ASPARAGUS GROWTH MODEL

By

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To the Faculty of Washington State University:

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ASPARAGUS GROWTH MODEL

Abstract

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The overall objective of this research was to develop a growth model for asparagus so that growers could better manage their operations and make more informed decisions in the field. The intention is for growers to use this model to predict daily gross yields and determine whether hand-harvesting or mechanical harvesting would be better utilized given the predicted daily yield.

Data was collected for this research model by obtaining daily average wind speed and solar radiation downloaded from the Washington State Agricultural Weather Network, and gross yield, air and ground temperatures collected in the field. This raw data was collected and downloaded from the Franklin County CBC Pasco substation located at the Columbia Basin Community College, two miles from the evaluation site and the evaluation site itself just east of Pasco, WA.

Stepwise regression was then used to evaluate the correlation of selected inputs and their influence on the gross yield for a 24 hour period. This method was used to determine the most influential factors in the growth of asparagus. A multiple regression model was used to create a growth model that included the inputs of maximum and minimum daily air temperature,

maximum and minimum ground temperature, wind speed, and solar radiation for each cultivar researched.

The development of this model will allow growers to gain insight on the influences of the growth of asparagus as well as to develop better management strategies for the crop. With the addition of this tool growers will be able to better manage their asparagus operations by increasing the efficiency of their harvest methods and efforts within the field.

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Dedication

This thesis is dedicated to my family

who provided both emotional and financial support

CHAPTER ONE

INTRODUCTION

The Asparagus Situation

Asparagus (*Aspragus officinalis)* is a widely cultivated perennial plant which the young shoots or cladodes are harvested and consumed. The origin can be traced back to the Mediterranean region of the world. The plant made its way to North America through the first colonists and was commercially harvested in the United States by the mid 1800's.

Historically the crop has been hand harvested by use of a labor intense work force walking down beds of asparagus and individually selecting and cutting the mature spears (7-9 inches in height) slightly underground or by snapping the spear off above ground for harvest. The ability of the asparagus plant to grow multiple young shoots in tight clusters emerging from the paternal crown, coupled with the fragile nature of the plant proves to be a difficult challenge in the harvesting of the crop. Ideally the shoots are harvested by using a V-shaped push knife to cut the selected spear roughly a half inch below the ground without damaging surrounding immature spears. Immature damaged spears that would be tomorrow's harvest are referred to as collateral damage. Due to these factors, typical asparagus harvest operations require large temporary manual labor forces for only the harvest season time period. In Washington State this is typically a 70-80 day period from mid April extending into June (Hooper, 1998). These factors of close growth proximity and fragile physical characteristics also make asparagus harvesting a difficult process to mechanize.

In the early 1990's, in order to reduce the amount of coca being grown, manufactured and distributed from Peru, Bolivia, Columbia, and Ecuador, the U.S. enacted the Andean Trade Preference Act (ATPA). This act eliminated tariffs on several products that were exported from these countries including asparagus in the hopes of giving incentive for local farmers within these countries to produce legal revenue generating crops rather than coca. This act was then renewed as the Andean Trade Promotion and Drug Eradication Act (ATPDEA). Mexico is also involved as they benefit from similar exports regulations based on the North American Free Trade Agreement. As of February 1, 2009, the U.S. Government has implemented the bilateral Peru Trade Promotion Agreement. This agreement was set up and designed to ease the trading of goods and services as well as encouraging private investment between both the United States and Peru (President, Proclamation 8341, 2009).

As a result of these movements from the United States Government to pursue its war on drugs, the American asparagus industry has taken heavy casualties. Fueled by an increase in per capita demand and a decrease in harvested acreage due to the imports from trade agreements, the American asparagus industry has rapidly left U.S. soil and migrated to locations of cheaper labor costs and year round production. As of 2007, Washington State asparagus has seen a loss in acreage of over 75% (25,000 ac) since its peak production in 1988 of 33,000 ac (USDA-ERS, Table 34, 2008). Further, the United States provides approximately $60 million dollars a year in the development of Peruvian asparagus farms (Egan, 2004).

From 1990 to 2007, the United States has reduced its asparagus production by 46% from 111,000 metric tons to 50,620 metric tons. While other leading producers such as China, Peru, Germany, and Mexico have seen dramatic increases (Figure 1).

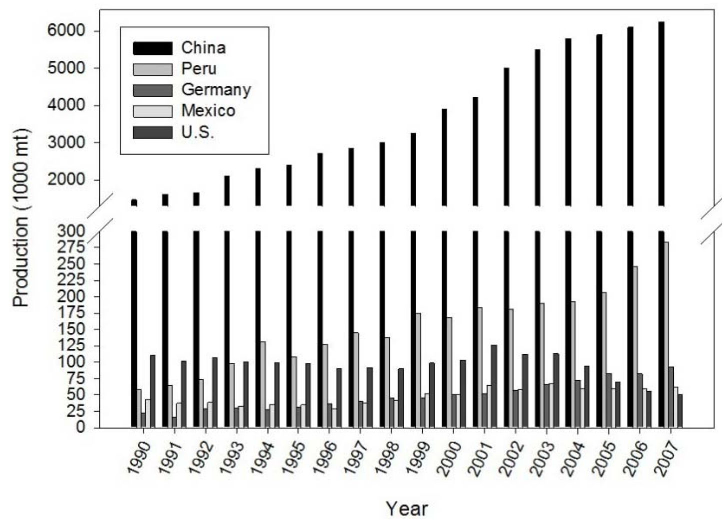

FIGURE 1. World Asparagus Production by Year
SOURCE: United Nations, Food and Agriculture Organization, FAOStat. 2008.

