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FARM MANAGEMENT OPTIMIZATION

By

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APPROVAL PAGE

FARM MANAGEMENT OPTIMIZATION

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A Thesis Approved On

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ABSTRACT

Horse farmers make yearly decisions concerning the management of feeding horses. These decisions are affected by the cost to grow hay, the cost to buy hay, the cost associated with selling hay, the expected crop yield under various weather conditions, and the likelihood of different weather conditions. Most farmers produce their own hay ranging from hundreds to thousands of bales of hay, but also buy hay from other farmers because they either need a different cutting of hay or they need more hay than they can produce.

The current method of buying and selling hay is based on the expected value of random factors. A lot of decisions are based on tradition within a farm or how things were done the year before. Because of the way horse farms are currently run, farmers encounter many problems when approaching a new hay season. First, there is often too much hay left over from the previous season. This hay is sold at a reduced price right before a new hay season because the storage area needs to be cleared in preparation for the new and better hay. Hay that has been sitting for an entire winter loses a lot of its nutrients. After a poor hay season, some farmers do not keep enough hay to feed their horses until the next season. They are hopeful for better hay early in the next year and this typically leads to having to purchase higher priced hay before the new hay season.

Therefore, it can be seen that, mathematically, taking the expectation as the realization will lead to practically poor solutions.

The paper presents a linear programming model to address the current issues with farm management feeding programs. The model will determine how many acres of hay a farm should harvest for their own horses' consumption, as well as how much hay to purchase and sell each period of the season. Solutions are generated for real world parameters provided by a Kentucky horse farmer and a sensitivity analysis is performed.

Using the parameters provided, the model concluded that the case study farm is operating with a cost, as opposed to a desired profit, on a yearly basis. The selling price of hay does not help the farm to overcome yearly costs of producing hay. Also, the model shows that the current method of planting all available farming acres is not optimal. This is causing the farm increased cost due to excess inventory. Planting fewer acres means holding inventory for multiple periods to meet demand late in the year. All hay that is not used to meet demand is sold to other farms.

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I. INTRODUCTION

In 2007 the Kentucky Breeders' Incentive Fund (BIF) program went in to effect. This program was designed to increase interest in the Quarter Horse breeding industry in Kentucky. According to the Kentucky Quarter Horse Association (2007), the program pays yearly earnings, based on horse performance, to the "breeders, owners, and owners of sires" of Kentucky bred horses. The BIF program caused many Kentucky horse farmers to increase the amount of brood mares they managed on their farms. Increasing the number of horses fed on a farm, increased the difficulty of managing the farm's feeding program.

Decisions concerning horse farm feed management include: how much hay to produce, how much to sell, how much to buy, and when to buy. These decisions are made based on number of horses fed, cost of producing hay, maximum amount of hay produced on the farm, price of hay, demand for hay from other farms, and available storage space. The maximum amount of hay produced on the farm is mainly dependent on the weather. Farms that produce enough hay to feed their horses typically do no purchase additional hay unless they have produced hay that is very poor quality. In this case they may purchase additional hay to feed their show horses or brood mares. Farms that must purchase hay must consider the trade off of buying an early cutting of hay with lower quality and paying a storage cost or paying additional costs for purchasing a later cutting of hay with higher quality.

A later cutting of hay is more expensive because it has a slightly higher quality and is more expensive to produce. The cost to produce the hay increases due to the successive cuttings yielding less hay. Although later cuttings yield less hay, they require the same amount of labor to produce. In Kentucky there are typically two to three cuttings of hay per year. The number of cuttings is dependent on the type of hay being grown (grass or alfalfa) and the weather conditions. Alfalfa hay has a quicker turn around between cuttings and therefore produces more cuttings of hay in a given hay season.

The difference in quality of hay between cuttings is sometimes a concern for farmers. A horse’s weight can be easily maintained with any cutting of hay, but often better quality hay helps to build the horse’s muscles by providing more nutrients. Also, because there are more nutrients in a later cutting of hay, feeding this hay reduces the amount of grain needed to be fed to the horses. Horses are fed grain for the purpose of supplementing their diet with additional nutrients (such as protein). For these reasons it is desirable to differentiate which cutting a particular bale of hay is from and typically farmers feed their horses hay from the most recent cutting first before older hay.

To address the farm management problem, a mathematical model was developed to optimize the decisions of horse farmers concerning the growing, buying and selling of hay. The model, explained in this paper, will consider the hay consumption (demand) on the farm, cost of producing hay, the maximum amount of hay produced on the farm, price of hay, available storage space, and predicted weather conditions. Realistic parameters were obtained from a local farm and a sensitivity analysis on the tradeoff between storage costs, ordering cost, and increased prices of hay is performed.

The unique aspect of the farm management model is the application of stochastic modeling to farm management. This is done using an expected value approach for determining weather conditions. Although the weather cannot be known with absolute certainty, the probability that certain weather conditions will occur can be estimated.

The remainder of this thesis is organized as follows. Chapter 2 presents a review of the literature pertinent to this work. Chapter 3 introduces the farm management model with an explanation of the objective of the model and the constraints. Chapter 4 presents the application of a case study to this model and the results that were obtained by this. And finally, chapter 5 describes the conclusion and recommendations for the case study farm, as well as possible extensions and future research for the farm management model.

II. LITERATURE REVIEW

The model discussed in this paper aims to minimize the costs associated with farm management by determining the best allocation of land for the crop (hay). It does this through the use of weather forecasts to predict expected crop yield. In this chapter, literature pertaining to farm management models and the use of weather predictions is discussed.

