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Risk preference and optimal crop combinations in upland Java, Indonesia: an application of stochastic programming

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ABSTRACT

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A stochastic programming model was used to evaluate the economic performance of a soybean-based farming system in upland Java. The model incorporates farmers' risk preferences, revenue fluctuations and resources restrictions. The results show that (1) changes in risk preference do affect the optimal crop combination, and (2) the typical cropping pattern is rational under the present level of the farmers' risk preference estimated in the study site.

Introduction

In Indonesia, following the success for the intensification programs referred to as BIMAS and INMAS[1] for rice in the previous Five-Year Plan *(Pelita)*, which resulted in national self-sufficiency in this staple food, *Pelita IV* (1984 – 1989) gave special attention to secondary crops (Falcon et al., 1984; Timmer, 1987). The secondary crops *(palawija)* including soybean are the major source of employment, income and nutrition for a large number of low income people especially in marginal upland areas (CGPRT, 1988; Hayami et al., 1988). Various aspects including policy, research programs, extension services, etc. in relation to the promotion and encouragement of

[1] BIMAS, *Bimbingan Masal* (Mass Guidance), INMAS, *Intensifikasi Masal* (Mass Intensification).

palawija agriculture in upland areas have also been considered in *Pelita V* which has been under way since April 1989.

Several studies (e.g. Smis, 1987) indicate that soybean cultivation with a highly intensive monocropping technology is very profitable under the current price conditions. In addition, it is reasonable to expect that farm-gate prices will remain relatively stable at the present level since demand is forecast to grow at an average of 2.7% per year while production is estimated to grow at 2.4% per year in the period 1987 to 2000 (Tabor and Gijsbers, 1987). Notwithstanding these economic conditions, the farmers have not rushed into soybean cultivation with the new high-yield technology. These studies also describe many constraints on the adoption of a new and/or improved technology, such as the difficulty of obtaining both quality seeds of high-yielding varieties and credit. The studies, however, do not explicitly take account of the farmer's risk preference which may be one of the more important factors for the adoption of new technology.

This paper aims to (1) determine how much the optimal crop combination is affected by changes in risk preference and (2) evaluate the advantage of soybean cultivation and the rationality of the popular cropping pattern presently employed in the study site. Intercropping *(tumpangsari)* as well as monocropping is analyzed in this paper, since the farmers in the upland area usually grow soybean together with several other crops within a given period, either in combination or in sequence.

Method and Scope

Stochastic programming presents a suitable method for the economic evaluation of farming systems under risk since it is able to simultaneously incorporate the major factors determining the relative advantage of the crops. These factors cover farmers' risk preferences, net returns fluctuations and constraints of both land and labor. Fluctuations of net returns are determined by many elements such as yield and product prices. The labor coefficients as well as yield reflect technological factors. Both farmers' risk preferences and skill in operations are related to human factors.

In this paper, the following three alternative criteria for stochastic programming are adopted for the analysis: (1) maximizing expected value of utility; (2) maximizing satisfactory level of revenue subject to a chance constraint on stochastic revenue; (3) maximizing probability of revenue being at least equal to a given satisfactory level. We call these models the U-model, S-model and P-model, respectively.

U-model

maximize $\mathrm{E}[u(r'x)]$
subject to

$Ax \leq b,\ x \geq 0$

where E is expectation, $u(r'x) = 1-\exp(-ar'x)$ is the utility function employed by Freund (1956), parameter a ($a \geq 0$) is a risk aversion constant which may be considered as a measure of the aversion to risk, r is the vector of stochastic net returns and costs, A is the matrix of resource requirements, b is the vector of resource availability, and x is the solution vector.

S-model

maximize g
subject to

$\mathrm{Prob}[g \leq r'x] \geq \eta,\ Ax \leq b,\ x \geq 0$

where Prob is probability, g is an aspiration level of revenue and parameter η ($0.5 \leq \eta < 1.0$) is a reliability constant, which may be considered as a measure of the reliability of the planning. Stochastic linear programming problems based on this criterion have been considered in several papers (e.g. Kataoka, 1963).