During this same time period, the U.S. import volume of asparagus has increased 545% from 19,860 metric tons to 108,320 metric tons (Figure 2), most of which is originating from Peru and Mexico (Food and Agriculture Organization of the United Nations, FAOStat).

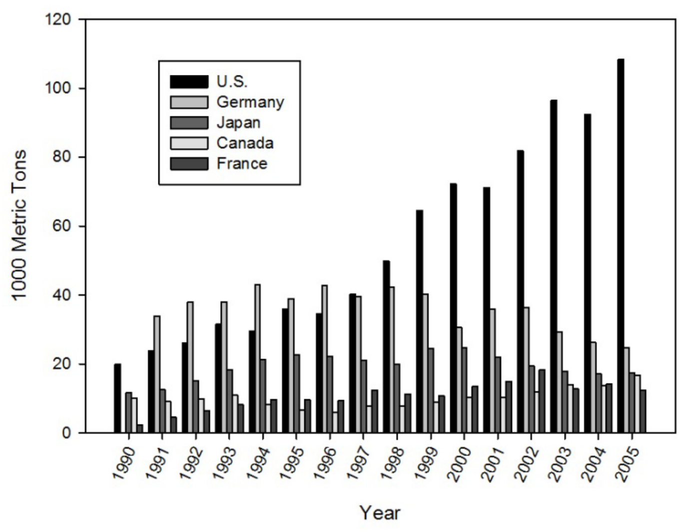

FIGURE 2. World Asparagus Imports by Year
SOURCE: United Nations, Food and Agriculture Organization, TradeStat, 2008.

While the United States has maintained its export volume and increased its imports the per capita consumption for asparagus has been on the rise. Since 1990, U.S. per capita consumption of asparagus has risen from 1.01 lbs to 1.40 lbs in 2007 (Figure 3).

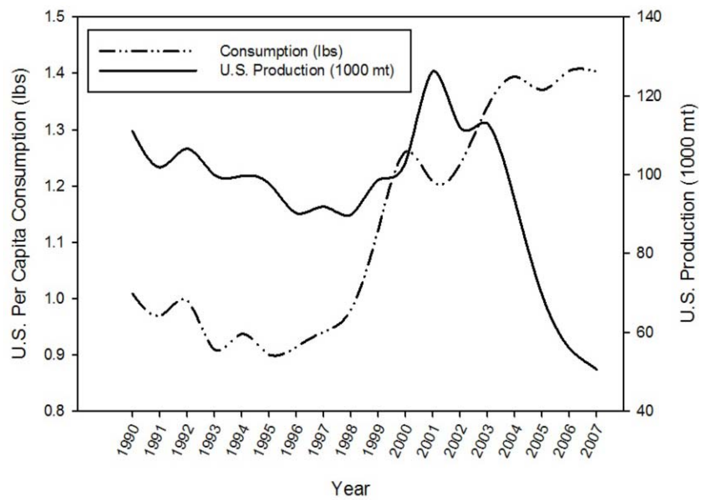

FIGURE 3. U.S. per Capita Consumption by Year
SOURCE: USDA, Economic Research Service.

This graph depicts the United States has the demand for its own asparagus and that the trading trends are not supporting the domestic product.

Within the United States it is typical of asparagus growers to harvest their crops on a daily basis during the production season. The harvest generally begins in the early morning and continues to early afternoon, depending on production, temperature, and availability of a work force.

By law, within the United States, labor must be paid at the minimum wage. In Washington State as of 2009, the minimum wage was $8.55 per hour and is currently the highest in the nation followed by California (Martinez, 2009). These high labor costs have made it difficult for U.S. asparagus growers to stay competitive within the international and state-side markets.

Since 1990, harvested Washington asparagus acreage has dropped from 30,000 acres harvested to 6,500 acres in 2008, a drop in production value of over $36 million U.S. dollars (USDA NASS, 2009). In 2006 Washington State had dropped from the second largest asparagus producer in the United States to the third where it currently resides, behind California and Michigan (Figure 4).

