# CORN PRICES, THE FUEL SHORTAGE AND OPTIMAL CORN HARVESTING STRATEGIES*

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The unprecedented demand for United States feed grains has boosted corn prices to record levels. If corn prices continue at these record levels, corn production practices and the demand for corn production inputs likely will be affected. One of the corn production practices that may be affected is harvesting. And because of the increased use of field shelling and artificial drying [1, 3], changes in corn-harvesting practices may have an impact on the demand for propane fuel used in corn drying. Future supplies of propane, however, may be limited, or higher priced, or both. The analysis reported in this paper is an attempt to estimate the impact of higher corn and propane prices on harvesting strategies, on the quantity of propane demanded, and on other related variables. The results of the analysis suggest that, given higher corn prices, the amount of propane demanded for corn drying will increase dramatically, even with much higher propane prices.

One of the main reasons for the adoption of field shelling and artificial drying in corn harvesting is that it allows the corn producer a greater degree of flexibility in choosing a harvesting strategy. Because field losses increase over time, a producer can hold those losses to a minimum by beginning the harvest early and equipping himself with enough harvesting machines to complete the job during a short time. On the other hand, because moisture content of corn decreases over time, he can cut artificial drying costs to a minimum by letting corn field dry and beginning harvest later. In addition, per-acre harvesting costs can be reduced by using fewer harvesting machines over a longer harvest period. With field shelling and artificial drying, then, a corn producer can choose an optimal harvest strategy; i.e., a starting date and length for the harvest period that maximizes net revenue in view of field loss, drying, and harvesting costs.

To outline the impact of changes in corn and propane prices on corn harvesting strategies and other related results, we develop a simple theoretical model depicting a profit-maximizing corn producer's selection of harvesting strategies. This theoretical model provides some qualitative results and is the basis for an empirical investigation. The empirical analysis offers estimates of the adjustments in harvesting strategies, propane demands, and some other variables resulting from increased corn and propane prices.

## A REVENUE-MAXIMIZING MODEL

We assume that the corn producer's objective in selecting a corn harvesting strategy is to maximize revenue from corn sales less drying and harvesting costs. His choice variables are the starting date ($t_0$) and length ($\Delta$) of the harvest period. The variable $t_0$ is defined as the number of days after the corn reaches 30 percent moisture (the highest moisture content at which corn can be harvested for grain). An optimal harvest strategy ($t_0^*$, $\Delta^*$), then, implies that harvest begins $t_0^*$ days after the corn reaches 30 percent mosture and is completed $\Delta^*$ days later.

Revenue per acre from corn sales depends on the average number of bushels per acre harvested and on the price per bushel. In this analysis, the price per bushel of No. 2 corn (P) is exogenously determined. The quantity of No. 2 bushels harvested per acre (q) is related to the harvest date, here postulated as a decreasing linear function:

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(1) $q = q_0 + q_1 t; q_0 > 0, q_1 < 0,$

where $q_0$ is the maximum potential yield of No. 2 bushels with no field loss, $q_1$ is the number of bushels lost each day the crop is left in the field, and t is the harvest date measured in days after the corn reaches 30 percent moisture. By use of equation (1), the average number of bushels harvested per acre (Q) during the interval beginning at $t_0$ and ending at $t_0 + \Delta$ is

(2) $Q(t_0, \Delta) = q_0 + q_1 (t_0 + \frac{\Delta}{2}).$

The revenue per acre from corn sales, then, is the product of P and Q.

Drying costs per acre depend in part on the average number of pounds of water removed from the harvested corn. Corn must be dried to 15.5 percent moisture to meet the requirement for No. 2 grade. The moisture content of the harvested corn and, therefore, the amount of water that must be removed per acre harvested depend on the harvest date. The postulated relationship between the pounds of water removed per acre (w) and the harvest date is:

(3) $w = w_0 + w_1 \exp(-rt); w_0, w_1, r > 0.$

The parameter $w_0$ in equation (3) represents the number of pounds of water per acre that must be removed from corn harvested at 18 percent moisture, the lowest moisture percentage that can be achieved through field drying. The sum $w_0 + w_1$ is the number of pounds of water per acre that must be removed from corn harvested at 30 percent moisture, and r is the rate of decline in water content per acre per day the corn is left in the field to dry. With use of equation (3), the average number of pounds of water (W) that must be removed per acre from corn harvested during the interval $t_0$ to $t_0 + \Delta$ is:

(4) $W(t_0, \Delta) = w_0 + \frac{w_1}{2} \left\{\exp(-rt_0) + \exp [-r (t_0 + \Delta)]\right\}.$

Given the average number of pounds of water to be removed, the per-acre drying cost (D) is:

(5) $D(t_0, \Delta) = d_0 + d_1 W(t_0, \Delta); d_0, d_1 > 0,$

where

(6) $d_1 = \delta_0 + \delta_1 F; \delta_0, \delta_1 > 0.$

The parameter $d_0$ is the per-acre drying cost not related to water removal (hauling, handling, etc.). The parameter $d_1$ represents the marginal cost of removing a pound of water from the corn harvested from one acre. The cost, in turn, is composed of a nonfuel cost per pound of water removed ($\delta_0$) and a component related to propane requirements. The parameter $\delta_1$ is the number of gallons of propane needed to remove one pound of water, and F is the exogenously determined price per gallon of propane.