P-model

maximize $\mathrm{Prob}[l \leq r'x]$
subject to

$Ax \leq b,\ x \geq 0$

where parameter l ($l \leq \max\{\mathrm{E}[r'x] | Ax \leq b,\ x \geq 0\}$) is an aspiration-level constant. Stochastic linear programming problems based on this criterion have been considered in several papers (e.g. Charnes and Cooper, 1963; Kataoka, 1967).

A solution of one of the deterministic equivalent problems (Charnes and Cooper, 1963) of the above-mentioned models can be interpreted as that of the other model by the equivalence theorem (see Appendix; Kataoka, 1967; Nanseki, 1989). The level of both the risk aversion constant and reliability constant can be estimated from a farmer's aspiration level of revenue by the theorem.

The U-model is often employed in empirical studies for modeling and simulating the economic behavior of a farmer under risk. However, it is not easy to estimate directly the level of farmer's risk aversion constant since farmers do not recognize their utility functions. In this paper, the level of a farmer's risk aversion is estimated from the expenditure for food by the equivalence relation between the U-model and the P-model, assuming that the farmer's aspiration level of revenue is equal to the expenditure for food. On the other hand, the S-model is useful in comparisons of the farmer's risk preferences at different levels of time and space, since the reliability constant is unit-free. The level of the reliability constant is also estimated from the expenditure for food by the equivalence relation between the S-model and the P-model. Thus, the equivalence relations among the models are useful because wider implications of the optimal solutions can be identified.

Study area and survey

The selected study site is a village in the District of Garut in West Java. It is a typical upland village in which various upland crops are grown in terraces under rainfed conditions. More than 80% of the total of 149 households are farm households and many of the villagers have second jobs. Farming is of a typically peasant mode, based mainly on family labor with the aid of hired or exchange labor in busy seasons such as during land preparation periods.

Most of the data used in the model are based on the results of a research project (Morooka and Mayrowani, 1990) of farm production and household economies in the village from 1985 to 1987. The project covered five detailed surveys. To identify which patterns of crop combination had been selected in the village, a baseline survey was conducted in April 1985. The interview was conducted for the whole-farm householders in the village. An integrated daily record survey on household and farm activities for selected sample farmers[2] was undertaken for a full period of 1 year from August 1985 to July 1986. An additional survey on crop yield variation and living expense for the same sample was conducted in March 1989.

The central part of the village is connected by about 1 km of unpaved road to a national highway that runs from the town of Garut to Bandung, the capital of West Java. Garut town, about 8 km away, is within easy access of the village by pony wagon and minibus. It represents a major market for villagers both selling their products, either directly or through middlemen, and buying urban commodities (Hayami et al., 1987).

[2] Twenty-five out of 121 farm households were randomly selected for the daily record survey. Eight were classified as small-size farms, with 0.5 ha as average operational land in the study site.

The total farmed area covering 57 ha is divided into 256 plots (averaging 0.22 ha per plot). Approximately 20% of the total households have no farm land and, 30% own less than 0.25 ha. On the other hand, 7% of them own more than 1 ha. Operational farm size on the average is estimated at 0.5 ha and twelve farmers cultivate more than 1 ha.

The annual gross return of upland crops per farm household with 0.5 ha in 1985 – 1986 is estimated at Rp. 625,000. The annual net return of upland crops, subtracting non-labor inputs from the gross return, is estimated at Rp. 511,000 per household[3]. The annual expenditure for food is estimated at Rp. 519,000.

Characteristics of Soybean-based Farming System

Under the *tumpangsari* system, there are many variations on how to combine upland crops from village to village. A majority of farmers, however, plant soybean together with maize and cassava for the first season (September – January), and with tobacco and cassava for the second season (January – June). In tobacco intercropping, cassava is usually planted at the edge of the field.

In 1985 – 1986, eight crops were cultivated under different combinations. These crops included soybean, maize, cassava, tobacco, upland rice, peanuts, fruits (mainly orange), and vegetables. Table 1 shows popular combinations of crops in the village. In the first season, soybean – maize and soybean – maize – cassava intercropping are two major combinations. Soybean – tobacco and soybean – cassava – other crops intercropping are popular in the second season. Consequently, soybean-based crop combinations account for more than 70% of the total plots in both the seasons. Moreover soybean-based intercropping accounts for 95% of the total upland area during the above-mentioned cropping period. Thus soybean has played a significant role as a basal crop for various cropping systems. The cropping system, therefore, may be called a 'soybean-based farming system'.