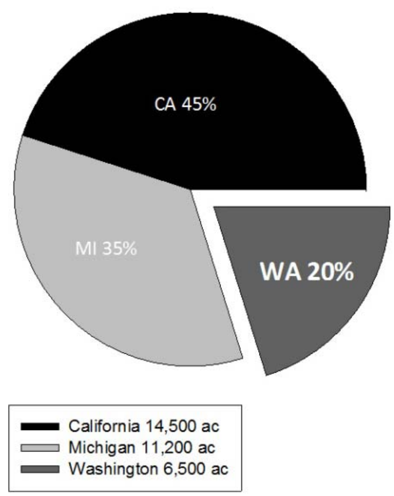

FIGURE 4. U.S. Asparagus Harvested Acres in 2008
SOURCE: USDA, National Agricultural Statistics Service

Mechanical Harvester Solution to the Current Asparagus Situation

Developing and adopting harvesting systems for asparagus provides an important means to address increasingly urgent concerns including the rising cost of labor and global competition. These systems will help to maintain Washington State's position in national and international markets. In addition to increases in the minimum wage to $8.55/hr, changes in international trade policies have presented significant challenges to the asparagus industry in Washington State. The asparagus industry has been impacted by imports from Peru. In addition to foreign competition, labor used for hand-harvesting asparagus has become scarce, particularly at the end of the season. It is increasingly common for fields to be abandoned prematurely due to lack of labor. This has prompted the industry to evaluate the need of mechanical harvesting in order to reduce production costs associated with hand labor and extend the harvest window when hand labor is not available.

In the spring of 2007, two selective mechanical asparagus harvesters were evaluated. A single row pull-behind asparagus harvester prototype developed by Geiger-Lund Harvesters, Stockton, CA was calibrated in the Stockton area (Phase I) and evaluated in Pasco, WA (Phase II). The harvester head employs parallel pairs of counter-rotating "rollers" that engage asparagus spears that have reached a specified height. As the machine moves down the row, the optical system senses a spear of the selected minimum height and then actuates a cutting system that drives the closest blade into the soil at the base of the spear. The spear is pulled through counter-rotating rollers onto a backstop and conveyer that transports spears to the rear of the machine. Economic analysis indicates that a three-row harvester must recover 70% of hand-harvested yield to be viable (Clary et al., 2007) though the Geiger-Lund machine exhibited good reliability from the standpoint of mechanical operation, collateral damage to the asparagus beds was extensive. The result was a decline in yield with an efficiency ranging from 20 to 60% compared to hand-harvesting; this can be seen in Figure 5.

FIGURE 5. Geiger-Lund Selective Mechanical Asparagus Harvester 2007

The other harvester was only evaluated during Phase II in Pasco, WA. Oraka Developments LTD from New Zealand tested a pull-behind selective mechanical harvester that utilized a horizontal and vertical moving cutter and pickup system cutting one spear at a time and delivery of the spear to a conveyor for collection. Oraka was also able to add one of their grading machines on the harvester. This machine will mechanically harvest and sort the asparagus directly in the field. Once the Oraka machine was calibrated, its recovery was 80 to 100% compared to hand-harvesting. Due to the early development stage of this harvester, it performed at a slow rate of <1 mph. This harvester is seen in Figure 6.

