Choice of Optimal Planting and Marketing Decisions for Fresh Vegetable Producers: A Mathematical Programming Approach

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Abstract

This study combines whole farm economic analysis with biophysical simulation techniques in order to achieve a twofold objective. First, the study seeks to develop a multiple enterprise vegetable farm model with a production and marketing decision interface and, second, to determine optimal production practices for Kentucky vegetable growers. Three vegetable crops are examined: tomatoes, bell peppers and sweet corn. The findings indicate that the risk associated with vegetable production can be significantly mitigated with diversification of production mix and with a greater number of transplanting dates. However, this reduction in risk comes at a high cost in terms of expected net returns.

Key Words: vegetable production, mean-variance, biophysical simulation, farm management

JEL Classifications: C61, C63, D81

Introduction

Farming and agricultural production in general are inherently risky and uncertain economic activities. USDA analysts and Hardaker et al. (2004) identify the following five broad sources of risk faced by producers and/or farm decision makers: 1) production risk, 2) price risk, 3) financial risk, 4) institutional risk and 5) human or personal risk.

In addition to the above mentioned factors vegetable growers face, especially in the fresh market, increased uncertainty due to the perishable characteristics of their products (Ligon, 2001). This is because perishability leads to lower storing opportunities; thus, a famer is often compelled to accept the prevailing market price during or close to the harvesting period. A second explanation for the higher volatility associated with fresh vegetable prices relates to quality issues (Hueth and Ligon 1999(a), 1999(b)). Specifically, if the vegetable product does not reach the quality standards required by the buyer (i.e. consumers, retailers, intermediaries, etc.) the grower has to sell at a lower price. The importance of this factor is even greater as consumer expectations regarding food safety and quality have risen during recent years. A third reason for the price uncertainty of vegetable production is related to policy measures. In detail, due to the absence of traditional policy measures such as price and income support programs from the federal government, growers depend heavily on market forces.

The preceding discussion highlights the fact that dealing with risk is an everyday challenge for the vegetable producers. Consequently, the ability to manage risk and enhance profitability is vital to the survival of individual farmers and for the growth of the industry in general.

In order to be able to efficiently tackle these issues, information regarding the economic consequences to producers of the farm management decisions they face is needed. Adequate examination of the topic requires consideration of several enterprises, production practices and the competition for resources such as land, labor and suitable field days across enterprises. Additionally, the interactions among marketing signals for timing of product sales are critical to economically successful operations.

The objective of the present paper is twofold. First, the study seeks to develop a multiple enterprise vegetable farm model with a production and marketing management decision interface focusing on economic optimization and, second, to determine optimal production practices. Mathematical programming modeling in conjunction with biophysical simulation techniques will be used to achieve these objectives.

The area of study for the present paper is Fayette County, Kentucky. Despite the fact that vegetable production in Kentucky was ranked as 41 out of 50 within U.S.A. based on the value of sales[1], the importance of specialty crops in the overall agricultural economy of the state is rising. Specifically, in contrast to the declining number of farms in Kentucky (from 91,198 farms in 1997 to 85,260 farms in 2007), the number of farms with some type of vegetable enterprise increased the same period from 1,086 to 2,123[2]. Likewise, there was a steady increase in the annual farm cash receipts from $8.7 million (1997) to $24.7 million (2007)[3], which, further underscores that vegetable production is a dynamic and growing sector in Kentucky.

However, it also indicates an opportunity for enhanced growth given that this represents a 51% increase in cash receipts per acre over a 10 year period which annualizes to a modest

[1] 2007 Census of Agriculture
[2] 1997,2002,2007 Census of Agriculture
[3] Vegetable and Melon outlook, ERS,USDA

growth of just over 4% annually or, slightly more than the inflation rate. Looking at the demand side, the percentage of adults who consumed vegetables three or more times per day in Kentucky is higher than the national average (29.4% compared to 26%). This, in conjunction with the growing interest among consumers for local products, due to the success of the Kentucky Proud program, highlight a great range of opportunities that producers can be benefit from.

Tomatoes, bell peppers and sweet corn are the enterprises that will be included in the proposed model. These vegetables were selected because they are among the top-ten vegetables produced in Kentucky, both in number of farms and in acres. Specifically, based on 2007 census of agriculture, sweet corn was ranked first among vegetables, in the examined region, in terms of acres and second in number of farms. Similarly, tomatoes were ranked first as far as farm number is concerned and third regarding acres. Finally, bell peppers were ranked ninth both in terms of acres and farm number.

Three main data sources are used in the paper. First, the required yield data are obtained with the use of biophysical simulation modeling. Second, price data are gathered from the Atlanta Agricultural Market Station (AMS). Finally, information regarding the different production practices for vegetables is obtained from the University of Kentucky Extension Service Bulletins.

The combination of biophysical simulation modeling and marketing risk for multiple vegetables constitute the main contribution of the present study to the literature. The findings of the paper will provide useful insights to producers. By answering several important questions. What is the optimal production mix? When should I plant? When should I harvest? The results may enable producers improve their economic outcomes.

