# **Case 6.2 Report: Farm Management**

**Prepared for** 

John Ploughman Manager Ploughman Family Farm

Date: September 21, 2016

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### **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 The probabilities for all six weather conditions (including good weather) is identified. 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.

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### 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 p	Frequency (%)				
Scenario	Soybeans	Corn	Wheat	Frequency (70)		
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:

С	denote the number of cows to purchase.	[cows]
Н	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; respectively]

**2. Total Number of Cows:** The total number of cows cannot exceed 42 due to the barn's housing limitations.

$$C + 30 \le 42$$
 $C \le 12$  [cows]

**3. Total Number of Hens:** The total number of hens cannot exceed 3,000 due to the chicken house's limitations.

$$H + 2,000 \le 5,000$$
  
 $H \le 3000$  [hens]

**4. Livestock Purchases:** The combined cost of cow and hen purchases cannot exceed the investment fund of \$20,000.

$$(1,500*C) + (3*H) \le 20,000$$
 [\$]

**5. Total Land Use:** The total acres of land required by all livestock and crops may not exceed 640 acres.

$$[2*(C+30)] + FeedC + FeedW + CashS + CashC + CashW + CashS \le 640$$
 [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  $\geq$  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  $0.05*H \ge 100$  [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.

$$[10*6*(C+30)] + [0.05*6*(H+2000)] + CashS + 0.9*(CashC + FeedC) + 0.6*(CashW + FeedW) \le 4000$$
 [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.

$$[10*6*(C+30)] + [0.05*6*(H+2000)] + 1.4*CashS + 1.2*(CashC + FeedC) + 0.7*(CashW + FeedW) \le 4500$$
 [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.

	Predicted
Weather Conditions	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 \	Neather		
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 
$$\geq$$
 (0.05)\*(H + 2000) [acres]  
FeedW  $-$  (0.05\*H)  $\geq$  100 [acres]

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

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

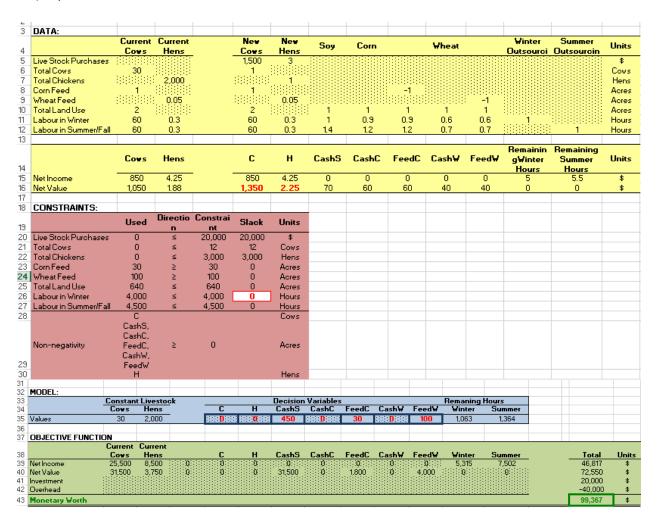
Net Value of Soybeans 
$$\left[\frac{\$}{acre}\right] = (70*0.40) + (-10*0.20) + (15*0.10) + (50*0.15) + (-15*0.10) + (10*0.05) = 34.00$$

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

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

# 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.



**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.

6	Variable 0	`alle					
7	Valiable C	) cii3	Final	Reduced	Objective	Allowable	Allowable
8	Cell	Name	Value	Cost	Coefficient	Increase	Decrease
9	\$E\$35	Values C	0	-53	700	53	1E+30
10	\$F\$35	Values H	0	-0.8575	3.5	0.8575	1E+30
11	\$G\$35	Values CashS	450	0	70	1E+30	8.4
12	\$H\$35	Values CashC	0	-8.4	60	8.4	1E+30
13	\$1\$35	Values FeedC	30	0	60	8.4	1E+30
14	\$J\$35	Values CashW	0	-24.15	40	24.15	1E+30
15	\$K\$35	Values FeedW	100	0	40	17.15	1E+30
16	\$L\$35	Values Winter	1063	0	5	57.3	0.91537133
17	\$M\$35	Values Summer	1364	0	5.5	34.5	0.929824561
4.0							
18							
19	Constrain	ts					
	Constrain	ts	Final	Shadow	Constraint	Allowable	Allowable
19	Constrain	ts Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
19 20						_	
19 20 <b>21</b>	Cell	Name	Value	Price	R.H. Side	Increase	Decrease
19 20 <b>21</b> 22	Cell \$B\$21	Name Total Cows Used	Value 0	Price 0	R.H. Side 12	Increase 1E+30	Decrease 12
19 20 <b>21</b> 22 23	Cell \$B\$21 \$B\$22	Name Total Cows Used Total Chickens Used	Value 0 0	Price 0 0	R.H. Side 12 3000	1E+30 1E+30	12 3000
19 20 <b>21</b> 22 23 24	Cell \$B\$21 \$B\$22 \$B\$23	Name Total Cows Used Total Chickens Used Corn Feed Used	0 0 30	Price 0 0 -8.4	R.H. Side 12 3000 30	1E+30 1E+30 450	12 3000 30
19 20 <b>21</b> 22 23 24 25	Cell \$B\$21 \$B\$22 \$B\$23 \$B\$24	Name Total Cows Used Total Chickens Used Corn Feed Used Wheat Feed Used	0 0 30 100	Price 0 0 -8.4 -24.15	R.H. Side 12 3000 30 100	1E+30 1E+30 1E+30 450 450	12 3000 30 100
19 20 <b>21</b> 22 23 24 25 26	Cell \$B\$21 \$B\$22 \$B\$23 \$B\$24 \$B\$20	Name Total Cows Used Total Chickens Used Corn Feed Used Wheat Feed Used Live Stock Purchases Used	0 0 30 100 0	Price 0 0 -8.4 -24.15	R.H. Side 12 3000 30 100 20000	1E+30 1E+30 450 450 1E+30	12 3000 30 100 20000

