RISK EFFICIENT PERENNIAL CROP SELECTION: A MOTAD APPROACH TO CITRUS PRODUCTION

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Abstract

Numerous studies have analyzed annual crop mix decisions in light of producer risk preferences. Few studies have focused on perennial crop mix decisions. This study attempts to identify not only the optimal mix of grapefruit and oranges for various risk-aversion levels, but also optimal planting densities within each species. Experimental plot data from a grapefruit and orange spacing trial over the 1970-82 period were used in a MOTAD formulation to address optimal perennial crop mix and planting density decisions under different capital constraints. An examination of results suggests crop mix and planting density diversification within and across species of citrus as a means of reducing income variability.

Key words: perennial crops, citrus, MOTAD, optimal mix, optimal density, risk.

The issue of crop diversification and producer decision behavior under risk and uncertainty in agriculture has received much attention in academic literature (Ratti and Ullah; Mapp et al.; Pope and Kramer; Anderson, Dillon, and Hardaker; Lin, Dean, and Moore). Generally, risk-efficient cropping patterns and diversification to manage risky alternatives have been discussed within the bounds of moving away from annual monoculture crop production and into alternative multicrop systems which may be more profitable or at least may have a greater profit potential. Due to the often risky nature of alternatives with greater potential returns, typical objectives have been to solve for the optimal production strategy under risk using such techniques as MOTAD (Brink and McCarl; Apland, McCarl, and Miller; Zimet and Spreen) or quadratic programming procedures (Falatoonzadeh, Conner, and Pope), or ranking alternatives with stochastic dominance procedures (Kramer and Pope; Rister, Skees, and Black). Less attention has been paid to perennial crops and attendant problems associated with decision making regarding optimal crop mix and planting density. The problem of perennial crops is fundamentally different from annual crop selection. This research is an attempt to address some of those differences.

Citrus producers in Florida and Texas are replanting large acreages due to loss of producing acreage from diseases and disastrous freezes in recent years. Several large producers and many smaller producers are moving towards higher than traditional tree densities for citrus (140-200 trees per acre vs. 100 trees per acre) in many new plantings (Hardy; Texas Dept. of Agr., 1987). The purpose of this study is to investigate the opportunities for selecting optimal citrus species mix and tree densities under risk. Specifically, this study examines the optimal crop mix of grapefruit and early oranges in a MOTAD framework (Hazell) for the Lower Rio Grande Valley of Texas (LRGV) where plant density of grapefruit and oranges is a decision variable affecting expected net returns and the variability of those returns. The expected returns from different planting densities has been investigated in other studies (Koo and Muraro; Teague, 1986). However, the decision to plant one density versus another has been treated as a mutually exclusive decision variable. This study attempts to identify not only the optimal mix of grapefruit and oranges for various categories of risk-averse producers, but also any efficiencies to be gained by allowing combinations of different planting densities within the species category. In addition, sensitivity of the optimal planting strategy to the availability of capital will be in-

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TABLE 1. SELECTED TREE DENSITIES AND SPACING CONFIGURATIONS FOR RUBY RED GRAPEFRUIT AND MARRS EARLY ORANGE

Species	Code	Trees Per Acre	Spacing
Grapefruit	G109	109	20 X 20
Grapefruit	G145	145	12 X 25
Grapefruit	G128	128	10 X 20
Grapefruit	G285	285	8.5 X 18
Oranges	O110	110	18 X 22
Oranges	O165	165	12 X 22
Oranges	O220	220	9 X 22
Oranges	O330	330	6 X 22

vestigated. The methodology used in this study is applicable to any perennial cropping alternative where plant density affects net returns, establishment costs, and capital requirements.

