A MATHEMATICAL PROGRAMMING MODEL FOR VEGETABLE ROTATIONS

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Abstract

Rotations have historically been used to alleviate pest problems in crop production. This paper considers methods of modeling rotations in linear programming models for Southeastern vegetable production. In such models, entering each possible crop rotation as a separate activity can be burdensome because of the large numbers of possible rotational alternatives. Conventional methodology for double crop rotations reduces the number of activities but must be adapted to accommodate triple crop rotational requirements in vegetable production. This paper demonstrates these methods both for a simple example and an empirical problem with numerous rotation alternatives. While the methods presented in this paper may have computational disadvantages compared to entering each rotation as a separate activity, they do have advantages in model design and data management.

Key words: rotations, mathematical programming, vegetables.

Vegetable production in the Southeast has historically been limited by unfavorable climatic conditions. While annual precipitation is adequate for multiple cropping, the distribution of the precipitation is often skewed. As a result, the area experiences frequent periods of drought that severely limit vegetable production. The development of new irrigation technology has helped alleviate the problem of irregular rainfall patterns (Tew et al.). However, disease and insect pressures remain a serious problem for Southeastern producers. One traditional management practice to mitigate pest problems is crop rotations. The vegetable rotation problem is similar but more complicated than rotating field crops. Rotational benefits are realized from eliminating continuous production of a particular crop and sequential production of vegetable crops with similar biological characteristics. A complicating analytical problem is the larger number of potential crops including multiple planting and harvesting dates for each crop. Furthermore, the potential for multiple cropping results in a rotation problem within each production year.

This paper presents a generalization of standard rotation methodology for firm mathematical programming models of the vegetable production situation. Problems were encountered with the conventional methodology for modeling rotations in programming models when an empirical model was being developed. The classic method of entering each rotation as a separate activity originally suggested by Hildreth and Reiter would have required a large number of activities due to the large number of vegetable alternatives being considered. While large models are compatible with the capacity of current linear programming computer software, model formulation, and data management problems existed. Another standard method utilized to model double crop small grains and row crops involves the use of land precedent constraints to require the second crop to be preceded by a first crop (McCarl et al. is an example of numerous applications of this method). However, this method has to be adapted to accommodate triple crop rotations. This paper presents a generalization of these methods which accommodates triple crop rotations without entering each

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rotation as a separate activity. Some preliminary results of vegetable research in Georgia are included to illustrate the methodology.

METHODOLOGY

The methodology presented in this paper reflects multiple planting dates for vegetable crops and the potential for triple crop production in the Southeastern United States. Multiple planting dates for each crop and different crops are accommodated in this research by dividing the growing season into production periods and including a land use constraint for each period similar to the standard treatment of labor availability. While many rotational assumptions are possible, this research based rotations on crops with similar botanical characteristics, which are identified as *vegetable families*. The basic rotational assumption in the model is that crops within a vegetable family are not repeated during a single year's growing season.

This rotation assumption is modeled with multiple activities for most crops and a set of rotation constraints. Multiple activities are required for each crop which has a feasible succeeding crop in a rotation; a separate activity must be included for each family which can succeed the crop. Also, idle activities must be included for each family for each period before the final planting period for a crop in that family. Families which have potential second crops in a triple crop rotation require separate idle activities for each preceding family of crops. Rotation constraints for each family are necessary for every production period from the second to the final period which the crop can be planted. Families which include potential second crops in a triple crop rotation require a set of these rotation constraints for each preceding family of crops.

A simplified example of a vegetable rotation model is presented in this section to illustrate the methodology previously outlined. For simplicity, three production periods, which are defined by harvesting of the previous crop, planting the current crop and subsequent planting, are assumed for a 1-year planning horizon. Crop activities for the example are listed in Table 1. Broccoli and cabbage are produced in periods one and three, snapbeans in periods one, one—two, and three while squash is produced in periods one and two. Under the rotation assumption, four triple crop rotations are feasible for the alternatives in Table 1 — cabbage-squash-snapbeans, broccoli-squash-snapbeans, snapbeans-squash-broccoli, and snapbeans-squash-cabbage. Fifteen double crop rotations are also feasible. Some of these rotations, such as BR1-SB3, have an idle production period so that idle activities are included to allow for these rotations. These idle activities are identified by the specific family or families of crops to be subsequently planted.

