Impact of Fuel and Nitrogen Prices on Profitability of Selected Crops: A Case Study

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ABSTRACT

Increasing prices for fuel and N fertilizer affect crop production decisions and profitability. Nitrogen response functions are estimated for corn (Zea mays L.), sugar beet (Beta vulgaris L.), dry bean (Phaseolus vulgaris L.), and malt barley (Hordeum vulgare L.) using data from field studies conducted in the Big Horn Basin of Wyoming. These N response functions are used to evaluate the impact of increases in N and fuel prices on the profitable level of N use. Enterprise budgets are developed for seven selected crops to determine return to management [Return to Management = Price × Yield – Total Cost (preplant, plant, growing, harvest, land, and other)] under price increases for fuel and N. Finally, a linear programming model is used to determine the impacts of increased prices for fuel and N on farm profit and crop mix. Results illustrate that impacts of increasing fuel and N prices on individual crops are quite different and also vary with the overall crop mix. In particular, adding alfalfa (Medicago sativa L.) and perennial ryegrass (Lolium spp.) seed production to the crop mix reduced the impacts of increasing fuel and N prices. This suggests producers should adjust production practices on individual crops and also analyze their crop mix when faced with rising fuel and N prices if they are to minimize impacts on profitability.

Fuel and N fertilizer prices have increased considerably in recent years. The U.S. price of ammonium nitrate increased from $0.64 kg⁻¹ of N in 2002 to $0.96 kg⁻¹ of N in 2005 (NASS, USDA, July 2006). Average U.S. bulk delivery fuel prices in 2002 were $0.36 and $0.26 L⁻¹ for gasoline and diesel, respectively (NASS, USDA, July 2006). In 2005, bulk delivery gasoline and diesel prices averaged $0.59 and $0.52 L⁻¹, respectively.

The diversity of crops grown in the Big Horn Basin in northwestern Wyoming makes this particular area a good case study. The major irrigated crops are malt barley, dry bean, sugar beet, alfalfa, and corn silage. In addition to these crops, ryegrass and alfalfa grown for seed are also included in the analyses.

With varied production practices and a different response to N by crop, increases in fuel and N prices impact production expenses and yield of each crop differently. This has implications for producers regarding production decisions and profitability.

METHODS

Yield responses to N are estimated and used to determine the most profitable levels of N fertilizer for corn silage, dry bean, malt barley, and sugar beet. Yield responses to N for alfalfa and alfalfa seed are not estimated because alfalfa is a N-fixing crop and if N is applied the rate is low. Results from a N rate study on irrigated perennial ryegrass in Alberta, Canada reported no significant differences in seed yield (Najda, 2004). As a result, single levels of N are used on alfalfa, ryegrass seed, and alfalfa seed.

Next, crop budgets are developed for these seven crops to determine return to management (profit) under increased prices for fuel and N. Finally, an economic model is used to determine the impact of price increases for fuel and N on overall farm profit and crop mix.

Nitrogen Response Functions

Much has been written about data collection and economic and statistical specification in estimating mathematical forms of production functions. Heady and Dillon (1961) indicate that none of these main aspects of production function research is independent but that each influences the others. Beattie and Taylor (1985) suggest theory does not typically provide much guidance in selecting a particular mathematical form and that the fit of different functional forms can be compared statistically. While theory does not provide much guidance in selecting functional form, it does specify the properties of the functional form.

Data from previous N rate field studies are used in regression analyses to estimate N response functions. The functional form of the estimated equations, Cobb–Douglas or quadratic, is based on the $R^2$, $P$ value, $t$-statistic, the sum of the squared differences of the actual vs. predicted values and consistency of the signs of the estimated coefficients with theory.

