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A Decision Aid to Help Farmers Find the Minimum Cost Fertilizer Combination

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ABSTRACT

Fertilizer recommendations are typically given as the pounds of nitrogen, phosphorus, and potassium needed per acre. Many crop budgets also list the fertilizer costs in terms of the N, P, and K. This can cause a problem for farmers as they must purchase their fertilizer in products that in some cases contain multiple nutrients. These multinutrient fertilizers make it difficult or impossible to calculate a price per unit of a nutrient. Thus, finding the minimum cost fertilizer combination by using a price per nutrient approach may not work. This paper shows how a linear programming approach will always give the minimum cost fertilizer combination and then shows how a decision aid is developed in Excel. The developed decision aid has many uses in extension services where farmers have little understanding of linear programming. The decision aid is also useful in helping farm management students learn about linear programming.

KEYWORDS

decision aid, fertilizer, minimum cost, extension, teaching

INTRODUCTION

Farmers have many fertilizer products available to them that can be used to help meet the nutrient requirements on a given field. For example, both DAP (diammonium phosphate) and MAP (monoammonium phosphate) can be used to meet a phosphorus requirement as well as provide nitrogen. Unfortunately, determining the lowest cost combination of fertilizers that will meet the recommended nutrient levels is not always a straightforward process. This paper details an extension decision aid that can help farmers find the lowest cost fertilizer combination that meets the required N-P-K needs for a given field. This decision aid always gives the correct fertilizer recommendation and avoids the limitations of other decision aids.

Single-nutrient fertilizers are uncomplicated when analyzing prices. Products such as anhydrous ammonia, urea, UAN (urea and ammonium nitrate), and others can be converted to a price per unit of that nutrient by dividing the price per pound by the percentage of that nutrient in the fertilizer. For example, urea contains 46% nitrogen, so calculating a price per pound of nitrogen for urea is just the price of urea divided by 0.46. Thus, comparing single-nutrient fertilizers to find the lowest cost fertilizer is straightforward.

Multinutrient fertilizer comparisons are more difficult. Most extension guides recommend pricing multinutrient fertilizers by pricing one nutrient based on the price of a single-nutrient fertilizer and then pricing the other nutrient from what is left. For example, DAP fertilizer contains 18% nitrogen and 46% phosphorus (P2O5). Under this approach, the price of the phosphorus would be calculated by first subtracting the value of the nitrogen where the value of the nitrogen is from a single nutrient source such as urea. The reverse process could also be used with DAP by first subtracting the value of the phosphorus based on superphosphate (0-46-0) and then calculating the nitrogen value based on the remainder (New Mexico State University).

The problem with these approaches is that they do not provide correct guidance for finding the minimum cost fertilizer combination in many cases. Additionally, there are no tools available that would help farmers correctly calculate this minimum cost fertilizer combination. This two-step approach (in some cases, a three-step approach) to pricing multinutrient fertilizers only works where the single-nutrient fertilizer used to help price the multinutrient fertilizer is the lowest price fertilizer for that nutrient and where that nutrient is needed on a field. For example, with corn production, the two-step approach will likely work and give a correct value for each nutrient as both nitrogen and phosphorus are likely needed in a fertilizer mix. However, using this method to value phosphorus is not correct for legumes where nitrogen is not needed. For these crops, the nitrogen contribution provided by a multinutrient fertilizer should have a value of $0 and the entire cost of the multinutrient fertilizer (i.e., DAP or MAP) should be allocated to the phosphorus content. Nielsen (2002) recognizes this problem in his discussion of a two- and three-step pricing approach to fertilizer.

Even where both nitrogen and phosphorus are required for a crop, pricing one element of a multinutrient fertilizer based on a single-element fertilizer could be incorrect if the price of the multi-element fertilizer is low enough. For example, there could be a situation where the price of a multinutrient fertilizer such as DAP or MAP is low enough that these two fertilizers are the lowest price source of nitrogen. The two-step approach just described would not reveal when DAP or MAP was the lowest cost source of nitrogen.