Finally, we assume that harvest costs per acre (H) decline as the length of the harvest period increases:

(7) $H(\Delta) = h_0 + h_1 \exp(-g\Delta); h_0, h_1, g > 0.$

Harvest costs per acre decrease as $\Delta$ increases because with a longer harvest period, fewer (or smaller) harvesting machines are needed for a given number of acres, and the annual fixed costs for each machine are either smaller or can be spread over more acres. In equation (7), the parameter $h_0$ represents the per-acre harvest cost associated with the longest practical harvest period. At the other extreme, the sum $h_0 + h_1$ is the harvest cost per acre associated with a zero value for $\Delta$. The parameter g is the rate of decline in harvest costs per acre as $\Delta$ increases.

The corn producer's objective function for selecting a harvest strategy, then is:

(8) $R = PQ(t_0, \Delta) - D[W(t_0, \Delta), F] - H(\Delta),$

where R is gross revenue per acre less drying and harvesting costs, or adjusted gross revenue. Only part of the costs incurred in corn production are included in this equation. But, if we assume that the remaining costs are independent of harvesting and drying costs, maximizing adjusted gross revenue is equivalent to maximizing profit per acre.

First-order conditions for a maximum with respect to $t_0$ and $\Delta$ require that:

(9) $$\frac{\partial R}{\partial t_0} = 0 = Pq_1 + \frac{(\delta_0 + \delta_1 F) r w_1}{2} \left\{\exp(-rt_0) + \exp[-r(t_0 + \Delta)]\right\} \text{ and}$$

(10) $$\frac{\partial R}{\partial \Delta} = 0 = \frac{Pq_1}{2} + \frac{(\delta_0 + \delta_1 F) r w_1}{2} \left\{\exp[-r(t_0 + \Delta)]\right\} + gh_1 \exp(-g\Delta).$$

Given the restrictions on the signs of the parameters in equations (1), (3), (5), (6), and (7), the second-order conditions are satisfied.

To determine the impact of changes in corn and propane prices on the optimal starting date $t_0^*$ and optimal length of the harvest period $\Delta^*$, we take the total differential of equations (9) and (10) with respect to $t_0$, $\Delta$, F, and P. First setting dF = 0 and, then, dP = 0, we find that

$$\frac{dt_0^*}{dP}, \frac{d\Delta^*}{dP} < 0; \frac{dt_0^*}{dF} > 0; \text{and } \frac{d\Delta^*}{dF} = 0.$$

Thus, ceteris paribus, increases in corn prices will cause profit maximizing corn producers to begin harvest earlier, and increases in propane prices will cause them to begin later. Further, increases in corn prices will cause producers to shorten the harvest period. Finally, given the equation forms specified here, propane costs have no impact on the optimal length of the harvest period.

## EMPIRICAL ANALYSIS

Quantitative results were obtained to supplement the qualitative results just discussed. The first step was to estimate the parameters in equations (1), (3), (5), (6), and (7). Then, with these parameter estimates, equations (9) and (10) were solved for $t_0^*$ and $\Delta^*$, given nine selected combinations of corn and propane prices. Finally, these solution values for $t_0^*$ and $\Delta^*$ and equations (1) to (8) were used to determine the impacts of changes in corn and propane prices on the optimal harvest strategy, the quantity harvested, the moisture content of the harvested corn, propane use, drying and harvesting costs, and gross revenue less harvesting and drying costs.