For evaluating the economic performance of *tumpangsari,* the distance between crops and their density are important factors. On-the-spot field observations revealed that the planting distance of soybean was usually determined by the farmers' own judgment based on their long experience.

Rp. rupiah (Rp. 1,745 = US $1.00, February 1989).

[3] In the first season of 1985, the yield of soybean did not correspond to that of a normal harvest due to insect damage. The annual return was thus lower than that of the average of the previous few years.

TABLE 1

Popular crop combinations in the study site, Garut, West Java, 1985 – 86

Season/crop combinations	Number of plots	(%)
1st season		
soybean and maize	93	36.6
soybean, maize and cassava	75	29.3
maize and other crops	18	7.0
soybean and other crops	12	4.7
upland rice and other crops	5	2.0
other combinations	17	6.6
monocropping	27	10.5
fallows	9	3.5
Total	256	100
2nd season		
soybean and tobacco	134	52.3
soybean, cassava and other crops	42	16.4
soybean and maize	9	3.5
other combinations	35	13.7
monocropping	27	10.5
fallows	9	3.5
Total	256	100

Other crops include upland rice, peanuts, fruits and vegetables. Combination of soybean and tobacco includes cassava which is planted at the edge of the field.

Under a soybean and maize *tumpangsari* system, maize is usually planted linearly. The distance between each row varies from 3 to 5 m in most cases, depending on the farmer's preference which takes into account agro-ecological and economic conditions. On the other hand, tobacco is planted squarely. The distance between tobacco plants varies from 80 cm *(tiga kaki)* to 1 m *(tiga kaki setengah).*

The annual total labor input for production including processing of upland crops is estimated at 228 work-days per household. Out of the total, family labor contributes 179 work-days. Land preparation and harvesting (including processing) account for approximately 60% of the total labor input, followed by weeding with 20%. Approximately 40% of the total hired labor input is used for land preparation, for which males are mostly in charge. Weeding and planting are mainly taken care of by females.

Model and Data

A representative farm with 0.5 ha (350 bata), which is the average size of the farms, is analyzed. Since the *bata* (700 bata = 1 ha) is a popular measure of land area in Indonesia, this unit is employed in the model. The representative farmer is assumed to be a rational decision maker under the given economic and technological conditions.

The model has the following features (see Table 2):

(1) 28 cropping activities which include intercropping as well as monocropping for both the first and second seasons.
(2) 36 ten-day periods (beginning, middle, end) of hired-labor activities.
(3) three seasonal land constraints.
(4) 36 ten-day periods for farming operations, e.g. planting, weeding and harvesting.
(5) 36 ten-day periods of constraints on family labor and hired labor.
(6) maximum area for tobacco planting (50% of total area), to avoid the problems caused by continuously planting in the same field, is indicated by a technical constraint.
(7) avoidance of sequential planting of peanuts in the same field is indicated by a constraint.
(8) total acreages of cassava in both the first and second seasons are equalized by an artificial constraint to reflect the all-year-round nature of this crop
(9) to isolate the effects of risk preference from the effects of cash constraints, the model is constructed without the cash flow constraints.

The programming model consists of 64 activities (or variables) and 77 constraints. The profit vector includes net returns for each cropping activity and non-stochastic hired-labor wages. The mean vector and covariance matrix of the deflated net returns per 0.14 ha (100 bata) for the 4-year period, 1982 – 1985, are estimated with standard methods.

Net returns of selected cropping activities shown in Table 3 indicate that soybean monocropping has the highest mean with the largest standard deviation in the first season. Soybean – tobacco intercropping is associated with maximum risk, but is profitable in the second season. The covariance matrix of net returns and the correlation matrix (Table 4) shows the structure of risk of selected cropping activities. It is evident that most correlations are positive but the net returns of maize and upland rice cultivation tend to be negatively correlated with those of other cropping activities.