**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.

DATA:	Curr	ent Curre		Nev	Nev							Winter	Summer	
	Con			Cows	Hens	Soy	Con	n	W	heat			Outsourcin	Units
Live Stock Purchase:		0000000		1,500	3	1111111111				11111111				\$
Total Cows	31	n		1										Cows
Total Chickens		2,000	n		4									Hens
Corn Feed	1,1,1,1,1,1		iga -	4				-1						Acres
Wheat Feed		0.05	141		0.05			:::::::::::::::::::::::::::::::::::::::			-:-:-:-:-:- -1			Acres
Total Land Use	2		:4:	2	. 0.03	10000000000000000000000000000000000000	***********	-1-1-1-1-1-1-1-	1-1-1-1-1-1-	3+3+3+3+ #	1			
	61		444	60		9 1	0.9	. 1	. ,	1				Acre:
Labour in Winter					0.3	1				0.6	0.6			Hour
Labour in Summer/Fa	ill 60	0 0.3	_	60	0.3	1.4	1.2	1.2		0.7	0.7	11111111111111111	<u> </u>	Hour
												B	В	
				С	н			c -				Remainin	Remaining	
	Co	s Hens	5	L	п	CashS	Cash	C Feed	ıc ca	sh₩	Feed₩	g₩inter	Summer	Unit
			<del></del>		4.05					_		Hours	Hours	
Net Income	85			850	4.25	0	0	0		0	0	5	5,5	\$
Net Value	1,0	50 1.88		1,350	2.25	70	60	60		57	57	0	0	\$
CONCTRAINTO														
CONSTRAINTS:		D: ·							_					
	Use	ed Direct n	io Constrai nt	Slack	Units									
Live Stock Purchase:	s 9,0	00 ≤	20,000	11,000	\$									
Total Cows	0	) ≤	12	12	Cows									
Total Chickens	3,0		3,000	Ö	Hens									
Corn Feed	31		30	ō	Acres									
Wheat Feed	10		100	ŏ	Acres									
Total Land Use	64		640	ŏ	Acres									
Labour in Winter	4.0		4.000	ŏ	Hours									
Labour in Summer/Fa			4,500	ő	Hours									
Labour III Junimeni a	4,3 C		4,300	- 0	Cows									
	Casi				COWS	_								
	Casi													
Non-negativity	Fee		0		Acres									
(World Hegativity	Cask		۰		moles									
	Fee H				ш	_	-		_					
					Hens		-							
MODEL:		_												
	Constant Cows	t Livestock Hens	С С	н	Decision CashS	Variables CashC	FeedC	Cash₩	E	Reman Winte	ing Hours	mmer .		
11.1									Feed₩					
Values	30	2,000	:(:::D):	3,000	300	HIII DIN	30	District Dis	250	223		569		
OBJECTIVE FUNCTION	L.													
ODJECTIVE FUNCTIC		Current												
	Cows	Hens	С	н	CashS	CashC	FeedC	Cash₩	Feed₩	Winte	er Su	mmer	Total	Un
Net Income	25,500	8,500 ::::		:: 12,750	Casho 0	U B	0	Casn <del>w</del>	0	1,115		,129	50,994	- 511
	31,500	3,750	0 0	6,750	21,000	ŭ	1,800	Ŭ.	14,288			000000000000000000000000000000000000000	79,088	- 1
Net Value		to the first test of the											11,000	4
Investment :														
													-40,000	4