METHODOLOGY

Four spacings each of grapefruit and oranges were selected from two spacing trial experiments conducted at the Texas A&I University Citrus Center (Fucik, 1983 and 1984). These treatments were selected to represent a range of densities from traditional (lowest trees/acre) to very high tree densities (see Table 1). With the possible exception of the very high densities, this range of tree densities is representative of current planting patterns in the LRGV and Florida. Most current spacings fall in the moderate to high categories for both citrus species. All trees were planted in 1967 and harvest began in 1970. Yield samples were taken from each density plot each year from 1970 to 1982. Yields from these experimental plantings are given in Table 2. Following Anderson, Dillon, and Hardaker (p. 300) yields were transformed into net returns for each spacing in each year using equation 1 as follows:

(1) $NR_{ij} = P_j Y_{ij} - PC_{ij}$,

where NR_{ij} = net return for the i^{th} spacing in the j^{th} year, $j = 1970\text{-}1982$;

P_j = season average packing house door returns/carton for grape-

TABLE 2. YIELDS FOR SELECTED TREE DENSITIES OF GRAPEFRUIT AND ORANGES IN TONS PER ACRE

	Species/Density code							
Year	G109	G145	G218	G285	O110	O165	O220	O330
1970	10	13	20	23	3	4	4	7
1971	9	14	15	16	6	10	8	10
1972	20	22	25	19	10	15	13	13
1973	13	15	12	15	10	13	12	15
1974	12	17	20	8	13	13	16	14
1975	18	18	20	22	11	12	13	14
1976	27	28	32	32	7	12	12	13
1977	19	17	16	16	12	15	16	16
1978	18	21	22	22	12	17	16	18
1979	23	22	23	23	16	19	22	21
1980	18	17	20	20	10	13	12	15
1981	29	22	24	24	16	18	19	17
1982	14	16	13	13	8	12	11	14
Partial means								
Year 1-6	13.67	16.50	18.67	17.17	8.83	11.17	11.00	12.17
Year 7-13	21.14	20.43	21.43	21.43	11.57	15.14	15.43	16.29
Overall mean	17.69	18.62	20.15	19.46	10.31	13.31	13.38	14.38
Std. Dev.	6.14	4.17	5.41	6.01	3.73	3.84	4.61	3.48

(Note higher mean yields in early years with higher densities.)

fruit and oranges;

Y_{ij} = yield in cartons/acre for the i^{th} spacing in the j^{th} year; and

PC_{ij} = production cost/acre for the i^{th} spacing in the j^{th} year.

Prices for grapefruit and oranges were obtained from the *Fruit and Pecan Statistics* (Texas Dept. of Agr.). The prices are weighted average prices for grapefruit and oranges (respectively) for all uses (fresh and processing) equivalent to F.O.B. price/carton less processing charges. Production cost estimates were obtained using enterprise budgets for grapefruit and oranges for different tree densities (Teague, 1987) and were adjusted to reflect costs for the j^{th} year using the Producer Prices Paid Index (U. S. Dept. of Agr., 1983).

The net returns were adjusted for inflation (following Barry, Hopkin, and Baker) using the Producer Prices Received Index (U. S. Dept. of Agr.). The resulting streams of real net returns for each variety and density were used to compute a matrix of absolute deviations from mean net return over the study period which is utilized in the risk analysis. Table 3 gives the real net returns per acre for each year and the mean net return over the study period for each species and density.

A linear programming MOTAD model was constructed such that expected net returns above variable costs less the cost of risk bearing were maximized subject to resource and technical constraints. The objective function is expected net returns less the risk aversion coefficient times an approximation of the standard deviations of net returns as in Brink and McCarl or Apland, McCarl, and Miller. The model can be expressed as follows:

$$\text{maximize} \sum_{j=1}^{N} \bar{C}_j X_j - \phi\sigma,$$

subject to

$$\sum_{j=1}^{N} A_h X_j \ \{> \ = \ <\} \ B_h \quad h=1,\ldots,H,$$

$$\sum_{j=I}^{N} (C_{mj} - \bar{C}_j) X_j + Y_m \geq 0 \quad m=1,\ldots,M,$$

$$\sum_{m=1}^{M} Y_m - TND = 0, \text{ and}$$

$$\psi \ TND - \sigma = 0,$$

where

$\bar{C}_j$ = the mean net return for the j^{th} crop;

X_j = the level of the j^{th} crop activity;

σ = an approximation of the standard error of income formed by using the Fisher transformation;

A_{hj} = usage of the h^{th} input by the j^{th} crop;

Table 3. Real Net Returns Per Acre for Various Grapefruit and Orange Tree Densities