Here is an example of how difficult it can be to find the minimum cost fertilizer combination. In this example, anhydrous ammonia (82-0-0) costs $500 a ton, DAP (18-46-0) costs $400 a ton, and MAP (11-52-0) costs $400 a ton. With a fertility recommendation of 100 lbs. of nitrogen and 100 lbs. of phosphorus, the minimum cost fertilizer combination is 217 lbs. of DAP and 74 lbs. of anhydrous ammonia. A two-step pricing process would likely lead to this result. However, as the nitrogen requirement decreases, the mix of fertilizers changes. When the fertility requirement is 35 lbs. of nitrogen and 100 lbs. of phosphorus, the minimum cost fertilizer combination in 167 lbs. of DAP and 44 lbs. of MAP. When the fertility requirement is 20 lbs. of nitrogen and 100 lbs. of phosphorus, the minimum cost fertilizer combination is 192 lbs. of MAP. A two-step pricing process would likely not show these last two solutions.

The problem for farmers is finding the minimum cost fertilizer combination that meets the recommended fertility requirements without resorting to a potentially incorrect procedure that tries to price fertilizers on a per nutrient basis. Linear programming can be used to find the optimal solution. This paper demonstrates how an Excel-based tool was developed to solve the cost minimization problem by using linear programming. The fertilizer cost minimization tool is available from Kansas State University on their AgManager.info site.

BACKGROUND

Many crop budgets being produced do not list the actual fertilizers but instead list the recommended amounts of nitrogen, phosphorus, and potassium (e.g., Iowa State, University of Missouri, Texas A&M, and the University of Georgia). Some, like the University of Illinois and the University of Minnesota, only give a dollar amount for the total fertilizer cost and do not even list the individual nutrients. As discussed in the introduction, trying to assign a price per nutrient for multinutrient fertilizers can be difficult if not impossible, which makes any price shown suspect. Because farmers are purchasing fertilizers and not actual nutrients, farmers may not be able to determine if current fertilizer prices are comparable to those shown in the budget. Budgets that use actual fertilizers make it easier for farmers to compare prices to those shown in the budgets. Several states still develop budgets based on the actual fertilizer product (e.g., Mississippi State and Kansas State).

The use of linear programming to find the least cost fertilizer mixture has been in use since at least the 1970s. Some of this work can be traced back to Nevins (1971). However, research about minimizing fertilizer costs with linear programming has been ongoing as various other elements have been added to the basic model. Babcock et al. (1984) included blending costs and application costs. Hassan and Sahrin (2012) included goal programming to consider not only a cost function but also various production goals.

Many of these additional elements require advanced techniques that make it difficult to apply to an Excel model that can be used by farmers. For example, the incorporation of an application charge requires the use of integer programming to solve. By leaving the model as a cost minimization problem that meets the required nutrient levels of a field, the simplex method can be used. With the basic solver available in Excel, this type of problem is easily solvable.

MODEL

The basic model to find the minimum cost fertilizer combination that meets the required nutrient level is shown in equation 1.

$$(1) \qquad Minimize \sum_{i=1}^{n} C_i \cdot Q_i$$

$$Subject\ to:$$

$$\sum_{i=1}^{n} Q_i \cdot N_i \geq Nitrogen_{min}$$

$$\sum_{i=1}^{n} Q_i \cdot P_i \geq Phosphorus_{min}$$

$$\sum_{i=1}^{n} Q_i \cdot K_i \geq Potassium_{min}$$

In some cases, there might be restrictions on the amount of nutrients applied. In these cases, there would be the following additional constraints.