The time series of net returns is calculated by subtracting their corresponding non-labor input (e.g. seeds, fertilizers, pesticides, etc.) costs in 1985 from the time series of deflated gross returns assuming that the input costs are almost the same each year. Multiplication of the gross returns in

TABLE 2

Available cropping activities for the representative farm

	Month/10-day period																																		
Cropping	August			September			October			November			December			January			February			March			April			May			June			July		
activities	B	M	E	B	M	E	B	M	E	B	M	E	B	M	E	B	M	E	B	M	E	B	M	E	B	M	E	B	M	E	B	M	E	B	M	E
1st season intercropping																																				
SMC1/1st		L	L	P	P	P	–	W	–	W	–	–	H	H	H																					
SMC2/1st			L	L	P	P	P	–	W	–	W	–	–	H	H	H																				
SM1/1st		L	L	P	P	–	–	W	–	W	–	–	H	H	H																					
SM2/1st			L	L	P	P	–	–	W	–	W	–	–	H	H	H																				
RC1/1st		L	L	–	P	P	W	–	W	–	W	–	–	–	H	H																				
RC2/1st			L	L	–	P	P	W	–	W	–	W	–	–	–	H	H																			
PM1/1st		L	L	L	P	P	–	W	–	W	–	W	–	H	H	H																				
PM2/1st			L	L	L	P	P	–	W	–	W	–	W	–	H	H	H																			
1st season monocropping																																				
S1/1st		L	L	L	P	–	–	W	–	W	–	–	–	H	H																					
S2/1st			L	L	L	P	–	–	W	–	W	–	–	–	H	H																				
M1/1st		L	L	P	–	–	W	–	W	–	–	–	H	H																						
M2/1st			L	L	P	–	–	W	–	W	–	–	–	H	H																					
R1/1st		L	L	L	P	–	W	–	W	–	W	–	–	–	H	H																				
R2/1st			L	L	L	P	–	W	–	W	–	W	–	–	–	H	H																			

2nd season intercropping																							
ST1/2nd	L	–	L	F	F	P	F	F	W	W	W	W	W	W	H	H	H	H	H	H	H	H	
ST2/2nd		L	–	L	F	F	P	F	F	W	W	W	W	W	W	H	H	H	H	H	H	H	H
SC1/2nd				L	L	P	–	–	W	–	W	–	–	–	H	H	–	H	–	H	–	H	
SC2/2nd					L	L	P	–	–	W	–	W	–	–	–	H	H	–	H	–	H	–	H
SM1/2nd				L	L	P	–	–	W	–	–	W	–	–	–	H	H	H					
SM2/2nd					L	L	P	–	–	W	–	–	W	–	–	–	H	H	H				
PM1/2nd					L	L	L	P	P	–	W	–	W	–	W	–	H	H	H				
PM2/2nd						L	L	L	P	P	–	W	–	W	–	W	–	H	H	H			
2nd season monocropping																							
S1/2nd				L	L	P	–	–	W	–	W	–	–	–	H	H							
S2/2nd					L	L	P	–	–	W	–	W	–	–	–	H	H						
T1/2nd	L	–	L	F	F	P	F	F	W	W	W	W	W	W	–	H	H	H	H	H	H	H	
T2/2nd		L	–	L	F	F	P	F	F	W	W	W	W	W	W	–	H	H	H	H	H	H	H
P1/2nd				L	L	L	P	–	–	W	–	W	–	W	–	H	H	H					
P2/2nd					L	L	L	P	–	–	W	–	W	–	W	–	H	H	H				

Notations for ten-day period:

B, the beginning of month; M, the middle of month; E, the end of month.

Notations for cropping activities:

S, soybean; M, maize; C, cassava; R, upland rice; P, peanuts; T, tobacco. For example, SMC stands for soybean, maize and cassava intercropping.

Notations for farming operations:

L, land preparation; P, planting/sowing; W, weed Control; F, fertilizer/insecticide applications; H, harvesting; – simply indicates that crops are in the field.

If more than one farm operation category at the same period exists, then the table displays the most time-consuming operation.

