Case 6.2 Report: Farm Management

Prepared for

John Ploughman
Manager
Ploughman Family Farm

Date: September 21, 2016

by Gurpal Bisra and Barend Lotter
Center for Operations Excellence

1 Executive Summary

The Ploughman family operates their 640-acre family-owned farm, which supports two types of livestock: dairy cows and laying hens, as well as three crops: soybeans, corn, and wheat. Our services were requested to help maximize the family's **monetary worth**, at the end of the coming year, by determining the optimal investment in livestock and crops. Throughout our analysis we differentiated between cash crops and feed crops.

This report discusses the constraints that the family business has and provides a linear programming model that is used to determine optimum investment solutions under different weather conditions. First we examine an optimistic, best case scenario which assumes that next year's weather conditions will be favourable. Following that we consider what effects adverse weather conditions would have on the family's monetary worth if this optimistic solution is used. To investigate the matter further, we remodel for different weather conditions and determine what the optimal solutions are if we assume that each of the five unfavourable weather scenarios will occur. This also enables us to determine the family's different monetary worth's for each of the new models, if instead the other unexpected (or unassumed) weather events occur. Given all this information, a conservative solution is identified. The probabilities for all six weather conditions (including good weather) is calculated based on historical data and an optimal solution assuming all possible weather conditions is provided. Throughout the report, post-optimality analysis is used to determine the sensitivity of the constraints. Finally, we evaluate the assumptions that the model is based on and we identify the constraints that are most sensitive to inaccurate estimates.

To maximize the family's monetary worth they should: "maximize the *sum* of the net income from the livestock for the coming year, *plus* the net value of the crops for the coming year, *plus* what remains from the investment fund, *plus* the value of the livestock at the end of the coming year, *plus* any income from working on a neighboring farm, *minus* living costs". Our model is subject to the following requirements:

- **Barn requirements:** The total number of cows cannot exceed 42.
- **Chicken house requirements:** The total number of hens cannot exceed 5,000.
- **Livestock purchasing requirements**: The combined cost of cow and hen purchases cannot exceed the investment fund of $20,000.
- **Total land use requirements:** The total acres of land required by all livestock and crops may not exceed 640 acres.
- **Cow feeding requirements:** The total acres of corn feed for cows must be greater or equal to the number of cows.
- **Hen feeding requirements:** The total acres of wheat feed for hens must be greater or equal to 0.05 times the number of hens.
- **Winter and spring outsourcing requirements:** The total number of labour hours cannot exceed 4,000 hours in winter and spring (6 months).
- **Summer and fall outsourcing requirements:** The total number of labour hours cannot exceed 4,500 hours in summer and fall (6 months).

If we assume good weather conditions, an optimal solution is to plant 450 acres of soybeans, 30 acres of feed corn, and 100 acres of feed wheat, while purchasing no additional livestock. This solution should yield an expected monetary worth of $99,367 and it remains optimal if the dollar value of each acre of crop remains in the following ranges:

$$\begin{cases} 61.6 < Acres\ of\ Soybeans < \infty \\ -\infty < Acres\ of\ Cash\ Corn < 68.4 \\ -\infty < Acres\ of\ Feed\ Corn < 68.4 \\ -\infty < Acres\ of\ Cash\ Wheat < 64.15 \\ -\infty < Acres\ of\ Feed\ Wheat < 57.15 \end{cases}$$

Furthermore, in this optimistic model we find that purchasing hens is not recommended, unless the value of wheat increases by than more than $17.15 / acre. Above this point, feed wheat should be planted to sustain additional hens. If the value of wheat increases by more than $24.15 / acre, additional wheat should be planted as a cash crop. Similarly, the value of corn must increase by at least $8.40 / acre before it becomes attractive as a cash crop and the value of soy must decrease by $8.40 / acre before it becomes an unattractive investment option.

For each of the adverse weather conditions we remodel and find optimal models with the following monetary worth's: (1) $67,864 for a drought; (2) $74,055 for a flood; (3) $88,767 for an early frost; (4) $66,649 for a drought and early frost; and (5) $69,860 for a flood and early frost. Given the uncertainty of next year's weather, the most conservative approach is to use the solution for flood and early frost. This solution will provide decent returns if good weather occurs and it will avoid overly small monetary worth under adverse weather conditions.

Assuming the probability of all possible weather conditions, we calculated the expected net value per acre of each crop to be: (1) $34.00 for soybeans; (2) $27.50 for corn; and (3) $20.75 for wheat. We remodeled based on this information and the optimal solution is to purchase 12 cows and to plant 414 acres of soybeans, 42 acres of feed corn, and 100 acres of feed wheat. With this probabilistic solution, the maximum end-of-year monetary worth decreases from $99,367 to $80,537. This probabilistic solution remains optimal if the dollar value of each acre of crop remains within the following ranges:

$$\begin{cases} 33.6 < Acres\ of\ Soybeans < 41.5 \\ -\infty < Acres\ of\ Cash\ Corn < 32.4 \\ 5 < Acres\ of\ Feed\ Corn < 32.4 \\ -\infty < Acres\ of\ Cash\ Wheat < 28.15 \\ -\infty < Acres\ of\ Feed\ Wheat < 21.15 \end{cases}$$

Since the shadow price of "livestock purchasing requirements" is zero, we concluded the Ploughman family should decline a bank loan with a 10 percent interest rate. Post-optimality analysis shows that the two most sensitive estimates in this model are those for soybeans and wheat. If the price of soybeans decreases by $0.40/acre or more, it becomes less profitable than other investments. Likewise, if the price of wheat increases by $0.40/acre or more, then planting more wheat is recommended. Moreover, the value of an acre of corn must increase by more than $4.90/acre to become an attractive cash crop.

Table of Contents

Table of Figures

Table of Tables

2 Introduction

The Ploughman family operates their 640-acre family-owned farm which supports two types of livestock: dairy cows and laying hens, as well as three crops: soybeans, corn, and wheat. Our services were requested to help maximize the family's monetary worth, at the end of the coming year, by determining the optimal investment in livestock and crops. Throughout our analysis we split the corn and wheat crops into two categories: cash crops and feed crops. This allowed us to more easily report how many acres of corn and wheat was planted for each of the two activities. The Ploughman family's long-term goal is remain self-sufficient so they are not taken over by large agricultural corporations.

Our analysis was conducted while meeting the following requirements:

- **Barn requirements:** The total number of cows cannot exceed 42.
- **Chicken house requirements:** The total number of hens cannot exceed 5,000.
- **Livestock purchasing requirements**: The combined cost of cow and hen purchases cannot exceed the investment fund of $20,000.
- **Total land use requirements:** The total acres of land required by all livestock and crops may not exceed 640 acres.
- **Cow feeding requirements:** The total acres of corn feed for cows must be greater or equal to the number of cows.
- **Hen feeding requirements:** The total acres of wheat feed for hens must be greater or equal to 0.05 times the number of hens.
- **Winter and spring outsourcing requirements:** The total number of labour hours cannot exceed 4,000 hours in winter and spring (6 months).
- **Summer and fall outsourcing requirements:** The total number of labour hours cannot exceed 4,500 hours in summer and fall (6 months).

The key objective here for the consultation was to maximize "the *sum* of the net income from the livestock for the coming year, *plus* the net value of the crops for the coming year, *plus* what remains from the investment fund, *plus* the value of the livestock at the end of the coming year, *plus* any income from working on a neighboring farm, *minus* living costs," while meeting the farm's aforementioned requirements.

To conduct the analysis, the following assumptions were made:

(1) Livestock can be purchased at the beginning of the year, but cannot be sold.

(2) Livestock will not die throughout the year.

(3) Additional barns or chicken houses are not available.

(4) Land used by feed corn is different than the land used by grazing by cows.

(5) Winter and spring constitutes the first half of the following year (i.e. 6 months).

(6) Summer and fall constitutes the second half of the following year (i.e. 6 months).

(7) Crops used for feeding livestock contribute to crop value.

2.1 Information Provided

Livestock and Crops

There are two types of livestock: dairy cows and laying hens and soybeans, corn, and wheat. As mentioned before, throughout this report we differentiate between cash crops and feed crops. We therefore identified five types of crops instead of three: (1) cash soybeans; (2) cash corn; (3); cash wheat; (4) feed corn; and (5) feed wheat. This was done to assist with the analysis process. It should be noted that the chosen denotation does not change the optimal solutions.

Investment Opportunities

There is $20,000 available for livestock purchases.

Livestock

The family owns 30 cows valued at $35,000 and 2000 hens valued at $5,000. Each additional cow costs $1500 and each hen $3. Moreover, the net annual cash income produced by each cow is $850 and each hen is $4.25.