The three sets of constraints utilized in the model are listed in Table 2. Land constraints control land use in each production period. The second set represents the constraints with a single family name and they are utilized for modeling the rotation of families of crops which can only be the terminal crop in a triple crop sequence. Two constraints for Legumes and Brassica are necessary because both can be planted in the third period. These constraints are similar to precedent constraints used in machinery planning models (Danok et al.). The third set of constraints is used to control rotations of squash which is the potential second crop in a triple crop

TABLE 1. ACTIVITIES FOR EXAMPLE OF VEGETABLE ROTATION MODEL

Production alternative	Family	Production period	Symbol
Broccoli	Brassica	One	BR1
Broccoli	Brassica	Three	BR3
Cabbage	Brassica	One	CA1
Cabbage	Brassica	Three	CA3
Snapbeans	Legume	One	SB1
Snapbeans	Legume	One and two	SB12
Snapbeans	Legume	Three	SB3
Squash	Cucurbit	One	S1
Squash	Cucurbit	Two	S2
Idle	Brassica	One	IB1
Idle	Brassica	Two	IB2
Idle	Legume	One	IL1
Idle	Legume	Two	IL2
Idle	Cucurbit-Legume	One	ICL1
Idle	Cucurbit-Brassica	One	ICB1

Table 2. Constraints for the Example Vegetable Rotation Problem

Resources	Period of constraint	Symbol
Land	One	LD1
Land	Two	LD2
Land	Three	LD3
Legumes	Two	L2
Legumes	Three	L3
Brassica	Two	B2
Brassica	Three	B3
Cucurbits following legumes or idle	Two	LC2
Cucurbits following brassica or idle	Two	BC2

Table 3. Schematic of Vegetable Rotation Tableau[a]

	BR1L	BR1C	CA1L	CA1C	SB1B	SB1C	SB12B	S1L	S1B	S2B	S2L	BR3	CA3	SB3	IB1	IB2	IL1	IL2	ICL1	ICB1	RHS[b]
LD1	+1	+1	+1	+1	+1	+1	+1	+1	+1						+1		+1		+1	+1	≤ LN
LD2							+1			+1	+1					+1		+1			≤ LN
LD3												+1	+1	+1							≤ LN
B2					−1				−1						−1	+1					≤ 0
B3							−1			−1		+1	+1			−1					≤ 0
L2	−1	−1						−1									−1	+1			≤ 0
L3											−1			+1				−1			≤ 0
LC2						−1				+1										−1	≤ 0
BC2		−1		−1							+1								−1		≤ 0

[a] Symbols on activities after the numbers refer to succeeding land use—L for Legume, C for Cucurbit and B for Brassica.

[b] Available land equals LN.

rotation. To maintain the rotation assumption, the previous land use, either Legumes in LC2 or Brassica crops in BC2, must be modeled. Only one time period is necessary for each of these constraints since squash is not planted in period three. These constraints also allow idle land use, ICL1 and ICB1, to precede squash.

The use of these activities and constraints in the model are illustrated in Table 3. Multiple entries for each of the activities in Table 1 are necessary when alternative families of crops can succeed the particular crop. For example, broccoli and cabbage in the first period can be succeeded by cucurbit or legume crops in subsequent periods. Thus, BR1L and CA1L both have −1 entries in L2, and BR1C and CA1C have −1 entries in BC2. Similarly, SB1B and SB1C have −1 entries in B2 and LC2, respectively, and S1L and S1B in L2 and B2, respectively. Crop activities planted after period one have positive entries in the rotation constraints. Squash, the potential second crop, has multiple activities—S2B and S2L have −1 entries in B3 and L3, respectively. The triple crop is modeled with a +1 in BC2 for S2L and in LC2 for S2B. Crops with only terminal positions in potential rotations have only one activity with a +1 and no −1 in a rotation constraints—BR3, CA3, and SB3 have +1 entries in B3, B3, and L3, respectively.

Idle activities are used to model rotations with no production in the first and/or second periods. IB1, IL1, ICL1, and ICB1 have +1 entries in LD1 and −1 entries in B2, L2, BC2, and LC2, respectively. These activities allow production of crops in the second period without production in the first; for example, ICL1-S2L-SB3 is a feasible rotation. Similarly, idle activities in the second period, IB2 and IL2, transfer rotation capacity from the second to the third period, and provide for rotations with no production in the second period. Idle activities for the second period allow rotations with idle land in the second period, such as BR1L-IL2-SB3, and with idle land in the first and second periods, such as IB1-IB2-CA3.