**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	Current		Nev	New	C	Corn		٧h		₩inter	Summer	11-:-
	Cows	Hens		Cows	Hens	Soy	Lorn		Wh	eat	Outsourci	Outsourcin	Unit
Live Stock Purchases				1,500	3								\$
Total Cows	30			1									Cow:
Total Chickens		2.000			1								Hen
Corn Feed	1			1				_1					Acre
Wheat Feed		0.05			0.05			-1		-			Acre
Total Land Use	2			2		1	1	1		1 1	***********		Acre
						1					***********		
Labour in Winter	60	0.3		60	0.3		0.9	0.9		.6 0.0			Hou
Labour in Summer/Fal	l 60	0.3		60	0.3	1.4	1.2	1.2	: U.	.7 0.1	/ <u>                                     </u>	: 1	Hou
											В	В	
	Cows	Hens		С	н	CashS	Cashl	C Fee	IC C		Remainin		
	LOWS	nens		L	п	Lasno	Lashi	. гее	dC Cas	h₩ Fee	dW gWinter Hours	Summer Hours	Unit
Net Income	850	4.25		850	4.25	0	0	0	-	0 0		5.5	\$
Net Value	1,050	1.88		1,350	2.25	70	60	60				0	\$
rvet value	1,030	1.00		1,000	2.20	10	- 00	- 00		- 0-			
CONSTRAINTS:													
OOMOTTIMIETO:		Directio	Constrai										
	Used	n	nt	Slack	Units								
Live Stock Purchases	9,000	≤	20,000	11,000	\$								
Total Cows	0	≤	12	12	Cows								
Total Chickens	3,000	≤	3,000	Ö	Hens								
Corn Feed	30	≥	30	ŏ	Acres								
Wheat Feed	100		100	ŏ	Acres								
Total Land Use	640		640	ŏ	Acres								
Labour in Winter	4,000	<u>-</u>	4,000	ő	Hours	_							
		<u> </u>				_							
Labour in Summer/Fal	1 4,500 C	<u>s</u>	4,500	0	Hours								
					Cows	_							
	CashS,												
	CashC,		_										
Non-negativity	FeedC,	≥	0		Acres								
	CashW,												
	FeedW												
	Н				Hens								
MODEL:													
_[	Constant Li					Variables				Remaning H			
		ens	С	Н	CashS	CashC	FeedC	CashW	Feed₩	Winter	Summer		
Values	30 2	,000	Base Date	3,000	0.00	HEEDER	30	300	250	343	779		_
DBJECTIVE FUNCTIO	N												
	Current Cu	rrent											
	Cows H	ens	С	н	CashS	CashC	FeedC	Cash₩	Feed₩	₩inter	Summer	Total	
Vet Income	25,500 8	,500 :::::::00		12,750	0	0	0	- 0	0	1,715	4,284	52,743	3
Vet Value .	31,500 3	,750 9	- 0	6,750	. 9	0	1,800	19,245	16,038	. 0	0::::	79,083	
nvestment												11,000	
Overhead :												-40,00	0
												102,83	3

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

3	DATA:														
1		Current Cows	Current Hens		New Cows	New Hens	Soy	Corr	,		Wheat		Winter Outsourc	Summer i Outsourcin	Units
5	Live Stock Purchases				1,500	3									\$
3	Total Cows	30			1										Cows
7	Total Chickens		2,000			1									Hens
3	Corn Feed	1			1				-	1					Acres
9	Wheat Feed		0.05			0.05						-1			Acres
)	Total Land Use	2			2		1	1	1		1	1			Acres
1	Labour in Winter	60	0.3		60	0.3	1	0.9	0.	9	0.6	0.6	1		Hours
2	Labour in Summer/Fall	60	0.3		60	0.3	1.4	1.2	1.3	2	0.7	0.7		1	Hours
3															
1		Cows	Hens		С	н	CashS	Cash	C Fee	dС	Cash₩	Feed₩	Remainin gWinter Hours	Remaining Summer Hours	Units
5	Net Income	850	4.25		850	4.25	0	0		)	0	0	5	5.5	\$
3	Net Value	1,050	1.88		1,350	2.25	70	69	6		40	40	ō	0	\$
7		,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,			7		1								
3	CONSTRAINTS:														
9		Used	Directio n	Constrai nt	Slack	Units									
)	Live Stock Purchases	0	٤	20,000	20,000	\$									
1	Total Cows	0	≤	12	12	Cows									
2	Total Chickens	0	≤	3,000	3,000	Hens									
3	Corn Feed	30	≥	30	0	Acres									
4	Wheat Feed	100	2	100	0	Acres									
5	Total Land Use	640	≤	640	0	Acres									
6	Labour in Winter	4,000	≤	4,000	0	Hours									
7	Labour in Summer/Fall	4,500	≤	4,500	0	Hours									
3		C CashS, CashC,				Cows									
	Non-negativity	FeedC,	2	0		Acres									
_		CashW,													
9 D		FeedW						-		-					
		Н				Hens				-					
	MODEL:														
3		onstant Live Cows He	estock ens	С	Н	Decision CashS	Variables CashC	FeedC	Cash₩	Fee		ning Hour	s immer		
4 5			000	100 D			450	30	Casn <del>u</del>	10			1.454		
3	Values	00 2,	500	200000000000000000000000000000000000000			100	00		- 10	. , ,	,	,,,,,,,		
7															
		urrent Cur		_		CLC	CLC	EIC	C	E.		6		T	11-5
8 9			ens 500 ::::::01	<u>C</u>	<u>H</u>	CashS 0	CashC	FeedC 0	Cash₩ 0	Fee:			<u>immer</u> 7,997	Total 47,537	Unit:
			750 9		0	9	31,050	2,070	Ö	4.0			:,331 ::0::::::::	72,370	\$
1	Investment													20,000	\$
2	Overhead													-40,000	
3	Monetary Worth													99,907	\$

# Appendix C. Variants of the Original Model

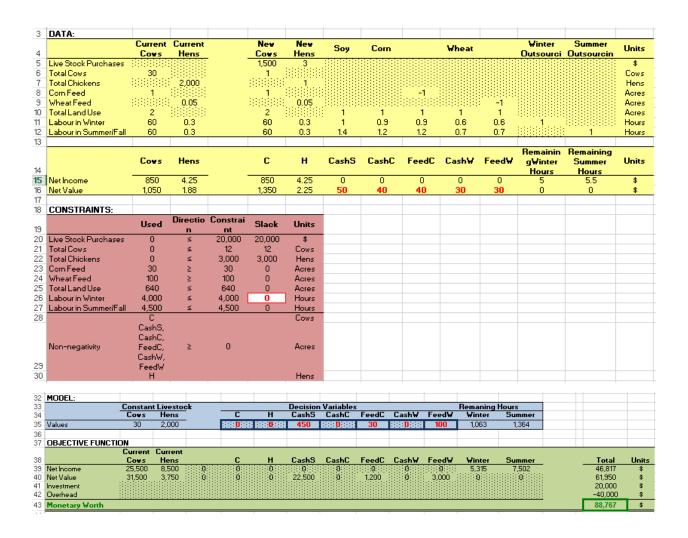
**FIGURE 6:** Optimal solution, assuming a drought occurs, yields a total end-of-year profit of \$67,864.

