables are linear combinations of the original variables within each set, constructed to maximize the correlation between the two sets. They are represented mathematically as:

$$U = a_1x_1 + a_2x_2 + \ldots + a_px_p \quad (1)$$

$$V = b_1y_1 + b_2y_2 + \ldots + b_qy_q \quad (2)$$

where U and V are the canonical variables, and a_1, a_2, ... a_p and b_1, b_2, ... b_q are the canonical coefficients (weights) assigned to each original variable in the X-set and Y-set, respectively.

The canonical correlation (r) is computed as: $r = Corr(U,V)$. The first canonical function (U_1, V_1) captures the strongest relationship, with subsequent functions (U_2, V_2, etc.) explaining additional, progressively weaker relationships that are statistically independent of the first.

Canonical Functions

Each canonical function consists of a pair of canonical variables (U and V) representing the strongest available correlation between the two variable sets at that stage of the analysis. Canonical functions are orthogonal to one another, meaning each function contributes a unique, non-overlapping portion of the explained variance. The first function accounts for the highest correlation, with each subsequent function accounting for a progressively smaller share, up to a maximum number of functions equal to the smaller of the two variable sets (in this study, three functions, matching the three variables in the X-set).

Steps in Canonical Correlation Analysis

Step 1: Data Preparation

Before performing CCA, the dataset was cleaned by addressing missing values, identifying outliers, and standardizing variables through z-score transformation. Key assumptions, including linearity, multivariate normality, homoscedasticity, and

the absence of multicollinearity, were tested to ensure the validity of the analysis (Hair et al., 2019).

Step 2: Compute Covariance Matrices

CCA relies on four covariance matrices: Rxx (independent variables), Ryy (dependent variables), Rxy (cross-covariances), and Ryx (transpose of Rxy). These matrices form the foundation for deriving canonical functions.

Step 3: Eigenvalue and Eigenvector Calculation

Eigenvalues (λ) determine the proportion of variance explained by each canonical function, while eigenvectors define the canonical coefficients that form the linear combinations U (independent variables) and V (dependent variables). The first function explains the highest correlation, with subsequent functions capturing weaker relationships.

Step 4: Compute Canonical Correlations

Canonical correlations measure the strength of the relationship between the canonical variables (U and V) obtained in the previous step. The first canonical correlation (r_1) is the highest possible correlation between the linear combinations of the independent and dependent variables, while subsequent correlations (r_2, r_3, etc.) capture weaker but still statistically significant relationships. The canonical correlation coefficient is calculated using the formula:

$$r_i = \sqrt{\lambda_i} \tag{3}$$

where λ_i is the eigenvalue associated with the i^{th} canonical function. The first canonical correlation (r_1) represents the highest possible correlation between any linear combination of the independent and dependent variables, while subsequent correlations (r_2, r_3, etc.) capture weaker, though often still statistically significant, relationships. Interpretation follows standard thresholds established in applied multivariate statistics: correlations above 0.7 indicate a strong relationship, values between 0.4 and 0.7 indicate a moderate relationship, and values below 0.4 indicate a weak relationship (Hair et al., 2019).

Step 5: Significance Testing

To confirm that the canonical correlations reflect a genuine relationship rather than chance variation, statistical significance was tested using Wilks' Lambda (Λ), calculated as:

$$\Lambda = \prod_{i=1}^{n}(1 - r_i^2) \quad (4)$$

where r_1, r_2, …, r_n are the canonical correlation coefficients for each function. Wilks' Lambda was then converted into an approximate Chi-square (χ^2) statistic to determine significance:

$$\chi^2 = -\left[n - 1 - \left(\frac{p+q+1}{2}\right)\right]\ln(\Lambda) \quad (5)$$

where n is the sample size, p is the number of independent variables, and q is the number of dependent variables. The resulting p-value was compared against the conventional 0.05 threshold, with values below 0.05 indicating a statistically significant relationship. When the first canonical function was found significant, each subsequent function was tested individually, and testing continued until a non-significant result was reached. This stepwise procedure ensured that only meaningful canonical functions were retained for interpretation. **3. Results and discussion**

To examine the relationship between fertilizer consumption (N, P_2O_5, K_2O) and crop yield (Jute, Potato, and Groundnut), a Canonical Correlation Analysis (CCA) was performed. The overall significance of the canonical functions extracted from the two variable sets is presented in Table 1.