Data Collection and Yield Validation

The present section has the following three objectives: 1) discuss the biophysical simulation model used for the estimation of production data, 2) illustrate how the biophysical simulation model was validated and, 3) describe the sources of data used in the study.

Production data estimation

One interesting strand of the applied economic/agricultural literature relates to efforts made by scholars with the goal of developing the most accurate possible model for yield forecasting. Following the previous literature (Walker, 1989, Gommes, 2006, Kauffmann and Snell, 1997) two of the most commonly used techniques for yield forecasting include statistical regression equations and simulation methods. The advantages and shortcomings of these two approaches have been discussed by several scholars (Walker, 1989; Kaufmann and Snell, 1997; Tannura et al., 2008; Jame and Cutforth, 1996).

Since the proposed study seeks to recommend an optimal planting schedule that will maximize farm net returns under different production practices and weather patterns, for a specific area, and in order to address data limitations a biophysical simulation model is used as a yield estimation approach (Dillon, 1991). Biophysical simulation techniques are extensively applied in the literature (e.g. Shockley et al., 2011; Deng et al., 2008; Jiang, 2009; Cristostomo et al., 1993).

Among the several biophysical models that have been developed and used , such as EPIC (Williams et al., 1984), APSIM (Keating et al.,2003) and ROTOR (Vereijken, 1997) the present study will use the Decision Support System (DSSAT v 4.0, Hoogenboom et al., 2003). DSSAT was selected for the following reasons: i) it is very well documented, ii) it has been used and

validated for a plethora of studies over the last 15 years and iii) it is well suited for the present study since it incorporates modules for the three examined vegetables (tomatoes, bell peppers, sweet corn).

The minimum data set required in order to generate yield estimates using DSSAT include weather data, soil data and production practices information. Daily weather data for 38 years and soil data for the examined area (Fayette County, Kentucky) were obtained from the University of Kentucky Agricultural Weather Center and from the National Cooperative Soil Survey of NRCS respectively. The most common soil type in the examined area was silty loams with deep and shallow silty loams best describing the area's soil types.

Based on the soil data gathered and following Shockley (2010) and Hoongeboom et al. (2004, Sbuild) the default soil types of DSSAT were modified in order to better depict the characteristics of Fayette County soil conditions. Soil color, runoff potential, drainage and percent slope were among the parameters modifies. The exact specifications of soil types are presented at Table 1. Weather data collection was finalized with the calculation of solar radiation from DSSAT weather module.

As far as the production practices are concerned, information about the three vegetables under consideration (tomatoes, bell peppers, sweet corn) was obtained from the University of Kentucky extension service bulletins (Coolong et al., 2010). Specifically, the production practices examined include eight biweekly planting dates and three harvesting dates for tomatoes, 10 weekly planting dates and 3 harvesting dates for bell peppers and 8 weekly planting dates and one harvesting date for sweet corn. One variety was examined for all three crops

because only one was available from DSSAT v4. Detailed information about the production practices examined is presented in Table 2.

Besides the data requirements for the biophysical simulation model the following supplementary data were needed in order to achieve the objectives of the present study: 1) price data for the examined vegetables, 2) suitable field days, 3) cost estimations and 4) land availability. Weekly price data for 12 years (1998-2010) were obtained from the Atlanta Agricultural Market Station. Regarding the suitable field days, following Shockley et al. (2011), the probability of not raining more than 0.15 inches per day over weekly periods for the 38 years of weather data available is first calculated. Those probabilities were multiplied with the days worked in a week and the hours worked in a day to determine expected suitable field hours per day. Lastly, information regarding land availability was obtained from the 2010 Kentucky Produce Planting and Marketing Intentions Grower Survey & Outlook.

Due to data limitation problems[4] two ad-hoc validation methods were used in the present paper. To begin with, the estimated yields were presented to Dr. Tim Coolong[5] and he was asked whether or not the estimated yields are a reasonable representation of reality based on his expert opinion. The parameters of the biophysical model were modified accordingly based on his recommendations. Moreover, the estimated trends were compared with existing literature. Table 3 presents a summary of the studies used for the validation of the simulated yields. Since the varieties and conditions examined were not the same, only the trends were compared and not the numerical values of the yields.

[4] The historical yield data available were too limited to do a validation through regression.
[5] Assistant extension professor, University of Kentucky.

Theoretical Framework

This section will provide the theoretical background for the economic model that will be implemented in the study. Mathematical programming formulations, in a whole farm setting, have been applied for more than 50 years in the agricultural economic literature (an early example is Heady, 1954). Among the major objectives that scholars seek to achieve when they use such techniques is to help producers answer important questions such as: What is the optimal crop mix? Should I invest in new technologies? What is the best rotation strategy? A review of related work is presented by Lowe and Preckel (2004).