1. Farm Management Models

Farm management models are used for the production, harvesting, storage, and distribution of crops (Ahumada & Villalobos,2009). These models typically have the objective of minimizing cost, maximizing revenue, or maximizing crop yield. They have been applied to areas of farm management such as land allocation (Biswas & Pal, 2005), farm technology utilization (Torkamani, 2005), agricultural supply chain networks (Apaiah & Hendrix, 2005), alternative planning for cropping systems (Abdulkadri & Ajibefun, 1998), and production process planning (Vitoriano, Ortuno, Recio, Rubio, & Alonso-Ayuso, 2003).

Biswas and Pal (2005), present a land allocation model that applies the concept of fuzzy goal programming (FGP). In the FGP model, land allocation goals are given a level of aspiration and upper and lower tolerance limits. Then a set of priority levels for land utilization are determined and the optimal priority structure is found. This will lead to a satisfactory decision regarding land allocation. The benefit of this model is that it does not require the aspiration levels to the goals of the problem to be defined precisely.

This allows for easier decision making in farm planning situations because a farm will only need to determine acceptable tolerance levels of performance.

The farm technology model, presented by Torkamani (2005), has a goal of increasing crop yield, without increasing land availability, through the implementation of new technologies. This is a discrete stochastic programming model and it applies yield data collected on existing and new farm technologies. The model is valuable in determining the "suitability and acceptability of technologies to farmers" (Torkamani, 2005). This allows farmers to see the prospective gain in crop yield from employing new technology as opposed to the traditional farming technology.

The agricultural supply chain network model developed by Apaiah and Hendrix (2005), is a mixed integer program that aims to minimize the total production and transportation cost for pea-based novel protein foods. The total production of peas is demand driven, much like the farm management model presented in this paper. This model, however, goes beyond just production and considers transportation of the product. Also, the total production is not from a single location but from a mix of four different locations. The model constrains the amount of production from each location so that the total supply is not dependent on one source. This model is beneficial in that it estimates the cost of operating a new product line (Ahumada & Villalobos,2009).

Abdulkadri and Ajibefun's (1998) modeling to generate alternative planning first follows the approach of a linear programming model with an objective of maximizing a farm's gross margin. Then alternative solutions are produced by allowing the optimal gross margin to be reduced by a certain percentage. These alternatives are important to farmers because the production goal may not be to just maximize profit, but also optimize other aspects such as minimizing risk. Finding alternative solutions allows for the farm to choose a solution that meets multiple objectives for the farm while still maintaining nearly optimal profit.

Production process planning is presented by Vitoriano et al. (2003) as a linear programming model and is designed to allow “crop production planning to be decided at the beginning of the agricultural year.” The objective of the model is to minimize total cost related to agricultural production. There are two modeling approaches considered by Vitoriano et al. (2003), discrete and continuous time. The discrete time planning model was found to be best in shorter term planning horizons and the continuous time planning model was best for medium to long term planning horizons. Farmers can benefit from this model because it provides them with the solution of how and when to perform the tasks required for agriculture production.

2. Affect of Weather Conditions on Crop Yield

Weather conditions, such as temperature and precipitation, greatly affect the annual yield of crops. Future weather conditions are not known with certainty and, therefore, need to be predicted in order to determine an estimated annual crop yield. Farms rely on the estimated crop yield to make decisions on the amount of land to plant for each crop so that they can try to meet demand. The application of weather probability in mathematical models has been used in determining crop yields such as rice grain (Sheehy, Mitchell, & Ferrer, 2006), wheat grain (Wheeler, Craufurd, Ellis, Porter, & Prasad, 2000), and soybean (Popp, Dillon, & Keisling, 2002). Weather probability has also been applied to existing crop yield simulation models to determine the effects on lead time predictions (Lawless and Semenov, 2005). And the effects of improved weather forecasts (Mjelde & Hill, 1999) have been analyzed.

Rice grain yield is said to be affected by temperature. This affect is due mainly to shorter crop durations at warmer temperatures (Wheeler, Craufurd, Ellis, Porter, and Prasad, 2000). Sheehy, Mitchell, and Ferrer (2006) developed a mechanistic and an empirical model to analyze this relationship between yield and temperature. It was determined that higher minimum daily temperatures do have a negative effect on yield. However, solar radiation was found to have the most negative effect on the yield.

Temperature is also said to affect wheat grain. However it was determined by Wheeler, Craufurd, Ellis, Porter, and Prasad (2000) that it is changes in variability in temperature, as opposed to changes in mean temperature, that have the largest impact on crop yield. There are critical stages in crop development that are most sensitive to periods of high temperatures. In order to predict the impact of the temperature variability on yield, Wheeler et al (2000) states that “reliable seasonal weather forecasts, robust predictions of crop development, and crop simulation models” are needed.

Weather conditions, in this case precipitation, were shown to affect soybean planting strategies, as discussed by Popp, Dillon, and Keisling (2003). A model was developed to determine the best planting strategy using weather predictions. The predictions were used to evaluate which strategy provided the lowest weather risk. The weather predictions were also used to determine the best field operating days, which will also affect the chosen planting strategy.

Lawless and Semenov (2005) have used a combination of a crop yield simulation model and a stochastic weather generator to predict wheat growth lead times. The lead time is the time frame in which there is a high probability of a successful crop yield prediction before the crop matures. It was found that the lead times can vary with crop characteristics even within the same location. The unique aspect of this model is that the stochastic weather generator contains temperature, radiation, and precipitation data to provide the full effect of weather on crop yield.