	Species/Density Code							
Year	G109	G145	G218	G285	O110	O165	O220	O330
1970	$233.25	$319.09	$549.65	$750.23	($107.02)	($ 79.29)	($ 79.29)	$ 3.92
1971	$315.35	$543.50	$570.23	$487.32	$ 68.58	$240.09	$154.34	$ 240.09
1972	$754.94	$809.19	$922.84	$893.20	$125.82	$279.70	$218.15	$ 218.15
1973	$179.71	$204.86	$120.76	$124.65	$ 53.86	$112.97	$ 93.27	$ 152.38
1974	$264.72	$406.21	$472.90	$253.17	$158.85	$158.85	$236.04	$ 184.58
1975	$320.76	$294.40	$321.21	$348.02	$106.85	$134.78	$162.72	$ 190.65
1976	$685.65	$683.98	$779.70	$716.73	$ 47.49	$254.53	$254.53	$ 295.94
1977	$366.36	$269.02	$203.34	$ 77.19	$622.91	$848.72	$923.99	$ 923.99
1978	$298.30	$346.41	$315.19	$289.55	$402.02	$653.96	$603.57	$ 704.35
1979	$474.74	$431.41	$439.00	$295.93	$420.69	$525.54	$630.39	$ 595.44
1980	$526.53	$465.85	$531.42	$324.65	$217.51	$337.34	$297.39	$ 417.22
1981	$734.19	$474.56	$515.37	$292.06	$579.57	$683.38	$735.29	$ 527.66
1982	$302.15	$333.12	$132.32	($120.55)	$282.64	$662.27	$567.36	$1136.81
Mean	$419.74	$429.36	$451.84	$364.01	$229.21	$370.22	$369.06	$ 430.09

B_h = amount of the h^{th} resource available;

C_{mj} = net return for the j^{th} crop generated by the m weather pattern;

Y_m = the deviation from mean income exhibited for the m^{th} state of nature;

TND = total negative deviations from the mean net return;

ϕ = risk-aversion coefficient;

ψ = $(2\pi/m(m-1))^{1/2}$ (i.e., the Fisher transformation which converts TND to an approximation of standard deviation as in Apland, McCarl, and Miller);

H = number of resource constraints;

M = number of weather patterns; and

N = number of crop activities.

The model has 8 activities representing 4 grapefruit and orange densities each. For convenience, the activities are referred to throughout the study by the code presented in Table 2 (e.g., G109 refers to grapefruit at 109 trees/acre). The expected net return is the mean real net return per acre over the study period given in Table 3. The deviation from mean net return was calculated using Table 3 and applied in a MOTAD framework to approximate the standard deviation of net returns for each activity. Intra-year dependence of net returns by spacing treatment is captured in the estimate of absolute deviation annually. Production risk due to weather variability is consistent across crop and planting density since all trials were established in the same year; therefore, each activity was subject to the same annual stochastic weather patterns. Thus, there are 13 weather patterns represented by the 13 years in the data base. The Fisher transformation was applied to absolute deviations to generate an unbiased and consistent estimate of the standard deviation.

Resource constraints included a 100-acre land constraint so that the activity levels in the solution could easily be expressed as percentages for the optimal combination of citrus production alternatives. A capital constraint was included which reflects the relative per-acre capital requirements between species and spacing alternatives. The cost of planting and maintaining different tree densities is a nearly linear relationship to the number of trees per acre. Of course, there is a perfect linear correlation between the cost of the trees per acre and number of trees per acre, and for the first two years, some maintenance costs are applied on a per-tree basis (e.g., fertilizer, insecticide, fungicide). After year 2, maintenance costs are assumed the same for all densities as most activities are mechanized and applied on a per-acre basis. Table 4 gives the estimated establishment and maintenance cost required to bring a new orchard through the fourth year (McGrann, Jenson, and Teague). Selecting four years for calculation of the capital required to establish an orchard was not arbitrary; rather, this period corresponds with the end of the citrus establishment capitalization period requirement and the point at which economically significant production occurs. For convenience, the capital constraint is expressed as a ratio where 1 unit of capital (UOC) is equal to \$2543.10, which is the 4-year accumulated cost per acre of establishing the lowest density of trees considered in this study (109 trees/acre). Thus, establishment of one acre G109 (the lowest per-acre cost) requires 1 unit of capital, while one acre of O330 requires 1.64 units of capital (see Table 4). Currently, in the LRGV, there is a surplus of suitable citrus land available (due to the freeze and other economic factors), and financing for land itself is readily available. However, financing for citrus establishment and production is very difficult to obtain. Given the close relationship of capital requirements and number of trees per acre, the capital constraint is considered the single most important resource requirement in selection of the optimal density.

