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FUZZY RULE-BASED SYSTEM FOR EVALUATION OF UNCERTAINTY TRANSACTION IN CASSAVA CHAIN

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ABSTRACT: A fuzzy ruled-based system was developed in this study and resulted in an index indicating the level of uncertainty related to commercial transactions between cassava growers and their dealers. The fuzzy system was developed based on Transaction Cost Economics approach. The fuzzy system was developed from input variables regarding information sharing between grower and dealer on "Demand/purchase Forecasting", "Production Forecasting" and "Production Innovation". The output variable is the level of uncertainty regarding the transaction between seller and buyer agent, which may serve as a system for detecting inefficiencies. Evidences from 27 cassava growers registered in the Regional Development Offices of Tupa and Assis, São Paulo, Brazil, and 48 of their dealers supported the development of the system. The mathematical model indicated that 55% of the growers present a Very High level of uncertainty, 33% present Medium or High. The others present Low or Very Low level of uncertainty. From the model, simulations of external interferences can be implemented in order to improve the degree of uncertainty and, thus, lower transaction costs.

KEYWORDS: fuzzy system, transactions, cassava, uncertainty.

SISTEMA BASEADO EM REGRAS FUZZY PARA AVALIAÇÃO DE INCERTEZA NA TRANSAÇÃO NA CADEIA DE MANDIOCA

RESUMO: Este trabalho apresenta um sistema baseado em regras fuzzy que resultou em um índice que indica o nível de incerteza relacionada com as transações comerciais entre produtores de mandioca e de seus compradores, com base na abordagem da Economia dos Custos de Transação. O sistema fuzzy foi desenvolvido utilizando como variáveis de entrada "Previsão de Demanda/compra", "Previsão de Produção" e "Compartilhamento de informações acerca de inovações de produção". A variável de saída consiste no nível de incerteza da transação entre vendedor e agente comprador, que pode servir como um sistema para a detecção de ineficiências. Entrevistas realizadas com 27 produtores de mandioca registrados nos Escritórios de Desenvolvimento Regionais de Tupã e Assis, São Paulo, Brasil, e 48 de seus compradores sustentaram o desenvolvimento do sistema. O modelo matemático aplicado na avaliação destes produtores indicou que 55% dos produtores têm relações comerciais com nível de incerteza Muito Alta, 25% Média ou Alta; e os demais, classificados entre Baixa ou Média. A partir dos resultados encontrados, simulações de ações poderiam ser implementadas para reduzir o grau de incerteza e os custos de transação envolvidos.

PALAVRAS-CHAVE: sistema fuzzy, transações, mandioca, incerteza.

INTRODUCTION

MENARD (2000) presents New Institutional Economics (NIE) as a theoretical approach to understand economic relationships that occur as an alternative form of organizing transactions. NIE

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considers the State and institutions as important factors in market functions, regulating the rules and the role of economic agents. Those respond by developing governance structures that affect the efficiency of transactions. WILLIAMSON (1998) considers that NIE comprises two analytical levels. The Institutional Environment, that is, the rules of the game, considering both formal and informal rules that govern individual behavior and structure social interactions. The second level is related to governance structures, under the attention of Transaction Cost Economic (TCE). Governance structures are appropriate choices to govern a transaction. TCE aims at explaining mechanisms and structures (hybrid structures, spot market or vertical integration) that were created to reduce risks and costs incurred in making an economic exchange.

According to WILLIAMSON (1998), some variables influence governance choice, as opportunism and bounded rationality (characteristics of agents); and asset specificity, frequency and uncertainty (characteristics of the transaction). The uncertainty corresponds to the lack of capacity to predict future events. Thus, the higher the uncertainty, the higher the possibility of losses due to opportunistic behavior of the parties involved. Uncertainty can be endogenous or exogenous. Considering transactions between farmers and dealers endogenous uncertainty is related to the difficulty of measuring the characteristics of the farming product. Exogenous uncertainty is related to the difficulty of predicting future situations related to the instability of demand and supply, or to agents behavior (WILLIAMSON, 1998).