One interesting feature of the model is that potential second crops in a triple crop rotation also can be included in the solution as single crops or double crops. Squash as a single crop could be modeled as either ICL1 and S2L or ICB1 and S2B. Examples of squash as a second crop in a double crop rotation are BR1C-S2L, CA1C-S2L, and SB1C-S2B. Similarly, ICL1-S2L-SB3, ICB1-S2B-BR3, and ICB1-S2B-CA3 are feasible double crop rotations with squash being the first crop.

The methods in this section do not create a smaller tableau for this example. Under the conventional methods of each rotation being a single activity, the 9 single crop, 15 double crop and 4 triple crop rotations would require 28 activities and one land constraint. In contrast, the tableau in Table 2 has 20 activities and nine constraints. However, more realistic problems which include several crops in all the families and more production periods result in more savings in tableau size. The subsequent sections of this paper demonstrate this proposition.

DATA

Most past vegetable production research in Georgia has included few rotations. Usually, vegetables with predominantly regional and ethnic markets such as greens and Southern peas were included. Due to the limited market potential for these crops, more recent research efforts have included vegetables with national markets. Recent research efforts also indicate that alternative planting and harvesting dates may facilitate entry into the national markets for Southeast producers (Tew et al.).

Production data for this study were obtained from a specially designed 1982 experiment including only vegetables with national markets, with several planting dates for most vegetables. Vegetables included in this study were divided into five family groups. The Legume family contained snapbeans and lima beans. The Cucurbit family included watermelons, squash, cucumbers, and cantaloupes. The Brassica family contained broccoli and cabbage, while the Capsicum family included green peppers and eggplant. Sweet corn was also included with no rotational requirements since sufficient production technology has been developed for this crop to preclude such requirements.

This research examined commercial production of these vegetable crops in single and multiple cropping sequences. Production data were obtained from experiments on Lakeland Sand soil, which is a deep sand soil common in the Southern Coastal Plain. Tillage, harvesting, packing, and grading operations were budgeted on the basis of normal farm operations. All budgets were calculated using 1982 prices. The majority of input price information was obtained from input supply firms in the production area. Product prices were obtained from wholesale vegetable markets in the state, on a weekly or monthly basis by grade. Irrigation costs were based on a 50-acre, diesel powered center-pivot sprinkler system and were calculated using the Oklahoma State University Irrigation Cost Generator (Kletke et al.). Budgets for the crops were constructed using the Oklahoma State Budget Generator (Kletke).

The planning horizon from February 1 to November 2, 1982 was divided into seven time periods based on harvesting and subsequent plantings of potential second or third crops. These periods are included in Table 4 and consist of 1 or more weeks. Period one begins on February 1 and continues for 17 weeks until May 29 when a potential rotation may begin. The first possible crop to be planted after a harvest is Eggplant 3 on June 1 which may follow Broccoli 1, Cabbage 1, Squash 1, or Snapbean 1. Therefore, period two begins the week of May 30. The second, third, and sixth periods consist of only 1 week since at least one crop is harvested in the previous week and at least one is planted in the subsequent week. Of course, the more conventional method of using calendar time such as 1 week for constraints, could have been used, but more constraints would have been necessary.

Under the assumption that crops within a family cannot utilize the same land during the planning horizon, a total of 227 potential crop rotations can be enumerated from the crops in Table 4. These rotations include 34 single crops, 179 double crop, and 14 triple crop possibilities. An example of a double crop rotation would be lima beans followed by watermelons while cabbage-squash-snapbean is a triple crop example. Crops in Table 4 yielding negative net returns were considered unfeasible. Therefore, among the potential rotations, 30 single crops, 143 double crops, and 10 triple crops for a total of 183 were viable possibilities. Since Eggplant 3, the only crop planted between May 30 and June 5, was not viable, this time period was included in the first production period. The model therefore had six production periods and land constraints.

THE PROGRAMMING MODEL

Implementation of the rotation methodology presented in this paper was simplified by some of the characteristics of the crops in Table 4. Based on the rotational requirements and the six production periods, only Cucurbit group members could be the second crop in triple crop rotations. In particular, only Squash 3 and Cucumber 1 were planted after Land 1 and harvested in Land 4 and Land 5 allowing fall crops to be planted. Capsicum group members were not feasible in any triple crop because early crops were not harvested before Land 2 and later crops were not viable; similarly sweet corn was all planted in Land 1 and none harvested before Land 2. Thus, first and third crops in a triple crop sequence were limited to the Brassica and Legume families.