Costs, input usage, and production are greatly affected by climate forecasts, as discussed by Mjelde and Hill (1999). Three different farm models were studied and all were found to have a positive net return with the use of climate forecasts. Though these models all currently show positive net return with present climate predictions, improving climate forecasts was shown to have different effects on these models. With the improvement of forecasts, some models may show negative net returns or decreased yield. Improved forecasts may not give the desired results for a model, but will allow farmers to determine their input values more efficiently by providing a more realistic representation of the farm's situation.

The models discussed above used the weather conditions to predict yield so that farmers can make better decisions. The model discussed in this paper extends that idea to make the farm planning decisions for the farms. The farm management model uses the probability of certain weather conditions, and the yields associated with these weather conditions, to determine land allocation for the crop. The objective of the model is to minimize costs by planting only as much hay as needed.

III. FARM MANAGEMENT MODEL

The hay management of a small horse farm can be modeled as a linear program (LP). The model includes decision variables for the amount of hay from each cutting to harvest, buy, and sell. The model also allows hay to be stored in inventory in a barn. Therefore the decision variables must consider when (i.e. which period) the hay is consumed, bought, or sold and when the hay was cut (i.e. which cutting). Weather prediction is an important aspect of the model because the annual weather conditions (dry, ideal, or rainy year) will have an effect on the yield of hay.

As mentioned previously, the LP model determines how many acres a farmer should plant to grow hay, how many bales should be harvested each cutting, how many bales to buy and sell as well as how many bales to store in inventory. The temporal relationship between cuttings of hay, periods, and inventory levels is shown below in Figure 1. The figure shows that first acreage level (Z_1) is planted early in the year before any hay is produced. The hay grows during a period (i.e. between cuttings) and is harvested at the beginning of each period. The beginning inventory (binv) for each period is the total amount of hay available to the farm and includes the hay harvested, bought, sold, and in inventory. The ending inventory (einv) for each period is the beginning inventory minus what was consumed by the farm's horses during the period. The farm may start the season with some (H) hay in inventory.

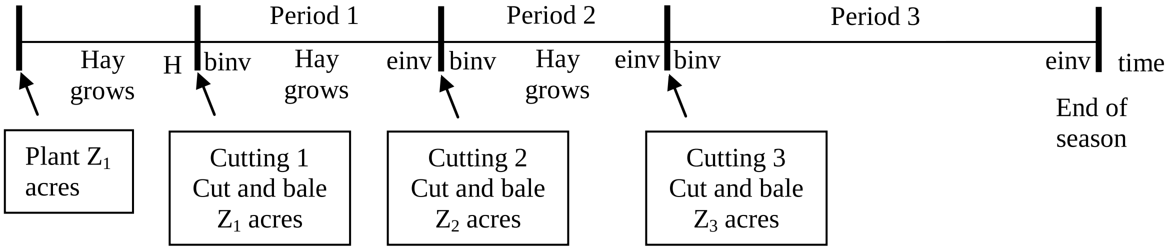

FIGURE 1 – TIMELINE FOR HAY PRODUCTION

The notation of the farm management LP model is as follows:

Decision Variables:

X_{ik} = # bales from cutting i sold at beginning of period k

Y_{ik} = # bales from cutting i bought at beginning of period k

U_{ik} = # bales from cutting i eaten by our horses during period k

Z_i =total acreage of farm harvested in cutting i

$einv_{ik}$ = # bales from cutting i in inventory at the end of period k

$binv_{ik}$ = # bales from cutting i in inventory at the beginning of period

* Note: variables X, Y, U, einv, binv variables only defined when $i \leq k$

Parameters:

i = cutting of hay {1st,2nd,3rd}

j = weather condition {dry,ideal,rainy}

k = period of time between cuttings {1,2,3}

C_{ij} = cost per acre to grow hay for cutting i in weather condition j

r_{ijk} = cost to buy a bale in period k of cutting i for weather condition j

q_{ijk} = price to sell a bale in period k of cutting i for weather condition j

V_k = inventory cost per bale during period k

S_{ik} = penalty cost per bale for consuming bales from cutting i in period k

D_k = # bales demanded during period k

W = storage capacity (in #bales)

M = maximum # acres available for planting

L = maximum selling capacity

H = # bales in inventory at beginning of season before first cutting

b_{ij} = predicted yield (bales/acre)from cutting i for weather condition j

P_j = probability that weather condition j will occur

The farm management LP model is shown below:

$$\text{Min} \quad \sum_i \sum_j \sum_k P_j \left[C_{ij} Z_i + V_k \text{binv}_{ik} + r_{ijk} Y_{ik} + S_{ik} U_{ik} - q_{ijk} X_{ik} \right] \tag{1}$$