The yield response functions for malt barley and dry bean are based on experimental data from the Powell Research and Extension Center. Experiment years ranged from 1984 to 1988 (Lauer and Partridge, 1990) and 1983 to 1986 (Hough and Partridge, 1987) for malt barley and dry bean, respectively. Nitrogen application rates for malt barley and dry bean vary from 0 to 202 kg of N ha⁻¹ and 0 to 168 kg of N ha⁻¹, respectively. The N response functions for malt barley and dry bean are Cobb–Douglas functions estimated linearly as follows:
where \( \pi \) is profit; \( P \) is profits from the production process. Algebraically, the profit equation can be stated as follows:

\[
\ln \pi = \ln a + b \ln n
\]  

where \( y \) is yield (kg ha\(^{-1}\)), \( n \) is N applied (kg ha\(^{-1}\)), \( a \) is a constant in kg ha\(^{-1}\), and \( b \) is the transformation ratio.

Experimental data collected at the Powell Research and Extension Center from 1989 to 1991 (Lauer, 1991) and 1983 and 1985 to 1987 (Partridge, 1983–1987) are used to estimate the \( N \) response functions for sugar beet and corn silage, respectively. For sugar beet and corn silage, \( N \) application rates vary from 0 to 336 kg of N ha\(^{-1}\) and 0 to 269 kg of N ha\(^{-1}\), respectively. Quadratic \( N \) response functions for both sugar beet and corn silage are estimated as follows:

\[
y = a + bn + cn^2
\]  

where \( y \) is yield (Mg ha\(^{-1}\)), \( n \) is N applied (kg ha\(^{-1}\)), \( a \) is a constant in Mg ha\(^{-1}\), and \( b \) and \( c \) are regression coefficients.

These estimated crop yield response functions to \( N \) are used to determine the most profitable level of \( N \) for various fuel and \( N \) prices (\( P_n \)). The economic optimum amount of a variable input in this case \( n \), is that amount which maximizes short-run profits from the production process. Algebraically, the profit equation can be stated as follows:

\[
\pi = P_y - TC
\]  

where \( \pi \) is profit; \( P_y \) is output price less per unit harvest cost (net price); \( y \) is the response function; \( TC \) is total cost, \( P_n \) is \( N \) + other costs; and where \( P_n \) is the price of N. To maximize this function with respect to input \( n \) (\( N \)), set the first derivative equal to zero and solve.

\[
\frac{d\pi}{dn} = \left(\frac{dy}{dn}\right) P_y - P_n = 0
\]  

\[
\left(\frac{dy}{dn}\right) P_y = P_n
\]  

To maximize profit, \( n \) will be increased to the level where the revenue generated by an additional unit of \( n \) is equal to the price of \( n \). Relative changes in the prices of \( y \) and \( n \) will alter the optimum level of \( n \) usage.

**Enterprise Budgets**

Base enterprise budgets are developed for malt barley, dry bean, sugar beet, corn silage, alfalfa, alfalfa seed, and ryegrass seed. Since, alfalfa, alfalfa seed, and ryegrass seed are perennial crops, establishment budgets are developed for each of these enterprises. Once established, alfalfa, alfalfa seed, and ryegrass seed remain in production for 4, 3, and 2 yr, respectively. In the enterprise budgets for these crops, establishment costs are depreciated over 4, 3, and 2 yr for alfalfa, alfalfa seed, and ryegrass seed, respectively. Base budgets for the crop enterprises use fuel prices from the 2000 to 2002 period (Wyoming Agricultural Statistics Service, 2003) and custom rates for farming operations from Hewlett et al. (2004). Individual field operations in the enterprise budgets are based on crop enterprise budgets for the Powell area as well as advice from Powell Research and Extension Center staff and area farmers. Prices for herbicides and fertilizers are from Simplot and Big Horn Co-op of Powell. Crop prices are 5-yr averages (Wyoming Agricultural Statistics Service, 2004, 2005) and are constant throughout the analysis. Since crop prices are generally determined in a national market, the increased acreage and output in Wyoming’s Big Horn Basin should not impact output prices. Increased production of alfalfa seed may be a case where output price would be impacted. However, alfalfa seed is grown under contract and a more likely factor limiting increased acres would be the ability of producers to obtain a contract. This also may be true for sugar beet, malt barley, and ryegrass seed, as those crops are also grown under contract. Additional enterprise budgets are developed for fuel price increases of $0.26 and $0.53 L\(^{-1}\) (100 and 200% increases, respectively) and for combinations of fuel price increases of $0.26 and $0.53 L\(^{-1}\) and \( N \) fertilizer prices of $0.88 and $1.10 kg\(^{-1}\) of N. The enterprise budgets provide an estimate of profitability of each crop under each scenario of fuel and \( N \) price increases.