DATA:	-											1.0	-	
		Current		New	New	Soy	Con	n	W	heat		₩inter	Summer	Unit:
11 0 10 1	Cows	Hens	-	Cows	Hens		1010101010		1010101010101			Uutsourci	Outsourcin	
Live Stock Purchases				1,500	3									. \$
Total Cows	30													Cow
Total Chickens		2,000			:									Hen:
Corn Feed	1			!					1					Acre
Wheat Feed		0.05			0.05						-1			Acre
Total Land Use	2			2		1	1	1		1	1			Acre
Labour in Winter	60	0.3		60	0.3	1	0.9	0.3	9 (	0.6	0.6	1		Hou
Labour in Summer/Fa	I 60	0.3		60	0.3	1.4	1.2	1.2	2 (	0.7	0.7		1	Hou
												Remainin	Remaining	
	Cows	Hens		С	Н	CashS	Cash	C Fee	dC Ca	sh₩	Feed₩	a₩inter	Summer	Unit
												Hours	Hours	
Net Income	850	4.25	-	850	4.25	0	0	0	1	0	0	5	5.5	\$
Net Value	1,050	1.88		1,350	2.25	-10	-15			Ō	0	ō	0	\$
	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,			,,								_		
CONSTRAINTS:														
oonommine.		Directio	Constrai											
	Used	n	nt	Slack	Units									
Live Stock Purchases	20,000	≤	20,000	0	\$									
Total Cows	12	<u>-</u>	12	ŏ	Cows									
Total Chickens	667	<u> </u>	3,000	2,333	Hens	_	-							
Corn Feed	30	2	30	0	Acres	_	-							
Wheat Feed	100		100	0	Acres	_								
		≥	640			_								
Total Land Use	259	<b>S</b>		381	Acres	_								
Labour in Winter	4,000	≤ .	4,000	0	Hours									
Labour in Summer/Fa		≤	4,500	0	Hours									
	С				Cows									
	CashS,													
	CashC,													
Non-negativity	FeedC,	≥	0		Acres									
	CashW,													
	FeedW													
	Н				Hens									
							1							
MODEL:														
	Constant Liv	estock			Decision	Variables				Beman	ing Hours			
-		ens	С	Н	CashS	CashC	FeedC	Cash₩	Feed₩	Winte		mmer		
Values	30 2,0	000	12	667	0	D	42	D	133	562	1,	.036		
OBJECTIVE FUNCTIO	N													
	Current Cur	rent												
		ens	С	Н	CashS	CashC	FeedC	Cash₩	Feed₩	₩inte		mmer	Total	Un
Net Income		500 :::::0	10,200		0	0	(i) (i) (i) (ii)	- 10	. 0	2,81		,699	55,544	\$
Net Value	31,500 3,	750 9	16,200	1,500	. 0	0	-630	-0	. 0	. 0		0	52,320	\$
Investment													10000	
Overhead													-40,000	. 1
Monetary Worth													67,864	_

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

3	DATA:														
			Current		Nev	Nev	Soy	Corr	,		Wheat		Winter	Summer	Units
5	Live Stock Purchases	Cows	Hens		1,500	Hens 3		1414141414		10101010	10101010		Uutsourci	Outsourcin	\$
6	Total Cows	30			1,500										Cows
7	Total Chickens		2.000		1000000	1									Hens
8	Corn Feed	1	2,000		1	10000000									Acres
9			0.05			0.05						-1			Acres
10	Total Land Use	2			2	0.00	1	1	1		1	1			Acres
11	Labour in Winter	60	0.3		60	0.3	i	0.9	0.5		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		С	н	CashS	Cash	C Fee	dC (	Cash₩	Feed₩	Remainin gWinter Hours	Remaining Summer Hours	Units
15	Net Income	850	4.25		850	4.25	0	0	0	ı	0	0	<u>nours</u> 5	5.5	\$
16	Net Value	1,050	1.88		1,350	2.25	15	20	20		10	10	ŏ	0	\$
17		,,			,,,,,,,,										•
18	CONSTRAINTS:														
19		Used	Directio n	Constrai nt	Slack	Units									
	Live Stock Purchases	20,000	≤	20,000	0	\$									
21	Total Cows	12	≤	12	0	Cows									
22	Total Chickens	667	≤	3,000	2,333	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									
	Labour in Summer/Fall	4,500	≤	4,500	0	Hours									
28		C CashS,				Cows	-								
		CashC,													
	Non-negativity	FeedC,	≥	0		Acres									
		CashW,													
29		FeedW													
30		Н	1			Hens		-							
	MODEL:														
33 34		onstant Liv Cows He	estock ens	С.	Н	Decision CashS	Variables CashC	FeedC	Cash₩	Feed		ning Hour	s mmer		
	Values		000	12	667	Casrio	381	42	Casri	133			579		
36															
37	OBJECTIVE FUNCTION														
		urrent Cur		_		CLC	CLC	EIC	C	E "	u u	6		T I	III-r-
38			ens 500 ::::::0	<u>C</u>	H 2,833	CashS 0	CashC 0	FeedC 0	Cash₩	Feed 0	<b>₩ Win</b>		mmer 3.187		Units \$
			750 9			9	7,613	840	Ö	1,333			;;i0:::::::::::::::::::::::::::::::::::	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.