TABLE 3

Net returns of selected cropping activities (unit: 1000Rp./ha)

Cropping activities	Mean	Standard deviation	Min	Max
1st season				
SMC1/1st	253.6	94.8	163.1	380.1
SM1/1st	284.0	103.4	179.2	420.7
RC1/1st	178.3	30.7	150.5	211.4
PM1/1st	157.0	42.7	107.1	206.5
S1/1st	312.4	157.3	195.3	530.6
M1/1st	182.7	73.9	119.7	274.4
R1/1st	200.0	34.0	169.4	236.6
2nd season				
ST1/2nd	1757.4	417.5	1259.3	2174.9
SC1/2nd	289.3	125.1	200.2	466.9
SM1/2nd	244.1	91.0	175.7	368.9
PM1/2nd	143.2	46.1	105.0	205.1
S1/2nd	284.4	139.9	174.3	480.9
T1/2nd	1567.1	367.2	1122.1	1983.1
P1/2nd	159.4	74.7	102.2	265.3

This table is obtained from estimated time series data for 1982 to 1985.
Notations for cropping activities: S, soybean; M, maize; C, cassava; R, upland rice; P, peanuts; T, tobacco. For example, SMC stands for soybean, maize and cassava intercropping.

1985 – 1986 obtained from the daily record survey by deflated gross return indices generates the 4-year time series of gross returns for each cropping activity. The gross returns indices for the periods are estimated based on the aggregated official data[4] of prices and yields in the Garut District.

The nonstochastic constraint matrix consists of the labor coefficient matrix, technological constraint matrix and artificial matrices to complete the model. The labor coefficient matrix shown in Table 5 is developed from the daily record survey, with careful treatment given to intercropping activities. Soybean – maize – cassava and soybean – tobacco intercropping are the most labor intensive cropping activities in the first and second seasons, respectively. Family and hired labor available for each 10-day period are estimated based on the output of the survey modified to fit the representative farmer. The hired-labor activities are charged at the levels of wages

[4] Data source: *Statistical Year Book of Indonesia* for yield and the office of agriculture in Garut for prices.

TABLE 4

Covariance (lower) and correlation (upper) matrix of net return of selected cropping activities (unit: 10^9 Rp./ha)

	SMC1/1st	SM1/1st	RC1/1st	PM1/1st	S1/1st	M1/1st	R1/1st	ST1/2nd	SC1/2nd	SM1/2nd	PM1/2nd	S1/2nd	T1/2nd	P1/2nd
SMC1/1st	8.988	0.998	−0.207	0.974	0.986	−0.337	−0.203	0.785	0.977	0.984	0.993	0.969	0.672	0.968
SM1/1st	9.785	10.691	−0.174	0.981	0.975	−0.285	−0.170	0.791	0.965	0.972	0.984	0.954	0.682	0.954
RC1/1st	−0.601	−0.551	0.941	0.019	−0.345	0.854	0.999	0.396	−0.401	−0.333	−0.268	−0.413	0.545	−0.425
PM1/1st	3.948	4.335	0.025	1.827	0.926	−0.139	0.023	0.890	0.905	0.926	0.951	0.893	0.808	0.890
S1/1st	14.694	15.849	−1.663	6.226	24.736	−0.491	−0.341	0.713	0.998	0.999	0.997	0.997	0.583	0.996
M1/1st	−2.357	−2.178	1.936	−0.440	−5.711	5.459	0.855	0.075	−0.524	−0.497	−0.434	−0.560	0.214	−0.560
R1/1st	−0.653	−0.596	1.042	0.033	−1.823	2.144	1.153	0.399	−0.398	−0.330	−0.265	−0.410	0.548	−0.422
ST1/2nd	31.078	34.160	5.077	15.876	46.818	2.325	5.660	174.294	0.666	0.725	0.767	0.665	0.985	0.652
SC1/2nd	11.584	12.483	−1.539	4.837	19.630	−4.844	−1.690	34.797	15.645	0.996	0.990	0.998	0.530	0.999
SM1/2nd	8.489	9.145	−0.931	3.604	14.308	−3.345	−1.021	27.569	11.339	8.286	0.997	0.996	0.597	0.995
PM1/2nd	4.339	4.691	−0.379	1.874	7.225	−1.478	−0.414	14.752	5.705	4.184	2.124	0.988	0.646	0.986
S1/2nd	12.843	13.793	−1.771	5.337	21.924	−5.784	−1.946	38.848	17.464	12.684	6.367	19.560	0.528	0.999
T1/2nd	23.386	25.901	6.144	12.682	33.680	5.809	6.832	151.050	24.331	19.968	10.937	27.124	134.834	0.514
P1/2nd	6.854	7.366	−0.975	2.840	11.701	−3.088	−1.071	20.343	9.333	6.764	3.394	10.442	14.084	5.578

This table is obtained from estimated time series data for 1982 to 1985.
Notations for cropping activites: S, soybean; M, maize; C, cassava;
R. upland rice; P, peanuts; T, tobacco. For example, SMC stands for soybean, maize and cassava intercropping.