**Impact Analysis**

Linear programming is a management tool used to determine the mix of crops that maximize profits for each scenario of fuel and \( N \) prices for a 243 ha case farm. Three quantitative components of linear programming are an objective function, alternative methods and restriction of the resource (Agrawal and Heady, 1972). The three quantitative components used in this impact analysis are; an objective function, alternative fuel and \( N \) prices, and a hectare constraint for each crop with an overall restriction of 243 ha. The acreage constraints for a given crop are based on 5-yr averages from Wyoming Agricultural Statistics Service (2005) and the overall constraint of 243 ha is representative of irrigated farms in the Big Horn Basin of Wyoming. The objective function and each individual crop constraint are as follows:

\[
\text{Maximize } \pi = r_A(x_A) + r_{AS}(x_{AS}) + r_{MB}(x_{MB}) + r_{CS}(x_{CS}) + r_{DB}(x_{DB}) + r_{RS}(x_{RS}) + r_{SB}(x_{SB})
\]  

Subject to:

\[
x_A \leq 81 \quad \text{Alfalfa}
\]  

\[
x_{AS} \leq 4 \quad \text{Alfalfa seed}
\]  

\[
x_{MB} \leq 81 \quad \text{Malt barley}
\]  

\[
x_{CS} \leq 20 \quad \text{Corn silage}
\]  

\[
x_{DB} \leq 28 \quad \text{Dry bean}
\]  

\[
x_{RS} \leq 4 \quad \text{Ryegrass seed}
\]  

\[
x_{SB} \leq 81 \quad \text{Sugar beet}
\]  

\[
x_i \geq 0
\]  

where \( r_i \) is return to management ha\(^{-1}\) for the \( i \)th crop, \( x_i \) is the hectares grown for the \( i \)th crop, and \( \pi \) is total profit for the 243-ha farm. Return to management \( r_i \) for alternative combinations of fuel and \( N \) prices for the \( i \)th crop are obtained from the enterprise budgets and are used in the economic model under four scenarios. The first scenario includes the major crops in the Big Horn Basin: malt barley, dry bean, sugar beet, corn silage, and alfalfa, with no alfalfa seed or ryegrass seed allowed. Scenario two includes these same major crops but hectares allowed of the three most profitable crops, sugar beet, dry bean, and corn silage, are increased 20, 12, and 10 ha, respectively.
Scenario three includes the same crops as scenario one with 4 ha each of alfalfa seed and ryegrass seed allowed. Scenario four includes the same crops and hectares as scenario two and allows 4 ha each of alfalfa seed and ryegrass seed.

RESULTS AND DISCUSSION

Optimal N fertilizer application rates, crop enterprise budgets, and overall farm profitability are evaluated for various combinations of fuel and N prices under four crop mix scenarios. These results illustrate that impacts of increasing fuel and N prices on individual crops are quite different and also vary with the overall crop mix.

Nitrogen Fertilizer Rates

Estimated N response functions for selected crops and statistical results are presented in Table 1. Signs of the coefficients for the N response functions are consistent with economic theory and each is significantly different from zero at α = 0.10, one tail test. Further, within the range of N applied for each crop, output levels are nonnegative.

Results from the estimated N response functions are used to determine optimal N fertilizer application rates and expected yield for malt barley, dry bean, corn silage, and sugar beet under the following scenarios: the base budget, increased fuel prices of $0.26 and $0.53 L\(^{-1}\) (100 and 200% increases, respectively), and fuel price increases of $0.26 and $0.53 L\(^{-1}\) combined with N prices of $0.88 and $1.10 kg\(^{-1}\) of N. The estimated levels of N to apply varied considerably for the various fuel and N prices (Table 2). Of the four crops, corn silage is the most responsive to changes in the price of N. For example, the optimal level of N for corn silage decreases 85 kg ha\(^{-1}\) when the price of N increases from $0.88 to $1.10 kg\(^{-1}\) and fuel price is increased $0.26 L\(^{-1}\). The optimum N rate for dry beans, on the other hand, is not very sensitive to fuel and N price increases. The optimal rate of N for dry beans decreases 11 kg ha\(^{-1}\) when the price of N increases from $0.88 to $1.10 kg\(^{-1}\) and fuel price is increased by $0.26 L\(^{-1}\). The varying response of crops to N is one of the reasons why increases in fuel and N prices impact profitability of crops differently.