There are also uncertainties related to macroeconomic and institutional environments. Aimin (2010) stated that the sources of uncertainty in agriculture are diverse, as events related to climate and to animal diseases; from changes of prices in agriculture products; and from financial uncertainties to policy and regulatory risks. As agricultural risks are composed by interrelated variables, a holistic approach is thus necessary. Uncertainty related to transaction is the focus of this study.

The use of fuzzy logic has become an extremely efficient and effective alternative in the face of recurrent stochastic methods in problems of assessing land, biological and production phenomena. Some examples are: decision making regarding energy efficiency in pine processing plants (CANEPPELE; SERAPHIM, 2013); predicting performance of poultry production (Ponciano et al., 2012); reducing losses and avoiding workers exposure to unhealthy environments by predicting the level of insalubrity in poultry production (Yanagi Jr. et al., 2012); testing process of control applied to refrigerated chambers (TIZZEI et al., 2011); controlling hybrid electric energy systems (CANEPPELE et al., 2013).

Other studies were developed as for estimating the broilers breeders welfare (PEREIRA et al., 2008); designing fuzzy body mass indexes of cattle to determine the optimal timing of slaughter (GABRIEL FILHO et al., 2011); management of energy use (CREMASCO et al., 2010); factors considered by farmers in the choice of agricultural regions (BAIMEI et al., 2003). These studies comprise the various applications that this theory, based on mathematical methods and computational intelligence, is able to cover.

Fuzzy logic has also been used for analyzing the economic problems since the late 1990´s as for: the theory of efficient prices for cost-benefit analysis; the risk exposure, considering the consequences in terms of time, cost, quality, and safety performance; risk and uncertainty and others. LOCATELLI et al. (2008), for example, applied a fuzzy multi-criteria analysis including socioeconomic, institutional, and cultural dimensions, based on the individual perception of landowners to evaluate the impacts of reforestation under the program Payment for Environmental Services on local development, in northern Costa Rica.

Using a TCE approach, ARBAGE (2004) developed a precise framework with the elements that rise transaction cost and their conditions of occurrence. The results were relevant for public policy in Brazilian agribusiness. VIANA et al. (2012) also used the cited framework. However, few academic works have been published about the evaluation of analytical categories related to the identification of characteristics of transactions between farmers / dealers. REYS et al. (2009; 2010) have used fuzzy theory to study categories of transaction costs with focus on opportunism, measured in terms of standards of behavior and trust. Using the fuzzy theory, they were able to model and manipulate mathematically vague and inaccurate information.

In order to fill this gap in the literature, this research aims at developing a fuzzy rule-based system that indicates the index level of uncertainty related to transactions between rural growers and their dealers. A model was developed in order to identify possible deficiencies in their trade relations regarding uncertainty under a TCE approach. An empirical research with cassava growers and their dealers in a particular region, Tupã and Assis municipalities, located in the Western São Paulo State, Brazil, was conducted in order to validate the model.

MATERIAL AND METHODS

A methodological framework was developed in order to develop a fuzzy rule-based system that indicates the index level of uncertainty related to transactions between rural growers and their dealers. The framework comprised three main steps.

The first step was to determine the fuzzy rules for evaluating uncertainty in the transaction. To create a fuzzy rule-based system it was necessary to define an input processor, a set of linguistic rules, a fuzzy inference method and an output processor, which generates a real number as exit, as done by PUTTI et al. (2014).

In order to achieve this goal, specialists have determined the premises to guide the study. The premises were based on relevant literature regarding TCE theory as discussed by AIMIN (2010), ARBAGE (2004), AZEVEDO (2000), MENARD (2000) and WILLIAMSON (1998). Based on the theory it was possible to identify variables that influence the level of transaction uncertainty (Figure 1). At first 12 indicators were identified for analyzing transaction costs. For this study, which aims at developing a fuzzy rule-based system that indicates the index level of uncertainty related to transactions between rural growers and its dealers, the input variable of the system based on fuzzy rules was “information sharing” between growers and dealers. Three indicators were used in order to analyze information sharing: "Demand/purchase Forecasting", “Production Forecasting” and “Production Innovation”. For each variable, we defined three membership functions called "Low" (L), "Medium" (M) and "High" (H), defined according to Table 1 and Figures 2, 3 and 4, in which the score 1, 2 and 3 have a degree of relevance 1 to the sets L, M and H, respectively (Figure 1).