Crop

The net value of each crop (cash and feed) is: (1) $70 / acre from cash soybeans; (2) $60 / acre from corn; and (3) $40 / acre for wheat.

Depreciation

As cows age their value decreases by 10% per annum. Whereas a hen's value decreases by 25% per annum as they age.

Real Estate

The family owns 640 acres of farmland which costs $40,000 for living expenses per year. Their barn can house 42 cows and each cow requires 2 acres of land for grazing. Although hens require no significant space, the maximum number that the chicken house can accommodate is 5,000. Additionally, corn and wheat is required to feed cows and hens, respectively. For example, cows require at least 1 acre of feed corn per cow; hens require at least 0.05 acres of feed wheat per hen.

Workers and Person Hours

There are size family members: (1) John Ploughman; (2) Eunice Ploughman; (3) Grandpa Ploughman; (4) Frank Ploughman; (5) Phyllis Ploughman; and (6) Carl Ploughman.

Together they can work 4,000 winter hours and 4,500 summer hours. Frank, Phyllis, and Carl can outsource their remaining winter and summer hours at $5 and $5.50 per hour, respectively. The total number of person-worth hours of labour, for both the first and second halves of the coming year, for livestock and crop activities are illustrated in Table 1.

TABLE 1: Person hours required for livestock and crops.

Livestock and Crops	Winter/Spring Labour [hours]	Summer/Fall Labour [hours]
Cows	60	60
Hens	0.3	0.3
Cash Soybeans	1	1.4
Cash Corn	0.9	1.2
Cash Wheat	0.6	0.7
Feed Corn	0.9	1.2
Feed Wheat	0.6	0.7

Weather Conditions

The data tabulated in Table 2 was collected from Grandpa Ploughman regarding the net value per acre planted crops assuming adverse weather conditions and their frequency of occurring.

TABLE 2: Frequency of adverse weather conditions occurring. For each condition, the net value of acre of the three planted crops is listed.

Scenario	Net Value per Acre Planted ($)			Frequency (%)
	Soybeans	Corn	Wheat	
Good Weather Conditions	70	60	40	40
Drought	-10	-15	0	20
Flood	15	20	10	10
Early Frost	50	40	30	15
Drought and Early Frost	-15	-20	-10	10
Flood and Early Frost	10	10	5	5

3 Analysis

3.1 Linear Programming Model

Decision Variables: For the coming year, let:

C	denote the number of cows to purchase.	[cows]
H	denote the number of hens to purchase.	[hens]
CashS	denote the acres of soybean to plant.	[acres]
CashC	denote the acres of cash corn to plant.	[acres]
CashW	denote the acres of cash wheat to plant.	[acres]
FeedC	denote the acres of corn to plant for cow feed.	[acres]
FeedW	denote the acres of wheat to plant for hen feed.	[acres]

Constraints: The following constraints define linear model to determine the optimal solution:

1. **Non-negativity:** The number of cows, hens, and acres of crops planted for the coming year cannot be negative.
   C, H, CashS, CashC, FeedC, CashW, FeedW ≥ 0
   [cows, hens, acres, acres, acres, acres, acres; respectively]

2. **Total Number of Cows:** The total number of cows cannot exceed 42 due to the barn's housing limitations.
   C + 30 ≤ 42
   C ≤ 12 [cows]

3. **Total Number of Hens:** The total number of hens cannot exceed 3,000 due to the chicken house's limitations.
   H + 2,000 ≤ 5,000
   H ≤ 3000 [hens]

4. **Livestock Purchases:** The combined cost of cow and hen purchases cannot exceed the investment fund of $20,000.
   (1,500*C) + (3*H) ≤ 20,000 [$]

5. **Total Land Use:** The total acres of land required by all livestock and crops may not exceed 640 acres.
   [2*(C+30)] + FeedC + FeedW + CashS + CashC + CashW + CashS ≤ 640 [acres]

6. **Acres of Corn Feed:** The total acres of corn feed for cows must be greater or equal to the number of cows.
   FeedC – C ≥ 30 [acres]

7. **Acres of Wheat Feed:** The total acres of wheat feed for hens must be greater or equal to 0.05 times the number of hens. This detailed calculation can be found in Appendix A.
   FeedW – 0.05*H ≥ 100 [acres]

8. **Winter and Spring Hours of Labour:** The total number of person-worth hours of labour cannot exceed 4,000 hours in winter and spring totaling 6 months.
   [10*6*(C+30)] + [0.05*6*(H+2000)] + CashS + 0.9*(CashC + FeedC) + 0.6*(CashW + FeedW) ≤ 4000 [hours]

9. **Summer and Fall Hours of Labour:** The total number of person-worth hours of labour cannot exceed 4,500 hours in summer and fall totaling 6 months.
   [10*6*(C+30)] + [0.05*6*(H+2000)] + 1.4*CashS + 1.2*(CashC + FeedC) + 0.7*(CashW + FeedW) ≤ 4500 [hours]

Objective Function:

The objective is to maximize the family's monetary worth at the end of the coming year (the *sum* of the net income from the livestock for the coming year, *plus* the net value of the crops for the coming year, *plus* what remains from the investment fund, *plus* the value of the livestock at the end of the coming year, *plus* any income from working on a neighboring farm, *minus* living. For the coming year, let:

NetIncome	= the net income from livestock and outsourcing.	[$]
NetValue	= the net value of livestock and crops for the coming year.	[$]
Remaing Cash	= the remainder of investment fund after livestock purcahses.	[$]
Overhead	= the living expenses of $40,000 for the year.	[$]
WinterOut	= the remaining labour hours in the winter	[hours]
SummerOut	= the remaining labour hours in the summer	[hours]

For outsourcing, the remaining labour hours were calculated in Appendix A.

Therefore, we seek to:

Maximize {Net Income + Net Value + Remaining Cash – Living Expenses} = Z

where:

Net Income	= Livestock Income + Labour Income
Net Value	= Livestock Value after Depreciation + Crop Value
Remaining Cash	= $20,000 – Livestock Purchases
Overhead	= - $40,000

Detailed calculations for net income, net value, and remaining cash are listed in Appendix A. The above data was entered in an Excel spreadsheet to facilitate manipulation of the model. A screenshot of the representation of the model in Excel model is provided in Appendix B.

3.2 Optimal Solution for Various Conditions

Question (c): Optimal Solution – Assuming Good Weather Conditions

Using the simplex method built-in to Excel's Solver add-on, we find that all aforementioned requirements can be met to produce as maximum end-of-year monetary worth of **$99,367**. This can be achieved by not purchasing any livestock, and, instead, planting 450 acres of soybeans, 30 acres of feed corn, and 100 acres of feed wheat. The constructed linear model, assuming good weather conditions, can be found as an Excel spreadsheet is found in Figure 1 in Appendix B.

Question (d): Optimal Solution – Sensitivity Analysis of 3 Crops

Additionally, as per request by the client, we generated an additional sensitivity output, of post-optimality analysis, which can be found in Appendix B as Figure 2. We were tasked to determine the allowable range for the net value of each of the three crops, so that the solution remains optimal. The solution remains optimal if the dollar value of each acre of crop remains in the following ranges:

$$\begin{cases} 61.6 < Acres\ of\ Soybeans < \infty \\ -\infty < Acres\ of\ Cash\ Corn < 68.4 \\ -\infty < Acres\ of\ Feed\ Corn < 68.4 \\ -\infty < Acres\ of\ Cash\ Wheat < 64.15 \\ -\infty < Acres\ of\ Feed\ Wheat < 57.15 \end{cases}$$

, where the lower bound is the objective coefficient minus the allowable decrease, and the upper bound is the objective coefficient plus the allowable increase.

Wheat

Based on our sensitivity analysis as depicted in Figure 3 in Appendix B, we conclude that purchasing hens is not recommended, unless the value of wheat increases by than more than $17.15 / acre. Above this point, feed wheat should be planted to sustain additional hens. If the value of wheat increases by more than $24.15 / acre, additional wheat should be planted as a cash crop. Our analysis is shown in Figure 4 in Appendix B.

Corn

Based on our sensitivity analysis as shown in Figure 5 in Appendix B, the value of corn must increase by at least $8.40 / acre before it becomes attractive as a cash crop.

Soy

The value of soy must decrease by $8.40 / acre before it becomes an unattractive investment.

Question (e): Optimal Solution – Optimal Solutions for Adverse Weather Conditions

Since adverse weather conditions would harm the crops and greatly reduce the resulting value, we considered how the maximum end-of-year monetary worth would change considering whether a drought, a flood, an early frost, both a drought and an early frost, and both a flood and an early frost occurs.

Pre request of the client, we found an optimal solution under each scenario after making necessary adjustments to the linear programming model originally formulated for good weather conditions. Annotated screenshots of the model variants are provided in Appendix C in Figures 6 through 10. The Ploughman family's predicted monetary worth for each weather condition is shown in Table 3.