In addition to fuel and N price increases, changes in output price also impact the level of N applied. Nitrogen application rates are evaluated for both 10 and 30% changes in output price, relative to the 5-yr average price, for each of the four crops. For a 10% change in output price, changes in the estimated economic optimum level of N to apply range from 47 kg ha\(^{-1}\) for corn silage to 4 kg ha\(^{-1}\) for dry bean which are changes of 35 and 9%, respectively. With a 30% change in output price, changes in the estimated economic optimum level of N to apply range from 116 kg ha\(^{-1}\) for corn silage to 15 kg ha\(^{-1}\) for dry bean which are changes of 87 and 34%, respectively. For the crops considered in this analysis, corn silage is the only crop for which the economic optimum level of N applied changes by more than 50% when output price changes by 30%. Note that, as of recent market experience, input price changes as a result of crude oil prices are also affecting commodity prices (corn to ethanol production as a substitute for crude oil has resulted in major commodity price increases as different crops vie for the same acreage). This suggests that the above increases in the economic optimum N rates are likely less given the expected direct relationship between crop, fuel, and fertilizer prices that has yet to become established consistently in the market place.

Return to Management by Crop

Profit for each crop decreases substantially as fuel and N prices are increased (Table 3). While all crops are impacted by increased fuel and N prices, there is a considerable difference in the impact on profit by crop. For example, comparing the base

<table>
<thead>
<tr>
<th>Crop</th>
<th>Alfalfa</th>
<th>Alfalfa seed</th>
<th>Malt barley</th>
<th>Dry bean</th>
<th>Corn silage</th>
<th>Ryegrass seed</th>
<th>Sugar beet seed</th>
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<tr>
<td>Base budget</td>
<td>45†</td>
<td>45†</td>
<td>134</td>
<td>67</td>
<td>224</td>
<td>157†</td>
<td>246</td>
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<td>Fuel prices:</td>
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<tr>
<td>$0.26 increase L(^{-1}) and $0.88 kg(^{-1}) N</td>
<td>103</td>
<td>54</td>
<td>216</td>
<td>226</td>
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<tr>
<td>$0.26 increase L(^{-1}) and $1.10 kg(^{-1}) N</td>
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<td>43</td>
<td>131</td>
<td>214</td>
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<td>$0.53 increase L(^{-1}) and $0.88 kg(^{-1}) N</td>
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<td>52</td>
<td>202</td>
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<tr>
<td>$0.53 increase L(^{-1}) and $1.10 kg(^{-1}) N</td>
<td>77</td>
<td>40</td>
<td>99</td>
<td>212</td>
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| † Nitrogen response functions were not estimated for these crops, so the level of N remained the same for alternative fuel and N prices.

Table 3. Return to management ha\(^{-1}\) for alternative fuel and N prices.

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<tr>
<th>Crop</th>
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<tr>
<td>$0.26 increase L(^{-1})</td>
<td>162.52</td>
<td>210.25</td>
<td>185.70</td>
<td>188.79</td>
<td>89.68</td>
<td>884.54</td>
<td>491.38</td>
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<td>$0.53 increase L(^{-1})</td>
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budget for sugar beet and corn silage with the budget when fuel price increases $0.53 L^{-1}$ with N priced at $1.10$ kg$^{-1}$, profit is reduced by $259$ and $211$ ha$^{-1}$, respectively. Making this same comparison for dry bean, profit is reduced by $99$ ha$^{-1}$. Increases in fuel and N prices impact production expenses of each crop differently because of differences in field operations, amount of N applied, and the crop’s response to N.