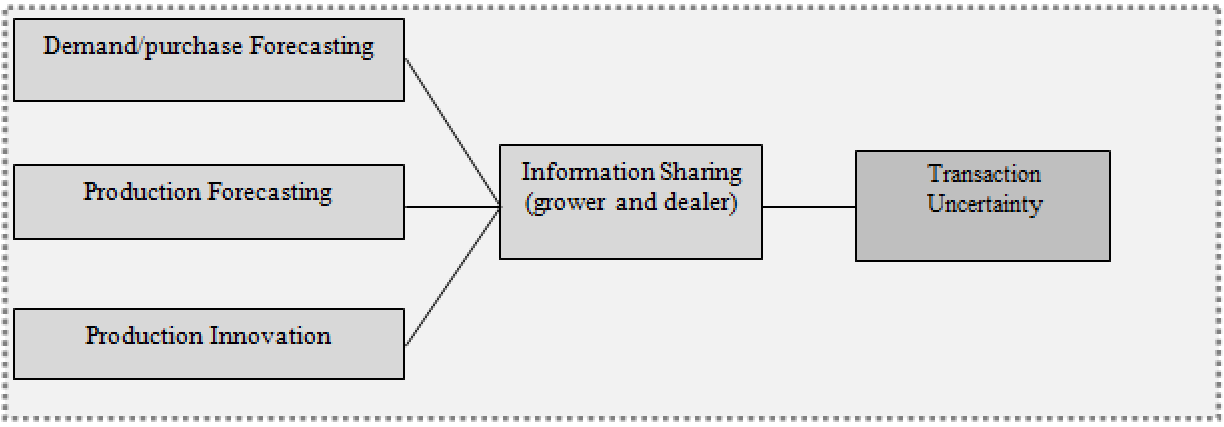

FIGURE 1. Fuzzy rules for evaluation of uncertainty level.

TABLE 1. Definition of membership functions of input variable.

Fuzzy Set	Type	Delimiters
“Low” (L)	Trapezium shaped	[-1, 0 , 1, 2]
“Medium”(M)	Triangle shaped	[1, 2, 3]
“High” (H)	Trapezium shaped	[2, 3, 4 5]