Similar simplifications exist for crops which can be included in double crop rotations. Both Capsicum crops and Sweet Corn are limited to first crops in these sequences; therefore, no provision has to be made for rotating land to these families. As in the earlier illustration, Legume and Brassica crops can assume either the first or second rotation positions and therefore require rotation constraints. Cucurbits present a special problem. Cucumber 1 and Squash 3 require treatment as second crops in triple crop sequences. However, Cantaloupe 3, Cantaloupe 4, Squash 4, and Watermelon 3 are potential second crops in double crop rotations. These two groups could either be treated as separate families for rotation purposes or the latter group treated as potential triple crops along with the former group. The first method would require extra activities for each potential preceding crop along with a separate set of Cucurbit rotation constraints while the second method requires sets of activities for the potential second crop groups Cucurbit alternatives. As the group of Cucurbit crops is much smaller than the group of preceding crops, the second method is utilized in the model.

The number of crop activities in the model for this empirical application is delineated in Table 5. The number of activities for each crop listed in Table 4 ranges from one to four. Broccoli 2, Lima Bean 3, Snapbean 3, and Snapbean 4, which have no succeeding crops in potential rotations have only one activity. Other Brassica and Legume crops, which are planted in the first period, have two activities because each can be succeeded by two crop families. Cucurbit crops planted

TABLE 4. GROWING SEASON AND NET RETURNS FOR SELECTED VEGETABLES IN GEORGIA, 1982

Vegetable family and crop		Planting dates	Harvest dates	Feb 1 to May 29 (LD1)	May 30 to June 5 (LD1)	June 6 to June 12 (LD2)	June 13 to July 3 (LD3)	July 4 to July 31 (LD4)	Aug 1 to Aug 7 (LD5)	Aug 8 to Nov 6 (LD6)	Net returns[a]
											(Dollars)
BRASSICA	Broccoli 1	2/1	4/30−5/12	X							202.88
	Broccoli 2	8/2	10/6−10/13						X	X	169.62
	Cabbage 1	2/2	5/24−5/27	X							4,957.48
CAPSICUM	Eggplant 1	3/1	5/26−6/28	X	X	X	X				1,071.51
	Eggplant 2	4/1	5/31−7/2	X	X	X	X				1,584.76
	Eggplant 3	6/1	7/16−9/7		X	X	X	X	X	X	−831.91
	Eggplant 4	7/6	8/18−9/27					X	X	X	−379.76
	Pepper 1	3/2	5/20−6/7	X	X	X					2,819.04
	Pepper 2	4/1	5/31−6/14	X	X	X	X				1,766.49
CUCURBIT	Cantaloupe 1	3/2	6/18−6/28	X	X	X	X				2,271.02
	Cantaloupe 2	4/1	6/30−7/6	X	X	X	X	X			1,508.51
	Cantaloupe 3	6/15	8/30−9/13				X	X	X	X	10.72
	Cantaloupe 4	7/6	9/10−9/29					X	X	X	783.15
	Cucumber 1	6/7	7/19−8/6			X	X	X	X		1,418.81
	Cucumber 2	8/1	9/13−10/1						X	X	−111.21
	Squash 1	3/2	4/26−5/14	X							1,394.25
	Squash 2	4/1	5/12−5/31	X	X						1,255.31
	Squash 3	6/7	7/12−7/30			X	X	X			751.31
	Squash 4	8/16	9/15−10/4							X	651.94
	Watermelon 1	3/2	6/21−6/28	X	X	X	X				1,973.04
	Watermelon 2	4/1	7/7 −7/12	X	X	X	X	X			2,945.04
	Watermelon 3	7/6	10/4					X	X	X	1,674.65
LEGUME	Limabean 1	3/2	6/11	X	X	X					2,312.35
	Limabean 2	4/1	6/25	X	X	X	X				1,446.42
	Limabean 3	8/2	10/19						X	X	727.57
	Limabean 4	8/10	11/2							X	−10.21
	Snapbean 1	3/2	5/13	X							235.09
	Snapbean 2	4/1	5/31	X	X						807.15
	Snapbean 3	8/2	9/24						X	X	959.73
	Snapbean 4	8/10	10/4							X	174.99
SWEET CORN	Corn 1	3/2	6/7	X	X	X					1,097.37
	Corn 2	3/15	6/10	X	X	X					1,206.79
	Corn 3	4/1	6/21	X	X	X	X				1,440.30
	Corn 4	4/16	6/28	X	X	X	X				358.09