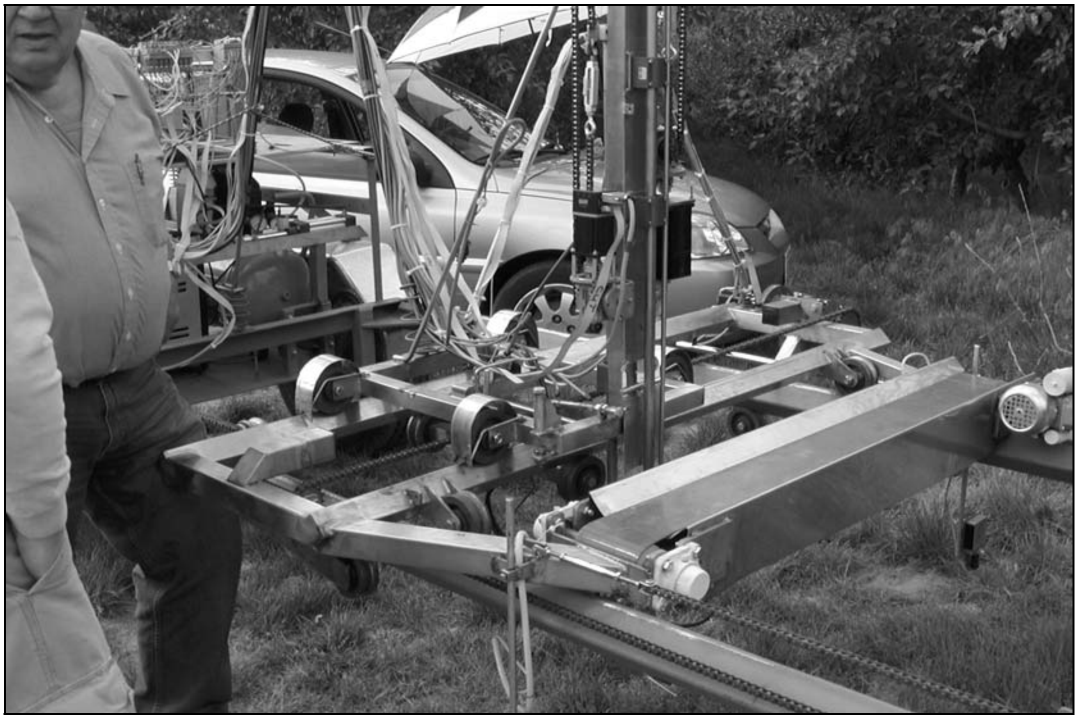

FIGURE 6. Oraka Selective Mechanical Asparagus Harvester 2007

Research Objectives

The primary objective of this research is to focus on the development of management and decision making tools for U.S. asparagus growers. With this information asparagus growers will be able to more accurately predict their daily gross yields. As a result asparagus growers will be able to make better economic decisions when producing asparagus. This model was formatted so that asparagus growers can easily enter environmental input measurements and acquire an estimated gross yield output.

Thesis Format:

This thesis is comprised of 4 chapters that analyze harvest yield data that was collected from the 2007 Washington State selective mechanical asparagus harvester trials in Pasco, WA. Chapter 1 contains information and history of asparagus to date, that gives the basis and justifies this research. Chapter 2 covers the methodology that was used to obtain the collected yield data, weather data, and the statistical methods of stepwise regression and multiple linear regression used to develop the final growth model. Chapter 3 reports the results for the analyzed data and the regression model findings and also specifies the asparagus growth model through multiple linear regression including the coefficients. Chapter 4 discusses the conclusions of this research as well as topics for future research.

CHAPTER 2

METHODOLOGY

This chapter discusses the methods for obtaining the raw field data used in this research including yields and weather figures. The process of refining that data and the methods used to analyze it are also discussed.

2007 Pasco Harvest Trials

A commercial asparagus field near Pasco, WA was leased for the asparagus harvester trials conducted April 24 to June 14, 2007. The material collected for this thesis was derived from the data collected from these 2007 Paso Harvester Trials. The harvester trials research field is located just south of the Pasco-Kahlotus road 1.5 miles north of Highway 12 and near the city limits of Pasco, WA. The center of the test plot field was located at 46°14'45.83"N 119°01'48.77"W. The field contained two asparagus varieties. The south half of the field was a six year old Del Monte asparagus cultivar and the north half of the field was Green Giant, also in its sixth year of production. The field was split into two plots (South end was plot 1 and North end was plot 2) across the cultivar change within the field. Buffer zones were created at both ends of the field as well as in between the plots. These measured 20 ft on the north end, 28 ft in the middle cultivar change and 10 ft on the south end of the field. The basis of this experimental design was to evaluate the mechanical harvesters in as close of a comparison to hand harvesting as possible.

Plot 1 consisted of 450 ft long plots and plot 2 had 465 ft long plots. Rows 6 and 7 were unusable by both machines due to conflict with the irrigation risers. Rows 1-18 were randomly divided into 9 hand-harvested rows as well as 9 machine harvested rows, to be harvested by the Geiger-Lund Harvester. Rows 19-21 were selected as practice rows used to calibrate and make adjustments on the harvesters. The Oraka harvester was assigned to row 18 and row 15 was used for hand-harvest comparison. The Oraka rows were taken from the 2 plot setup to a 4 plot by simply dividing the existing rows by two, making plot 1, 225 ft long and plot 2, 232.5 ft long.

Weather Data

In-field weather data was taken from an Oregon Scientific Professional Weather Station, model number WMR968 (http://www2.oregonscientific.com/). Air temperature was collected through Oregon Scientific's wireless thermometer (THGR968) and ground temperature using Oregon Scientific's wireless waterproof temperature sensor (THC268). Due to complications in some of the Oregon Scientific weather equipment, average daily wind speed and average solar radiation were taken at 24 hour intervals and collected through a WSU affiliated weather station. The location of this collection site was the Franklin County CBC Pasco station and accessed through the AgWeatherNET service located on the WSU server.

Stepwise Regression

While multiple linear regression was used to build the final growth model for this research, it was not used to initially determine what independent variables should be included and how they affected the final model. Within the model building process several tools can be utilized to develop a model. One of these tools is stepwise regression. Stepwise regression aids in the model building process through parsimony. The goal of parsimony is to develop a regression model that includes the fewest number of independent variables (temperature, wind speed, etc.) that permit an adequate interpretation of the dependant variable of interest (gross yield). To determine this, MiniTab15, developed by MiniTab Inc. (www.Minitab.com, 2007) was used to analyze the data set and compute a stepwise regression on the data.

One common problem with building a model using multiple linear regression is co-linearity. Co-linearity refers to the situation in which one or more of the independent variables are highly correlated with each other. For example, average daily temperature was initially removed by MiniTab15 because it was highly correlated with maximum and minimum daily air temperatures. To remove all aspects of co-linearity from the model, stepwise regression was utilized within MiniTab15.