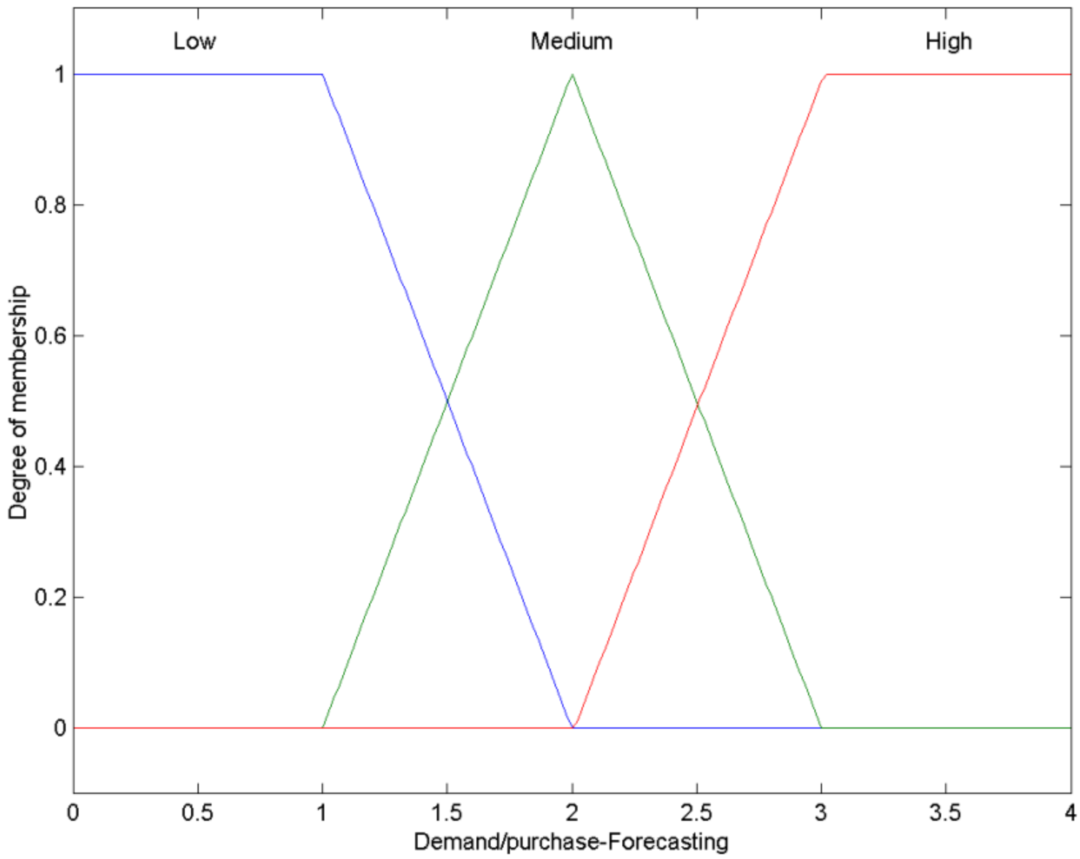

FIGURE 2. Membership functions defined for fuzzy sets of input variable "Demand/purchase Forecasting".