[a] Net returns to land, labor, overhead, risk, and management.

in the first period similarly have two activities; the Cucurbit crops which potentially can be included in the triple crop rotations also have two activities because Legume and Brassica crops can precede them. Sweet corn and Capsicum crops all have three activities because they can be succeeded by Brassica, Cucurbit, and Legume crops. Finally, Cantaloupe 3, Cantaloupe 4, Squash 4 and Watermelon 3, which are potential second crops, have four activities because they can be preceded by all other families other than Cucurbits.

The number of idle activities listed in Table 6 also follows from the production characteristics of crops in Table 4. Five idle activities are necessary for Brassica and Legume crops because crops in each of these families are planted in the sixth period, and this set of idle activities allows these crops to be planted as single crops. Cucurbits are also planted in the sixth period so five Brassica-Cucurbit activities are included which jointly allow late single Cucurbit crops and Brassica-Cucurbit rotations. In contrast, the other Cucurbit idle activities did not have to accom-

TABLE 5. NUMBER OF CROP ACTIVITIES FOR EMPIRICAL MODEL, GEORGIA, 1982

Crop	Succeeding crops			Preceding crops for cucurbits after period 1				Number of activities
	Brassica	Legume	Cucurbit	Brassica	Legume	Capsicum	Sweet corn	
Broccoli 1		X	X					2
Broccoli 2								1
Cabbage 1		X	X					2
Eggplant 1	X	X	X					3
Eggplant 2	X	X	X					3
Pepper 1	X	X	X					3
Pepper 2	X	X	X					3
Cantaloupe 1	X	X						2
Cantaloupe 2	X	X						2
Cantaloupe 3				X	X	X	X	4
Cantaloupe 4				X	X	X	X	4
Cucumber 1				X	X			2
Squash 1	X	X						2
Squash 2	X	X						2
Squash 3				X	X			2
Squash 4				X	X	X	X	4
Watermelon 1	X	X						2
Watermelon 2	X	X						2
Watermelon 3				X	X	X	X	4
Lima Bean 1	X		X					2
Lima Bean 2	X		X					2
Lima Bean 3								1
Snap Bean 1	X		X					2
Snap Bean 2	X		X					2
Snap Bean 3								1
Snap Bean 4								1
Corn 1	X	X	X					3
Corn 2	X	X	X					3
Corn 3	X	X	X					3
Corn 4	X	X	X					3
Total								72

TABLE 6. NUMBER OF IDLE ACTIVITIES AND CONSTRAINTS FOR EMPIRICAL MODEL, GEORGIA, 1982

Activity or constraint	Periods	Number
Idle activities:		
Brassica	1-5	5
Legume	1-5	5
Brassica-Cucurbit	1-5	5
Legume-Cucurbit	2-5	4
Capsicum-Cucurbit	3-5	3
Sweet Corn-Cucurbit	3-5	3
Total		25
Constraints:		
Land	1-6	6
Brassica	2-6	5
Legume	2-6	5
Brassica-Cucurbit	2-6	5
Legume-Cucurbit	2-6	5
Capsicum-Cucurbit	3-6	4
Sweet Corn-Cucurbit	3-6	4
Total		34

modate single crops so fewer activities were necessary: four Legume-Cucurbit and three Capsicum-Cucurbit and Sweet Corn-Cucurbit idle activities are included because the earliest Legume crops are harvested in period one and the earliest Capsicum and Sweet Corn crops are harvested in period two. The provision for late single crop Cucurbits is arbitrary. Idle activities beginning in period one could have been included for any or all of the other Cucurbit family idle groups; however, a complete set for all groups would have introduced some redundant activities.

The number of constraints are also listed in Table 6 and are similar to the idle activities. Six land restraints are of course necessary. Five Brassica, Legume, Brassica-Cucurbit, and Legume-Cucurbit rotation constraints are necessary because preceding crops for all these groups are harvested in the first period and crops in these groups are planted in the sixth period. Capsicum and Sweet Corn crops are first harvested in the second period so only four Capsicum-Cucurbit and Sweet Corn-Cucurbit constraints are necessary.