To accomplish this, stepwise regression utilizes an extended partial F-test statistic to model with any number of independent variables. By doing this, stepwise regression adds or removes independent variables at each step of the model building sequence and will terminate when a best fitting model is selected. The r^2 (adj.) value is the coefficient of determination adjusted or the variation in the dependant variable Y (Daily Gross Yield kg/ha) that can be explained by the independent variable X, adjusted for the given number of independent variables and sample size. This is calculated for each regression model within the stepwise regression. The p-value and net regression coefficient for each independent variable are calculated at each step as well.

These values can then be used to analyze the model that MiniTab15 selects at the termination of the stepwise regression. This final model can then be used to determine what environmental factors measured are of significant influence on daily gross yield for asparagus and those variables can then be entered into a multiple linear regression equation to produce an asparagus growth model.

Multiple Linear Regression

The objective of this research was to collect easily obtained environmental data, analyze it, and develop a growth model for asparagus allowing growers to predict daily gross yields. The model that best fits the requirements of this research is the multiple linear regression model. The multiple linear regression model was selected based on its ability to calculate the amount of change in the gross yield associated with the units of change in air temperature and ground temperature.

The reason multiple linear regression can be used to predict the numerical value of a dependant variable Y_i, is based on the numerical values of independent variables, $X_1, X_2, \ldots X_p$. In addition to the prediction of values for Y_i based on given values of X_p, multiple linear regression can also be used to analyze the relationship between the independent variables, $X_1, X_2, \ldots X_p$ and the dependant variable, Y_i through an analysis of variance. The model for multiple linear regression with p explanatory variables is contained within Table 1 in the form of Equation (1):

TABLE 1. Model for Multiple Linear Regression

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \ldots + \beta_p X_{ip} + \varepsilon_i, \qquad (i = 1, \ldots, n) \tag{1}$$

where,

β_0 = Y intercept

β_1 = slope of Y with variable X_1 holding variables $X_2, X_3, \ldots, X_k$ constant

β_2 = slope of Y with variable X_2 holding variables $X_1, X_3, \ldots, X_k$ constant

β_3 = slope of Y with variable X_3 holding variables $X_1, X_2, X_4, \ldots, X_k$ constant

β_k = slope of Y with variable X_k holding variables $X_1, X_2, X_3, \ldots, X_{k-1}$ constant

ε_i = random error in Y for observation i

Within this model containing multiple independent variables, the Y intercept, when all variables are set to zero is represented by β_0. The net regression coefficient or the slope β_1, represents the change in the mean of dependant variable Y per unit of change in X_{i1} while taking into account the effect of X_{i1+1} and so forth. While ε_i is the random error in Y for the given observation i and refers to the vertical distance that Y_i is above the determined regression line.

Once the data set has been analyzed and refined through the multiple linear regression model within MiniTab15, a regression equation, an adjusted r^2 value, and an analysis of variance tables are then produced. These factors can then be analyzed to explain and justify the determined asparagus growth model.

CHAPTER 3

RESULTS

This chapter discusses the findings of analyzed and collected environmental input measurements and the resulting asparagus growth model in which daily gross yield is the output.

The daily environmental independent variables measured for each asparagus cultivar included:

- Average wind speed (mph)
- Maximum air temperature (°F)
- Minimum air temperature (°F)
- Average air temperature (°F)
- Maximum ground temperature (°F)
- Minimum ground temperature (°F)
- Average ground temperature (°F)
- Solar radiation (MJ/m^2)

These measurements were then analyzed to determine their individual influence on the overall growth of asparagus using the functions of stepwise regression and multiple linear regression within the software program MiniTab15.

High winds and sporadic rainfall combined with the sandy soil at our location proved to be a difficult combination for our precipitation sensor. The harsh winds drove the rain and sand into the sensors of our precipitation measuring unit rendering it inaccurate. But after finding out that little rain fell during the harvest period and yields did not seem to be affected by this natural rainfall it was determined that consistent irrigation schedules were meeting the asparagus water requirements and it would be acceptable to remove irrigation from the independent variables list.

The next step was to see what the effect each of the two cultivars had on gross yield. By observing the data in Figure 7, it can be seen that cultivars evaluated in this study do not have a distinct effect on gross yield based on their similar regression slopes. The general trend was a lower gross yield and was explained and attributed to the overall lower daily air temperature over time. After this was observed, individual cultivars were removed from the independent variables list as well.