TABLE 3: Ploughman family's predicted monetary worth for each weather condition.

Weather Conditions	**Predicted Monetary Worth [$]**
Good Weather	99,367
Drought	67,864
Flood	74,055
Early Frost	88,767
Drought and Early Frost	66,649
Flood and Early Frost	69,860

Question (f): Optimal Solution – Results for All Modelled Scenarios

After obtaining the above results, we compared the Ploughman family's predicted monetary worth for each weather condition when a specific solution was used. The results can be found in Table 4 (below) and also in Table 5 in Appendix C.

TABLE 4: The Ploughman's family's expected monetary worth for each weather condition according to the assumed weather conditions in the model.

	Actual Weather					
Model Used	**Good Weather**	**Drought**	**Flood**	**Early Frost**	**Drought and Early Frost**	**Flood and Early Frost**
Good Weather	$99,367	$57,117	$70,417	$88,767	$53,717	$67,367
Drought	$76,347	$67,864	$70,667	$74,174	$66,320	$69,580
Flood	$94,962	$57,928	$74,055	$85,175	$54,482	$69,162
Early Frost	$99,367	$57,117	$70,417	$88,767	$53,717	$67,367
Drought and Early Frost	$75,009	$67,859	$70,329	$73,169	$66,649	$69,409
Flood and Early Frost	$80,476	$67,676	$71,483	$77,230	$64,990	$69,860

The three most balanced models appear to be the ones that prepare for: (1) drought; (2) drought and early frost; and (3) Flood and early frost. Of these three the largest potential loss is from flood and early frost, however for this model the potential reward in the case of good weather outweighs the risk. The solution which provides the best balance between yielding a large monetary worth under good weather conditions and avoiding an overly small monetary worth under adverse weather conditions is therefore flood and early frost.

Question (g and h): Optimal Solution – Average Net Value Under All Weather Conditions

As per request of the client, the average net value under all weather conditions used for each crop was calculated and can be found in Appendix A. The average net value per acre of each crop is: (1) $34.00 for soybeans; (2) $27.50 for corn; and (3) $20.75 for wheat. These values were calculated by weighing the net values under the various scenarios by the frequencies, provided by Grandpa Ploughman, found in Table 2.

Using the simplex method built-in to Excel's Solver add-on, we find that all aforementioned requirements can be met to predict as maximum end-of-year profit of **$80,537**. This can be achieved by purchasing 12 cows, planting 414 acres of soybeans, 42 acres of feed corn, and 100 acres of feed wheat. The constructed linear model, assuming good weather conditions, can be found as an Excel spreadsheet is found in Figure 11 in Appendix C. Additionally, as per request of the client, we generated an additional sensitivity output, of post-optimality analysis, which can be found in Appendix C as Figure 12.

Question (i): Shadow Price

The Ploughman family should not consider obtaining a bank loan with a 10 percent interest rate to purchase more livestock beyond what can obtained from their current $20,000 investment fund. With this model we only used $18,000 to purchase livestock, leaving $2,000 remaining as slack. Since we have not used all the available investment funds to purchase livestock, it would not make sense to obtain a bank loan. This is confirmed in the sensitivity analysis, as shown in Figure 12 in Appendix C, which reports the shadow price to be $0.

Furthermore, for a loan to be profitable, the shadow price would have to be greater than or equal to the cost of loan plus interest. In this case, the shadow price would need to be more than $1.10 since the bank loan has a 10 percent interest rate.

Question (j): Sensitivity Analysis – Average Net Value Under All Weather Conditions

When studying the resulting sensitivity report we generated as shown in Figure 12 in Appendix C, we aimed to identify how much latitude for error is available in estimating the net value per acre planted for that crop without changing the optimal solution. The solution remains optimal if the dollar value of each acre of crop remains in the following ranges:

$$\begin{cases} 33.6 < Acres\ of\ Soybeans < 41.5 \\ -\infty < Acres\ of\ Cash\ Corn < 32.4 \\ 5 < Acres\ of\ Feed\ Corn < 32.4 \\ -\infty < Acres\ of\ Cash\ Wheat < 28.15 \\ -\infty < Acres\ of\ Feed\ Wheat < 21.15 \end{cases}$$

,where the lower bound is the objective coefficient minus the allowable decrease, and the upper bound is the objective coefficient plus the allowable increase.

The two most important net values that have to be estimated most carefully are soybeans and wheat. If the price of soybeans decreases by $0.40 or more, then the family should have planted a different crop or purchased more livestock. Similarly, if the price of wheat increases by $0.40 or more, then the family should have planted more wheat.

If the estimates of acres of soybean and what are incorrect simultaneously, one can use the 100% Rule to guarantee our solution is still the optimal one. The rule guarantees that our solution is still an optimal one if the combined total % of change of both soybeans and wheat does not exceed 100% of their allowable change. In other words, the cumulative change of both the acres of soybeans and wheat should not exceed 0.4. For example, if the price of wheat increases by $0.30 then the 100% rule applies as long as the price of soybeans does not decrease by more than $0.10.

Since the Ploughman family needs to choose their level of activities, but the unit contribution of each activity to the overall measure of performance is greatly affected by which scenario unfolds, we report how much the value of corn and wheat can change while retaining the optimal solution.

Corn

Based on our sensitivity analysis, the value of an acre of corn must decrease by more than \$22.50 before it becomes less profitable to farm corn as a cash crop. Conversely, once the value of an acre of corn increases by more than \$4.90, then it becomes more profitable to plant corn as a cash corn instead of soybean. Annotated screenshots of the model variants are provided in Figures 13 and 14 in Appendix C.

Wheat

Based on our sensitivity analysis, the value of an acre of wheat must increase by more than \$0.40, but less than \$7.40, before it becomes profitable to purchase hens. Consequently, it's more profitable to farm corn and wheat instead of soybeans. Once the value of an acre of wheat increases by \$7.40, then it becomes profitable to purchase the maximum number of hens and even farm cash wheat. Annotated screenshots of the model variants are provided in Figures 15 and 16 in Appendix C.

Question (k): Similar Situations Outside Farm Management

These types of uncertain situations, where organizations have to consider multiple scenarios are very common. In the forest products industry, for example, saw mills have to produce lumber long before the market demands it, because the lumber needs to be dried and shipped before it reaches the customer. The sawmill manager does not know which dimensions will be in demand it in the short and medium term future. There is a large amount of uncertainty with regards to the optimal production schedule.

Another example could be an online company that has a warehouse full of various different products. The warehouse manager has to decide which products to keep in stock and how much stock to keep of each product. If the manager keeps too much of an unpopular product, he pays a penalty in the form of inventory cost and low cash flow. Conversely, if the he does not stock enough of a popular stock, he will lose sales. The manager does not know with certainty which products will be popular.

Another example can be the scheduling of nurses and doctors in an emergency room. Or what food a catering company should supply at a large sports event, since the food that will be in demand depends on the weather.

4 Appendices

Appendix A. Cost Conversions

The calculation to determine the constraint for the acres of feed wheat is as follows:

FeedW ≥ (0.05)*(H + 2000) [acres]

FeedW – (0.05*H) ≥ 100 [acres]

The equations to determine the objective function are listed as follows:

StockValue [$] = 0.9*35,000 + 0.9(1500*C) + 0.75*2000 + 0.75(3*H)

= 1350* C + 2.25*H +33,000

Livestock Income [$] = 850(C + 30) + 4.25(H + 2000)

Labour Income [$] = 5(WinterOut) + 5.5(SummerOut)

WinterOut [$] = 4000 - { [10*6*(C+30)] + [0.05*6*(H+2000)] + CashS + 0.9*(CashC + FeedC) + 0.6(CashW + FeedW) }

SummerOut [$] = 4500 – { [10*6*(C+30)] + [0.05*6*(H+2000)] + 1.4*CashS + 1.2*(CashC + FeedC) + 0.7(CashW + FeedW) }

Remaining Cash [$] = $20,000 – Livestock Purchases = $20,000 – (1500*C + 3*H)

Livestock Value [$] = 0.9(35000/30)*(30) + 0.9(1500)C + 0.75(5000/2000) *(2000) + 0.75(3)H

Crop Value [$] = (70*CashS) + 60*(CashC + FeedC) + 40*(CashW + FeedW)

The average net value, under all weather conditions, for each crop was calculated as follows:

Net Value of Soybeans $[\frac{\$}{acre}]$ = (70*0.40)+(-10*0.20)+(15*0.10)+(50*0.15) +(-15*0.10)+(10*0.05) = 34.00

Net Value of Corn $[\frac{\$}{acre}]$ = (60*0.40)+(-15*0.20)+(20*0.10)+(40*0.15) +(-20*0.10)+(10*0.05) = 27.50

Net Value of Wheat $[\frac{\$}{acre}]$ = (40*0.40)+(0*0.20)+(10*0.10)+(30*0.15)+(-10*0.15) +(5*0.10)+(*) = 20.75

Appendix B. Representation of Model in Excel with the Optimal Solution

FIGURE 1: Optimal solution, assuming good weather conditions, yields a total end-of-year profit of $99,367.