Subject to

$$Z_1 \leq M \tag{2}$$

$$Z_i \geq Z_{i+1} \quad \forall\ i = 1,2 \tag{3}$$

$$\text{binv}_{11} = H + \sum_j P_j Z_1 b_{1j} + Y_{11} - X_{11} \tag{4}$$

$$\text{binv}_{ik} = \sum_j P_j Z_i b_{ij} + Y_{ik} - X_{ik} \quad \forall\ i = k, k \geq 2 \tag{5}$$

$$\text{binv}_{ik} = Y_{ik} + \text{einv}_{i,k-1} - X_{ik} \quad \forall\ i < k, k \tag{6}$$

$$\sum_i \text{binv}_{ik} \leq W \quad \forall\ k \tag{7}$$

$$\text{einv}_{ik} = \text{binv}_{ik} - U_{ik} \quad \forall\ k \tag{8}$$

$$\sum_i U_{ik} = D_k \quad \forall\ k \tag{9}$$

$$\sum_i \sum_k X_{ik} = L \tag{10}$$

$$Z_i \geq 0 \qquad \forall\, i \tag{11}$$

$$X_{ik}, Y_{ik}, U_{ik}, binv_{ik}, einv_{ik} \geq 0 \qquad \forall\, i, k \tag{12}$$

The objective of the farm management model is to minimize cost. The objective function, shown in equation (1), is the weighted average of total cost over each possible weather condition. Total cost is the sum of the cost to produce hay, the inventory holding cost, the cost of purchasing any additional hay needed, and the penalty cost for horses not being fed the highest quality hay minus the profit from selling hay.

The constraints for the farm management model relate to planting acreage for hay, fulfilling demand for hay, and storing hay. The first constraint, shown in equation (2) is the acreage constraint. This states that the . Constraints (3) state the acreage for each successive cutting of hay must be less than or equal to the acreage for the previous cutting. The initial acreage of planted hay (Z_1) will limit the successive harvest since hay is only planted at the beginning of a season.

The constraints (4) – (8) are inventory constraints. Constraint (4) is the beginning inventory constraint for the first period. The beginning inventory for this period must be equal to the sum of the inventory remaining from last year's crop, the predicted yield for the first cutting of hay, and any additional first cutting hay purchased minus what is sold from the first cutting production. Similarly, equation (5) is the beginning inventory constraint for hay in the period in which it is cut. Constraints (6) calculate beginning inventory levels for hay which was cut in a previous period.

By definition the maximum amount of hay in inventory will occur at the beginning of a period; therefore constraints (7) ensure the total inventory at the beginning of each period does not exceed the storage capacity. Constraints (8) calculate the ending inventory as the beginning inventory minus what was consumed by the farm’s horses during the period.

Constraints (9) state the amount of hay consumed each period meets the projected demand. Constraints (10) limit the total amount of hay sold in a year to yearly outside demand. And, finally, constraints (11) and (12) are non-negativity constraints.

IV. FARM MANAGEMENT MODEL CASE STUDY AND RESULTS

The farm management LP presented in section 2 was applied to a real-world case study based on costs and data provided by a local horse farm.

1. Case Study Model Parameter Values

The values of the parameters for the farm management model will vary according to location and size of a farm as well as traditions on the farm. The farm modeled for this case study is located in northern Kentucky and consists of approximately 130 total acres. Only 60 of these acres are available for producing hay. The other acreage is occupied by barns, forest areas, and pure grazing lands (for horses not fed hay and grain daily). The consumption rate of hay is about 3.5 bales of hay per day. The demand is deterministic and is based on the number of horses consuming hay.

There is one barn on the property that was designed for storing hay, but it is not insulated and, as the barn ages, holes develop in the roof. This barn can hold approximately 3000 bales of hay. If this barn is chosen to store hay, it must be maintained often to ensure the hay is protected from all precipitation. Any hay that becomes wet will be ruined and even slightly damp hay in combination with heat will be ruined. The cost of storing hay is estimated to be about $0.01 per bale per day.

The producing season for this farm is between May and September and depends largely on precipitation. It is assumed that there are about two months between the 1st and 2nd cuttings and the 2nd and 3rd cuttings of hay. The time between cuttings is also dependent on the weather. During a dry season there may be longer periods of time between cuttings and during rainy seasons a much shorter time between cuttings. The predicted yield for each cutting of hay for the different weather conditions was determined from approximations of previous years. Each successive cutting of hay yields roughly half of the hay from the previous cutting. This is due to each successive cutting occurring at an earlier phase (more leaf and less stem) in the hay's growth.

For each weather condition, the farm provided an estimated production amount based on past data. It was found that during dry years, each cutting yields only about 40% of the hay it yields in an ideal year. And during rainy years, each cutting yields about 50% of the hay it yields in an ideal year. Dry years make the hay grow slower and sparser. Rainy years make hay grow rapidly, but leave little time for the hay to be cured before baling. Hay cannot even be baled with moisture from dew because it will become moldy (if not fed immediately) and non edible for horses. Excessive raining on hay after it has been cut, ruins that cutting of hay. This is why not all acreage is cut for baling at exactly the same time. Often a cutting of hay will take a couple weeks to complete.

To determine the probability of certain weather conditions, 58 years of previous precipitation data, for the northern Kentucky area, was analyzed from the Weather Underground (2009). It was determined that ideal rain conditions over a year occur about 69% of the time. Rainy years occur about 17% of the time and dry years about 14% of the time. Ideal weather conditions were determined by average rainfall. The farm bases its percent yield on the average production of hay and therefore ideal weather conditions occur a majority of the time.

The pricing of hay used in the model is from the 2008 producing season. The selling price used for cuttings 1, 2, and 3 is \$4.50, \$5.50, and \$6.50, respectively, per bale. The buying price used for each cutting is $5, $6, and $7 per bale. The case study farm sells hay locally to friends and tries to maintain lower selling prices. Larger farms sell hay all over the state and often have higher costs of producing due to expensive equipment costs and additional labor. Due to local selling, the farm estimates that it can sell a maximum of about 3000 bales of hay for the year. The farm has consistent yearly buyers whose demand is deterministic. These buyers purchase slightly less than 3000 bales of hay total and the remaining hay is purchased by sporadic buyers.