Estimates for the parameters in the quantity, water and harvest cost equations were obtained by regression analysis.[1] The quantity equation is as follows:

$$\text{(1a)}\quad q = 113.02 - 0.12t, \; R^2 = 0.97, \; n = 14.$$
$$[-18.39]$$

Here, t is the number of days beyond the date at which corn reaches 30 percent moisture. The value in brackets is the t-ratio, and n is the sample size. The water equation was estimated to be

$$\text{(3a)}\quad \ln(w - w_0) = 6.85 - 0.08t, \; R^2 = 0.97, \; n = 14,$$
$$[-19.04]$$

and gives values for the parameters $w_1$ and r of 943.88 and 0.08, respectively. For this estimation it was assumed that the minimum amount of water to be removed per acre ($w_0$) was 180 pounds. The harvest cost equation was estimated as follows:

$$\text{(7a)}\quad \ln[H(\Delta) - h_0] = 4.07 - 0.59\Delta, \; R^2 = 0.92, \; n = 9,$$
$$[-9.09]$$

and gives values for $h_1$ and g of \$58.56 and 0.59, respectively. Here, the minimum per-acre harvest cost ($h_0$) was assumed to be \$9. Values for the parameters in the drying cost equation were calculated to be $d_0$ = \$3.50 per acre; $\delta_0$ = \$0.013 per pound of water removed, and $\delta_1$ = 0.019 gallons per pound of water removed.

With these parameter estimates, equations (9) and (10) could be used to obtain optimal values for $t_0$ and $\Delta$ for different corn and propane price combinations. Solutions were obtained for combinations of three corn and three propane price levels. The three corn price levels were \$1.12 per bushel, the average price received by Iowa farmers for the period 1967-1972 [2], twice this price of \$2.24 per bushel, and three times this price or \$3.36 per bushel. The propane price levels used were \$0.15 per gallon, the average price paid by Iowa farmers in 1972 [4], \$0.30 and \$0.45 per gallon.

## RESULTS

Results for each of the nine combinations of corn and propane prices are shown in Table 1. Values reported in the first row of Table 1 are for a corn price of \$1.12 per bushel and a propane price of \$0.15 per gallon. The optimal starting date for harvest is 22 days after corn reaches 30 percent moisture, and the optimal length of the harvest period is 12 calendar days (or about 9.5 working days). The average yield over the harvest period, from equation (2), is 109.6 bushels per acre, and the average field loss is 3.0 percent.[2] The initial moisture percentage, 19.7, was obtained by dividing $w(t_0^*)$ from equation (3) by $Q(t_0^*, \Delta^*)$ and then converting this value to a moisture percentage. Propane used per acre is 5.4 gallons.[3] The drying and harvest costs and the gross revenue less these costs (labeled adjusted gross revenue) were calculated by

[1] Data were obtained from George Ayres, extension agricultural engineer at Iowa State University, and Winterboer [5]. Additional information on the data and estimation procedure can be obtained from the authors upon request.

[2] The average field loss is given by:

$$L^* = [1 - Q(t_0^*, \Delta^*)/q_0]100.$$

[3] Propane use per acre is given by:

$$G^* = \delta_1 W(t_0^*, \Delta^*).$$

**Table 1. OPTIMUM HARVEST STRATEGIES AND RELATED RESULTS FOR SELECTED LEVELS OF CORN AND PROPANE PRICES**

| | Starting date [$t_0^*$] | Harvest period [$\Delta^*$] | Average yield [$Q(t_0^*\Delta^*)$] | Field loss [$L^*$] | Initial moisture | Propane usage [$G^*$] | Drying cost [$D(t_0^*\Delta^*)$] | Harvest cost [$H(\Delta^*)$] | Adjusted gross revenue [$R^*$] |
|---|---|---|---|---|---|---|---|---|---|
| | days | days | bu./acre | percent | percent | gal./acre | $/acre | $/acre | $/acre |
| Corn: $1.12/bu. | | | | | | | | | |
| Propane: | | | | | | | | | |
| $0.15/gal... | 22 | 12 | 109.6 | 3.0 | 19.7 | 5.4 | $ 8.00 | $9.05 | $105.72 |
| $0.30/gal... | 24 | 12 | 109.4 | 3.2 | 19.4 | 5.1 | 8.51 | 9.05 | 104.93 |
| $0.45/gal... | 26 | 12 | 109.2 | 3.4 | 19.2 | 4.9 | 9.02 | 9.05 | 104.19 |
| Corn: $2.24/bu. | | | | | | | | | |
| Propane: | | | | | | | | | |
| $0.15/gal... | 14 | 11 | 110.7 | 2.1 | 21.4 | 7.4 | 9.64 | 9.10 | 229.14 |
| $0.30/gal... | 16 | 11 | 110.4 | 2.3 | 20.6 | 6.8 | 10.15 | 9.10 | 228.08 |
| $0.45/gal... | 18 | 11 | 110.2 | 2.5 | 20.5 | 6.3 | 10.66 | 9.10 | 227.10 |
| Corn: $3.36/bu. | | | | | | | | | |
| Propane: | | | | | | | | | |
| $0.15/gal... | 10 | 9 | 111.3 | 1.5 | 22.9 | 9.3 | 11.28 | 9.27 | 353.39 |
| $0.30/gal... | 12 | 9 | 111.0 | 1.7 | 22.2 | 8.4 | 11.79 | 9.27 | 352.06 |
| $0.45/gal... | 14 | 9 | 110.8 | 1.9 | 21.6 | 7.8 | 12.31 | 9.27 | 350.84 |

using equations (5) to (8).