For this empirical application, 72 crop activities, Table 5, and 25 idle activities, Table 6, were necessary for a total of 97 activities. This total is 39 percent of the 184 activities necessary to include all viable single crop, double crop and triple crop rotations as separate activities. The methods in this paper increase the number of constraints to model land use and rotations to 34, Table 6, compared to one under the conventional method. In contrast to the simpler example presented earlier, the methodology developed in this paper does significantly reduce the activities in this empirical example. As more alternatives in each family are included in the model, presumably more savings in activities and a minimal increase in constraints would occur.

A solution was obtained for the alternatives in Table 4 with the rotation methods presented in this paper. The optimal solution is a triple crop of Cabbage 1-Squash 3-Snapbean 3 with net returns of $6,669 per acre. These results can be easily reconciled with the budgetary data in Table 3. Cabbage is clearly the most profitable of all early crop alternatives. Squash 3 is less profitable than Cucumber 1. However, the combination of Squash 3 and Snapbean 3 yields total profits of $1,711 compared to $1,594 for Cucumber 1 and Snapbean 4. Profits from the second two crops in the optimal solution are greater than any single crop planted in Land 2 or later, although Watermelon 3 is nearly as profitable as Squash 3-Snapbean 3 and is superior to Cucumber 1-Snapbean 4. Like most programming solutions with limited constraints, this solution could have been obtained with budgetary analysis. However, when other realistic constraints such as labor availability, irrigation capacity, and/or market constraints are added to the model, the solutions will likely be more complex. For example, sufficient harvest labor may not be available for a large acreage of cabbage since it is harvested in the Spring.

CONCLUSIONS

The methodology presented in this paper represents an efficient method of accounting for land and rotational requirements in this example. This methodology could be expanded to encompass more complicated triple cropping alternatives. Potential second crops would have activities to reflect all families of preceding crops and additional rotational constraints would be necessary to model previous land use. Presumably, the methodology could also be generalized to quadruple crop rotations. If sufficient production data were available, the effect of rotations on yields and/or input costs for pesticides and/or fertilizers could be included instead of assuming equal net returns independent of preceding land use. Such a modification could require more constraints—previous land use would have to be modeled for all second and third crops rather than just second crops in the triple crop rotations as in this paper. The advantages of this method arise with large numbers of production alternatives and particularly with several crops in each rotational family. Thus, the methodology is probably useful only in situations with large numbers of vegetable alternatives. However, El-Nazer and McCarl recently demonstrated the use of similar methods for multi-year rotations of field crops.

It must be stressed that the advantages of these methods largely appear to be in model design and data management. Computational requirements would be less for the conventional method. The number of constraints are less since size of the basic matrix in the empirical application in the previous section would have been (34 activities by 34 land constraints) for this method compared to (1 activity by 1 land constraint) for conventional methods. Similar computational requirements would hold as more realistic constraints are added. However, computational requirements are not a serious problem with linear programming software except on some current microcomputers. The reduction in activities may also be an advantage for some microcomputer software packages—for example, Laughlin has developed a program with a maximum of 150 activities which would be met by these methods but exceeded by conventional requirements for 184 activities.

The advantages of these methods in this paper are readily apparent. With production data such as in Table 3, specification of the activities and constraints such as in tables 4 and 5 are quite straightforward. Only potential second crops in triple crop rotations must be identified along with families which can precede and succeed specific crops. In contrast, enumeration of all potential rotations can be tedious with a large potential for errors in omission. Combining resource requirements and objective functions of the component crops also creates potential for errors. Revision of objective functions and resource requirements of a crop can be accomplished with changes in activities rather than adjustments of rotational requirements and then changes in activities. Thus, the methods in this paper do have advantages but are not a panacea for all rotation problems.

Besides the need to consider labor availability, irrigation capacity, and market availability, a complete analysis of vegetable production combinations must consider the risks associated with these enterprises. Vegetable price variability associated with marketing windows in the Southeast is well known. Combined with production variability, movements in price can result in significant gross income variability. The differences in profits for Snapbean 3 and 4, which are planted 1 week apart, illustrate the risk problem. Of course, the risks associated with this production require several years of data to model this problem. For the example, in this paper, only data for 1 year were available. As more data become available, risks of vegetable production will be modeled. Methods developed in this paper would be especially useful for quadratic risk programming where activity numbers become increasingly important (McCarl and Tice).

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