The selling price of hay is based largely on the cost of producing it. This cost is a function of the labor cost, for baling hay, and the fuel costs. Fuel is used when the hay is cut, prepared for baling (tethered), and baled. Therefore, a tractor may drive over the acreage three or four times for each cutting of hay. The cost per acre of producing hay was estimated to be $50.

2. Case Study Results And Sensitivity Analysis

LINGO was used to solve the LP model. With the parameters outlined in the previous section, the model generated a cost of $262.42 per year. This cost is obtained by planting only 39 of the 60 available acres for the production of hay during all three cuttings and not purchasing any additional hay. After the first cutting, only hay that is needed to meet demand for the immediate period is kept in inventory. Planting only 39 acres will result in the third cutting of hay not producing enough to feed the horses during the third period. Therefore, after the second cutting, inventory is held to feed the horses during the second period and to meet the remaining demand predicted for the third period. The remaining hay is sold as it is produced and the ending inventory for periods one and three is zero, while the ending inventory for period two is 247 bales.

The solution provided by the model differs from the farm's current strategy. Each year all available acreage is planted for the production of hay. This results in the third cutting of hay producing enough to meet demand during the third period as well as additional third cutting hay to be sold. Also, the current strategy involves carrying excess inventory (300 to 400 bales) through all periods. Often, hay produced in the first cutting will still be in inventory at the beginning of the following season and sold at a reduced price to clear the barn for new hay. The outside buyers are forced to buy their hay from the farm in segments (during different periods) regardless of the cutting because of the farm's desired safety stock. This increases the farm's cost of producing the hay and therefore increases the total cost of selling hay.

The cost for the farm management model is directly affected by the probability of ideal weather conditions. Currently, the model assumes a 69% probability of ideal weather conditions for the growing season. A dry or rainy season yields only around half of the hay bales as the ideal conditions. Therefore, as the probability of ideal weather conditions decreases, the cost per bale to produce hay increases and the total cost increases. The decreasing probability causes the model to recommend cutting and producing more acreage of hay. Figure 2 shows the relationship between the decreasing probability of ideal weather conditions and the cost

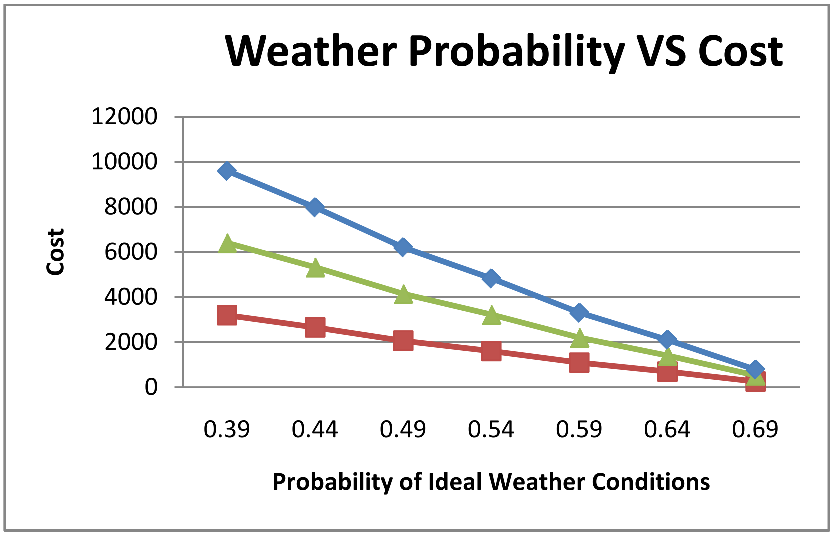

FIGURE 2 – WEATHER PROBABILITY VERSUS COST

The model's sensitivity to the buying and selling prices of hay is one that can be concluded logically. As the selling price increases past the buying price of hay, the model recommends buying hay for the horses from other sellers and selling all hay produced (if buyers would be willing to buy). The same scenario occurs when buying prices reduce. As mentioned earlier, the pricing of hay is directly affected by the cost of producing hay. Therefore, a more interesting result occurs when analyzing how the model is affected by the cost of producing hay. Pricing is often determined at the beginning of a producing season regardless of changes in cost throughout the season.

The cost of producing hay is directly affected by labor costs and fuel costs. The labor costs fluctuate only slightly and therefore would rarely have a drastic effect on the cost of hay production. The fluctuating fuel costs throughout a hay season, however, will have the largest affect on the total cost. An increase of slightly less than $3/gallon, after the first cutting of hay, would cause producing later cuttings of hay to be a larger loss (with current pricing). Predicting such an increase prior to the producing season would drastically change the model. This would mean suggest planting all acres for the first cutting and 11.5 acres for the second and third cuttings. The second and third cutting hay would be used solely to meet demand. The first cutting hay would be used to meet the predicted remaining demand for following periods and what is left would be sold in the first period. This is an interesting conclusion for two reasons. First, gas prices often increase in the summer which is when hay is being produced. Second, the case study farm did not change the price of their hay this past year when fuel prices were reaching record highs.