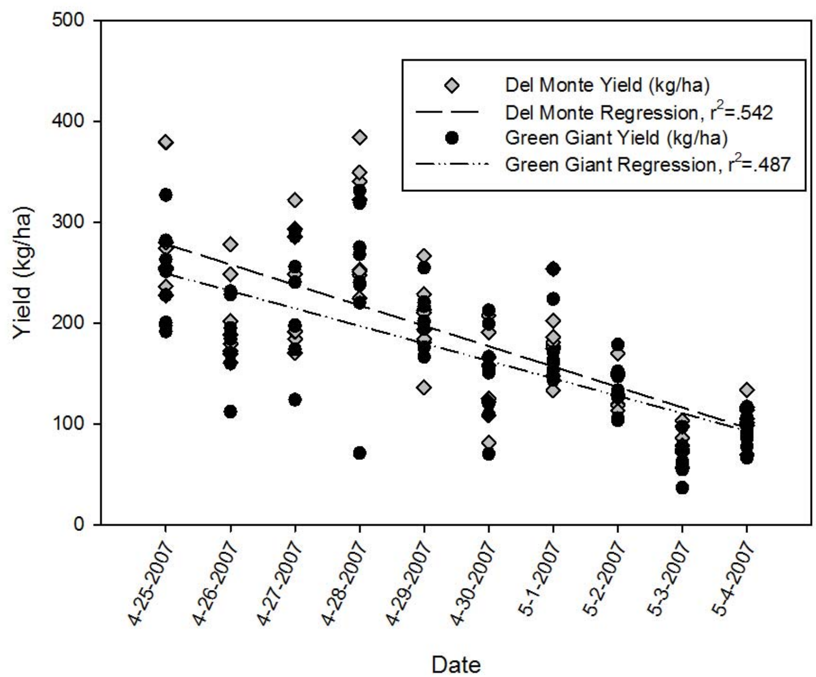

FIGURE 7. Daily Yield by Cultivar

The initial hypothesis was that daily air temperature could be directly related to the daily gross yield in asparagus growth. This trend was observed and validated throughout the research conducted for this growth model. Figure 8 represents the linear relationship between maximum air temperature and total daily gross yield. A regression of this data shows an r^2 of 0.868 and the confidence interval of 95%. With this data, a direct relationship between maximum air temperature and gross yield was investigated and determined that: as maximum air temperature increases, gross yield has a direct positive linear relationship and increases as well.

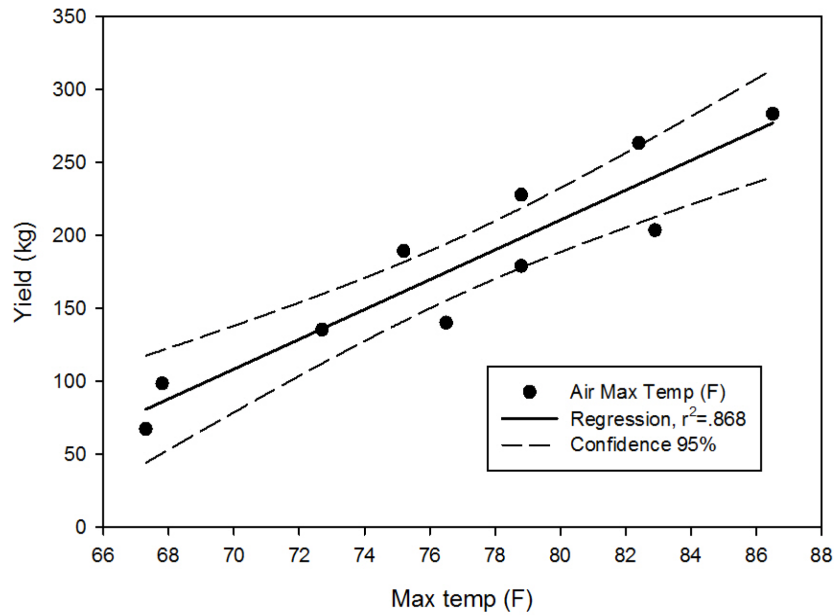

FIGURE 8. Total Daily Gross Yield vs Temperature from April 25 to June 4th of 2007

After this relationship was interpreted, further investigation into the relationship between daily gross yield and maximum air temperature ensued. The following graph (Figure 9) portrays the relationship between daily gross yield and maximum air temperature for each day of harvest.