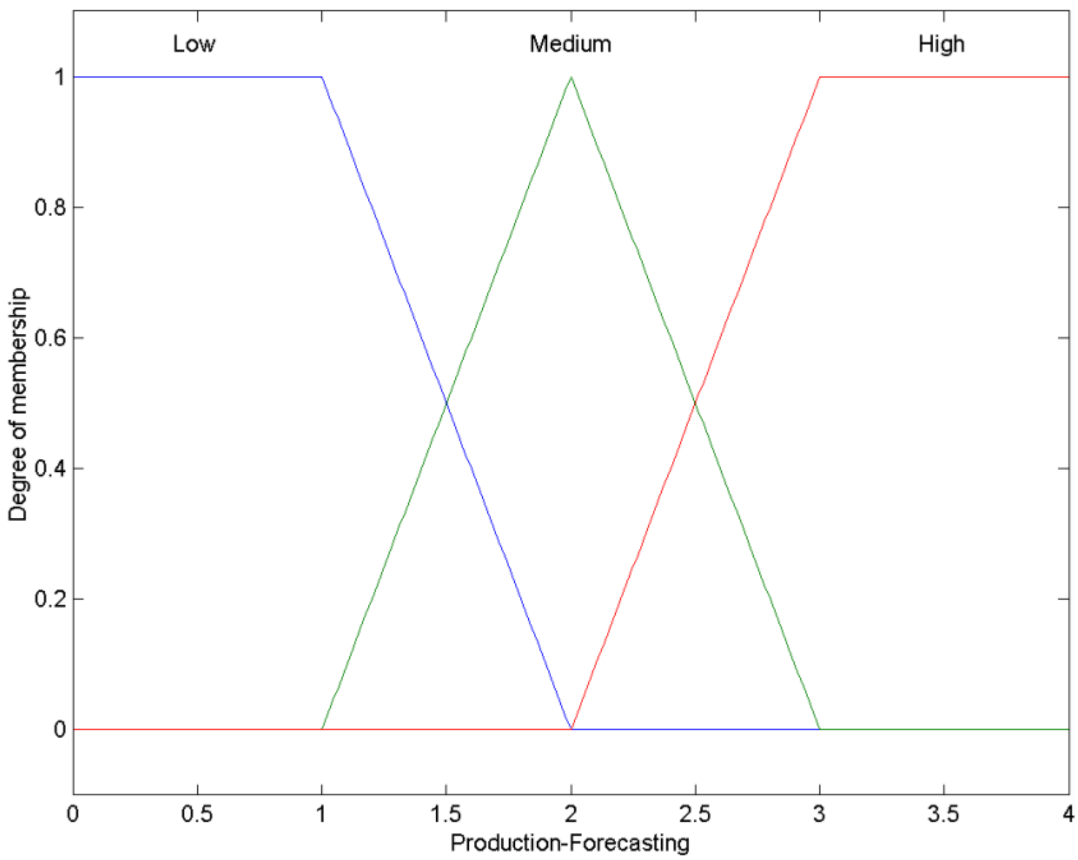

FIGURE 3. Membership functions defined for fuzzy sets of input variable "Production Forecasting".

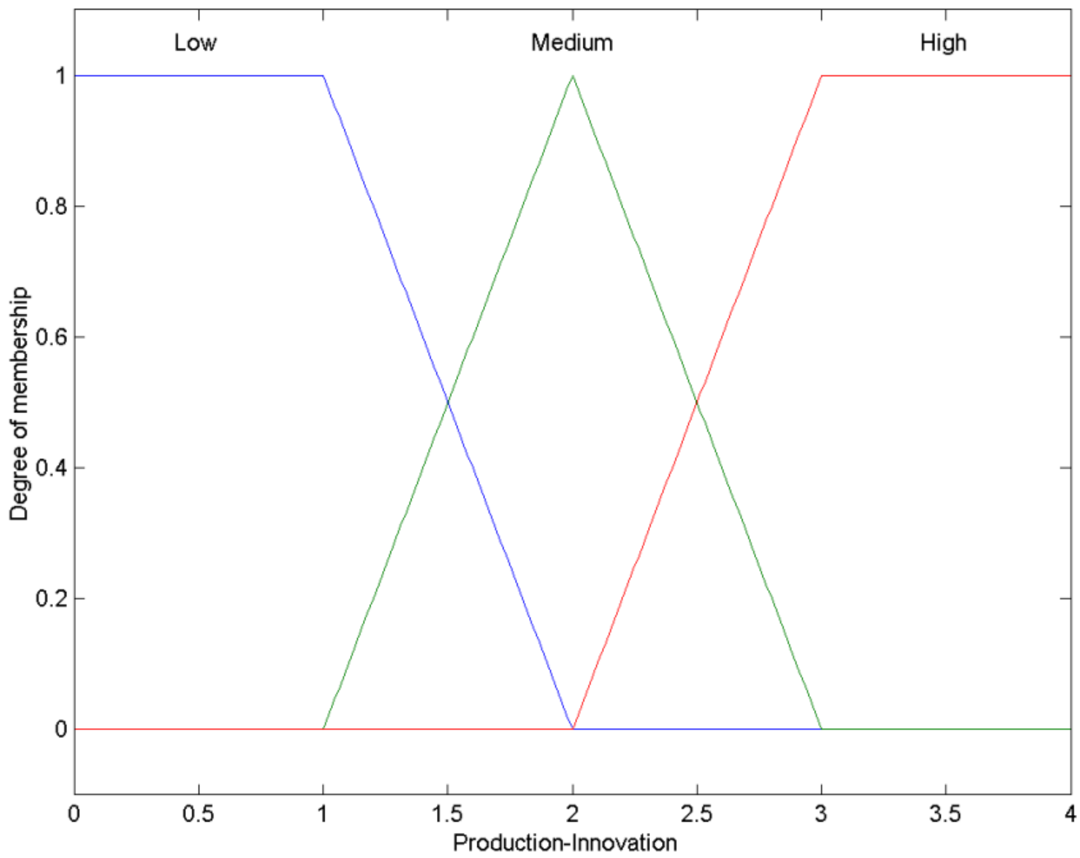

FIGURE 4. Membership functions defined for fuzzy sets of input variable "Production Innovation".