The risk constraints were formulated such that the total negative deviation from mean net returns were accumulated and transformed to a measure of standard deviation (σ). The risk-aversion coefficient (ϕ) was varied parametrically from 0 to 2.2. A value of $\phi=0$ represents a risk-neutral producer's preference structure and corresponds to the linear programming solution. The use of the Fisher transformation and σ facilitates comparison of the risk aversion coefficient (ϕ) with risk aversion coefficients found in studies utilizing similar objective functions (such as Hazell et

TABLE 4. COST PER ACRE FOR DIFFERENT SPACING OF TEXAS CITRUS

Species/ Density Code	Trees/ac	Year 1	Year 2	Year 3	Year 4	4 Year Accum. Costs/acre	Capital Ratio
G109	109	$1,254.31	$336.88	$459.45	$492.46	$2,543.10	1
G145	145	$1,500.55	$355.57	$459.45	$492.46	$2,808.03	1.10
G218	218	$1,999.87	$393.45	$459.45	$492.46	$3,345.23	1.32
G285	285	$2,458.15	$428.23	$459.45	$492.46	$3,838.29	1.51
O110	110	$1,261.15	$337.40	$459.45	$492.46	$2,550.46	1.00
O165	165	$1,637.35	$365.95	$459.45	$492.46	$2,955.21	1.16
O220	220	$2,013.55	$394.49	$459.45	$492.46	$3,359.95	1.32
O330	330	$2,765.95	$451.58	$459.45	$492.46	$4,169.44	1.64

al.; Simmons and Pomareda; Niewoudt, Bullock, and Mathia; Brink and McCarl; and Apland, McCarl, and Miller). These studies suggest that an upper bound in the neighborhood of 2.2 for ϕ is reasonable.

Using this type of MOTAD formulation, the optimal solution is allowed to contain not only a combination of grapefruit and oranges, but an optimal combination of tree densities within each species such that net returns are maximized less the cost of risk bearing subject to the amount of capital required for establishment of various densities.

RESULTS

For the risk-neutral (RN) producer, in an unlimited capital situation, the optimal solution is to plant 100% of acreage in G218. (See Table 5 for all results.) This is expected since this spacing exhibits the highest net return of all activities and the RN producer is not concerned with income variability. As the risk-aversion coefficient is varied from 0, the optimal crop mix changes considerably. The levels of ϕ reported in Table 5 represent points at which significant basis changes occur. Basis changes were judged significant (not in a statistical sense) where acreage and density shifts were of sufficient magnitude to represent a recognizably different planting strategy. Where $\phi=2.158$, a level of risk aversion is represented such that subsequent increases would cause a very risk-averse (VRA) producer to idle acreage. This finding, coupled with an unlimited capital situation, lends support to the notion that the neighborhood of $\phi=2.2$ is a reasonable upper bound for the risk aversion coefficient in this type of application.

As ϕ is increased and capital remains unlimited, the very slightly risk-averse (VSRA, $\phi=.3522$) and the slightly risk-averse (SRA, $\phi=1$) producers prefer about 69% to 66% G218, respectively, and the balance (31–34%) in oranges at 330 trees per acre. It is interesting to note that this ratio is very near the historical grapefruit-to-orange ratio over many years (Whitlock). Note from Table 3 that O330 is the only orange activity that is comparable to any grapefruit activity in terms of net returns. At the risk-aversion level for a moderately risk-averse producer (MRA, $\phi=1.678$), orange acreage remains about the same while the optimal combination of grapefruit acreage is 44% G218 and 21% G285. For the very risk-averse producer (VRA, $\phi=2.158$), further diversification within the grapefruit acreage occurs where 9.3% G145, 19.3% G218, and 36.3% G285 and 35% O330 is the optimal combination. These results imply that, indeed, there is a risk-efficient combination of grapefruit and orange production as well as a risk-efficient combination of planting densities within that category. As the risk-aversion coefficient is changed to represent the preferences of a very risk-averse producer, G285 is a major component in the optimal crop mix, implying that it lends stability to income.