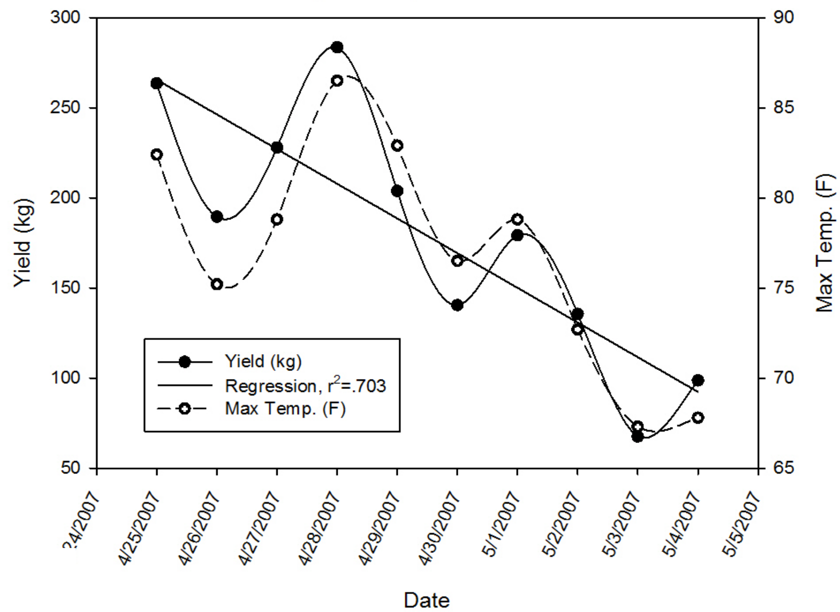

FIGURE 9. Daily Gross Yield and Maximum Air Temperature per Day

As it can be seen, daily gross yield can be directly related to the maximum air temperature for that given day, as the maximum daily temperature falls, so too does the daily gross yield. The regression line with an r^2 of 0.703 reiterates the tendency for gross yields to be directly related to daily maximum air temperature.

With these observations noted, the data could then be entered into MiniTab15 and analyzed further to develop the Asparagus Growth Model. MiniTab15 analyzed the data of maximum and minimum air temperature, maximum and minimum ground temperature, wind speed, solar radiation, and cultivar against daily gross yield to develop a stepwise regression as follows:

TABLE 2. Stepwise Regression on 2007 Harvest Data – Step 1

Step	1	2	3	4	5
Constant	-598.3	-786.2	-812	-745.7	-725.4
Air Max (°F)	10.10	8.65	6.52	3.90	3.90
P-Value	0.000	0.000	0.000	0.011	0.010
Ground Max (°F)		4.80	8.60	11.50	11.50
P-Value		0.001	0.000	0.000	0.000
Total Solar Rad (MJ/m^2)			*-199.00*	*-274.00*	*-274.00*
P-Value			0.005	0.000	0.000
Avg Wind Speed (mph)				-9.00	-9.00
P-Value				0.020	0.019
Cultivar Code					-13.6
P-Value					*0.047*
r^2 (adj)	63.33	65.61	67.09	68.03	68.64

Upon analysis of the above report, a determination of what should or should not be included in the final model can be made. The constants within this stepwise process show what the asparagus growth will be in kg/ha if the independent variables are set to zero. The next data of interest are the net regression coefficients listed horizontally from their corresponding variable, given each step. At this stage, it was noticed that all independent variables had logical values except solar radiation.

Maximum air temperature and maximum ground temperature both showed positive effects on gross daily yield which was to be expected, as temperature increases yield also increases. Average wind speed had a negative effect on daily gross yield and cultivar did as well which were accepted as logical findings. Solar radiation, however, shows a significant decrease in daily gross yield, which is not to be expected. There is no true explanation as to why such a significant decrease in yield was associated with solar radiation prompting removing it from the asparagus growth model list of independent variables.

The next variable analyzed was cultivar. A single digit code consisting of a 1 or 2 was assigned to each cultivar, Del Monte 1 and Green Giant 2. Minitab15 could then analyze and include cultivar in the stepwise regression. Given the chosen significance level of 95%, cultivar barely made the cut off of 0.050 with a p-value of 0.047. This supported earlier findings that cultivar did not make any significant change in daily gross yield and it was removed from the model.

Once this refining process was complete, another stepwise regression was conducted (Table 3). In this regression, MiniTab15 removed all variables except air maximum and ground maximum, in which it determined to be significant.

TABLE 3. Stepwise Regression for Asparagus Growth Model – Step 2

Step	1	2
Constant	-598.3	-786.2
Air Max (°F)	10.10	8.65
P-Value	0.000	0.000
Ground Max (°F)		4.80
P-Value		0.001
r^2 (adj)	63.33	65.61

By analyzing the p-values, significance is confirmed by the values being below the threshold of 0.050, given our desired confidence level of 95%. The net regression coefficients have logical influences on daily gross yield and the r^2 (adj) is higher with both variables included. As a result, step 2 is selected as the best fit.

The two independent variables: maximum air temperature and maximum ground temperature were then analyzed using the multiple linear regression function within MiniTab15. It was at this time that the program determined a regression equation with logical coefficients and an accepted r^2 (adj.) of 65.6%. The program also flagged eight (points of data) observations within the original data set to have large residuals or variance from the regression line, ranging from -112 to 147. These individual points were then removed from the data set with justification based on the random uncontrolled environmental variations within agriculture. This process was repeated twice in which a total of 16 data points were removed from the original dataset of 160 points.

Model Specification

A multiple linear regression model was then developed to predict daily gross yield for asparagus given maximum daily air temperature and maximum daily ground temperature (≈8 in. depth) as predictors. The developed asparagus growth model is discussed within this section.