An interesting modeling aspect of the whole farm analysis is associated with the efforts made to incorporate risk in the objective function. Several approaches have been developed to cope with this issue (Hardaker et al. 2004, Kaiser and Messer, 2011). Among the most often implemented techniques is the mean-variance (E-V) formulation originally developed by Markowitz (1952). Under the assumptions that more is preferred to less and that the decision maker is universally not risk preferring then the E-V rule states that "an alternative A is preferred to alternative B if $E(A) \geq E(B)$ and $V(A) \leq V(B)$ with at least one strict inequality" (Hardaker et al. 2004). One of the following conditions must be satisfied in order for the results of E-V analysis to be equivalent to expected utility theory: i) the utility function of the decision maker is quadratic, ii) normal distribution of outcomes (net returns), iii) Meyer's location-scale condition or iv) the utility function can be truncated after the second-order moment of its Taylor series (Dillon, 1999, Kaiser and Messer, 2011).

Among the most commonly used methods to generate E-V efficient frontiers is quadratic programming. The formulation of a quadratic risk programming model can follow a number of

alternative options (Hardaker et al. 2004). The present study utilizes a formulation consistent with Freund (1956).

Empirical Framework

This section will discuss in detail the formulation of the economic model that is used in this paper. Specifically, an E-V formulation will be used to depict the economic environment of a hypothetical fresh vegetable farm in Fayette County, Kentucky. In line with Dillon (1999) the proposed model incorporates accounting variables as well as endogenous calculation of net returns variance instead of a variance-covariance matrix.

The objective function (O.F.) of the proposed model is the maximization of net returns ($\bar{Y}$) over selected costs, less the risk aversion coefficient (Φ) multiplied by the variance of net returns. Φ is the measure of risk aversion for the hypothetical producer and will be estimated following the approach developed by McCarl and Bessler (1989). The model includes constraints regarding suitable field days, land availability, marketing and input purchases. The specification of the model follows:

(1) $\mathrm{MAX}\ \bar{\mathrm{Y}} - \Phi\sigma_{\mathrm{y}}^{2}$

(2) $$\sum_{TTD}\sum_{TH} T_{TTD,TH,S} + \sum_{BTD}\sum_{BH} BP_{BTD,BH,S} + \sum_{P} SC_{P,S} \leq ACRES_S$$

(3) $$\left(\sum_{TTD}\sum_{TH}\sum_{S} LABT_{TTD,TH,WK}\, T_{TTD,TH,S}\right) + \left(\sum_{BTD}\sum_{BH}\sum_{S} LABBP_{BTD,BH,WK}\, BP_{BTD,BH,S}\right)$$
$$+ \left(\sum_{P}\sum_{S} LABSC_{P,WK} SC_{P,S}\right) \leq FLDDAY_{WK,}\ \forall\, WK$$

$$(4i)\ \sum_{TTD}\sum_{TH}\sum_{S} TEXPYLD_{YR,TS,TTD,TH,WK}T_{TTD,TH,S} - TSALES_{TS,YR,WK} = 0,\ \forall\, TS, WK, YR$$

$$(4ii)\ \sum_{BTD}\sum_{BH}\sum_{S} BPEXPYLD_{YR,BPS,BTD,BH,WK}BP_{BTD,BH,S} - BPSALES_{BPS,YR,WK} = 0,$$

$$\forall\, BPS, WK, YR$$

$$(4iii)\ \sum_{P}\sum_{S} SCEXPYLD_{YR,P,S,WK} - SCSALES_{YR,WK} = 0, \forall\, YR, WK$$

$$(5i)\ \sum_{TTD}\sum_{TH}\sum_{S} TREQ_I T_{TTD,TH,S} - TPURCH_I = 0, \forall\, I$$

$$(5ii)\ \sum_{BTD}\sum_{BH}\sum_{S} BPREQ_I BP_{BTD,BH,S} - BPPURCH_I = 0, \forall\, I$$

$$(5iii)\ \sum_{P}\sum_{S} SCREQ_I SC_{P,S} - SCPURCH_I = 0, \forall\, I$$

$$(6i)\ \sum_{I} IP_I TPURCH_I - \sum_{TS}\sum_{WK} P^{TS} TSALES_{TS,YR,WK} + TNR_{YR} = 0, \forall\, YR$$

$$(6ii)\ \sum_{I} IP_I TPURCH_I - \sum_{BPS}\sum_{WK} P^{BPS} BPSALES_{BPS,YR,WK} + BPNR_{YR} = 0, \forall\, YR$$

$$(6iii)\ \sum_{I} IP_I SCPURCH_I - P^{SC} SCSALES_{YR} + SCNR_{YR} = 0, \forall\, YR$$

$$(7)\ \sum_{YR}\frac{1}{N} TNR_{YR} + \sum_{YR}\frac{1}{N} BNR_{YR} + \sum_{YR}\frac{1}{N} SCNR_{YR} - \bar{Y} = 0$$

$$(8i)\ TSOILRATIO_{"SSL"}T_{TTD,TH,S} - TSOILRATIO_{"DSL"}T_{TTD,TH,S} = 0, \forall\, S$$

$$(8ii)\ BPSOILRATIO_{"SSL"}BP_{BTD,BH,S} - BPSOILRATIO_{"DSL"}BP_{BTD,BH,S} = 0, \forall\, S$$

$(8iii)\ SCSOILRATIO_{"SSL"}SC_{P,S} - SCSOILRATIO_{"DSL"}SC_{P,S} = 0, \forall S$

Where, constraints include:

(2): Land resource limitation

(3): Weekly labor resource limitation

(4): Marketing balance by crop, crop size and year

(5): Input purchases by input

(6): Net returns by crop, crop size and year

(7): Expected profit balance

(8): Soil depth ratio

Activities include:

$\overline{Y}$: Expected net returns above selected costs (mean across years);

$T_{TTD,TH,S}$, $BP_{BTD,BH,S}$: Tomato and bell pepper production under transplant dates TTD and BTD, harvesting dates TH and BH, on soil depth S in acres;

$SC_{P,S}$: Sweet corn production under planting period P on soil depth S in acres;

$TSALES_{TS,YR,\ WK}$: Tomato sales in pounds by tomato size, year and week;

$BPSALES_{BPS,YR,\ WK}$: Bell pepper sales in pounds by pepper size, year and week;

$SCSALES_{YR}$: Sweet Corn sales in dozens of ears by year;

$PURCH_I$: Purchases of input I;

TNR_{YR}, $BPNR_{YR}$, $SCNR_{YR}$: Net returns above selected costs for tomatoes, bell peppers and sweet corn;

Coefficients include;

Φ: Risk aversion coefficient;

P^{TS}, P^{BPS}: Price for tomatoes and bell peppers for different sizes (TS,BPS) per pound;

P^{SC}: Sweet corn price per ear;

IP_I: Input price per input;

$TEXPYLD_{YR,TS,TTS,TH,S}$: Expected yield for tomatoes per size (TS), transplant date (TD), harvest period (TH) for year YR and soil depth (S) in pounds;

$BPEXPYLD_{YR,BPS,BTD,BH,S}$: Expected yield for bell peppers per size (BPS), transplant date (BTD), harvest period (BH) for year YR and soil depth (S) in pounds;

$SCEXPYLD_{YR,P,S}$: Expected yield for sweet corn per planting period (P) and soil depth (S) for year YR in dozens of ears;

$LABT_{TTD,TH,WK}$: Weekly labor requirements for tomatoes with transplant date (TTD) and harvest date (TH);

$LABBP_{BTD,BH,WK}$: Weekly labor requirements for bell peppers with transplant date (BTD) and harvest date (BH);

$LABSC_{P,WK}$: Weekly labor requirements for sweet corn with planting date (P);

$FLDDAY_{WK}$: Weekly available field days at various probabilities;

$TREQ_I$, $BPREQ_I$, $SCREQ_I$: Input requirements for tomatoes, bell peppers and sweet corn respectively;

$SOILRATIO_S$: Ratio of total acres allocated to each soil depth

Indices include:

T,BP,SC: Tomato, bell pepper and sweet corn;

TTD,BTD: Tomato transplant date and bell pepper transplant date respectively;

BPS,TS: Bell peppers and tomatoes marketing size (medium, large, extra large);

P: Sweet corn planting date;

S: Soil depth (DSL or SSL);

I: Input;

YR: Year

WK: Week

N: number of years

Results

The results obtained from the mean-variance quadratic formulation, in conjunction with a discussion about them, are presented in this section. In addition to the risk neutral case, nine levels or risk aversion were examined. Each of these corresponds to 5% increments from the previous one, starting from 50% (risk neutral) until 95% based on McCarl and Bessler's (1989) approach as discussed previously. Tables 4 and 5 report results for three of those nine risk levels:

low (65% significance level), medium (75% significance level) and high (85% significance level) risk aversion, as well as for the risk neutral case. The selection of the previously mention risk aversion attitudes was made in order to better depict the changes that take place in the optimal planting decisions and in the economic outcomes as the risk aversion level increases.

To begin with, in line with the underlying theory, net returns above variable costs are negatively related with the risk aversion levels (Table 4). An interesting finding relates to the comparison among net returns for the different risk aversion levels. For example, the mean net returns for a highly risk averse grower correspond to 84% of the risk neutral case, while for the low risk aversion scenario correspond to 92%. However, the risk neutral case is associated with relatively high values of standard deviation and coefficient of variation (almost two times greater than the highly risk averse case). The high volatility of fresh vegetable prices is a main reason for these observed differences. For instance, the coefficient of variation (C.V.) for tomato prices if transplanting date is July 10 and harvesting period 77 days is 38.5% in contrast to 6.7% for yields. Similarly, for 77 days harvesting and transplanting date July 10 the C.V. is equal to 17% and 7.6% for prices and tomato yields respectively.