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

DATA:					<u></u>								
	Current Cows	Current Hens		New Cows	New Hens	Soy	Corn		Wheat		₩inter Outsourci	Summer Outsourcin	Unit
Live Stock Purchases				1,500	3								\$
Total Cows	30			1									Cows
Total Chickens		2,000			1								Hen:
Corn Feed	1			1				-1					Acres
Wheat Feed		0.05			0.05					-1			Acre
Total Land Use	2			2		1	1	1	1	1			Acre
Labour in Winter	60	0.3		60	0.3	1	0.9	0.9	0.6	0.6	1		Hour
Labour in Summer/Fall	60	0.3		60	0.3	1.4	1.2	1.2	0.7	0.7		1	Hour
	Cows	Hens		С	н	CashS	Cash(	: FeedC	Cash₩	Feed₩	Remainin gWinter Hours	Remaining Summer Hours	Unit
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	18,000	<b>S</b>	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	226	≤	640	414	Acres								
Labour in Winter	4,000	≤	4,000	0	Hours								
Labour in Summer/Fall	4,500	≤	4,500	0	Hours								
	C CashS, CashC,				Cows								
Non-negativity	FeedC, CashW,	2	0		Acres								
	FeedW												
	Н				Hens								
MODEL:													
	onstant Live	estock			Decision	Variables			Rema	aning Hou	rs		
	Cows He		С	Н	CashS	CashC	FeedC	Cash₩ Fe			ummer		
/alues	30 2,0	00	12	0	0	District District	42	19090 <b>D</b> 80808	100 7	82	1,260		
OD IECTIVE ELIMOTICA													
OBJECTIVE FUNCTION	urrent Curi	ent											
	Cows He		С	н	CashS	CashC	FeedC	CashW Fe	ed∀ Wir	nter Si	ummer	Total	Ur
	25,500 8,5	00 :::::0:	::::: 10,200	) [[::::0::::	0	0:::::	.0.	Ø	0::::: 3,	.911	6,928	55,039	
Vet Value nvestment Overhead	31,500 3,7	50 9	16,200	0	9	Ö	-840	10 -1	,000	9	0	49,610 2,000	
												-40,00	D :

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

DATA:	Current	Current		New	Nev	_	_				Winter	Summer	
	Cows	Hens		Cows	Hens	Soy	Corn	1	₩heat			Outsourcin	Unit
Live Stock Purchases				1,500	3								\$
Total Cows	30			1									Cow
Total Chickens		2.000			1								Hen
Corn Feed	1			1				-1					Acre
Wheat Feed		0.05			0.05					-1			Acre
Total Land Use	2			2		1	1	1	1	1			Acre
Labour in Winter	60	0.3		60	0.3	i	0.9	0.9		0.6	1		Hou
Labour in Summer/Fall	60	0.3		60	0.3	1.4	1.2	1.2		0.7		1	Hou
Labour III Summem all	- 00	0.5		- 00	0.0	1.7	1.2	1.2	0.1	0.1	1-1-1-1-1-1-1-1-1	<u>'</u>	Hou
											Remainin	Remaining	
	Cows	Hens		С	н	CashS	Cash	C Feed	IC CashW	Feed₩		Summer	Unit
	0013			_							Hours	Hours	
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	10	10	5	5	ŏ	0	\$
act a dide	1,000	1.00		1,000	2.20		- 10	- 10					
CONSTRAINTS:													
		Directio	Constrai	·									
	Used	n	nt	Slack	Units								
Live Stock Purchases	20,000	≤	20,000	0	\$								
Total Cows	7	≤	12	5	Cows								
Total Chickens	3.000	≤	3.000	0	Hens								
Corn Feed	30	≥	30	ō	Acres								
Wheat Feed	100	≥	100	0	Acres								
Total Land Use	362	5	640	278	Acres								
Labour in Winter	4,000	≤	4,000	0	Hours								
Labour in Summer/Fall	4,500	<b>S</b>	4.500	ō	Hours								
	C		.,		Cows								
	CashS.												
	CashC.												
Non-negativity	FeedC.	≥	0		Acres								
	CashW.												
	FeedW												
	Н				Hens								
	1	1											
MODEL:													
	Constant Liv	estock			Decision	Variables			Ron	aning Hou	rc		
-		ens	С	Н	CashS	CashC	FeedC	Cash₩			ummer		
/alues	30 2	.000	7	3,000	0	D	37	D	250	76	540		
DBJECTIVE FUNCTION													
		rrent											
0.71		ens	<u>C</u>	H 40.750	CashS	CashC	FeedC	CashW			ummer	Total	
Vet Income Vet Value		500 0 .750 0		12,750 6,750	0 0	0	373	0 0		382 (0::::::::::::::::::::::::::::::::::::	2,971 :::0::::::::	56,336 53,523	
Net Value nvestment ::	31,500 3	rad U	3,300	0,150			313	·	1,250			53,523	
nvestment Overhead												-40,000	
												40,000	

**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 \	Veather		
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.