3	**DATA:**													
4		**Current Cows**	**Current Hens**		**New Cows**	**New Hens**	**Soy**	**Corn**		**Wheat**		**Winter Outsourci**	**Summer Outsourcin**	**Units**
5	Live Stock Purchases				1,500	3								$
6	Total Cows	30			1									Cows
7	Total Chickens		2,000			1								Hens
8	Corn Feed	1			1				-1					Acres
9	Wheat Feed		0.05			0.05					-1			Acres
10	Total Land Use	2			2		1	1	1	1	1			Acres
11	Labour in Winter	60	0.3		60	0.3	1	0.9	0.9	0.6	0.6	1		Hours
12	Labour in Summer/Fall	60	0.3		60	0.3	1.4	1.2	1.2	0.7	0.7		1	Hours
13														
14		**Cows**	**Hens**		**C**	**H**	**CashS**	**CashC**	**FeedC**	**CashW**	**FeedW**	**Remainin gWinter Hours**	**Remaining Summer Hours**	**Units**
15	Net Income	850	4.25		850	4.25	0	0	0	0	0	5	5.5	$
16	Net Value	1,050	1.88		1,350	2.25	70	60	60	40	40	0	0	$
17														

18	**CONSTRAINTS:**					
19		**Used**	**Directio n**	**Constrai nt**	**Slack**	**Units**
20	Live Stock Purchases	0	≤	20,000	20,000	$
21	Total Cows	0	≤	12	12	Cows
22	Total Chickens	0	≤	3,000	3,000	Hens
23	Corn Feed	30	≥	30	0	Acres
24	Wheat Feed	100	≥	100	0	Acres
25	Total Land Use	640	≤	640	0	Acres
26	Labour in Winter	4,000	≤	4,000	0	Hours
27	Labour in Summer/Fall	4,500	≤	4,500	0	Hours
28		C				Cows
29	Non-negativity	CashS, CashC, FeedC, CashW, FeedW	≥	0		Acres
30		H				Hens

31																
32	**MODEL:**															
33		**Constant Livestock**			**Decision Variables**							**Remaning Hours**				
34		**Cows**	**Hens**		**C**	**H**	**CashS**	**CashC**	**FeedC**	**CashW**	**FeedW**	**Winter**	**Summer**			
35	Values	30	2,000		0	0	450	0	30	0	100	1,063	1,364			
36																
37	**OBJECTIVE FUNCTION**															
38		**Current Cows**	**Current Hens**		**C**	**H**	**CashS**	**CashC**	**FeedC**	**CashW**	**FeedW**	**Winter**	**Summer**		**Total**	**Units**
39	Net Income	25,500	8,500	0	0	0	0	0	0	0	0	5,315	7,502		46,817	$
40	Net Value	31,500	3,750	0	0	0	31,500	0	1,800	0	4,000	0	0		72,550	$
41	Investment														20,000	$
42	Overhead														-40,000	$
43	**Monetary Worth**														99,367	$

FIGURE 2: Sensitivity report of optimal solution assuming good weather conditions. The red rectangle highlights the sections considered when determining the allowable range, per acre planted for each of the three crops, to stay optimal for the net value.

Variable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
E35	Values C	0	-53	700	53	1E+30
F35	Values H	0	-0.8575	3.5	0.8575	1E+30
G35	Values CashS	450	0	70	1E+30	8.4
H35	Values CashC	0	-8.4	60	8.4	1E+30
I35	Values FeedC	30	0	60	8.4	1E+30
J35	Values CashW	0	-24.15	40	24.15	1E+30
K35	Values FeedW	100	0	40	17.15	1E+30
L35	Values Winter	1063	0	5	57.3	0.91537133
M35	Values Summer	1364	0	5.5	34.5	0.929824561

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
B21	Total Cows Used	0	0	12	1E+30	12
B22	Total Chickens Used	0	0	3000	1E+30	3000
B23	Corn Feed Used	30	-8.4	30	450	30
B24	Wheat Feed Used	100	-24.15	100	450	100
B20	Live Stock Purchases Used	0	0	20000	1E+30	20000
B25	Total Land Use Used	640	57.3	640	974.2857143	450
B26	Labour in Winter Used	4000	5	4000	1E+30	1063
B27	Labour in Summer/Fall Used	4500	5.5	4500	1E+30	1364

FIGURE 3: The value of an acre of wheat must increase by more than \$17.15, but less than \$24.15, before it becomes profitable to purchase the maximum number of possible hens and plant enough feed wheat to sustain them.

3	**DATA:**													
4		**Current Cows**	**Current Hens**		**New Cows**	**New Hens**	**Soy**	**Corn**		**Wheat**		**Winter Outsourci**	**Summer Outsourcin**	**Units**
5	Live Stock Purchases				1,500	3								$
6	Total Cows	30			1									Cows
7	Total Chickens		2,000			1								Hens
8	Corn Feed	1			1				-1					Acres
9	Wheat Feed		0.05			0.05					-1			Acres
10	Total Land Use	2			2		1	1	1	1	1			Acres
11	Labour in Winter	60	0.3		60	0.3	1	0.9	0.9	0.6	0.6	1		Hours
12	Labour in Summer/Fall	60	0.3		60	0.3	1.4	1.2	1.2	0.7	0.7		1	Hours
13														
14		**Cows**	**Hens**		**C**	**H**	**CashS**	**CashC**	**FeedC**	**CashW**	**FeedW**	**Remainin gWinter Hours**	**Remaining Summer Hours**	**Units**
15	Net Income	850	4.25		850	4.25	0	0	0	0	0	5	5.5	$
16	Net Value	1,050	1.88		1,350	2.25	70	60	60	57	57	0	0	$

17						
18	**CONSTRAINTS:**					
19		**Used**	**Directio n**	**Constrai nt**	**Slack**	**Units**
20	Live Stock Purchases	9,000	≤	20,000	11,000	$
21	Total Cows	0	≤	12	12	Cows
22	Total Chickens	3,000	≤	3,000	0	Hens
23	Corn Feed	30	≥	30	0	Acres
24	Wheat Feed	100	≥	100	0	Acres
25	Total Land Use	640	≤	640	0	Acres
26	Labour in Winter	4,000	≤	4,000	0	Hours
27	Labour in Summer/Fall	4,500	≤	4,500	0	Hours
28		C				Cows
29	Non-negativity	CashS, CashC, FeedC, CashW, FeedW	≥	0		Acres
30		H				Hens

32	**MODEL:**												
33		**Constant Livestock**			**Decision Variables**							**Remaning Hours**	
34		**Cows**	**Hens**		**C**	**H**	**CashS**	**CashC**	**FeedC**	**CashW**	**FeedW**	**Winter**	**Summer**
35	Values	30	2,000		0	3,000	300	0	30	0	250	223	569

36															
37	**OBJECTIVE FUNCTION**														
38		**Current Cows**	**Current Hens**		**C**	**H**	**CashS**	**CashC**	**FeedC**	**CashW**	**FeedW**	**Winter**	**Summer**	**Total**	**Units**
39	Net Income	25,500	8,500	0	0	12,750	0	0	0	0	0	1,115	3,129	50,994	$
40	Net Value	31,500	3,750	0	0	6,750	21,000	0	1,800	0	14,288	0	0	79,088	$
41	Investment													11,000	$
42	Overhead													-40,000	$
43	**Monetary Worth**													**101,082**	$

FIGURE 4: Once the value of an acre of wheat increases by $24.15, then it becomes profitable to plant more cash wheat.