Furthermore, a comparison of the estimated net returns above variable costs from our model (Table 4) with the 2008 vegetable budget, developed from the University of Kentucky Extension service, results in some thought provoking observations. Specifically, the estimated net returns (on a per acre basis) are from three (highly risk averse) to four times (risk neutral) greater than the ones reported on the 2008 vegetable enterprise budget. This difference can be attributed to several factors. First, the estimated yields from the biophysical simulation are substantially higher compared the ones in the enterprise budget (i.e. for tomatoes for the 77 days harvest period the average number of 25 pound boxes is 2440 compared to 1600 boxes used in

the enterprise budget). This difference in the yields can be attributed to the fact that biophysical simulation represents yields that may be achieved by best of vegetable growers in Kentucky. Second, the AMS price per box for each of the examined vegetables is higher than the price per box used in the vegetable budgets. For example the weighted average price for tomatoes from AMS is $14 per 25 pound box, while the price used by the enterprise budgets is $8.5 per 25 pound box. Third, due to data limitation our model does not include a capital constraint. The inclusion of such a constraint may alter the optimal results. However, these differences can act as a further indication of the potential that vegetable production has in Kentucky.

The results regarding the optimal planting schedule and production mix are reported at Table 5. The findings of the optimization model suggest that the risk neutral growers should focus solely on tomato production rather than a mix with corn and bell peppers. However, as risk aversion level increases we notice changes both in the production mix and in the optimal transplanting schedule. As far as the former is concerned, instead of a tomato monoculture the model indicates as optimal mix a combination between tomatoes and bell peppers. Regarding the latter the increase in the risk aversion levels results in two changes. First, the number of selected planting dates increases from three (risk neutral and low risk) to four (medium and high risk aversion) for tomatoes and from one planting date (low and medium risk) to three planting dates (high risk) for peppers. Second, there is a transition towards earlier planting dates for tomato. Specifically, instead of July 10 and July 24 (risk neutral case) the model distributes the highest number of acres to June 12.

The selection of tomatoes as a main enterprise, regardless of the risk aversion level, is not considered as a surprise especially if we take into account the high value of tomatoes and their overall significance in the Kentucky vegetable production. Furthermore, the low correlation

coefficient between tomatoes and bell peppers estimated yields (0.357) and the fact that bell peppers are also a high value crop explain the inclusion of bell peppers in the optimal production mix for risk averse growers. Tomatoes and sweet corn have even lower correlation coefficient (0.02) mainly because the two crops belong into different biological families. However, sweet corn is a low profit per acre crop and less work intensive compared to tomatoes and bell peppers. As a result, it is more suitable for farms with larger amount of acres available. This is the main reason why the model did not select sweet corn.

Regarding the choice of optimal transplanting and harvesting schedules (Table 5) a number of interesting facts can be highlighted. To begin with, for the risk neutral case, the suggested combinations (July 10, July 24 as transplanting dates and 77 dates of harvest) correspond to a mixture that can achieve the highest possible average price. However, this comes at a cost of greater risk and variability of net returns. On the other hand, for the risk aversion cases, the combination with the most acres of tomatoes suggested by the model, June 12 and 77 days harvesting period puts more emphasis on achieving higher yield and lower price variations. These factors explain the relatively high differences for mean net returns and coefficient of variation between the risk neutral and low risk aversion cases. Weighted average yield and prices for tomatoes, in conjunction with the Coefficient of variation (C.V.) values are reported in Table 6. As far as bell peppers are concerned, the mix of July 10 as transplant day and 70 days of harvest correspond to the highest possible combination of yield and prices (Table 7). However, as the risk aversion level increases the model recommends greater distribution of acres devoted to bell peppers among transplanting dates in order to mitigate the variation associated with prices.

Finally, for the case of tomatoes, the model always recommends as optimal harvesting period 77 days after transplant and 70 days for bell peppers (Table 5). The higher yields and

prices associated with these periods (in contrast with 63 and 70 days after transplant for tomatoes and 56 and 63 days for pepper) in conjunction with the minimal differences in variability explain this choice.

Conclusions

This study used a combination of biophysical simulation and mathematical programming modeling to estimate an optimization model that will provide some guidelines regarding the optimal production mix and planting decisions for vegetable production. Three different enterprises, tomatoes, bell pepper and sweet corn were considered in the analysis. The area of study was Fayette County, Kentucky.

Despite the difficulties related to data limitations the empirical results indicate that vegetable producers have the potential to improve their economic results if they follow a structured farm management plan. In detail, the findings indicate opportunities to mitigate risk by diversifying the optimal production mix and with a greater number of transplanting periods. However, this reduction in risk comes at a high cost in terms of expected net returns. On the other hand, the optimal production practices under risk neutrality indicated that monoculture of tomato can provide significant net returns if the grower is willing to accept the related risk. These findings and recommendations, although they must not be seen as a panacea, can provide useful information to vegetable growers in their continuous effort to better manage risk, improve and stabilize their farm income.

A limitation of this study is mainly associated with the nature of the biophysical simulation model used. Specifically, we had yield estimations only for one variety. Examination

of different varieties may lead to different results if we take into consideration the different performance each variety has under different weather patterns.