Currently, farmers carry a lot of inventory during the year that they consider safety stock. As mentioned earlier, this is often sold during the following season at a reduced price. The model is recommending only carrying inventory to meet demand with highest quality hay. This is due to the inventory cost and the penalty cost associated with feeding less quality hay. In the case study results, inventory is carried from the second to third period in order to meet demand and reduce the penalty cost. The penalty cost on hay quality adds to the inventory costs when hay is not used in the period immediately following its production. If the penalty cost was to decrease to \$0.35 per bale per period, the model would recommend holding first cutting hay to feed the horses for the year. The horses would consume a lower quality product and the farm would sell the high quality product to decrease cost. The preference for quality hay varies greatly among horse owners and depends largely on the quality of horses that are being fed. Therefore, the penalty cost may vary over periods or yearly.

The results of the farm management model are evaluated using a stochastic programming approach (Birge & Louveaux, 1997). To determine the value of considering weather information in the model, the cost when each weather condition occurs was found using the LP. The total cost associated with the dry, ideal, and rainy weather occurrences are $10,670.10, -$1738.07, and $8396.10 respectively. These costs are weighted by the probability of each weather condition occurring (69% ideal, 17% rainy, 14% dry) to provide an upper bound on the costs associated with these weather probabilities of $1721.88. To obtain the value of weather information, the difference between the upper bound cost and the stochastic cost of $262.42 (found in the case study results) was found. As a result, the value of considering weather information was found to be $1459.46

Additionally the value of using the stochastic programming approach is evaluated by determining the cost of the solution under the most likely (i.e. ideal) weather condition for each remaining weather condition. The costs associated with using the ideal weather solution for the dry, ideal, and rainy weather occurrences are $11,499.28, -$1738.07, and $9,394.26 respectively. Again, these costs are weighted by the probability of each weather condition occurring (69% ideal, 17% rainy, 14% dry) to provide an upper bound of $1745.23. To obtain the value of the stochastic programming approach, the difference between the upper bound cost and the stochastic cost of $262.42 (found in the case study results) was found. As a result, the value of the stochastic programming approach of considering the probabilities of all three weather conditions simultaneously rather than just considering the most likely weather condition was found to be $1482.81.

V. CONCLUSIONS AND RECOMMENDATIONS

The case study farm is currently producing and selling hay at a loss. The farm tries to maintain low prices because of their close relationship with customers. The current pricing does cover the expense of producing the hay sold and selling hay decreases the annual expense of producing hay for the farm. However, it would be to the advantage of the farm to increase prices $0.25 per bale. This would allow the farm to retain a negative cost on a yearly basis and still allow customers to pay prices below competitor prices. If the farm is able to find additional buyers who agree to buy a total of 300 bales each year, the farm could reduce its prices back to the original (assuming producing costs don't increase).

A second change the farm could make is to decrease inventory costs by finding alternative uses for the unused space. The current storage space is designated specifically for hay. The model recommends that the current storage area should never meet full capacity. Only about one third of the current available space is suggested to be used. The remaining space could be utilized for additional storage of equipment or even modified to hold additional horses. This will reduce the holding cost directly associated with the hay.

The farm management model suggests an alternative method of managing the production of hay. The model offers feasible changes to current farming methods. The current method of producing hay is typically to plant all available acreage, keep excess inventory, and hope to find additional buyers for hay not needed by the farm. The model suggests planting only enough hay to meet demand for the farm and the expected yearly demand from buyers. This method does not allow the farm to feed the highest quality of hay year round, but it does minimize the cost of producing and feeding hay. These changes will decrease costs, time, and space utilized in the production of unnecessary hay. Producing only needed hay is a more lean approach to farm management.

There are many possible extensions and future research opportunities for the farm management model. This model could be applied to different types of farms and a variety of crops with slight alterations. For example, cattle farmers could easily use this model with only slight alterations of yield quantities. And any crop would be applicable to the model. If there is not consumption of the crop on the farm, the model would just be simplified so that production would be based mainly on selling capacity.

There are also other factors that could be introduced to the model. One addition to the model could be considering the renting out of unused land. At the beginning of the producing season, it may be decided to allow another producer to rent land for the production of another crop (such as tobacco). The farmer may receive payment for this rental in the form of a flat payment or in a percentage of profit made from the crop.

Also, the model could incorporate the selling of hay that has been cut and not yet baled. This would occur when cut hay has been ruined by rain. Though this hay is not usable for square baling, it could possibly be used for round baling. The case study farm does not have equipment for round baling because they do not feed their horses round bale hay. Therefore, a farmer who does have this equipment and feeds this type of hay may purchase the cut hay.

Future research for the farm management model could include the use of chance constraint programming. This type of programming would more explicitly incorporate the weather condition probabilities in the model constraints. This may potentially yield a more useful application of stochastic programming than the expected value model approach presented in this paper.