DATA:

	Current Cows	Current Hens		New Cows	New Hens	Soy	Corn		Wheat		Winter Outsourci	Summer Outsourcin	Units
Live Stock Purchases				1,500	3								$
Total Cows	30			1									Cows
Total Chickens		2,000			1								Hens
Corn Feed	1			1				-1					Acres
Wheat Feed		0.05			0.05					-1			Acres
Total Land Use	2			2		1	1	1	1	1			Acres
Labour in Winter	60	0.3		60	0.3	1	0.9	0.9	0.6	0.6	1		Hours
Labour in Summer/Fall	60	0.3		60	0.3	1.4	1.2	1.2	0.7	0.7		1	Hours

	Cows	Hens		C	H	CashS	CashC	FeedC	CashW	FeedW	Remainin gWinter Hours	Remaining Summer Hours	Units
Net Income	850	4.25		850	4.25	0	0	0	0	0	5	5.5	$
Net Value	1,050	1.88		1,350	2.25	70	60	60	**64**	**64**	0	0	$

CONSTRAINTS:

	Used	Direction	Constraint	Slack	Units
Live Stock Purchases	9,000	≤	20,000	11,000	$
Total Cows	0	≤	12	12	Cows
Total Chickens	3,000	≤	3,000	0	Hens
Corn Feed	30	≥	30	0	Acres
Wheat Feed	100	≥	100	0	Acres
Total Land Use	640	≤	640	0	Acres
Labour in Winter	4,000	≤	4,000	0	Hours
Labour in Summer/Fall	4,500	≤	4,500	0	Hours
	C				Cows
Non-negativity	CashS, CashC, FeedC, CashW, FeedW	≥	0		Acres
	H				Hens

MODEL:

	Constant Livestock			Decision Variables							Remaning Hours	
	Cows	Hens		C	H	CashS	CashC	FeedC	CashW	FeedW	Winter	Summer
Values	30	2,000		**0**	**3,000**	**0**	**0**	**30**	**300**	**250**	343	779

OBJECTIVE FUNCTION

	Current Cows	Current Hens		C	H	CashS	CashC	FeedC	CashW	FeedW	Winter	Summer	Total	Units
Net Income	25,500	8,500	0	0	12,750	0	0	0	0	0	1,715	4,284	52,749	$
Net Value	31,500	3,750	0	0	6,750	0	0	1,800	19,245	16,038	0	0	79,083	$
Investment													11,000	$
Overhead													-40,000	$
Monetary Worth													**102,833**	$

FIGURE 5: Once the value of an acre of wheat increases by $24.15, then it becomes profitable to plant more cash wheat.

		Current Cows	Current Hens		New Cows	New Hens	Soy	Corn		Wheat		Winter Outsourci	Summer Outsourcin	Units
3	**DATA:**													
5	Live Stock Purchases				1,500	3								$
6	Total Cows	30			1									Cows
7	Total Chickens		2,000			1								Hens
8	Corn Feed	1			1				-1					Acres
9	Wheat Feed		0.05			0.05					-1			Acres
10	Total Land Use	2			2		1	1	1	1	1			Acres
11	Labour in Winter	60	0.3		60	0.3	1	0.9	0.9	0.6	0.6	1		Hours
12	Labour in Summer/Fall	60	0.3		60	0.3	1.4	1.2	1.2	0.7	0.7		1	Hours
13														
14		**Cows**	**Hens**		**C**	**H**	**CashS**	**CashC**	**FeedC**	**CashW**	**FeedW**	**Remainin gWinter Hours**	**Remaining Summer Hours**	**Units**
15	Net Income	850	4.25		850	4.25	0	0	0	0	0	5	5.5	$
16	Net Value	1,050	1.88		1,350	2.25	70	69	69	40	40	0	0	$

		Used	Direction	Constraint	Slack	Units
18	**CONSTRAINTS:**					
20	Live Stock Purchases	0	≤	20,000	20,000	$
21	Total Cows	0	≤	12	12	Cows
22	Total Chickens	0	≤	3,000	3,000	Hens
23	Corn Feed	30	≥	30	0	Acres
24	Wheat Feed	100	≥	100	0	Acres
25	Total Land Use	640	≤	640	0	Acres
26	Labour in Winter	4,000	≤	4,000	0	Hours
27	Labour in Summer/Fall	4,500	≤	4,500	0	Hours
28		C				Cows
29	Non-negativity	CashS, CashC, FeedC, CashW, FeedW	≥	0		Acres
30		H				Hens

		Constant Livestock		Decision Variables							Remaning Hours	
32	**MODEL:**											
34		**Cows**	**Hens**	**C**	**H**	**CashS**	**CashC**	**FeedC**	**CashW**	**FeedW**	**Winter**	**Summer**
35	Values	30	2,000	0	0	0	450	30	0	100	1,108	1,454

		Current Cows	Current Hens		C	H	CashS	CashC	FeedC	CashW	FeedW	Winter	Summer	Total	Units
37	**OBJECTIVE FUNCTION**														
39	Net Income	25,500	8,500	0	0	0	0	0	0	0	0	5,540	7,997	47,537	$
40	Net Value	31,500	3,750	0	0	0	0	31,050	2,070	0	4,000	0	0	72,370	$
41	Investment													20,000	$
42	Overhead													-40,000	$
43	**Monetary Worth**													99,907	$

Appendix C. Variants of the Original Model

FIGURE 6: Optimal solution, assuming a drought occurs, yields a total end-of-year profit of $67,864.

DATA:

	Current Cows	Current Hens		New Cows	New Hens	Soy	Corn		Wheat		Winter Outsourci	Summer Outsourcin	Units
Live Stock Purchases				1,500	3								$
Total Cows	30			1									Cows
Total Chickens		2,000			1								Hens
Corn Feed	1			1				-1					Acres
Wheat Feed		0.05			0.05					-1			Acres
Total Land Use	2			2		1	1	1	1	1			Acres
Labour in Winter	60	0.3		60	0.3	1	0.9	0.9	0.6	0.6	1		Hours
Labour in Summer/Fall	60	0.3		60	0.3	1.4	1.2	1.2	0.7	0.7		1	Hours

	Cows	Hens		C	H	CashS	CashC	FeedC	CashW	FeedW	Remainin gWinter Hours	Remaining Summer Hours	Units
Net Income	850	4.25		850	4.25	0	0	0	0	0	5	5.5	$
Net Value	1,050	1.88		1,350	2.25	-10	-15	-15	0	0	0	0	$

CONSTRAINTS:

	Used	Directio n	Constrai nt	Slack	Units
Live Stock Purchases	20,000	≤	20,000	0	$
Total Cows	12	≤	12	0	Cows
Total Chickens	667	≤	3,000	2,333	Hens
Corn Feed	30	≥	30	0	Acres
Wheat Feed	100	≥	100	0	Acres
Total Land Use	259	≤	640	381	Acres
Labour in Winter	4,000	≤	4,000	0	Hours
Labour in Summer/Fall	4,500	≤	4,500	0	Hours
	C				Cows
Non-negativity	CashS, CashC, FeedC, CashW, FeedW	≥	0		Acres
	H				Hens

MODEL:

	Constant Livestock			Decision Variables							Remaning Hours	
	Cows	Hens		C	H	CashS	CashC	FeedC	CashW	FeedW	Winter	Summer
Values	30	2,000		12	667	0	0	42	0	133	562	1,036

OBJECTIVE FUNCTION

	Current Cows	Current Hens		C	H	CashS	CashC	FeedC	CashW	FeedW	Winter	Summer	Total	Units
Net Income	25,500	8,500	0	10,200	2,833	0	0	0	0	0	2,811	5,699	55,544	$
Net Value	31,500	3,750	0	16,200	1,500	0	0	-630	0	0	0	0	52,320	$
Investment													0	$
Overhead													-40,000	$
Monetary Worth													67,864	$

FIGURE 7: Optimal solution, assuming a flood occurs, yields a total end-of-year profit of $74,055.

DATA:

	Current Cows	Current Hens		New Cows	New Hens	Soy	Corn		Wheat		Winter Outsourci	Summer Outsourcin	Units
Live Stock Purchases				1,500	3								$
Total Cows	30			1									Cows
Total Chickens		2,000			1								Hens
Corn Feed	1			1				-1					Acres
Wheat Feed		0.05			0.05					-1			Acres
Total Land Use	2			2		1	1	1	1	1			Acres
Labour in Winter	60	0.3		60	0.3	1	0.9	0.9	0.6	0.6	1		Hours
Labour in Summer/Fall	60	0.3		60	0.3	1.4	1.2	1.2	0.7	0.7		1	Hours
	Cows	**Hens**		**C**	**H**	**CashS**	**CashC**	**FeedC**	**CashW**	**FeedW**	**Remainin gWinter Hours**	**Remaining Summer Hours**	**Units**
Net Income	850	4.25		850	4.25	0	0	0	0	0	5	5.5	$
Net Value	1,050	1.88		1,350	2.25	15	20	20	10	10	0	0	$

CONSTRAINTS:

	Used	Directio n	Constrai nt	Slack	Units
Live Stock Purchases	20,000	≤	20,000	0	$
Total Cows	12	≤	12	0	Cows
Total Chickens	667	≤	3,000	2,333	Hens
Corn Feed	30	≥	30	0	Acres
Wheat Feed	100	≥	100	0	Acres
Total Land Use	640	≤	640	0	Acres
Labour in Winter	4,000	≤	4,000	0	Hours
Labour in Summer/Fall	4,500	≤	4,500	0	Hours
Non-negativity	C CashS, CashC, FeedC, CashW, FeedW H	≥	0		Cows Acres Hens

MODEL:

	Constant Livestock		Decision Variables							Remaning Hours	
	Cows	Hens	C	H	CashS	CashC	FeedC	CashW	FeedW	Winter	Summer
Values	30	2,000	12	667	0	381	42	0	133	220	579

OBJECTIVE FUNCTION

	Current Cows	Current Hens		C	H	CashS	CashC	FeedC	CashW	FeedW	Winter	Summer	Total	Units
Net Income	25,500	8,500	0	10,200	2,833	0	0	0	0	0	1,098	3,187	51,318	$
Net Value	31,500	3,750	0	16,200	1,500	0	7,613	840	0	1,333	0	0	62,737	$
Investment													0	$
Overhead													-40,000	$
Monetary Worth													74,055	$

FIGURE 8: Optimal solution, assuming an early frost occurs, yields a total end-of-year profit of $88,767.