Finally, future research can use extensive field surveys with farm managers in order to obtain information regarding their actual economic performance and be able to validate or reject our findings.

References

Ciardi, J.A., C.S. Vavrina, and M.D. Orzolek. 1998. "Evaluation of Tomato Transplant Production Methods for Improving Establishment Rates". *Hortscience* 33(2): 229-232.

Coolong, T., R. Bessin, T. Jones, J. Strang, and K. Seebold. 2010. "2010-11 Vegetable Production Guide for Commercial Growers". University of Kentucky, Extension Service Bulletins (ID-36).

Crisostomo, M.F., R.O. Burton, A.M. Featherstone, and K.W. Kelley. 1993. "A Risk Programming Analysis of Crop Rotations Including Double-Cropping". *Review of Agricultural Economics* 15(3): 443-461.

Csizinszky, A.A. 1999. "Yield Nutrient Uptake of "Capistrano" Bell Peppers in Compost-Amended Sandy Soil". *Proc. Fla. State hort. Soc.* 112:333-337.

Deng, X., B.J. Barnett, G. Hoogenboom, Y. Yu, and A.G. Garcia. 2008. "Alternative Crop Insurance Indexes". *Journal of Agricultural and Applied Economics* 40(1): 223-237.

Dillon, C.R. 1999. "Production Practice Alternatives for Income and Suitable Field Day Risk Management". *Journal of Agricultural and Applied Economics* 31(2): 247-261.

Dillon, C.R., J.W., Mjelde, and B.A. McCarl.. 1991. "Biophysical Simulation Models: Recommendations for Users and Developers". *Computers and Electronics in Agriculture* 6(3): 213-224.

Freund, R.J. 1956. "The Introduction of Risk into a Programming Model". *Econometrica* 24(3): 253-263.

Gommes, R. 2006. “Non- Parametric Crop Yield Forecasting. A Didactic Case Study for Zimbabwe”. Paper presented at the EU/JRC meeting on Remote Sensing Support to Crop Yield Forecast and Area Estimates, 30 Nov. - 1 Dec., Stresa, Italy.

Hardaker, J.B., R.B.M., Huirne, J.R., Anderson, and G. Lien. 2004. *Coping With Risk in Agriculture,* 2nd.ed. Wallingford: CABI Publishing.

Heady, E.O. 1954. “Simplified Presentation and Logical Aspects of Linear Programming Technique”. *Journal of Farm Economics* 36(5): 1035-1048.

Hodges, L., D.C. Sanders, K.B. Perry, K.M. Eskridge, K.M. Batal, D.M. Granberry, W.J. McLaurin, D. Decoteau, R.J. Dufault, J.T. Garret, and R. Nagata. 1995. “Adaptability and Reliability of yield for four Bell Pepper Cultivars Across Three Southern States”. *Hortscience* 30(6): 1205-1210.

Hoogenboom, G., J.W. Jones, P.W. Wilkens, C.H. Porter, W.D. Batchelor, L.A. Hunt, K.J. Boote, U. Singh, O. Urgasev, W.T. Bowen, A.J. Gijsman,. A. du Toit, J.W. White, and G.Y. Tsuji. 2004. *Decision Support System for Agrotechnology Transfer (DSSAT V.4),* ICASA, IFDC.

Hueth, B., and E. Ligon. 1999 (a). “Agricultural Supply Response Under Contract”. *American Journal of Agricultural Economics* 81(3): 610-615.

—— . 1999 (b). “Producer Price Risk and Quality Measurement”. *American Journal of Agricultural Economics* 81(3): 512-524.

Huevelink, E. 1999 “Evaluation of a dynamic simulation model for tomato crop growth and development”. *Annals of Botany* 83: 413-422.

Jame, Y.W., and H.W. Cutforth. 1996. “Crop Growth Models for Decision Support Systems”. *Canadian Journal of Plant Science* 76(1):9-19.

Jiang, Q. 2009. “An Agro-Economic Model to Analyze Climate Change Impacts on Farmers’ Income”. Paper presented at the Australian Agricultural & Resource Economics Society’s Annual Conference, Feb. 11-13, Cairns.

Kaiser, H.M., and K.D. Messer. 2011. *Mathematical Programming for Agricultural, Environmental, and Resource Econmics.* Hoboken, NJ: John Wiley and Sons, Inc.

Kaufmann, R.K., and S.E. Snell. 1997. “A Biophysical Model of Corn Yield: Integrating Climatic and Social Determinants”. *American Journal of Agricultural Economics* 79(1): 178-190.

Keating, B.A., P.S. Carbery, C.L. Hammer, M.E. Probert, M.J. Robertson, Z. Holzworth, C. McLean, K. Verburg, V. Snow, J.P. Dimes, M. Silburm, E. Wang, S. Brown, K.L. Bristow, S. Asseng, S. Chapman, R.L. McCrown, O.M. Freebrain, and C.J. Smith. 2003. “An Overview of APSIM, a Model Designed for Farming System Simulation”. *European Journal of Agronomy* 18(34):267-288.