DATA:	Current	Current		Nev	New	-	-				Winter	Summer	11 %
	Cows	Hens		Cows	Hens	Soy	Corn		Wheat			Outsourcin	Unit
Live Stock Purchases			-	1,500	3			8888888			88888888		\$
Total Cows	30			1									Cow
Total Chickens		2,000			1								Hen
Corn Feed	1			4									Acre
Wheat Feed		0.05		analana	0.05			-1		_1-1-1-1-1-1-1-1 _4			
		0.05			0.03		-1-1-1-1-1-1	*1*1*1*1*1*1*1*1	· ( · ( · ( · ( · ( · ( · ( · ( · ( · (	: -1			Acre
Total Land Use	2			2		: !	1	1	1				Acre
Labour in Winter	60	0.3		60	0.3	1	0.9	0.9	0.6	0.6		anangana	Hou
Labour in Summer/Fall	60	0.3		60	0.3	1.4	1.2	1.2	0.7	0.7		1	Hou
											D	D	
	C	ш		С	н	CLC	CLC	F1C	CLU	E40	Remainin	Remaining	11_:-
	Cows	Hens		L	п	CashS	CashC	reedu	Cash₩	reed₩	g₩inter	Summer	Unit
					4.05						Hours	Hours	
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	20.75	20.75	0	0	\$
CONCTRAINTC													
CONSTRAINTS:		Diametria	Constrai										
	Used	Directio	nt	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	ŏ	Acres								
Total Land Use	640	3	640	ŏ	Acres								
Labour in Winter	4,000	- -	4,000	Ö	Hours								
	4,500	<u> </u>	4,500	0	Hours	_	-		_	-			
Labour in Summer/Fall			4,300					_					
	C				Cows		-		-	-			
	CashS,												
	CashC,												
Non-negativity	FeedC,	≥	0		Acres								
	CashW,												
	FeedW												
	Н				Hens								
MODEL:													
	onstant Liv		C	н		Variables		C		aning Hou			_
Values		ons	12		CashS 414	CashC D			_	nter Su 168	ımmer 680		
values	30 2,	J00	12	Harris Utaria	414	atata <b>U</b> tatan	42	(rep. <mark>D</mark> (rep.)	100	100	000		
OBJECTIVE FUNCTION	1												
	urrent Cur	rent											
		ens	С	Н	CashS	CashC					ummer	Total	
Net Income		500 0			0	Ű	0	. 0			3,740	49,781	
Net Value	31,500 3,	750 0	16,200	0	14,076	10	1,155	0 2	.075	0	0	68,756	
												2,000	
Investment Overhead												-40,000	

**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.

_	V	N-III-					
7	Variable (	elis	Final	Dodusod	Objective	Allowable	Allowable
	C-11	N		Reduced		_	_
8	Cell	Name	Value	Cost	Coefficient	Increase	Decrease
9	\$E\$35	Values C	12	0	700	1E+30	22.5
10	\$F\$35	Values H	0	-0.02	3.5	0.02	1E+30
11	\$G\$35	Values CashS	414	0	34	7.5	0.4
12	\$H\$35	Values CashC	0	-4.9	27.5	4.9	1E+30
13	\$1\$35	Values FeedC	42	0	27.5	4.9	22.5
14	\$J\$35	Values CashW	0	-7.4	20.75	7.4	1E+30
15	\$K\$35	Values FeedW	100	0	20.75	0.4	1E+30
16	\$L\$35	Values Winter	368.2	0	5	0.388601036	0.071428571
17	\$M\$35	Values Summer	680	0	5.5	0.394736842	0.075471698
18							
19	Constrain	ts					
20							
21			Final	Shadow	Constraint	Allowable	Allowable
41	Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
22	Cell \$B\$21	Name Total Cows Used					_
			Value	Price	R.H. Side	Increase	Decrease
22	\$B\$21	Total Cows Used	Value 12	Price 22.5	R.H. Side 12	Increase 1.333333333	Decrease 12
22 23	\$B\$21 \$B\$22 \$B\$23	Total Cows Used Total Chickens Used	Value 12 0	Price 22.5 0	R.H. Side 12 3000	Increase 1.333333333 1E+30	Decrease 12 3000
22 23 24	\$B\$21 \$B\$22 \$B\$23	Total Cows Used Total Chickens Used Corn Feed Used	12 0 30	Price 22.5 0 -4.9	R.H. Side 12 3000 30	Increase 1.333333333 1E+30 414	12 3000 42
22 23 24 25	\$B\$21 \$B\$22 \$B\$23 \$B\$24	Total Cows Used Total Chickens Used Corn Feed Used Wheat Feed Used	Value 12 0 30 100	Price 22.5 0 -4.9 -7.4	R.H. Side 12 3000 30 100	Increase 1.333333333 1E+30 414 414	12 3000 42 100
22 23 24 25 26	\$B\$21 \$B\$22 \$B\$23 \$B\$24 \$B\$20	Total Cows Used Total Chickens Used Corn Feed Used Wheat Feed Used Live Stock Purchases Used	Value 12 0 30 100 18000	22.5 0 -4.9 -7.4	R.H. Side 12 3000 30 100 20000	Increase 1.333333333 1E+30 414 414 1E+30	12 3000 42 100 2000
22 23 24 25 26 27	\$B\$21 \$B\$22 \$B\$23 \$B\$24 \$B\$20 \$B\$25	Total Cows Used Total Chickens Used Corn Feed Used Wheat Feed Used Live Stock Purchases Used Total Land Use Used	12 0 30 100 18000 640	Price 22.5 0 -4.9 -7.4 0 21.3	R.H. Side 12 3000 30 100 20000 640	Increase 1.333333333 1E+30 414 414 1E+30 368.2	12 3000 42 100 2000 414