DATA:

	Current Cows	Current Hens		New Cows	New Hens	Soy	Corn		Wheat		Winter Outsourci	Summer Outsourcin	Units
Live Stock Purchases				1,500	3								$
Total Cows	30			1									Cows
Total Chickens		2,000			1								Hens
Corn Feed	1			1				-1					Acres
Wheat Feed		0.05			0.05					-1			Acres
Total Land Use	2			2		1	1	1	1	1			Acres
Labour in Winter	60	0.3		60	0.3	1	0.9	0.9	0.6	0.6	1		Hours
Labour in Summer/Fall	60	0.3		60	0.3	1.4	1.2	1.2	0.7	0.7		1	Hours
	Cows	Hens		C	H	CashS	CashC	FeedC	CashW	FeedW	Remainin gWinter Hours	Remaining Summer Hours	Units
Net Income	850	4.25		850	4.25	0	0	0	0	0	5	5.5	$
Net Value	1,050	1.88		1,350	2.25	50	40	40	30	30	0	0	$

CONSTRAINTS:

	Used	Direction	Constraint	Slack	Units
Live Stock Purchases	0	≤	20,000	20,000	$
Total Cows	0	≤	12	12	Cows
Total Chickens	0	≤	3,000	3,000	Hens
Corn Feed	30	≥	30	0	Acres
Wheat Feed	100	≥	100	0	Acres
Total Land Use	640	≤	640	0	Acres
Labour in Winter	4,000	≤	4,000	0	Hours
Labour in Summer/Fall	4,500	≤	4,500	0	Hours
Non-negativity	C CashS, CashC, FeedC, CashW, FeedW H	≥	0		Cows Acres Hens

MODEL:

	Constant Livestock		Decision Variables							Remaning Hours	
	Cows	Hens	C	H	CashS	CashC	FeedC	CashW	FeedW	Winter	Summer
Values	30	2,000	0	0	450	0	30	0	100	1,063	1,364

OBJECTIVE FUNCTION

	Current Cows	Current Hens		C	H	CashS	CashC	FeedC	CashW	FeedW	Winter	Summer	Total	Units
Net Income	25,500	8,500	0	0	0	0	0	0	0	0	5,315	7,502	46,817	$
Net Value	31,500	3,750	0	0	0	22,500	0	1,200	0	3,000	0	0	61,950	$
Investment													20,000	$
Overhead													-40,000	$
Monetary Worth													88,767	$

FIGURE 9: Optimal solution, assuming a drought and early frost occurs, yields a total end-of-year profit of $66,649.

3	DATA:													
4		Current Cows	Current Hens		New Cows	New Hens	Soy	Corn		Wheat		Winter Outsourci	Summer Outsourcin	Units
5	Live Stock Purchases				1,500	3								$
6	Total Cows	30			1									Cows
7	Total Chickens		2,000			1								Hens
8	Corn Feed	1			1				-1					Acres
9	Wheat Feed		0.05			0.05					-1			Acres
10	Total Land Use	2			2		1	1	1	1	1			Acres
11	Labour in Winter	60	0.3		60	0.3	1	0.9	0.9	0.6	0.6	1		Hours
12	Labour in Summer/Fall	60	0.3		60	0.3	1.4	1.2	1.2	0.7	0.7		1	Hours
13														
14		Cows	Hens		C	H	CashS	CashC	FeedC	CashW	FeedW	Remainin gWinter Hours	Remaining Summer Hours	Units
15	Net Income	850	4.25		850	4.25	0	0	0	0	0	5	5.5	$
16	Net Value	1,050	1.88		1,350	2.25	-15	-20	-20	-10	-10	0	0	$

18	CONSTRAINTS:					
19		Used	Direction	Constraint	Slack	Units
20	Live Stock Purchases	18,000	≤	20,000	2,000	$
21	Total Cows	12	≤	12	0	Cows
22	Total Chickens	0	≤	3,000	3,000	Hens
23	Corn Feed	30	≥	30	0	Acres
24	Wheat Feed	100	≥	100	0	Acres
25	Total Land Use	226	≤	640	414	Acres
26	Labour in Winter	4,000	≤	4,000	0	Hours
27	Labour in Summer/Fall	4,500	≤	4,500	0	Hours
28–30	Non-negativity	C CashS, CashC, FeedC, CashW, FeedW H	≥	0		Cows Acres Hens

32	MODEL:													
33		Constant Livestock			Decision Variables							Remaning Hours		
34		Cows	Hens		C	H	CashS	CashC	FeedC	CashW	FeedW	Winter	Summer	
35	Values	30	2,000		12	0	0	0	42	0	100	782	1,260	

37	OBJECTIVE FUNCTION														
38		Current Cows	Current Hens		C	H	CashS	CashC	FeedC	CashW	FeedW	Winter	Summer	Total	Units
39	Net Income	25,500	8,500	0	10,200	0	0	0	0	0	0	3,911	6,928	55,039	$
40	Net Value	31,500	3,750	0	16,200	0	0	0	-840	0	-1,000	0	0	49,610	$
41	Investment													2,000	$
42	Overhead													-40,000	$
43	**Monetary Worth**													66,649	$

FIGURE 10: Optimal solution, assuming a flood and early frost occurs, yields a total end-of-year profit of $69,860.

3	**DATA:**													
4		**Current Cows**	**Current Hens**		**New Cows**	**New Hens**	**Soy**	**Corn**		**Wheat**		**Winter Outsourci**	**Summer Outsourcin**	**Units**
5	Live Stock Purchases				1,500	3								$
6	Total Cows	30			1									Cows
7	Total Chickens		2,000			1								Hens
8	Corn Feed	1			1				-1					Acres
9	Wheat Feed		0.05			0.05					-1			Acres
10	Total Land Use	2			2		1	1	1	1	1			Acres
11	Labour in Winter	60	0.3		60	0.3	1	0.9	0.9	0.6	0.6	1		Hours
12	Labour in Summer/Fall	60	0.3		60	0.3	1.4	1.2	1.2	0.7	0.7		1	Hours
13														
14		**Cows**	**Hens**		**C**	**H**	**CashS**	**CashC**	**FeedC**	**CashW**	**FeedW**	**Remainin gWinter Hours**	**Remaining Summer Hours**	**Units**
15	Net Income	850	4.25		850	4.25	0	0	0	0	0	5	5.5	$
16	Net Value	1,050	1.88		1,350	2.25	**10**	**10**	**10**	**5**	**5**	0	0	$

18	**CONSTRAINTS:**					
19		**Used**	**Direction**	**Constraint**	**Slack**	**Units**
20	Live Stock Purchases	20,000	≤	20,000	0	$
21	Total Cows	7	≤	12	5	Cows
22	Total Chickens	3,000	≤	3,000	0	Hens
23	Corn Feed	30	≥	30	0	Acres
24	Wheat Feed	100	≥	100	0	Acres
25	Total Land Use	362	≤	640	278	Acres
26	Labour in Winter	4,000	≤	4,000	0	Hours
27	Labour in Summer/Fall	4,500	≤	4,500	0	Hours
28–30	Non-negativity	C CashS, CashC, FeedC, CashW, FeedW H	≥	0		Cows Acres Hens

32	**MODEL:**											
33		**Constant Livestock**		**Decision Variables**							**Remaning Hours**	
34		**Cows**	**Hens**	**C**	**H**	**CashS**	**CashC**	**FeedC**	**CashW**	**FeedW**	**Winter**	**Summer**
35	Values	30	2,000	**7**	**3,000**	**0**	**0**	**37**	**0**	**250**	76	540

37	**OBJECTIVE FUNCTION**														
38		**Current Cows**	**Current Hens**		**C**	**H**	**CashS**	**CashC**	**FeedC**	**CashW**	**FeedW**	**Winter**	**Summer**	**Total**	**Units**
39	Net Income	25,500	8,500	0	6,233	12,750	0	0	0	0	0	382	2,971	56,336	$
40	Net Value	31,500	3,750	0	9,900	6,750	0	0	373	0	1,250	0	0	53,523	$
41	Investment													0	$
42	Overhead													-40,000	$
43	**Monetary Worth**													**69,860**	$

TABLE 5: Ploughman family's predicted monetary value for each weather condition when a specific is model for each actual weather that occurs. Values with green backgrounds have relatively higher values, orange/yellow backgrounds have medium-sized values, and those with red-backgrounds have the smallest relative values.