$$(2) \qquad \sum_{i=1}^{n} Q_i \cdot N_i \leq Nitrogen_{max}$$

$$\sum_{i=1}^{n} Q_i \cdot N_i \leq Phosphorus_{max}$$

$$\sum_{i=1}^{n} Q_i \cdot N_i \leq Potassium_{max}$$

In the objective function, C_i is the price per pound of each fertilizer while Q_i is the quantity to apply of each fertilizer and is the decision variable. In the constraints, N_i is the percentage of nitrogen in the fertilizer, P_i is the percentage of phosphorus in the fertilizer, and K_i is the percentage of potassium in the fertilizer. The percentages of N, P, and K are stated for a given fertilizer. The required pounds of nitrogen, phosphorus, and potassium for a field are stated on the right-hand side of the constraints. In addition to these constraints, there are also non-negative constraints for the quantities of each fertilizer (i.e., $Q_i >= 0$).

This linear programming solution was developed into an Excel spreadsheet tool available from the Kansas State AgManager.info site. There are two main pages for the tool (in addition to the instruction page and the introduction page). The home page (see Figure 1) is where most of the user interaction takes place while the fertilizer list page (see Figure 2) shows the percentage of each nutrient in the fertilizer. This second page doesn't need updating as the nutrient percentage should never change. There are blank rows to allow for fertilizers not listed.

The home page is where the user inputs are entered and where the solution is presented. The list of fertilizers, the price per ton of each fertilizer, and whether to include the fertilizer in a possible solution are listed in the upper left-hand table. The other user input table is in the upper right-hand corner. Here a user enters the required and maximum nutrient pounds of N, P, and K. To find a solution, a user clicks on the red "Find Minimum Cost" button. The solution is presented in the next two tables. A user can save the scenario if desired. Saving scenarios is particularly useful if the application cost might vary with different fertilizer choices.

This decision aid uses the solver to find a solution and also a limited amount of VBA code, so a user needs to make sure that the solver is enabled and that macros can run. Finally, the solving method should be set to Simplex LP. The solver provides two other solving engines, but they are for more complicated problems. As long as the objective and constraints are linear functions of the decision variables (which equation 1 is), the solver will find a globally optimal solution.

APPLICATION

Current national fertilizer prices (as of the first week of January 2023) are shown in Figure 1. With these prices, both the Excel fertilizer tool using a linear programming model and pricing fertilizers using a two-stage process will yield the exact same solution. For a field needing 200 pounds of N and 100 pounds of both P and K, the optimal solution is to use 196 pounds of anhydrous ammonia, 217 pounds of DAP, and 167 pounds of potash. The total cost of this fertilizer mix is \$258.43. In the two-stage process where N is priced based on the urea price, DAP has a P cost of \$0.638 per pound, while MAP has a P cost of \$0.675. Thus, the two-stage process would pick DAP to use for the P requirement just as the linear programming solution did.

When prices change, though, it can be demonstrated that the two-stage process will give an

Fertilizer	Price per ton	Use or not	Minimum lbs	Maximum lbs
Anhydrous Ammonia	$ 1,302	☑		
Urea	$ 739	☑		
UAN28	$ 573	☑		
UAN32	$ 673	☑		
DAP	$ 876	☑		
MAP	$ 879	☑		
10-34-0	$ 754	☑		
Potash	$ 752	☑		
Ammonium nitrate	$ 250	☐		
AMS	$ 200	☐		
		☐		
		☐		
		☐		
		☐		

SOLVER MUST BE ENABLED IN ADD-INS

Fertilizer recommendations

	N	P	K
Required	200	100	100
Maximum			

Find Minimum Cost

Fertilizer Prices Need to Be Updated Before Using!