**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.

DATA:													
	Cows	Current Hens		New Cows	New Hens	Soy	Corn		Wheat	t	Winter Outsourci	Summer Outsourcin	Units
Live Stock Purchases	COWS	Hens		1,500	3	(4) (4) (4) (4)		: 4: 4: 4: 4: 4: 4: 4: 4: 4: 4: 4: 4: 4:			Outsoulei	Outsourcin	\$
Total Cows	30			1									Cows
Total Chickens		2,000			4								Hens
Corn Feed	4	2,000		4				-1					Acre
Wheat Feed		0.05			0.05			::::					
Total Land Use		1:1:1:1:1:1:1:			0.05		· 1	:-:-:-:-:-:-:-: 1	*:*:*:*:*:*: 1	:): -1 1			Acre
	2 60	1111111111111		2 60		: !	0.9	0.9					Acre
Labour in Winter		0.3			0.3	1				0.6	and the second		Hour
Labour in Summer/Fall	60	0.3		60	0.3	1.4	1.2	1.2	0.7	0.7		: 1	Hour
											Remainin	Remaining	
	Cows	Hens		С	н	CashS	Cash	Feed	C Cash\	/ Feed₩	q₩inter	Summer	Unit
				_							Hours	Hours	
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	4.00				ō	0	\$
	7			7								_	
CONSTRAINTS:													
	Used	Directio	Constrai	Slack	Units								
	usea	n	nt	эгаск	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	Ō	Acres								
Labour in Winter	4,000	≤	4,000	0	Hours								
Labour in Summer/Fall	4,500	<b>S</b>	4,500	0	Hours								
	C		.,		Cows								
	CashS,												
	CashC,												
Non-negativity	FeedC,	≥	0		Acres								
	CashW,	_	_										
	FeedW												
	H				Hens								
	1												
MODEL:													
	Constant Liv					Variables				naning Hou			
		ens	С	Н	CashS	CashC	FeedC				ımmer		
Values	30 2,	000	D.	0	450	D	30	0	100	1,063	1,364		
OBJECTIVE FUNCTION													
		rent ens	С	н	CashS	CashC	FeedC	Cash₩	Feed₩ ₩	/inter Sc	ımmer	Total	Un
Net Income		ens 500 :::::::::::::::::::::::::::::::::::			Lasno 0	LasnL U	reeac	Casnw U			<u>7,502</u>	46,817	
Net Value		750 9		0	15,300	ŭ	120	Ö	2.075	0.00	1,002	52,745	
Investment												20,000	
Overhead												-40,000	
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.

3	DATA:													
4		Current Cows	Current Hens		New Cows	New Hens	Soy	Corn	,	Wheat		Winter	Summer Outsourcin	Units
	_ive Stock Purchases	CUTS	Hens		1,500	3	-					Outsoulci	Outsourcin	\$
		30			1,300									
	Total Cows													Cows
	Total Chickens		2,000											Hens
	Corn Feed								111					Acres
	Wheat Feed		0.05			0.05					: -1			Acres
	Total Land Use	2			2		1	1	1	1	1			Acres
	_abour in Winter	60	0.3		60	0.3	1	0.9	0.9	0.6	0.6	1		Hours
	_abour in Summer/Fall	60	0.3		60	0.3	1.4	1.2	1.2	0.7	0.7		1	Hours
3														
												Remainin	Remaining	
		Cows	Hens		C	Н	CashS	Cash	C Feed	C Cash₩	Feed₩	g₩inter	Summer	Units
1												Hours	Hours	
5 1	Vet Income	850	4.25		850	4.25	0	0	0	0	0	5	5.5	\$
	Vet Value	1,050	1.88		1,350	2.25	34.00	32.4	1 32.4	1 20.75	20.75	0	0	\$
7														
3	CONSTRAINTS:													
		Used		Constrai	Slack	Units								
9	. 0. 10 1	40.000	n	nt	0.000									
_	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								
5	Total Land Use	640	≤	640	0	Acres								
3	Labour in Winter	4,000	≤	4,000	0	Hours								
	Labour in Summer/Fall	4,500	≤	4,500	0	Hours								
3 ]		С				Cows								
1		CashS,												
П		CashC,												
П	Von-negativity	FeedC,	≥	0		Acres								
ı		CashW,												
3		FeedW												
		Н				Hens								
	MODEL:													
3 4		onstant Liv Cows He	<u>estoc</u> k ens	C	н	Decision CashS	Variables CashC	FeedC	Cash₩		aning Hou inter S	rs ummer		
	/alues		000	12	10000 <b>(</b> 0000	Casno O	414	42	Casn <del>W</del>		410	763		
3	raiues	JO 2,	000	12	(1.1.1.1 <u>V</u> .1.1.1	mini Valor	414	42		100	710	103		
	OBJECTIVE FUNCTION													
Ì			rent											
8	Ī	Cows He	ens	С	Н	CashS	CashC	FeedC	Cash₩			ummer	Total	
			500 :::::::0			. 0		.O:	Ű			4,195	50,440	
D 🛭		31,500 3,	750 9	16,200	0	. 0	13,418	1,361	0	2,075	Q	0	68,304	
	nvestment 💠												2,000	
2 [	Overhead Monetary Worth												-40,00 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	Current Hens		New Cows	New Hens	Soy	Corr	1	Wheat		₩inter Outsourci	Summer Outsourcin	Unit
Live Stock Purchases				1,500	3								\$
Total Cows	30			1									Cow
Total Chickens		2,000			1								Hen
Corn Feed	1			1				-1					Acre
Wheat Feed		0.05			0.05					-1			Acre
Total Land Use	2			2		1	1	1	1	1			Acre
Labour in Winter	60	0.3		60	0.3	1	0.9	0.9	0.6	0.6	1		Hou
Labour in Summer/Fall	60	0.3		60	0.3	1.4	1.2	1.2	0.7	0.7		1	Hou
	_			_							Remainin	Remaining	
	Cows	Hens		С	н	CashS	Cash	C FeedC	CashW	Feed₩	g₩inter Hours	Summer Hours	Uni
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	27.5			21.16	ŏ	0	\$
	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,			,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,									
CONSTRAINTS:													
	Used		Constrai	Slack	Units								
Live Stock Purchases	20,000	<u>n</u> ≤	20,000	0	\$	_							
Live Stock Purchases Total Cows	20,000	<u> </u>	20,000	0					_				
Total Cows Total Chickens	667	<u> </u>	3,000	2,333	Cows Hens	-							
Corn Feed	30	2	30	2,333	Acres	_							
Wheat Feed	100	2	100	Ö	Acres	_							
Total Land Use	640	<u>-</u> 5	640	Ö	Acres	_							
Labour in Winter	4,000	<u> </u>	4,000	ő	Hours	-							
Labour in Summer/Fall	4,500	- -	4,500	ő	Hours	_			-				
Labour in Summern an			4,300		Cows								
	CashS.				00#3								
	CashC,												
Non-negativity	FeedC,	≥	0		Acres								
	CashW,												
	FeedW												
	Н				Hens								
								'		'	'	·	
MODEL:													
	onstant Live Cows He		C	н	Decision CashS	Variables CashC	FeedC	Cash₩ Fo		aning Hours	mmer		-
Values	30 2.0		12	667	381	HILL DIESE	42				503		_
- divides	2,0									-	333		
OBJECTIVE FUNCTION	1												
	urrent Cur												
	Cows He		<u>C</u>	2 022	CashS	CashC	FeedC				mmer	Total	Un
	25,500 8,5 31,500 3,7		16,200		12,943	16 10	1.155	0 0		08 2 9::::::::::::::::::::::::::::::::::::	,768 ::0:::::::	50,709 69,869	:
nvestment		"	10,200		12,343		,,,,,,,		,021			:::::::::::::::::::::::::::::::::::::::	
Dverhead												-40,000	111
												,	