The output variable is the level of uncertainty regarding the business transaction between seller and buyer agent, which can serve as a system for detecting inefficiencies and excellent relations that exist between cassava growers and their dealers with a level qualitatively ranked by linguistic fuzzy sets "Very Low", "Low" "Medium 1", "Medium 2", "Medium 3", "High" and "Very High" (Table 2 and Figure 5).

TABLE 2. Definition of membership functions of input variable.

Fuzzy Set	Type	Delimiters
"Very Low" (VL)	Triangle shaped	[-1, 0, 1.33]
"Low" (L)	Triangle shaped	[1, 1.33, 1.67]
"Medium 1"(M1)	Triangle shaped	[1.33, 1.67, 2]
"Medium 2"(M2)	Triangle shaped	[1.67, 2, 2.33]
"Medium 3"(M3)	Triangle shaped	[2, 2.33, 2.67]
"High"(H)	Triangle shaped	[2.33, 2.67, 3]
"Very High" (VH)	Triangle shaped	[2.67, 3, 4]

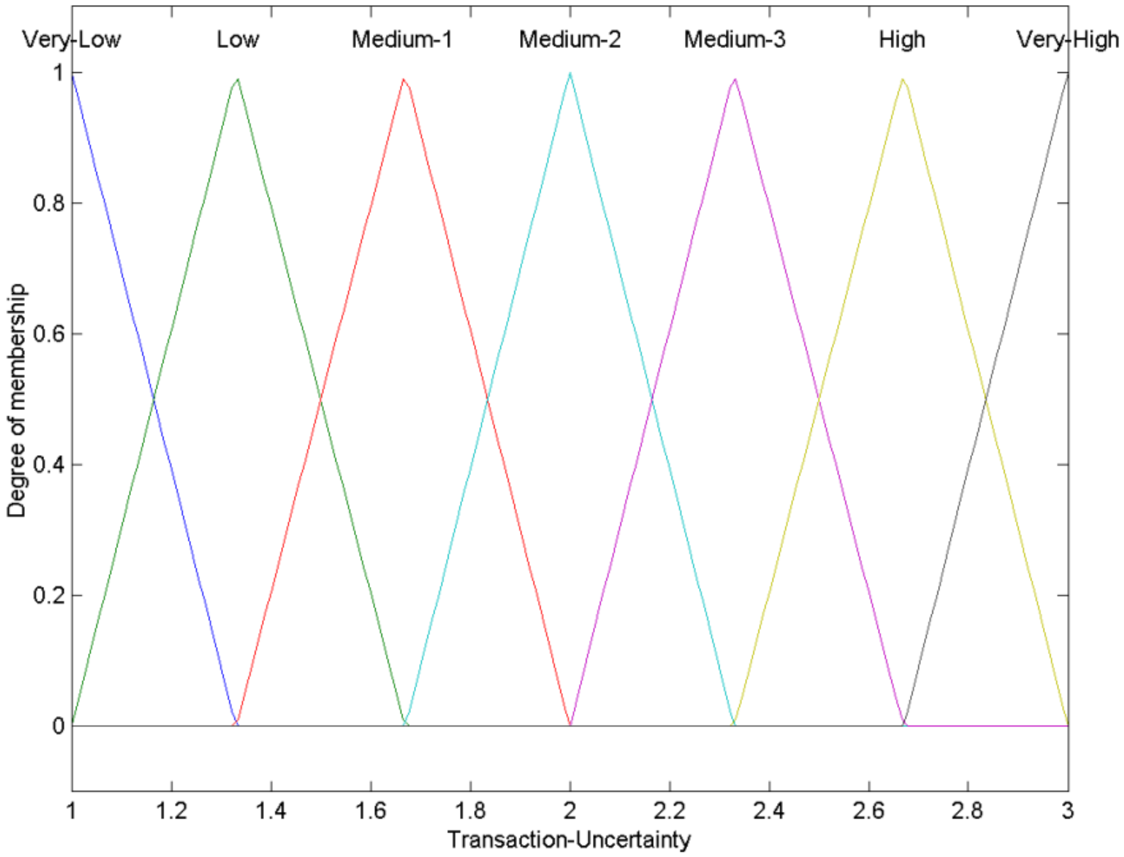

FIGURE 5. Membership functions defined for fuzzy sets of output variable “Transaction Uncertainty”.