Solutions

Fertilizers to use	Pounds	Cost
DAP	217	$ 95.05
Anhydrous Ammonia	196	$ 127.60
Potash	167	$ 62.79
	Total	$ 285.43

Nutrients Applied

	N	P	K
Lbs applied	200	100	100
Cost per unit	$ 0.794	$ 0.642	$ 0.627

Add Scenario

Delete All Scenarios

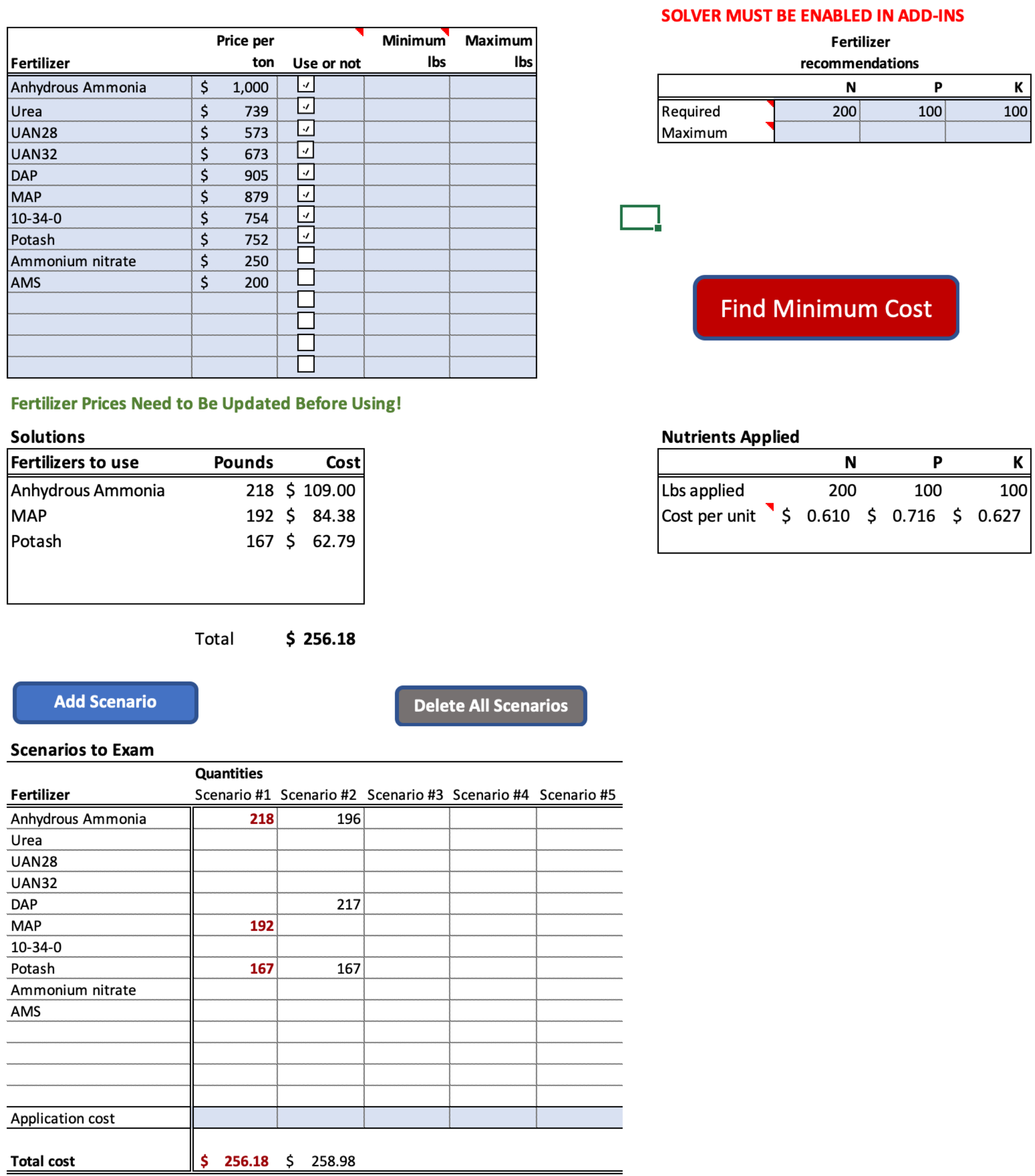
Scenarios to Exam

Fertilizer	Quantities Scenario #1	Scenario #2	Scenario #3	Scenario #4	Scenario #5
Anhydrous Ammonia	196				
Urea					
UAN28					
UAN32					
DAP	217				
MAP					
10-34-0					
Potash	167				
Ammonium nitrate					
AMS					
Application cost					
Total cost	$ 285.43				

Figure 1. Main page of fertilizer cost tool.