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APPENDIX

1. Lingo Input

```
Sets:
Cutting /1..3/:z;
       !Z = Acreage planted;
WC /1..3/: P;
      !P = Probability that weather condition j will occur;
Period /1..3/: t, V, D;
      !t = time of period k, V = inventory cost, D = demand;
Comboij(Cutting, WC): b, C;
      !b = Predicted yield from cutting i for weather condition j, C = Cost to grow hay;
Comboik(Cutting, Period)|&1 #LE# &2: X, Y, U, binv, einv, S;
      !X = Bales of hay to sell, Y = hay to buy, U = bales eaten, binv = beginning
      inventory, einv = ending inventory, S = penalty cost for consuming bales;
Comboijk(Cutting, WC, Period): q, r;
      !r = penalty cost/bale, q =Selling price;
Endsets

Data:
!Penalty cost per bale for consuming bales from cutting i in period k;
S = 0 1 2
    0 1
    0;
!Time for period k;
t = 60 60 245;
!Demand for period k;
D = 210 210 858;
!Selling price per bale of cutting i during weather condition j in period k;
q = 4.5 4.5 4.5
    4.5 4.5 4.5
    4.5 4.5 4.5
    5.5 5.5 5.5
    5.5 5.5 5.5
```

```
   5.5 5.5 5.5
   6.5 6.5 6.5
   6.5 6.5 6.5
   6.5 6.5 6.5;
!Predicted yeid (bales/acre) from cutting i for weather condition j;
b = 30 75 37.5
   15 37.5 18.25
   7.5 18.75 9.325;
!Storage space (bales);
w = 3000;
!Cost per acre to grow hay for cutting i during weather condition j;
C = 50 50 50
   50 50 50
   50 50 50;
!Cost per bale of hay from cutting i during weather condition j;
r = 5 5 5
   5 5 5
   5 5 5
   6 6 6
   6 6 6
   6 6 6
   7 7 7
   7 7 7
   7 7 7;
!Probability that weather condition j will occur (Dry, Normal, Rainy);
P = 0.14 0.69 0.17;
!Total possible acres to plant;
M =60;
!Inventory cost per bale per day during period k;
V = 0.01 0.01 0.01;
!starting inventory in # bales;
H = 0;
!Maximum demand for hay from other farms;
L=3000;
End Data

!Objective Function;
Min = @Sum(WC(j): @Sum(Cutting(i): @Sum(Period(k)|i #LE# k:
P(j)*((S(i,k)*U(i,k))+
     (C(i,j)*Z(i)) + (V(k)*binv(i,k)*t(k)) + (Y(i,k)*r(i,j,k)) - (X(i,k)*q(i,j,k))))));
!Acre constraint;
@For(Cutting(i): Z(i)<= M);
!Cutting constraint;
@For(Cutting(i)| i #LE# 2: Z(i)>= Z(i+1));
!Inventory constraints;
binv(1,1) = H + Y(1,1) - X(1,1) + @sum(WC(j):P(j)*Z(1)*b(1,j));
```

```
@For(period(k)|k #GE# 2:@For(cutting(i)|i #EQ# k:
    @sum(WC(j):P(j)*Z(i)*b(i,j)) + Y(i,k) - X(i,k)= binv(i,k)));
@For(period(k)|k #GE# 2:@For(cutting(i)|i #LT# k:
    einv(i,k-1) + Y(i,k) - X(i,k)= binv(i,k)));
@For(period(k):@For(cutting(i)|i #LE# k:
    einv(i,k) = binv(i,k) - U(i,k)));
!Demand constraint;
@For(period(k): @sum(cutting(i)|i #LE# k: U(i,k)) = D(k));
!Storage constraint;
@For(period(k): @Sum(cutting(i)|i #LE# k: binv(i,k)) <= w);
!Selling constraint;
@Sum(period(k): @Sum(cutting(i)|i #LE# k:    X(i,k))) <= L;
```