TABLE 5

Labor coefficients of selected cropping activities (Unit: Man-day/ha)

		SMC1/1st	SM1/1st	RC1/1st	PM1/1st	S1/1st	M1/1st	R1/1st	ST1/2nd	SC1/2nd	SM1/2nd	PM1/2nd	S1/2nd	T1/2nd	P1/2nd
August	B														
	M	24.5	24.5	21.0	24.5	24.5	24.5	21.0							
	E	12.3	12.3	10.5	12.3	12.3	10.5	10.5							
September	B	17.5	12.3		12.3	12.3	17.5	10.5							
	M	11.9	24.5	21.0	17.5	17.5		23.1							
	E	14.0		11.9	10.5										
October	B			14.0			7.0	14.0							
	M	17.5	12.3		10.5	15.8									
	E			15.4			3.5	15.4							
November	B	17.5	12.3		7.0	15.8									
	M			14.0				14.0							
	E				7.0										
December	B	10.5	14.0				10.5								
	M	14.0	14.0		14.0	10.5	10.5		14.0					14.0	
	E	7.0	7.0	7.0	14.0	10.5		14.0							
January	B			7.0	14.0			7.0	24.5					24.5	
	M								21.0	21.0	21.0		21.0	21.0	24.5
	E								14.0	3.5	21.0	24.5	21.0	14.0	12.3

February	B								17.5	24.5	24.5	12.3	17.5	17.5	12.3
	M								7.0			12.3		7.0	17.5
	E								7.0			17.5		7.0	
March	B								10.5	14.0	12.3	10.5	15.8	7.0	
	M								14.0					14.0	14.0
	E								7.0	17.5		10.5	15.8	3.5	
April	B								3.5		12.3			3.5	10.5
	M								3.5			7.0		3.5	
	E								3.5					3.5	10.5
May	B								7.0	10.5		7.0	10.5		
	M								21.0	10.5	14.0		10.5	14.0	10.5
	E								21.0		14.0	14.0		17.5	10.5
June	B								21.0	7.0	7.0	14.0		17.5	10.5
	M								14.0			14.0		14.0	
	E								10.5	7.0				10.5	
July	B								7.0					7.0	
	M								3.5	3.5				3.5	
	E														
Total		146.7	133.2	121.8	143.6	119.2	84.00	129.5	252.0	119.0	126.1	143.6	112.1	224.0	133.1

Notations for ten-day period:

B, the beginning of month; M, the middle of month; E, the end of month.

Notations for cropping activities:

S, soybean; M, maize; C, cassava; R, upland rice; P, peanuts; T, tobacco. For example, SMC stands for soybean, maize and cassava intercropping.

prevalent in the study area, which are Rp. 1000 per day for males and Rp. 600 per day for females. The complete structure of the basic model is presented in the report of Nanseki et al. (1989).

Results

Table 6 gives the optimal solutions[5] for various levels of the risk aversion constant of the U-model. The corresponding values of the parameters of both the S-model and the P-model are obtained by Theorems 1 and 2 (see Appendix), respectively.

The risk aversion coefficient is first set at 0.0 (Solution I), assuming that the decision maker is risk neutral. The solution consists of 0.5 ha (100% of the total farm land) of soybean monocropping for the first season, and 0.25 ha (50%) of soybean – tobacco intercropping and 0.25 ha (50%) of soybean monocropping for the second season. This result is mathematically equivalent to the solution of a linear programming model maximizing expected net return as the objective.

Progressively higher levels of risk aversion are then analyzed. As the risk aversion increases, the optimal solutions consist of a lower acreage of soybean monocropping and a greater acreage of upland rice. This change in crop combination is caused by the higher variance of the net return of soybean monocropping compared to those of the other crops except tobacco. Acreage of soybean-maize-cassava intercropping initially increases up to 0.17 ha (35%) in Solution III and then decreases. Respective acreages of soybean-maize intercropping in the first season and soybean-cassava intercropping in the second season also increase to 0.32 ha (64%) and 0.18 ha (36%) in Solution IV; Both then decrease in Solution V. The acreage of soybean-tobacco intercropping is constant due to the upper limit restriction.