The multiple linear regression model was used based on its ability to calculate the amount of change in the gross yield associated with the units of change in air temperature and ground temperature. The following multiple linear regression model (Equation 2) was then determined by analyzing the harvest data within MiniTab15 which the results are contained in Table 4:

TABLE 4. Asparagus Growth Model Based on Temperature

$$(2) \qquad \text{Gross Yield (kg/ha)} = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2}$$

Variable	**Net Regression Coefficient**	**Decomposition (SSE_{Xi}/SSR)**
Constant	$\beta_0 = -741$	
X_{i1} = Air Max. Temp. (°F)	$\beta_1 = 8.07$	0.962
X_{i2} = Ground Max. Temp. (°F)	$\beta_2 = 4.74$	0.037
	$r^2 = 76.4\%$	

Since an acceptable r^2 of 76.4% was achieved and all computed coefficients have logical influences on daily gross yield, this model was accepted as the best fit to explain daily gross yield given maximum air and ground temperatures. At this time, a decomposition of the sum of squares was conducted to determine the significance of each included variable.

Based on the multiple regression equation, 76.4% of the variation in daily gross yield can be accounted for by maximum air temperature and maximum ground temperature. The results of the decomposition of the regression sum of squares revealed that within our asparagus growth model maximum air temperature accounted for 96.2% of the variation and maximum ground temperature for 3.7% of the variation in daily gross yield.

It is important to note the relevant range of this asparagus growth model. When using regression models for prediction it is important not to exceed this relevant range. For this model, the relevant range was determined to be 67.8 to 86.5°F for maximum air temperature and 58.5 to 67.3°F for maximum ground temperature. It is possible that gross yield has a point of diminishing returns at some given point and predictions should not be made outside of these relevant ranges.

CHAPTER 4

SUMMARY AND CONCLUSIONS

As a result of increased labor costs and current trade policies, the U.S. asparagus industry has seen a significant decline. Over the past two decades, imports within the U.S. for asparagus have been increasing to meet the demand as per capita consumption increases, while production has shown a dramatic decrease. Since these known influencing factors do not show signs of change in the near future to benefit the U.S. asparagus industry, it is in our best interest to find alternative solutions and search for an answer to keep as much of the industry as we can within our borders. One of these solutions is the mechanization of current asparagus harvesting methods supported by the economic analysis. Another solution, spawned by the economic analysis and mechanical asparagus harvester trials is the development of this asparagus growth model.

Since it is unlikely the U.S. asparagus industry will switch over to the adaptation of selective mechanical harvesting in the near future, it will be necessary to have tools available to aid in the transition. Because asparagus can be harvested on a daily basis, this model will help a grower determine whether hand harvesting or mechanical harvested is best suited for that day. Further, if a grower is able to anticipate harvest yields based on specific factors such as ground and air temperature, they can use this model as a predictor of the yield. Predicting yield will be a major factor in determining whether it is worth investing in mechanical harvesting equipment as compared to employing labor.

It is out of this necessity that this research focuses on the development of the asparagus growth model. By having yield prediction tools available, growers will be better able to determine whether or not yields for a given day warrant the use of a hand crew or mechanical harvester, therefore aiding in the transition of phasing out hand crews and adapting the selective mechanical harvesters.

This research focused on the development of management and decision making tools for U.S. asparagus growers. This information will provide a tool for asparagus growers to more accurately predict their daily gross yields. As a result asparagus growers will be able to make better economic decisions when producing asparagus. This model was formatted so that asparagus growers can easily enter environmental input measurements and acquire an estimated gross yield output.

Suggestions for Further Research

Throughout the research and experimentation that was conducted in the completion of this project, several factors were noted that could better aid in the development of this model. This chapter discusses those noted factors in detail.

The first area noted, was in the data collecting stage of this research. This inability of our self emptying rain gauge to maintain its accuracy throughout the duration of the research forced us to remove precipitation as a growth determining factor within the asparagus growth model. This error was attributed to the wind and sand that was forced into the gauge housing and plugged up the sensor system. It would be advisable to design and create a wind and debris shield for the sensor cup. This would allow the sensor to function free of error caused by the wind and sand. If accurate measure of precipitation can be obtained, this element could then be added to the stepwise regression and a determination of significance could then be obtained. This process would then be able to definitively remove or add precipitation to the asparagus growth model.

Another area of improvement noted within the research process was the use of a 9" pay weight instead of gross yield as the dependant variable *Y*, within the asparagus growth model. It was decided that the best way to use the collected data was to use a consecutive set of days in which a dependant variable, gross yield, was collected against independent variables such as temperatures, wind speed, solar radiation, etc. Unfortunately as the mechanical harvesters encountered unpredictable malfunctions, down days occurred where data was only collected on a gross yield basis and was not graded out to reflect a 9" pay wt. This made for an inconsistent data set and as a result the 9" pay weight was replaced with the more constant dataset comprised of daily gross yield.

Expanding the model to include a wider range would also benefit this asparagus growth model. The final asparagus growth model determined for this research and dataset can only be deemed accurate for the range of variables used to develop the model. For this model and dataset the accuracy rage for the two significant variables were 67.8-86.5°F for maximum air temperature and 58.5-67.3°F for maximum ground temperature. Due to complications in the weather station and harvester data collection gaps, a consistent dataset was not obtained until the second half of the Washington State asparagus season. For future research and a more developed asparagus growth model, data should be accurately collected and recorded throughout the entire harvest season.

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