	Actual Weather					
Model Used	**Good Weather**	**Drought**	**Flood**	**Early Frost**	**Drought and Early Frost**	**Flood and Early Frost**
Good Weather	$99,367	$57,117	$70,417	$88,767	$53,717	$67,367
Drought	$76,347	$67,864	$70,667	$74,174	$66,320	$69,580
Flood	$94,962	$57,928	$74,055	$85,175	$54,482	$69,162
Early Frost	$99,367	$57,117	$70,417	$88,767	$53,717	$67,367
Drought and Early Frost	$75,009	$67,859	$70,329	$73,169	$66,649	$69,409
Flood and Early Frost	$80,476	$67,676	$71,483	$77,230	$64,990	$69,860

TABLE 6: Ploughman family's range in predicted monetary value for each weather condition when a specific is model for each actual weather that occurs. Values with green backgrounds have relatively higher values, orange/yellow backgrounds have medium-sized values, and those with red-backgrounds have the smallest relative values.

Model Used	**max**	**min**	**range**	**mean**
Good Weather	$99,367	$53,717	$45,650	$72,792
Drought	$76,347	$66,320	$10,027	$70,825
Flood	$94,962	$54,482	$40,480	$72,627
Early Frost	$99,367	$53,717	$45,650	$72,792
Drought and Early Frost	$75,009	$66,649	$8,360	$70,404
Flood and Early Frost	$80,476	$64,990	$15,486	$71,953

FIGURE 11: Optimal solution, using the average net value under each weather condition for each crop, yields a total end-of-year profit of $80,537.

3	**DATA:**													
4		**Current Cows**	**Current Hens**		**New Cows**	**New Hens**	**Soy**	**Corn**		**Wheat**		**Winter Outsourci**	**Summer Outsourcin**	**Units**
5	Live Stock Purchases				1,500	3								$
6	Total Cows	30			1									Cows
7	Total Chickens		2,000			1								Hens
8	Corn Feed	1			1				-1					Acres
9	Wheat Feed		0.05			0.05					-1			Acres
10	Total Land Use	2			2		1	1	1	1	1			Acres
11	Labour in Winter	60	0.3		60	0.3	1	0.9	0.9	0.6	0.6	1		Hours
12	Labour in Summer/Fall	60	0.3		60	0.3	1.4	1.2	1.2	0.7	0.7		1	Hours
13														
14		**Cows**	**Hens**		**C**	**H**	**CashS**	**CashC**	**FeedC**	**CashW**	**FeedW**	**Remainin gWinter Hours**	**Remaining Summer Hours**	**Units**
15	Net Income	850	4.25		850	4.25	0	0	0	0	0	5	5.5	$
16	Net Value	1,050	1.88		1,350	2.25	34.00	27.50	27.50	20.75	20.75	0	0	$

17						
18	**CONSTRAINTS:**					
19		**Used**	**Directio n**	**Constrai nt**	**Slack**	**Units**
20	Live Stock Purchases	18,000	≤	20,000	2,000	$
21	Total Cows	12	≤	12	0	Cows
22	Total Chickens	0	≤	3,000	3,000	Hens
23	Corn Feed	30	≥	30	0	Acres
24	Wheat Feed	100	≥	100	0	Acres
25	Total Land Use	640	≤	640	0	Acres
26	Labour in Winter	4,000	≤	4,000	0	Hours
27	Labour in Summer/Fall	4,500	≤	4,500	0	Hours
28		C				Cows
29	Non-negativity	CashS, CashC, FeedC, CashW, FeedW	≥	0		Acres
30		H				Hens

31												
32	**MODEL:**											
33		**Constant Livestock**		**Decision Variables**							**Remaning Hours**	
34		**Cows**	**Hens**	**C**	**H**	**CashS**	**CashC**	**FeedC**	**CashW**	**FeedW**	**Winter**	**Summer**
35	Values	30	2,000	12	0	414	0	42	0	100	368	680

36															
37	**OBJECTIVE FUNCTION**														
38		**Current Cows**	**Current Hens**		**C**	**H**	**CashS**	**CashC**	**FeedC**	**CashW**	**FeedW**	**Winter**	**Summer**	**Total**	**Units**
39	Net Income	25,500	8,500	0	10,200	0	0	0	0	0	0	1,841	3,740	49,781	$
40	Net Value	31,500	3,750	0	16,200	0	14,076	0	1,155	0	2,075	0	0	68,756	$
41	Investment													2,000	$
42	Overhead													-40,000	$
43	**Monetary Worth**													80,537	$

FIGURE 12: Sensitivity report of optimal solution, using the average net value under each weather condition for each crop, yields a total end-of-year profit of $80,537. The red rectangle highlights the sections considered when determining whether the Ploughman family should consider obtaining a 10 percent interest rate loan. The green rectangle highlights the sections considered for determining the optimal range of acres planted for each crop.

Variable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
E35	Values C	12	0	700	1E+30	22.5
F35	Values H	0	-0.02	3.5	0.02	1E+30
G35	Values CashS	414	0	34	7.5	0.4
H35	Values CashC	0	-4.9	27.5	4.9	1E+30
I35	Values FeedC	42	0	27.5	4.9	22.5
J35	Values CashW	0	-7.4	20.75	7.4	1E+30
K35	Values FeedW	100	0	20.75	0.4	1E+30
L35	Values Winter	368.2	0	5	0.388601036	0.071428571
M35	Values Summer	680	0	5.5	0.394736842	0.075471698

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
B21	Total Cows Used	12	22.5	12	1.333333333	12
B22	Total Chickens Used	0	0	3000	1E+30	3000
B23	Corn Feed Used	30	-4.9	30	414	42
B24	Wheat Feed Used	100	-7.4	100	414	100
B20	Live Stock Purchases Used	18000	0	20000	1E+30	2000
B25	Total Land Use Used	640	21.3	640	368.2	414
B27	Labour in Summer/Fall Used	4500	5.5	4500	1E+30	680
B26	Labour in Winter Used	4000	5	4000	1E+30	368.2

FIGURE 13: The value of an acre of corn must decrease by more than \$22.50 before it becomes unprofitable to farm corn as a cash crop.

3	**DATA:**													
4		**Current Cows**	**Current Hens**		**New Cows**	**New Hens**	**Soy**	**Corn**		**Wheat**		**Winter Outsourci**	**Summer Outsourcin**	**Units**
5	Live Stock Purchases				1,500	3								$
6	Total Cows	30			1									Cows
7	Total Chickens		2,000			1								Hens
8	Corn Feed	1			1				-1					Acres
9	Wheat Feed		0.05			0.05					-1			Acres
10	Total Land Use	2			2		1	1	1	1	1			Acres
11	Labour in Winter	60	0.3		60	0.3	1	0.9	0.9	0.6	0.6	1		Hours
12	Labour in Summer/Fall	60	0.3		60	0.3	1.4	1.2	1.2	0.7	0.7		1	Hours
13														
14		**Cows**	**Hens**		**C**	**H**	**CashS**	**CashC**	**FeedC**	**CashW**	**FeedW**	**Remainin gWinter Hours**	**Remaining Summer Hours**	**Units**
15	Net Income	850	4.25		850	4.25	0	0	0	0	0	5	5.5	$
16	Net Value	1,050	1.88		1,350	2.25	34.00	4.00	4.00	20.75	20.75	0	0	$
17														

18	**CONSTRAINTS:**					
19		**Used**	**Direction**	**Constraint**	**Slack**	**Units**
20	Live Stock Purchases	0	≤	20,000	20,000	$
21	Total Cows	0	≤	12	12	Cows
22	Total Chickens	0	≤	3,000	3,000	Hens
23	Corn Feed	30	≥	30	0	Acres
24	Wheat Feed	100	≥	100	0	Acres
25	Total Land Use	640	≤	640	0	Acres
26	Labour in Winter	4,000	≤	4,000	0	Hours
27	Labour in Summer/Fall	4,500	≤	4,500	0	Hours
28		C				Cows
29	Non-negativity	CashS, CashC, FeedC, CashW, FeedW	≥	0		Acres
30		H				Hens

31															
32	**MODEL:**														
33		**Constant Livestock**			**Decision Variables**							**Remaning Hours**			
34		**Cows**	**Hens**		**C**	**H**	**CashS**	**CashC**	**FeedC**	**CashW**	**FeedW**	**Winter**	**Summer**		
35	Values	30	2,000		0	0	450	0	30	0	100	1,063	1,364		
36															
37	**OBJECTIVE FUNCTION**														
38		**Current Cows**	**Current Hens**		**C**	**H**	**CashS**	**CashC**	**FeedC**	**CashW**	**FeedW**	**Winter**	**Summer**	**Total**	**Units**
39	Net Income	25,500	8,500	0	0	0	0	0	0	0	0	5,315	7,502	46,817	$
40	Net Value	31,500	3,750	0	0	0	15,300	0	120	0	2,075	0	0	52,745	$
41	Investment													20,000	$
42	Overhead													-40,000	$
43	**Monetary Worth**													79,562	$

FIGURE 14: Once the value of an acre of corn increases by more than \$4.90, then it becomes more profitable to plant corn as a cash corn instead of soybean.