The mean of total net return in Table 6 decreases with higher levels of risk aversion since a risk averter prefers to trade higher levels of net return for lower levels of variance. The aspiration levels also decrease with higher levels of the reliability coefficient. The coefficient indicates the probability that the real total net return exceeds the aspiration level. Non-labor input costs for the optimal solutions decrease as the risk aversion increases. The result implies that a risk averter needs less cash for production.

Table 6 also demonstrates that family labor inputs increase and then decrease as risk aversion increases. Although the survey shows that hired labor accounts for 20% of total labor inputs, the optimal levels of hired labor are negligible. This may be caused by the (1) loose constraint on labor

[5] The model was solved by a mathematical programming system, 'micro-NAPS' (Nanseki et al., 1989), on a personal computer.

TABLE 6

Summary of optimal solutions for selected levels of risk aversion constant

		I	II	III	IV	V
Risk aversion constant	–	0.000	0.003	0.004	0.005	0.006
Reliability constant	–	0.500	0.722	0.761	0.805	0.826
Aspiration level	(Rp. 1000)	665.311	546.905	523.788	498.737	485.180
Mean of total net return	(Rp. 1000)	665.311	662.842	650.358	645.133	632.027
SD of total net return	(Rp. 1000)	201.009	196.585	177.884	171.111	156.444
Optimal planting area:						
1st season intercropping						
soybean, maize and cassava	(ha)	0	0.062	0.171	0.147	0
soybean and maize	(ha)	0	0	0.248	0.318	0.281
upland rice and cassava	(ha)	0	0	0	0.035	0.121
peanuts and maize	(ha)	0	0	0	0	0
1st season monocropping						
soybean	(ha)	0.500	0.440	0.081	0	0
maize	(ha)	0	0	0	0	0
upland rice	(ha)	0	0	0	0	0.098
2nd season intercropping						
soybean and tobacco	(ha)	0.250	0.250	0.250	0.250	0.250
soybean and cassava	(ha)	0	0.062	0.171	0.182	0.121
soybean and maize	(ha)	0	0	0	0	0
peanuts and maize	(ha)	0	0	0	0	0
2nd season monocropping						
soybean	(ha)	0.250	0.188	0.079	0.068	0.129
tobacco	(ha)	0	0	0	0	0
peanuts	(ha)	0	0	0	0	0
Optimal labor inputs						
Family labor inputs	(days)	148.353	151.908	159.906	160.385	156.649
Hired labor inputs	(days)	2.146	0.737	0	0	0
Total	(days)	150.499	152.645	159.906	160.385	156.649
Non-labor inputs cost for the optimal solutions:						
1st season	(Rp. 1000)	25.000	23.944	17.869	15.989	12.921
2nd season	(Rp. 1000)	42.013	41.424	40.388	40.284	40.863
Total	(Rp. 1000)	67.013	65.368	58.257	56.273	53.784

Null solutions (0.000) are indicated by 0 in the table, for convenience.

during the period of land preparation and (2) underestimation of labor coefficients.

The average expenditure for food (Rp. 519,000) of the farmers is located between Rp. 499,000 and Rp. 524,000 which correspond to the aspiration levels of Solutions III and IV, respectively. The equivalence relation between the U-model and the P-model (see Appendix) implies that the level of risk aversion constant of the farmers is between 0.004 (Solutions III) and 0.005 (Solutions IV) since the expenditure for food can be assumed to be the aspiration level of the farmers. Furthermore, the Solutions III and IV are similar to the typical cropping pattern at the study site (see Table 1). The results indicate that Solutions III and IV realistically simulate the economic behavior of the farmers. By the equivalence relation between the S-model and the P-model (see Appendix), the estimated value of the farmer's reliability constant ranges from 0.761 to 0.805, assuming normality of distribution of net revenue. This implies that the farmers are obliged to shoulder the risk that actual net income does not reach the aspiration level. The estimated probability ranges from $0.239 = 1-0.761$ (once in 4 years) to $0.195 = 1-0.805$ (once in 5 years).