**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:		nt Curre		New	New	Soy	Corr	1		Wheat		Winter	Summer	Unit
Live Over I. Donela e e e	Cow	s Hen	<u> </u>	1,500	Hens		1-1-1-1-1-1		-1-1-1-1			Uutsourci	Outsourcin	\$
Live Stock Purchases			iii —	1,500	3									
Total Cows	30	111111111111111111111111111111111111111	311											Cow
Total Chickens	1111111	2,000	J 141											Her
Corn Feed			111					:::: <u>-</u>	1					Acr
Wheat Feed		0.05			0.05						: -1			Acr
Total Land Use	2	11111111	44	2		1	1		1	1	1			Acr
Labour in Winter	60			60	0.3	1	0.9			0.6	0.6			Hou
Labour in Summer/Fa	II 60	0.3		60	0.3	1.4	1.2	1.	2	0.7	0.7		1	Hot
	_			_								Remainin	Remaining	
	Cow	s Hen:	5	С	Н	CashS	Cash	C Fee	edC	Cash₩	Feed₩	g₩inter	Summer	Uni
												Hours	Hours	
Net Income	850			850	4.25	0	0		)	0	0	5	5.5	\$
Net Value	1,05	0 1.88		1,350	2.25	34.00	27.5	0 27.	.50	28.25	28.25	0	0	\$
CONSTRAINTS:		D: .												
	Use	d Direct	io Constrai nt	Slack	Units									
Live Stock Purchases	17,70	)6 ≤	20,000	2,294	\$									
Total Cows	6	≤	12	6	Cows									
Total Chickens	3,00	0 ≤	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	4,00	0 ≤	4,000	0	Hours									
Labour in Summer/Fa	II 4,50	0 ≤	4,500	0	Hours									
	C				Cows									
	Cash	S,												
	Cash	c.												
Non-negativity	Feed	C. ≥	0		Acres									
- ·	Cash'													
	Feed													
	Н				Hens									
				1							1	1	·	
MODEL:														_
	Constant	Livestock				Variables				Rema	ning Hours			
	Cows	Hens	С	Н	CashS	CashC	FeedC	Cash₩	Feed			mmer		
/alues	30	2,000	6	3,000	0	D D	36	283	25	0		136		
OBJECTIVE FUNCTIO														
	Current   Cows	Current Hens	С	н	CashS	CashC	FeedC	Cash₩	Feed	d <b>V</b> Vin	tor C	mmer	Total	Uı
Net Income	25,500	8,500 ::::	:0:::::: 4,933		Lasho	LashL 0	reedL	LashW	reed ::::0			<u>mmer</u> ,398		Ui
vet income Vet Value	31,500	3,750	9 7,835		8	0	985	7.983	7.06			,550 10:11:11:1	65,865	
nvestment :													2,294	
Dverhead													-40,000	
												<u> </u>	82,241	_