Table 1: Canonical Correlation Coefficients and Tests of Significance for Fertilizer Consumption and Crop Yield

Correlation	*Eigenvalue*	*Wilks Statistic (λ)*	*F*	*Sig.*
0.990	49.592	0.014	85.912	<0.001
0.476	0.293	0.699	6.571	<0.001
0.311	0.107	0.903	7.265	0.009

Table 1 shows that, the first canonical function shows a very strong relationship (canonical correlation = 0.990) between fertilizer consumption (N, P_2O_5, K_2O) and agricultural yield (Jute, Potato, Groundnut), indicating that fertilizer levels significantly impact crop yields. The Wilks' λ (0.014) and p-value (<0.001) confirm its high statistical significance, meaning this function explains the majority of the variance between the two sets. Among the fertilizers, Nitrogen (N) and Phosphorus (P_2O_5) have the strongest influence, particularly affecting Potato production. The second and third functions have moderate to weak correlations (0.476 and 0.311), but they are still statistically significant. The first canonical function is the most important, showing that fertilizer consumptions, particularly nitrogen and phosphorus, play a major role in determining crop yields, especially Potatoes.

The contribution of each fertilizer consumption to the three canonical functions is presented in Table 2.

Table 2: Standardized Canonical Coefficients for Fertilizer Variables

Variable	*1*	*2*	*3*
N	-0.969	4.887	-4.993
P_2O_5	-0.075	-8.200	3.146
K_2O	0.046	3.421	1.992

Table 2 shows that, among the fertilizer consumptions variables, Nitrogen (N) plays the most significant role in the first function (-0.969), indicating its strong negative impact. However, it has a high positive influence in Function 2 (4.887), suggesting that it may behave differently under varying conditions. Phosphorus (P_2O_5) is highly negative in Function 2 (-8.200) but shows a moderate positive influence in Function 3 (3.146). Potassium (K_2O) contributes positively to Functions 2 and 3, but its impact is relatively smaller. The contribution of each crop's yield to the three canonical functions is presented in Table 3.

Table 3: Standardized Canonical Coefficients for Crop Yield Variables

Variable	*1*	*2*	*3*
Jute yield	-0.267	1.512	0.658
Potato yield	-0.724	-1.666	0.374
Groundnut yield	-0.069	0.416	-1.315

From Table 3, the most strongly affected crop is Potato yield (-0.724 in Function 1 and -1.666 in Function 2), indicating that fertilizer consumptions, particularly Nitrogen and Phosphorus, play a dominant role in its yield. Jute yield shows a moderate positive effect in Function 2 (1.512), meaning it responds positively to a different fertilizer combination. Groundnut yield has a weak influence overall but shows a strong negative impact in Function 3 (-1.315).

Canonical loadings represent the correlation between the original variables and the canonical functions. Higher absolute values indicate stronger associations, showing how well each variable contributes to defining the canonical structure. The correlation between each fertilizer and the canonical functions is presented in Table 4.

Table 4: Canonical Loadings for Fertilizer Variables

Variable	*1*	*2*	*3*
N	-1.000	0.011	0.004
P_2O_5	-0.989	-0.063	0.131
K_2O	-0.943	0.126	0.307

Table 4 shows that all three fertilizers load strongly on Function 1, with Nitrogen close to perfect loading. This confirms that Function 1 represents the combined effect of Nitrogen, Phosphorus, and Potassium acting together.

The correlation between each crop's yield and the canonical functions is presented in Table 5.

Table 5: Canonical Loadings for Crop Yield Variables

Variable	*1*	*2*	*3*
Jute yield	-0.886	0.426	0.181
Potato yield	-0.985	-0.173	-0.003
Groundnut yield	-0.723	0.164	-0.671

Table 5, shows that Jute yield has a strong negative loading in Function 1 (-0.886), with weaker influences in Functions 2 (0.426) and 3 (0.181). Potato yield is highly correlated with Function 1 (-0.985), while its impact in the other functions is minimal. Groundnut yield has a moderate negative loading in Function 1 (-0.723) but a slightly stronger role in Function 3 (-0.671). Overall, Function 1 has the strongest influence, particularly on Potato and Jute yield. The correlation between the fertilizer variables and the yield canonical variate is presented in Table 6.

Table 6: Cross Loadings for Fertilizer Variables on Crop Yield Canonical Variates

Variable	*1*	*2*	*3*
N	-0.990	0.005	0.001
P_2O_5	-0.980	-0.030	0.041
K_2O	-0.934	0.060	0.095

Table 6 shows that, Nitrogen (N) has a strong negative cross loading in Function 1 (-0.990), showing a strong inverse relationship with agricultural output, while its effect in Functions 2 and 3 is minimal. Phosphorus (P_2O_5) also has a strong negative cross loading in Function 1 (-0.980), with weaker contributions in the other functions. Potassium (K_2O) is significantly related to Function 1 (-0.934) but

plays a slightly stronger role in Functions 2 (0.060) and 3 (0.095). Overall, Function 1 captures the strongest impact of these fertilizers on agricultural production. The correlation between the yield variables and fertilizer canonical variate is presented in Table 7.