Fertilizer	Formulation N	P	K
Anhydrous Ammonia	82	0	0
Urea	46	0	0
UAN28	28	0	0
UAN32	32	0	0
DAP	18	46	0
MAP	11	52	0
10-34-0	10	34	0
Potash	0	0	60
Ammonium nitrate	34	0	0
AMS	21	0	0
0			
0			
0			
0			

Figure 2. List of fertilizers from fertilizer cost tool.


SOLVER MUST BE ENABLED IN ADD-INS

Fertilizer	Price per ton	Use or not	Minimum lbs	Maximum lbs
Anhydrous Ammonia	$ 1,000	☑		
Urea	$ 739	☑		
UAN28	$ 573	☑		
UAN32	$ 673	☑		
DAP	$ 905	☑		
MAP	$ 879	☑		
10-34-0	$ 754	☑		
Potash	$ 752	☑		
Ammonium nitrate	$ 250	☐		
AMS	$ 200	☐		
		☐		
		☐		
		☐		
		☐		

Fertilizer recommendations

	N	P	K
Required	200	100	100
Maximum			

Find Minimum Cost

Fertilizer Prices Need to Be Updated Before Using!

Solutions

Fertilizers to use	Pounds	Cost
Anhydrous Ammonia	218	$ 109.00
MAP	192	$ 84.38
Potash	167	$ 62.79
Total		$ 256.18

Nutrients Applied

	N	P	K
Lbs applied	200	100	100
Cost per unit	$ 0.610	$ 0.716	$ 0.627

Add Scenario

Delete All Scenarios

Scenarios to Exam

Fertilizer	Quantities Scenario #1	Scenario #2	Scenario #3	Scenario #4	Scenario #5
Anhydrous Ammonia	218	196			
Urea					
UAN28					
UAN32					
DAP		217			
MAP	192				
10-34-0					
Potash	167	167			
Ammonium nitrate					
AMS					
Application cost					
Total cost	$ 256.18	$ 258.98			

Figure 3. Example of when the two-step pricing technique does not work.

incorrect solution. This is illustrated in Figure 3. Here, the anhydrous price has decreased to $1000/ton while the DAP price has increased to $905/ton. All the other fertilizer prices are the same as in Figure 1. The two-stage process would again pick DAP for the P requirement ($0.669 vs. $0.675 per pound of P). However, the lowest cost fertilizer combination now includes MAP instead of DAP as the two-stage process did not allocate the costs correctly. These differences are shown in the two scenarios at the bottom of Figure 3.

DISCUSSION

Crop budgets at many states seem to have become less detailed over time. Whether this is due to fewer personnel working in the budgeting area or some other reason, one consequence has been less information about fertilizers. Agronomists make fertility recommendations based on soil levels and the nutrient requirements of a particular crop. They provide these recommendations in the form of pounds of N, P, and K. In many states now, this is how budgets list the fertility costs. However, in doing so, a value must be assigned to each nutrient and with multinutrient fertilizers, this value could be incorrect or misleading.

Farmers also do not purchase N, P, and K directly. They purchase fertilizers that contain some combination of these nutrients. As shown in this paper, using linear programming via the solver tool of Excel is an easy way to calculate the minimum cost fertilizer combination that meets the required levels of N, P, and K. The linear programming approach will always give the correct solution that minimizes costs. The other approaches that price multinutrient fertilizers based on other single-nutrient fertilizers often do not work and can lead to a farmer using a fertilizer combination that does not minimize costs. The Excel decision aid presented here is an easy way for producers to solve this linear programming problem without knowing anything about linear programming.

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