DATA:

	Current Cows	Current Hens		New Cows	New Hens	Soy	Corn		Wheat		Winter Outsourci	Summer Outsourcin	Units
Live Stock Purchases				1,500	3								$
Total Cows	30			1									Cows
Total Chickens		2,000			1								Hens
Corn Feed	1			1				-1					Acres
Wheat Feed		0.05			0.05					-1			Acres
Total Land Use	2			2		1	1	1	1	1			Acres
Labour in Winter	60	0.3		60	0.3	1	0.9	0.9	0.6	0.6	1		Hours
Labour in Summer/Fall	60	0.3		60	0.3	1.4	1.2	1.2	0.7	0.7		1	Hours

	Cows	Hens		C	H	CashS	CashC	FeedC	CashW	FeedW	Remainin gWinter Hours	Remaining Summer Hours	Units
Net Income	850	4.25		850	4.25	0	0	0	0	0	5	5.5	$
Net Value	1,050	1.88		1,350	2.25	34.00	32.41	32.41	20.75	20.75	0	0	$

CONSTRAINTS:

	Used	Direction	Constraint	Slack	Units
Live Stock Purchases	18,000	≤	20,000	2,000	$
Total Cows	12	≤	12	0	Cows
Total Chickens	0	≤	3,000	3,000	Hens
Corn Feed	30	≥	30	0	Acres
Wheat Feed	100	≥	100	0	Acres
Total Land Use	640	≤	640	0	Acres
Labour in Winter	4,000	≤	4,000	0	Hours
Labour in Summer/Fall	4,500	≤	4,500	0	Hours
	C				Cows
Non-negativity	CashS, CashC, FeedC, CashW, FeedW	≥	0		Acres
	H				Hens

MODEL:

	Constant Livestock		Decision Variables							Remaning Hours	
	Cows	Hens	C	H	CashS	CashC	FeedC	CashW	FeedW	Winter	Summer
Values	30	2,000	12	0	0	414	42	0	100	410	763

OBJECTIVE FUNCTION

	Current Cows	Current Hens		C	H	CashS	CashC	FeedC	CashW	FeedW	Winter	Summer	Total	Units
Net Income	25,500	8,500	0	10,200	0	0	0	0	0	0	2,048	4,195	50,443	$
Net Value	31,500	3,750	0	16,200	0	0	13,418	1,361	0	2,075	0	0	68,304	$
Investment													2,000	$
Overhead													-40,000	$
Monetary Worth													80,747	$

FIGURE 15: the value of an acre of wheat must increase by more than \$0.40, but less than \$7.40, before it becomes profitable to purchase hens. Consequently, it becomes more profitable to farm corn and wheat instead of soybeans.

DATA:

	Current Cows	Current Hens		New Cows	New Hens	Soy	Corn		Wheat		Winter Outsourci	Summer Outsourcin	Units
Live Stock Purchases				1,500	3								$
Total Cows	30			1									Cows
Total Chickens		2,000			1								Hens
Corn Feed	1			1				-1					Acres
Wheat Feed		0.05			0.05					-1			Acres
Total Land Use	2			2		1	1	1	1	1			Acres
Labour in Winter	60	0.3		60	0.3	1	0.9	0.9	0.6	0.6	1		Hours
Labour in Summer/Fall	60	0.3		60	0.3	1.4	1.2	1.2	0.7	0.7		1	Hours

	Cows	Hens		C	H	CashS	CashC	FeedC	CashW	FeedW	Remainin gWinter Hours	Remaining Summer Hours	Units
Net Income	850	4.25		850	4.25	0	0	0	0	0	5	5.5	$
Net Value	1,050	1.88		1,350	2.25	34.00	27.50	27.50	21.16	21.16	0	0	$

CONSTRAINTS:

	Used	Direction	Constraint	Slack	Units
Live Stock Purchases	20,000	≤	20,000	0	$
Total Cows	12	≤	12	0	Cows
Total Chickens	667	≤	3,000	2,333	Hens
Corn Feed	30	≥	30	0	Acres
Wheat Feed	100	≥	100	0	Acres
Total Land Use	640	≤	640	0	Acres
Labour in Winter	4,000	≤	4,000	0	Hours
Labour in Summer/Fall	4,500	≤	4,500	0	Hours
Non-negativity	C	≥	0		Cows
	CashS, CashC, FeedC, CashW, FeedW				Acres
	H				Hens

MODEL:

	Constant Livestock		Decision Variables							Remaning Hours	
	Cows	Hens	C	H	CashS	CashC	FeedC	CashW	FeedW	Winter	Summer
Values	30	2,000	12	667	381	0	42	0	133	182	503

OBJECTIVE FUNCTION

	Current Cows	Current Hens		C	H	CashS	CashC	FeedC	CashW	FeedW	Winter	Summer	Total	Units
Net Income	25,500	8,500	0	10,200	2,833	0	0	0	0	0	908	2,768	50,709	$
Net Value	31,500	3,750	0	16,200	1,500	12,943	0	1,155	0	2,821	0	0	69,869	$
Investment													0	$
Overhead													-40,000	$
Monetary Worth													80,578	$

FIGURE 16: Once the value of an acre of wheat increases by $7.40, then it becomes profitable to purchase the maximum number of hens and even farm cash wheat.

DATA:

	Current Cows	Current Hens	New Cows	New Hens	Soy	Corn		Wheat		Winter Outsourci	Summer Outsourcin	Units
Live Stock Purchases			1,500	3								$
Total Cows	30		1									Cows
Total Chickens		2,000		1								Hens
Corn Feed	1		1				-1					Acres
Wheat Feed		0.05		0.05					-1			Acres
Total Land Use	2		2		1	1	1	1	1			Acres
Labour in Winter	60	0.3	60	0.3	1	0.9	0.9	0.6	0.6	1		Hours
Labour in Summer/Fall	60	0.3	60	0.3	1.4	1.2	1.2	0.7	0.7		1	Hours

	Cows	Hens	C	H	CashS	CashC	FeedC	CashW	FeedW	Remainin gWinter Hours	Remaining Summer Hours	Units
Net Income	850	4.25	850	4.25	0	0	0	0	0	5	5.5	$
Net Value	1,050	1.88	1,350	2.25	34.00	27.50	27.50	28.25	28.25	0	0	$

CONSTRAINTS:

	Used	Direction	Constraint	Slack	Units
Live Stock Purchases	17,706	≤	20,000	2,294	$
Total Cows	6	≤	12	6	Cows
Total Chickens	3,000	≤	3,000	0	Hens
Corn Feed	30	≥	30	0	Acres
Wheat Feed	100	≥	100	0	Acres
Total Land Use	640	≤	640	0	Acres
Labour in Winter	4,000	≤	4,000	0	Hours
Labour in Summer/Fall	4,500	≤	4,500	0	Hours
Non-negativity	C CashS, CashC, FeedC, CashW, FeedW H	≥	0		Cows Acres Hens

MODEL:

	Constant Livestock		Decision Variables							Remaning Hours	
	Cows	Hens	C	H	CashS	CashC	FeedC	CashW	FeedW	Winter	Summer
Values	30	2,000	6	3,000	0	0	36	283	250	0	436

OBJECTIVE FUNCTION

	Current Cows	Current Hens		C	H	CashS	CashC	FeedC	CashW	FeedW	Winter	Summer	Total	Units
Net Income	25,500	8,500	0	4,933	12,750	0	0	0	0	0	0	2,398	54,081	$
Net Value	31,500	3,750	0	7,835	6,750	0	0	985	7,983	7,063	0	0	65,865	$
Investment													2,294	$
Overhead													-40,000	$
Monetary Worth													82,241	$