The second and third rows in Table 1 show the impacts of higher propane prices with the corn price unchanged. The changes in $t_0^*$ and $\Delta^*$ are consistent with the comparative static results presented earlier. Harvest begins later, but the length of the harvest period and harvest costs per acre are unchanged. Yields are lower because field losses are higher, and the harvested grain is dryer. Propane use per acre is slightly less, but increased propane prices increase drying costs. Because of lower yields and higher drying costs, adjusted gross revenue per acre is slightly lower.

The remaining rows in Table 1 can be used to compare results for higher corn prices with the same or different propane prices. Perhaps the most striking result is that, for the corn and propane price levels considered, corn price changes have a much greater impact on the optimal harvest strategy than do propane price changes. Even with the highest propane prices, harvest begins earlier with higher corn prices. Yields are higher, and field losses are lower. Because the harvested grain is wetter, propane use per acre is much higher, and drying costs are higher. Harvesting costs per acre increase because the harvest period is shortened. Finally, adjusted gross revenue per acre increases nearly in proportion to the corn price.

## IMPLICATIONS

A number of implications are suggested by these results. Because the quantity of propane used per acre is quite unresponsive to changes in the price of propane but highly responsive to changes in the corn price, propane use in corn drying may increase sharply with higher corn prices, even if propane prices also increase. This is shown in Figure 1. With a propane price of $0.15 per gallon, propane use per acre increases 72 percent as corn price increases from $1.12 to $3.36 per bushel. Even if the propane price triples, this increase in the corn price increases propane use by 44 percent. And, these estimates of the increase in propane use would be even higher if increased corn acreage and the continuing shift toward field shelling and artificial drying were taken into account.

Corn and propane price changes also may have a noticeable impact on the quantity of corn harvested, aside from impacts due to changes in acreage. As corn prices increase, field losses are reduced. For example, with a propane price of $0.15 per gallon, the quantity harvested increases (i.e., field losses are reduced) by 1.5 percent if corn price increases from $1.12 to $3.36 per bushel. The increase in quantity is reduced, but not eliminated, if propane price also increases.

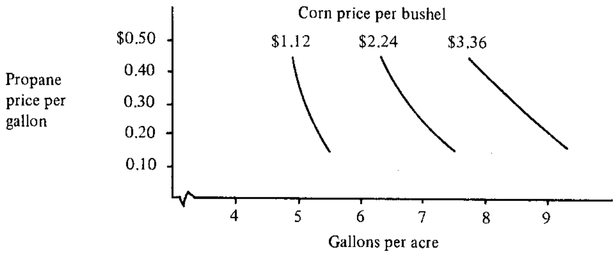


**Figure 1. PROPANE DEMAND CURVES FOR SELECTED CORN PRICE LEVELS**

Finally, changes in the length of the harvest period may place heavy demands on firms supplying grain-handling and drying services and harvesting equipment. More harvesting equipment is needed to complete harvest during a shorter time. And with a shorter harvest period, local elevators' handling and drying capacity must be greater. These demands will be aggravated by the larger quantity and higher moisture content of the harvested grain.

## SUMMARY

With the advent of field shelling and artificial drying, corn producers have increased flexibility in choosing a harvesting strategy. This study suggests that, for given corn and propane prices, a unique optimal harvest strategy exists. And, as corn and propane prices change, so does the optimal harvest strategy.

Two limitations of the study might be noted. First, the results are normative and were not compared with the actual harvest strategies used by corn producers to check their validity. Also, the results might be altered somewhat if an opportunity cost were included for delaying harvest and reducing the time available in the fall for post-harvest field work.

The normative analysis and results, however, strongly suggest: (a) that, for a given corn price, even relatively large changes in propane prices do not greatly affect optimal harvest strategies; (b) that, for a given propane price, optimal harvest strategies are markedly affected by changes in corn prices, and (c) that, if corn producers make the optimal adjustments in their harvest strategies, the demand for propane in corn drying will be affected. In particular, given higher corn prices and no rationing of propane, propane use for corn drying would increase sharply, even with much higher propane prices.

Finally, even though this analysis applies only to corn harvesting, it may have broader implications. Corn harvesting may be similar to several other fuel-consuming production activities in that fuel cost is a relatively small part of total production costs and there are limited opportunities to substitute other inputs for fuel. For these production activities, very drastic price increases likely will be required in order to significantly reduce fuel consumption, especially in instances where product prices have increased.

## REFERENCES


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