Table 7: Cross Loadings for Crop Yield Variables on Fertilizer Canonical Variates

Variable	*1*	*2*	*3*
Jute yield	-.878	.203	.056
Potato yield	-.975	-.082	-.001
Groundnut yield	-.716	.078	-.208

From Table 7, Jute yield has a strong negative cross loading in Function 1 (-0.878), indicating a significant inverse correlation with fertilizer levels, while its influence in Functions 2 (0.203) and 3 (0.056) is weaker. Potato yield is highly associated with Function 1 (-0.975), with minimal impact in Functions 2 and 3, confirming its primary dependence on fertilizer levels in the first function. Groundnut yield has a moderate negative cross-loading in Function 1 (-0.716) but a slightly stronger presence in Function 3 (-0.208), suggesting a more distributed influence. Overall, Function 1 captures the strongest relationship between fertilisers and crop yield. The proportion of variance explained shows how much of the variability within each variable set (independent and dependent) is accounted for by each canonical function. It helps determine the relative importance of each function in explaining the relationship between Set 1 and Set 2, is presented in Table 8.

Table 8: Proportion of Variance Explained by Canonical Functions

Canonical Variable	*Set 1 by Self 2*	*Set 1 by Set 2*	*Set 2 by Self 1*	*Set 2 by Set 1*
1	0.956	0.937	0.760	0.745
2	0.007	0.002	0.079	0.018
3	0.037	0.004	0.161	0.016

Table 8 shows that Function 1 explains most of the variance, accounting for 95.6% of fertilizer variance and 76.0% of yield variance. It also explains 93.7% of the shared fertilizer variance and 74.5% of the shared yield variance. Functions 2 and 3 add very little extra explanation. Overall, this confirms that a single strong relationship, led by Nitrogen and Phosphorus and most visible in Potato yield, explains almost all of the connection between fertilizer consumptions and crop production.

CONCLUSION

Understanding the relationship between fertilizer consumptions and crop yield is important because fertilizer decisions directly affect farm income, food supply, and soil health, yet farmers often apply Nitrogen, Phosphorus, and Potassium in fixed or generalized ratios without knowing which fertilizer actually drives yield for a given crop. This study addresses that gap by using Canonical Correlation Analysis to show, with statistical evidence, which fertilizer s matter most and for which crop, rather than relying on general assumptions or one-size-fits-all recommendations. CCA works by taking two sets of variables, in this case, fertilizer consumptions (N, P_2O_5, K_2O) and crop yields (Jute, Potato, Groundnut), and finding the strongest possible correlation between them by combining each set into new composite variables called canonical variates. Instead of testing each fertilizer against each crop separately, CCA looks at the fertilizers and crops together as whole systems, revealing the overall pattern connecting fertilizer use to agricultural output in a single, unified analysis.

REFERENCES

Akour, I., Al-Rahamneh, A., Al-Kurdi, B., Alhamad, A., Al-Makhariz, I., Alshurideh, M., & Al-Hawary, S. (2023). Using the canonical correlation analysis method to study students' level in face-to-face and online education in Jordan. *Information Sciences Letters, 12*(2), 901–910.

Balkaya, A., Cankaya, S., & Ozbakir, M. (2011). Use of canonical correlation analysis for determination of relationships between plant characters and yield components in winter squash (*Cucurbita maxima* Duch.) populations. *Bulgarian Journal of Agricultural Science, 17*(5), 606–614.

Black, W. N., & White, R. P. (1973). Effects of nitrogen, phosphorus, potassium, and manure factorially applied to potatoes in a long-term study. *Canadian Journal of Soil Science, 53*(4), 315–330.

Cankaya, S., Balkaya, A., & Karaagac, O. (2010). Canonical correlation analysis for the determination of relationships between plant characters and yield components in red pepper (*Capsicum annuum* L. var. *conoides* (Mill.) Irish) genotypes. *Spanish Journal of Agricultural Research, 8*(1), 55–63.

da Rosa, G. B., Follmann, D. N., Bolzan, F. T., Eggers, H., Lucio, A. D., Jacques, R. J. S., & Maldaner, I. C. (2024). Canonical correlations of maize yield components with biological and chemical soil indicators in a subtropical climate. *Australian Journal of Crop Science, 18*(11), 715–722.

Ebenezer, O. R., & Iyaniwura, J. O. (2012). Canonical correlation analysis of poverty and literacy levels in Ekiti State, Nigeria. *Mathematical Theory and Modelling, 2*(9), 31–39.