2. Lingo Output

```
Global optimal solution found.
Objective value:                    262.4213
Total solver iterations:                  10


                Variable          Value        Reduced Cost
                       W       3000.000            0.000000
                       M       60.00000            0.000000
                       H       0.000000            0.000000
                       L       3000.000            0.000000
                   Z( 1)       39.25662            0.000000
                   Z( 2)       39.25662            0.000000
                   Z( 3)       39.25662            0.000000
                   P( 1)      0.1400000            0.000000
                   P( 2)        0.69000            0.000000
                   P( 3)        0.17000            0.000000
                   T( 1)       60.00000            0.000000
                   T( 2)       60.00000            0.000000
                   T( 3)       245.0000            0.000000
                   V( 1)     0.1000E-01            0.000000
                   V( 2)     0.1000E-01            0.000000
                   V( 3)     0.1000E-01            0.000000
                   D( 1)       210.0000            0.000000
                   D( 2)       210.0000            0.000000
                   D( 3)       858.0000            0.000000
                B( 1, 1)       30.00000            0.000000
                B( 1, 2)       75.00000            0.000000
                B( 1, 3)       37.50000            0.000000
```

```
  B( 2, 1)         15.00000            0.000000
  B( 2, 2)         37.50000            0.000000
  B( 2, 3)         18.25000            0.000000
  B( 3, 1)         7.500000            0.000000
  B( 3, 2)         18.75000            0.000000
  B( 3, 3)         9.325000            0.000000
  C( 1, 1)         50.00000            0.000000
  C( 1, 2)         50.00000            0.000000
  C( 1, 3)         50.00000            0.000000
  C( 2, 1)         50.00000            0.000000
  C( 2, 2)         50.00000            0.000000
  C( 2, 3)         50.00000            0.000000
  C( 3, 1)         50.00000            0.000000
  C( 3, 2)         50.00000            0.000000
  C( 3, 3)         50.00000            0.000000
  X( 1, 1)         2236.669            0.000000
  X( 1, 2)         0.000000           0.6000000
  X( 1, 3)         0.000000            1.200000
  X( 2, 2)         763.3311            0.000000
  X( 2, 3)         0.000000           0.6000000
  X( 3, 3)         0.000000           0.6000000
  Y( 1, 1)         0.000000            2.903805
  Y( 1, 2)         0.000000            2.303805
  Y( 1, 3)         0.000000            1.703805
  Y( 2, 2)         0.000000            2.903805
  Y( 2, 3)         0.000000            2.303805
  Y( 3, 3)         0.000000            2.303805
  U( 1, 1)         210.0000            0.000000
  U( 1, 2)         0.000000           0.6000000
  U( 1, 3)         0.000000           0.6000000
  U( 2, 2)         210.0000            0.000000
  U( 2, 3)         246.6665            0.000000
  U( 3, 3)         611.3335            0.000000
BINV( 1, 1)        210.0000            0.000000
BINV( 1, 2)        0.000000            0.000000
BINV( 1, 3)        0.000000            0.000000
BINV( 2, 2)        456.6665            0.000000
BINV( 2, 3)        246.6665            0.000000
BINV( 3, 3)        611.3335            0.000000
EINV( 1, 1)        0.000000            0.000000
EINV( 1, 2)        0.000000            0.000000
EINV( 1, 3)        0.000000            5.746195
EINV( 2, 2)        246.6665            0.000000
EINV( 2, 3)        0.000000            6.146195
EINV( 3, 3)        0.000000            7.146195
  S( 1, 1)         0.000000            0.000000
```

```
   S( 1, 2)        1.000000              0.000000
   S( 1, 3)        2.000000              0.000000
   S( 2, 2)        0.000000              0.000000
   S( 2, 3)        1.000000              0.000000
   S( 3, 3)        0.000000              0.000000
Q( 1, 1, 1)       4.500000              0.000000
Q( 1, 1, 2)       4.500000              0.000000
Q( 1, 1, 3)       4.500000              0.000000
Q( 1, 2, 1)       4.500000              0.000000
Q( 1, 2, 2)       4.500000              0.000000
Q( 1, 2, 3)       4.500000              0.000000
Q( 1, 3, 1)       4.500000              0.000000
Q( 1, 3, 2)       4.500000              0.000000
Q( 1, 3, 3)       4.500000              0.000000
Q( 2, 1, 1)       5.500000              0.000000
Q( 2, 1, 2)       5.500000              0.000000
Q( 2, 1, 3)       5.500000              0.000000
Q( 2, 2, 1)       5.500000              0.000000
Q( 2, 2, 2)       5.500000              0.000000
Q( 2, 2, 3)       5.500000              0.000000
Q( 2, 3, 1)       5.500000              0.000000
Q( 2, 3, 2)       5.500000              0.000000
Q( 2, 3, 3)       5.500000              0.000000
Q( 3, 1, 1)       6.500000              0.000000
Q( 3, 1, 2)       6.500000              0.000000
Q( 3, 1, 3)       6.500000              0.000000
Q( 3, 2, 1)       6.500000              0.000000
Q( 3, 2, 2)       6.500000              0.000000
Q( 3, 2, 3)       6.500000              0.000000
Q( 3, 3, 1)       6.500000              0.000000
Q( 3, 3, 2)       6.500000              0.000000
Q( 3, 3, 3)       6.500000              0.000000
R( 1, 1, 1)       5.000000              0.000000
R( 1, 1, 2)       5.000000              0.000000
R( 1, 1, 3)       5.000000              0.000000
R( 1, 2, 1)       5.000000              0.000000
R( 1, 2, 2)       5.000000              0.000000
R( 1, 2, 3)       5.000000              0.000000
R( 1, 3, 1)       5.000000              0.000000
R( 1, 3, 2)       5.000000              0.000000
R( 1, 3, 3)       5.000000              0.000000
R( 2, 1, 1)       6.000000              0.000000
R( 2, 1, 2)       6.000000              0.000000
R( 2, 1, 3)       6.000000              0.000000
R( 2, 2, 1)       6.000000              0.000000
R( 2, 2, 2)       6.000000              0.000000
```

```
R( 2, 2, 3)        6.000000            0.000000
R( 2, 3, 1)        6.000000            0.000000
R( 2, 3, 2)        6.000000            0.000000
R( 2, 3, 3)        6.000000            0.000000
R( 3, 1, 1)        7.000000            0.000000
R( 3, 1, 2)        7.000000            0.000000
R( 3, 1, 3)        7.000000            0.000000
R( 3, 2, 1)        7.000000            0.000000
R( 3, 2, 2)        7.000000            0.000000
R( 3, 2, 3)        7.000000            0.000000
R( 3, 3, 1)        7.000000            0.000000
R( 3, 3, 2)        7.000000            0.000000
R( 3, 3, 3)        7.000000            0.000000

      Row    Slack or Surplus        Dual Price
       1      262.4213               -1.000000
       2      20.74338               0.000000
       3      20.74338               0.000000
       4      20.74338               0.000000
       5      0.000000               -19.35466
       6      0.000000               -23.13267
       7      0.000000               2.096195
       8      0.000000               -3.096195
       9      0.000000               -4.696195
      10      0.000000               -2.696195
      11      0.000000               -3.296195
      12      0.000000               -3.696195
      13      0.000000               2.696195
      14      0.000000               3.296195
      15      0.000000               3.696195
      16      0.000000               5.746195
      17      0.000000               6.146195
      18      0.000000               7.146195
      19      0.000000               -2.696195
      20      0.000000               -3.696195
      21      0.000000               -7.146195
      22      2790.000               0.000000
      23      2543.334               0.000000
      24      2142.000               0.000000
      25      0.000000               2.403805
```

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