### Farm Profitability

The linear programming model is run for seven variations in fuel and N prices under four different crop mix scenarios. Results show there is considerable change in estimated profit and optimal crop mix for the various combinations of fuel and N prices under the four crop mix scenarios (Table 4).

Compared to the base budget, profit under scenario 1 decreases by 37 and 72% with fuel price increases of $0.26$ L$^{-1}$ and $0.53$ L$^{-1}$, respectively. When the $0.53$ L$^{-1}$ increase in fuel price is combined with N priced at $1.10$ kg$^{-1}$, profit decreases 84%, relative to the base budget. By adjusting the crop mix, as well as the N applied, producers can reduce the impact of fuel and N price increases. Compared to the base budget for scenario 1, profit under scenario 2 increases 10% when the price of fuel increases $0.26$ L$^{-1}$ and decreases 30% for the $0.53$ L$^{-1}$ increase in fuel price. Under scenario 2, profit decreases 44% for the $0.53$ L$^{-1}$ increase in fuel price with N priced at $1.10$ kg$^{-1}$ relative to the base budget in scenario 1. Under scenario 2, hectares of the three most profitable primary crops, sugar beet, dry bean, and corn silage increase. Given this is a case study of Wyoming’s Big Horn Basin, the increased acreage and output for dry bean and corn silage should not impact output price. The factor most likely to limit scenario 2 would be the ability of producers to obtain contracts from sugar companies to increase sugar beet acres.

The impact of fuel and N price increases on profitability is reduced compared to scenario 1, when alfalfa and ryegrass seed production is allowed in scenarios 3 and 4. Under scenario 3, profit is $20,569$ for the $0.53$ L$^{-1}$ increase in fuel price with N priced at $1.10$ kg$^{-1}$ compared to $6,946$ in scenario 1. This reduction in impact is largely due to the increased profitability of these seed crops, as well as reduced field operations once these crops are established and the level of N applied. As in the case of sugar beet, a limiting factor for scenarios 3 and 4 would be the ability of producers to obtain contracts to grow alfalfa seed and ryegrass seed. If producers are to minimize impact on profit under rising fuel and N prices, both the level of N applied and the mix of crops to grow must be considered.

### SUMMARY

Results show rising prices of N fertilizer and fuel have a major effect on production decisions and profitability. For individual crops, case study results illustrate that impacts of increasing fuel and N prices are quite different by crop. In this study, corn silage is most sensitive to price increases of N. The optimal level of N applied decreases 85 kg ha$^{-1}$ when the price of fuel increases $0.26$ L$^{-1}$ and price of N increases $0.22$ kg$^{-1}$. For fuel and N price increases of $0.53$ L$^{-1}$ and $0.22$ kg$^{-1}$, respectively, profit for corn silage is a negative ($54.99$) ha$^{-1}$ compared to $157.51$ ha$^{-1}$ in the base budget. For these same increases in fuel and N prices, profit for dry bean is $133.78$ ha$^{-1}$ compared to $232.77$ ha$^{-1}$ for the base budget.

Under scenario 1, profitability of the 243 ha irrigated farm decreases by 37 and 72% with fuel price increases of $0.26$ and $0.56$ L$^{-1}$, respectively, compared to the base budgets. Combining the $0.26$ L$^{-1}$ increase in fuel price with a N price increase of $0.22$ kg$^{-1}$ results in profitability decreasing by 51% relative to the base budgets under scenario one. The profitability analysis indicates that impacts of rising fuel and N prices can be substantially reduced by making adjustments in the crop mix. Under scenario 2, where hectares of the three most profitable crops increase, profit increases 10% when fuel price increases $0.26$ L$^{-1}$ and decreases 30% with a $0.53$ L$^{-1}$ increase in fuel price, compared to the base budgets for scenario 1. In addition,
adding seed crops to the crop mix reduces the impacts of increasing fuel and N prices. This means producers must adjust production practices on individual crops and also analyze their crop mix when faced with rising fuel and N prices if they are to minimize impacts. Finally, increases in commodity prices as an indirect result of higher fuel and fertilizer prices, complicate the above issues further and are beyond the scope of this research.

ACKNOWLEDGMENTS

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REFERENCES