Next, tests of the sensitivity of the optimal solutions at different levels of risk aversion to changes in the amount of capital available resulted in shifts towards less dense (and less capital intensive) plantings as expected. (Again, solutions are reported at significant basis changes.) The levels of available capital presented in Table 5, for each level of the risk-aversion coefficient, represent levels at which basis changes occurred due to changes in capital availability. The lowest level of capital presented is that level at which acreage would be idled if a subsequent (more restrictive) capital limitation were implemented. The VSRA producer begins to shift to lower grapefruit densities and less orange acreage. At the most severely limited capital situation, the VSRA prefers to produce 52% G109 and 48% G145. On the other hand, the RN producer prefers 56% G109 and 44% G218 in a very limited capital situation. A comparison of this result for the same limited capital situation for the RN and VSRA producer implies that income variability is less with G145 than with G218, and, therefore, G145 is less risky. Under limited capital, preferences of the SRA and MRA producers shift towards lower densities of both grapefruit and oranges resulting in the first optimal solutions including lower orange planting densities. The SRA producer prefers 77% G145 and 21% O165 and 2% O330 under the most limited capital scenario, while the MRA prefers 77% G145 along with 14% O220, 5% O330, and 4% O165.

CONCLUSIONS

An examination of the results suggests that any risk averse producer would prefer some combination of grapefruit and oranges. Further, depending on the level of risk averseness and capital available, there is some opportunity to manage the variability in income (risk) by diversification into different tree densities within the same species category. Of course, these results are a mathematical solution which requires scrutinization in terms of practicality of application. The risk preferences of producers will not be the sole deciding factor

TABLE 5. OPTIMAL CROP PATTERNS AMONG AND ACROSS VARIOUS GRAPEFRUIT AND ORANGE DENSITIES FOR DIFFERENT LEVELS OF RISK AVERSION AND DECREASING CAPITAL AVAILABILITY

	Units of Capital[a]	Grapefruit				Oranges			
		G109	G145	G218	G285	O100	O165	O220	O330
	200 (RN)			100[c]					
($\phi = 0$)[b]	141 Risk Neutral	12		88					
	116	20		80					
	109	36		64					
	104	56		45					
	200 (VSRA)			69					31
($\phi = .3522$)	141 Very Slightly		3	66					31
	116 Risk Averse		89						11
	109	5	95						
	104	52	48						
	200 (SRA)			66.7					33.3
($\phi = 1.0$)	142 Slightly Risk			67				2	31
	141 Averse		1	66				4	29
	116		77				4	14	5
	114		76				13	8	3
	112		77				21		2
	200 (MRA)			44.17	21.25				34.5
($\phi = 1.678$)	147 Moderately			46	20				34
	143 Risk			62	5			2	31
	141 Averse			62	2			4	29
	121				6			15	9.5
	116						4	14	5
	114						12	9	2
	200 (VRA)		9.3	19.3	36.3				35
($\phi = 2.158$)	148 Very		11	19	36				34
	146 Risk		17	15	35				33
	137 Averse		42		31				27

[a] Units of Capital = 200 is unlimited. Other levels of capital are reported at basis change levels.
[b] ($\phi = 0$) = Risk neutral; ($\phi = 2.158$) very risk averse.
[c] Activity level can be interpreted as percent of land available (based on 100 acres).

in the species or planting density decision. The physical characteristics of the proposed orchard site, equipment requirements and/or limitations, and other management considerations will weigh in the determination of whether or not some optimal combination of planting densities is in reality a practical solution to the management of risk in citrus production. The experiments upon which this study is based consisted of several different densities planted on the same block of land. With regard to spacing strategies where the trees were planted in a straight row, both horizontally and vertically, (as is the case with all of the spacings examined in this study), there were no significant management problems arising from variation in distance across rows or down rows. Thus, where practical management is feasible, the risk-efficient production strategy may include consideration of planting density as a decision variable.

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