Georgescu, I., Tvaronavičienė, M., Androniceanu, A., & Androniceanu, A. M. (2020). Canonical correlation analysis and a new composite index on digitalization and labor force in the context of the Industrial Revolution 4.0. *Sustainability, 12*(17), Article 6812.

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2019). *Multivariate data analysis* (8th ed.). Cengage Learning.

Hasan, M., Uddin, M. K., Mohamed, M. T. M., Zuan, A. T. K., Motmainna, M., & Haque, A. N. A. (2021). Effect of nitrogen and phosphorus fertilizers on growth, yield, nodulation and nutritional composition of Bambara groundnut [*Vigna subterranea* (L.) Verdc.]. *Legume Research, 44*, 1437–1442.

Heinilä, E., Hämäläinen, S., et al. (2024). Penalized canonical correlation analysis reveals a relationship between temperament traits and brain oscillations during mind wandering. *Brain and Behavior, 14*, Article e3428.

Islam, A., Hossain, M. S., Sayeed, A., Ibrahim, M., Mondal, H., & Absar, N. (2010). Effect of NPK fertilizers and cowdung in combination with foliar spray of chemicals on jute fibre. *Journal of Agronomy, 9*(2), 52–56.

Jiang, M.-Z., Aguet, F., Ardlie, K., Chen, J., Cornell, E., Cruz, D., et al. (2023). Canonical correlation analysis for multi-omics: Application to cross-cohort analysis. *PLOS Genetics, 19*(5), Article e1010517.

Kabir, A., Merrill, R. D., Shamim, A. A., Klemm, D. W., Labrique, A. B., Christian, P., West, K. P., Jr., & Nasser, M. (2014). Canonical correlation analysis of infant's size at birth and maternal factors: A study in rural Northwest Bangladesh. *PLOS ONE, 9*(2), Article e89928.

Khan, C., Memon, N. un nisa, Wahocho, N. A., Akhtar, N., Majeedano, M. I., Sharif, N., Jamali, M. F., & Khan, Q. (2023). Effect of potash fertilizer on vegetative growth and pod yield of groundnut (*Arachis hypogaea* L.) in semiarid region. *Journal of Applied Research in Plant Sciences, 4*(2), 647–652.

Li, L., Wang, P., Li, S., Liu, Q., Yu, F., Guo, Z., Jia, S., & Wang, Z. (2023). Canonical correlation analysis of depression and anxiety symptoms among college students and their relationship with physical activity. *Scientific Reports, 13*, Article 11356.

Li, X., et al. (2022). Effects of nitrogen and potassium fertilizers on potato growth and quality under multimodal sensor data fusion. *Mobile Information Systems, 2022*, Article 6726204.

Majumdar, B., Saha, A. R., Ghorai, A. K., Sarkar, S. K., Chowdhury, H., Kundu, D. K., & Mahapatra, B. S. (2014). Effect of fertilizer treatments on jute (*Corchorus olitorius*), microbial dynamics in its rhizosphere and residual fertility status of soil. *Indian Journal of Agricultural Sciences, 84*(4), 429–435.

Martín, N. F., Bollero, G., & Bullock, D. G. (2005). Associations between field characteristics and soybean plant performance using canonical correlation analysis. *Plant and Soil, 273*(1), 39–55.

Que, S., Luo, H., Wang, L., Zhou, W., & Yuan, S. (2020). Canonical correlation study on the relationship between shipping development and water environment of the Yangtze River. *Water, 12*(3), Article 655.

Silva, R. R. D., Moura, G. B. D. A., Lopes, P. M. O., Nascimento, C. R., & Giongo, P. R. (2025). Canonical analysis of the impact of climate predictors on sugarcane yield in the eastern region of Pernambuco, Brazil. *Agriculture, 15*(20), Article 2162.

Song, W., Wei, X., Tian, M., et al. (2026). Drivers of microbial communities and water-quality forecasting in an industrial coastal river. *Water, Air, & Soil Pollution, 237*, Article 336.

Thompson, B. (1984). *Canonical correlation analysis: Uses and interpretation* (Vol. 47). Sage.

Tischler, A. L., Lúcio, A. D. C., Maldaner, I. C., Nardino, M., Diel, M. I., de Lima Tartaglia, F., & Lambrecht, D. M. (2025). Canonical correlations between wheat traits in multienvironment trials. *New Zealand Journal of Crop and Horticultural Science, 53*(5), 1653–1664.

Usherwood, N. R., & Segars, W. I. (2001). Nitrogen interactions with phosphorus and potassium for optimum crop yield, nitrogen use effectiveness, and environmental stewardship. *The Scientific World Journal, 1*(Suppl. 2), 57–60.