Ligon, E. 2001. “Contractual Arrangements for Fresh Produce in California”. *Agricultural and Resource Economics Update* 5(2):1-2.

Lowe, T.J., and P.V. Preckel. 2004. “Decision Technologies for Agribusiness Problems: A Brief Review of Selected Literature and a Call for Research”. *Manufacturing and Service Operations Management* 6(3): 201-208.

Markowitz, H. 1952. “Portfolio Selection”. *The Journal of Finance* 7(1): 77-91.

McCarl, B.A. and D. Bessler. 1989. “Estimating an Upper Bound on the Pratt Risk Aversion Coefficient When the Utility Function is Unknown”. *Australian Journal of Agricultural Economics* 33 (1):56-63.

McCarl, B.A., and T.H. Spreen. 1997. *Applied Mathematical Programming Using Algebraic Systems.* Department of Agricultural Economics, Texas A&M University, College Station TX.

Musser, W.N., and B.V. Tew. 1984. “Use of Biophysical Simulation in Production Economics”. *Southern Journal of Agricultural Economics* 16(1):77-86.

Schweers, V.H. and D.W. Grimes. 1976. “Drip and Furrow Irrigation of Fresh Market Tomatoes on a Slowly Preamble Soil: Part 1 Production”. *California Agriculture 30: 8-10.*

Shockley, J.M. 2010. “Whole Farm Modeling of Precision Agricultural Technologies”. Unpublished Ph.D dissertation. University of Kentucky, Dept. of Agricultural Economics.

Shockley, J.M., C.R. Dillon, and T.S. Stombaigh. 2011. “A Whole Farm Analysis of the Influence of Auto-Steer Navigation on Net Returns, Risk and Production Practices”. *Journal of Agricultural and Applied Economics* 43(1): 57-75.

Tannura, M.A., S.H. Irwin, and D.L. Good. 2008. “Weather, Technology and Corn and Soybean Yields in the U.S. Corn Belt.” Marketing and Outlook Research Report 2008-01, Department of Agricultural and Consumer Economics, University of Illinois.

Walker, G.K. 1989. “Model for Operational Forecasting of Western Canada Wheat Yield”. *Agricultural and Forest Meteorology* 44: 339-351.

Waterer, D.R. 1992. “Influence of planting date and row covers on yields and crop values for bell peppers in Saskatchewan”. *Can. J. Plant Sci.* 72: 527-533.

Williams, J.R., C.A. Jones, and P.T. Dyke. 1984. “A Modeling Approach to Determining the Relationship Between Erosion and Soil Productivity”. *Transactions of the ASAE* 27:129-144.

Williams M.M. 2008. “Sweet Corn Growth and Yield Responses to Planting Dates of the North Central United States”. *HortScience* 43(6): 1775-1779.

Williams, M.M., and J.L. Lindquist. 2007. “Influence of Planting Date and Weed Interference on Sweet Corn Growth and Development”. *Agronomy Journal* 99: 1066-1072.

Vereijken, P. 1997. “A Methodological Way of Prototyping Integrated and Ecological Arable Farming Systems (I/EAFS) in Interaction with Pilot Farms”. *European Journal of Agronomy* 7:235-250.

Table 1: Soil Characteristics

Soil	Color	Drainage	Runoff Potential	Slope (%)	Runoff Curve #	Albedo	Drainage rate
Deep Silty Loam (65%)	Brown	Moderately Well	Lowest	3	64	0.12	0.4
Shallow Silty Loam (35%)	Brown	Somewhat Poor	Moderately Low	9	80	0.12	0.2

Table 2: Summary of Production Practices Used in the Biophysical Simulation Model

1) Tomato Production Practices	
Transplanting date	May 1, May 15, May 29, June 12, June 26, July 10, July 24, August 7
Harvesting period	63, 70, 77 days after transplant
Cultivar	BHN 66
Actual N/week (lbs./acre)	10
Irrigation	Drip irrigation, 1 inch water/week
Plant population (plants/acre)	5,000
Transplant age	42 days
Planting depth	2.5 inches
Assumptions	Dry Matter = 6%, Cull ratio = 20%
2) Bell Pepper Production Practices	
Transplanting date	May 7, May 14, May 21, May 28, June 5, June 12, June 19, June 26, July 3, July 10
Harvesting period	56, 63, 70 days after transplant
Cultivar	Capistrano
Actual N/week (lbs./acre)	8 lb. 5 oz.
Irrigation	Drip irrigation, 0.5 inch water/week
Plant population (plants/acre)	14,500
Transplant age	52 days
Planting depth	3 inches
Assumptions	Dry Matter= 6%, Cull ratio =10 %
3) Sweet Corn Production Practices	
Planting Date	April 25, May 2, May 9, May 16, May 23, May 30, June 7, June 14, June 28
Harvesting Period	84 days after planting
Cultivar	Sweet corn cultivar of DSSAT v. 4
Actual N/week	2 applications of Ammonium Nitrate. One pre-plant (90 lb. actual N/acre) and a second 4 weeks after planting (50 lb. actual N/acre)
Irrigation	Drip irrigation, 1 inch water/acre
Plant Population (plants/acre)	20,000
Planting Depth	2 inches
Assumptions	Dry matter =24%, Cull ratio= 3%, Ear weight = 0.661 pounds