Conclusions

The results illustrate that the optimal crop combination is sensitive to variations in risk preference. Risk aversion can influence the relative advantage of soybean monocropping against other crops. Yield of soybean in the study site is considerably lower than the national level (0.6 vs. 0.9 t/ha, on average, for 1982 to 1985). However, in the case of risk neutrality, soybean monocropping is fully adopted in the total farmland in the first season. Soybean monocropping in the second season also accounts for the total farmland with soybean – tobacco intercropping. On the other hand, as risk aversion increases, soybean-based intercropping, such as soybean – maize – cassava, soybean – maize and soybean – cassava, has a higher relative advantage against monocropping.

The results also show that, at the present level of risk aversion of the farmers, the optimal crop combination is close to the popular cropping pattern in the study site. Therefore we can conclude that the farmer's decision in the selection of the cropping pattern is rational under the given economic and technological conditions.

The above observations imply that, for a wider adoption of soybean monocropping with high yield technology by the farmers, the yields should be stable even with a lower average. It is suggested that new technical packages which enable yield to withstand unexpected changes in weather conditions, and are highly reliable in on-farm practice, should be developed.

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t, metric tonne = 1000 kg.

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Appendix

Deterministic equivalents and the equivalence relations among the models

We make the following assumptions:

Assumption 1
$r'x$ is a random variable and has a normal distribution $N(\mu'x, x'\Sigma x)$, where μ and Σ are a mean vector and a variance–covariance matrix of r, respectively.

Assumption 2
$x'\Sigma x > 0$ for all $x \neq 0$.

Assumption 3
An optimal solution of Problem 0 exists and is finite.

Problem 0:

maximize $\mu'x$

subject to

$Ax \leq b, x \geq 0$

Assumption 4
$C = \{x | Ax \leq b, x \geq 0\}$ does not include $x = 0$.

The deterministic equivalent problems (Charnes and Cooper, 1963) of the U-model, S-model and P-model are the following programming problems 1, 2, and 3, respectively, under the assumption 1 [see Kataoka (1967) and Nanseki (1989) for details].

Problem 1. U-model:

maximize

$$f(x) = \mu'x - \frac{a}{2}x'\Sigma x$$

subject to

$Ax \leq b, x \geq 0$

where $a \geq 0$, and μ and Σ are the mean vector and covariance matrix of r, respectively.

Now define:

$$\Phi(k) = \int_{-k}^{+\infty} \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{\varrho^2}{2}\right) d\varrho$$

where

$\varrho \equiv N(0, 1)$

Problem 2. S-model:
maximize

$$g(x) = \mu' x - k\sqrt{x' \Sigma x}$$

subject to

$$Ax \leq b, \; x \geq 0$$

where

$$k = \Phi^{-1}(\eta), \; k \geq 0$$

Problem 3. P-model:
maximize

$$h(x) = \frac{\mu' x - l}{\sqrt{x' \Sigma x}}$$

subject to

$$Ax \leq b, \; x \geq 0$$

where

$$l \leq \max \{\mu' x | Ax \leq b, \; x \geq 0\}$$

A solution of one of the above formulations can be interpreted as that of the other formulation by the following equivalence theorem under the assumptions [see Kataoka (1967) and Nanseki (1989) for details]. Assumptions 2 and 4, however, can be removed in the applied study.

Theorem 1

An optimal solution of Problem 1, $\hat{x}(a)$, is that Problem 2, $\tilde{x}(k)$, if the value of parameter k satisfies $k = a\sqrt{\hat{x}(a)' \Sigma \hat{x}(a)}$. An optimal solution of Problem
2, $\tilde{x}(k)$, is also that of Problem 1, $\hat{x}(a)$, if the value of parameter a satisfies:
$a = k/\sqrt{\tilde{x}(k)' \Sigma \tilde{x}(k)}$

Theorem 2

An optimal solution of Problem 2, $\tilde{x}(k)$, is that of Problem 3, if the value of parameter l satisfies:

$$l = \mu' \tilde{x}(k) - k\sqrt{\tilde{x}(k)' \Sigma \tilde{x}(k)}$$

An optimal solution of Problem 3, $x^*(l)$, is also that of Problem 2, $\tilde{x}(k)$, if the value of parameter k satisfies:

$$k = \frac{\mu' x^*(l) - l}{\sqrt{x^*(l)' \Sigma x^*(l)}}$$