Table 3: Validation Studies

1) Tomato Validation Studies
Ciardi, J.A., C.S. Vavrina, and M.D. Orzolek. 1998. "Evaluation of Tomato Transplant Production Methods for Improving Establishment Rates". *Hortscience* 33(2): 229-232.
Huevelink, E. 1999 "Evaluation of a dynamic simulation model for tomato crop growth and development". *Annals of Botany* 83: 413-422.
Schweers, V.H. and D.W. Grimes. 1976. "Drip and Furrow Irrigation of Fresh Market Tomatoes on a Slowly Preamble Soil: Part 1 Production". *California Agriculture 30: 8-10.*
2) Bell Pepper Validation Studies
Csizinszky, A.A. 1999. "Yield Nutrient Uptake of "Capistrano" Bell Peppers in Compost-Amended Sandy Soil". *Proc. Fla. State hort. Soc.* 112:333-337.
Hodges, L., D.C. Sanders, K.B. Perry, K.M. Eskridge, K.M. Batal, D.M. Granberry, W.J. McLaurin, D. Decoteau, R.J. Dufault, J.T. Garret, and R. Nagata. 1995. "Adaptability and Reliability of yield for four Bell Pepper Cultivars Across Three Southern States". *Hortscience* 30(6): 1205-1210.
Waterer, D.R. 1992. "Influence of planting date and row covers on yields and crop values for bell peppers in Saskatchewan". *Can. J. Plant Sci.* 72: 527-533.
3) Sweet Corn Validation Studies
Williams M.M. 2008. "Sweet Corn Growth and Yield Responses to Planting Dates of the North Central United States". *HortScience* 43(6): 1775-1779.
Williams, M.M., and J.L. Lindquist. 2007. "Influence of Planting Date and Weed Interference on Sweet Corn Growth and Development". *Agronomy Journal* 99: 1066-1072.

Table 4: Net Returns by Risk Attitude

	Risk Neutral	Low Risk Aversion	Medium Risk Aversion	High Risk Aversion
Objective Function Value($)	98553.8	78435.3	70391.9	62403.9
Mean($)	98553.8	90706.2	87287	83368.3
Max($)	237689.97	151335.55	134210.61	125832.56
Min($)	29997.02	34096.55	34480.47	32955.09
Std. Dev.($)	44500.99	26632.66	23598.45	21208.05
Coeff of Var.	45.15	29.36	27.04	25.44

Table 5: Summary of Production Practices by Risk Attitude

	Tomatoes				Bell Peppers			
Risk Levels	Planting Day	Harvesting Period	Acres		Planting Day	Harvesting Period	Acres	
			DSL	SSL			DSL	SSL
Risk Neutral	June 12	77	0.561	0.302				
	July 10	77	1.359	0.732				
	July 24	77	1.330	0.716				
Low Risk Aversion	June 12	77	1.365	0.735	July 10	70	1.189	0.640
	July 10	77	0.589	0.317				
	July 24	77	0.107	0.0057				
Medium Risk Aversion	May 29	77	0.244	0.132	July 10	70	1.245	0.67
	June 12	77	1.359	0.732				
	July 10	77	0.087	0.047				
	July 24	77	0.301	0.162				
High Risk Aversion	May 29	77	0.215	0.116	June 19	70	0.470	0.253
	June 12	77	1.360	0.733	June 26	70	0.056	0.030
	June 26	77	0.120	0.065	July 10	70	0.816	0.431
	July 24	77	0.212	0.114				

Table 6: Tomato yields and prices for selected transplant days and harvest periods

		Price ($/25 pound boxes)			Yield (pounds)		
Transplant Day	Harvest Period	Weighted Average	Std. Dev.	Coeff. of Var.	Weighted Average	Std. Dev.	Coeff. of Var.
June 12	77 days	13.5	0.09	0.167	50484	4054.6	0.076
July 10	77 days	16.25	0.25	0.385	48568	2944	0.067
July 24	77 days	17	0.24	0.35	42310	3796	0.089

Table 7: Bell pepper yields and prices for selected transplant days and harvest periods

		Price ($ per 1 1/9 bushel boxes)			Yield (pounds)		
Transplant Day	Harvest Period	Weighted Average	Std. Dev.	Coeff. of Var.	Weighted Average	Std. Dev.	Coeff. of Var.
June 19	70	10.89	1.353	0.120	17440	3740	0.21
June 26	70	10.95	1.4	0.122	17842	3147	0.17
July 10	70	12.9	2.7	0.206	17555	3125	0.17