According to REYS et al. (2010), a framework to formalize, mathematically, the set of options of a risky transaction, could have at least two approaches. First, the classic one, determines the value (risk), in which a business option/transaction is considered risky. In this situation, the case is sharply defined and the set is clear-cut. The second, less conventional, is given thus all the business-oriented options/transaction are considered risky with more or less intensity, that is, there are elements that would belong more to the class of the risky ones than others. This means that the lesser the risk associated to a determined element, the smaller will be its degree of membership to this class. In this sense, all the elements belong to the class of the risky options of business/ transaction, with greater or minor intensity.

This research adopted the less conventional approach discussed by REYS et al. (2010), which considered that transaction uncertainty is related to the level of information sharing measured by three variables (Figure 1). In order to create a mathematical model, it was necessary to determine the relationship between input and output variables, which is equivalent to an Intelligent System (Artificial Intelligence). This fuzzy rule-based system considered the 27 ($3 \times 3 \times 3$) combinations of the three fuzzy sets of input variables. The classification of each combination was adjusted from interviews with experts.

The inference method used to calculate the numerical value of the output variable according to the rule base was that of the Mamdani (MASSAD et al., 2008). With the tool Fuzzy Logic Toolbox of MATLAB® R2013b, it was possible to create a fuzzy rule-based system computationally and determine a surface and a contour map representation of the system.

The following step was the validation of the model using empirical data, i.e., primary data regarding commercial transactions were converted into values and inserted into the fuzzy model. The data were extracted from 27 cassava growers who were interviewed in Tupa and Assis Rural Development Office (geographical region delimitated by Coordenadoria de Assistência Técnica Integral/ CATI), Sao Paulo, Brazil, and 48 dealers. This number is explained by the analysis of the two main dealers in terms of revenue, for the period from 2008 to 2010. As some growers only sell to one dealer, the number of responses was 48.

For the global analysis of the degree of uncertainty in commercial transactions between growers and their dealers, the data quartiles (three points that divide the data set into four equal groups, each group comprising a quartile of the data) were analyzed, as well as their simulations using the fuzzy rule-based system.

RESULTS AND DISCUSSION

The relationships shown in Table 3 represent the base of the fuzzy rules. The first line represents relationships as: - IF information sharing between grower and dealers the "Demand/purchase Forecasting" is Low, AND the "Production Forecasting" is Low AND the "Production Innovation" is Low THEN the " Transaction Uncertainty " is "Very High".

TABLE 3. Rule base from the relations between the input and output variables.

Demand/purchase Forecasting	Production Forecasting	Shared information on production innovation	Transaction Uncertainty
L	L	L	VH
L	L	M	H
L	L	H	M3
L	M	L	H
L	M	M	M3
L	M	H	M2
L	H	L	M3
L	H	M	M2
L	H	H	M1
M	L	L	H
M	L	M	M3
M	L	H	M2
M	M	L	M3
M	M	M	M2
M	M	H	M1
M	H	L	M2
M	H	M	M1
M	H	H	L
H	L	L	M3
H	L	M	M2
H	L	H	M1
H	M	L	M2
H	M	M	M1
H	M	H	L
H	H	L	M1
H	H	M	L
H	H	H	VL

L = Low, M = Medium, H = High, VL = Very Low, M1= Medium 1, M2 = Medium 2, M3 = Medium 3, VH = Very High.

Using the Mamdani inference method, the centroid method (or center of gravity) for defuzzification (output processor) and the rules based on 27 linguistic propositions, we get the surface given in Figure 6 as a solution of the fuzzy system, with contour map given by Figure 7.

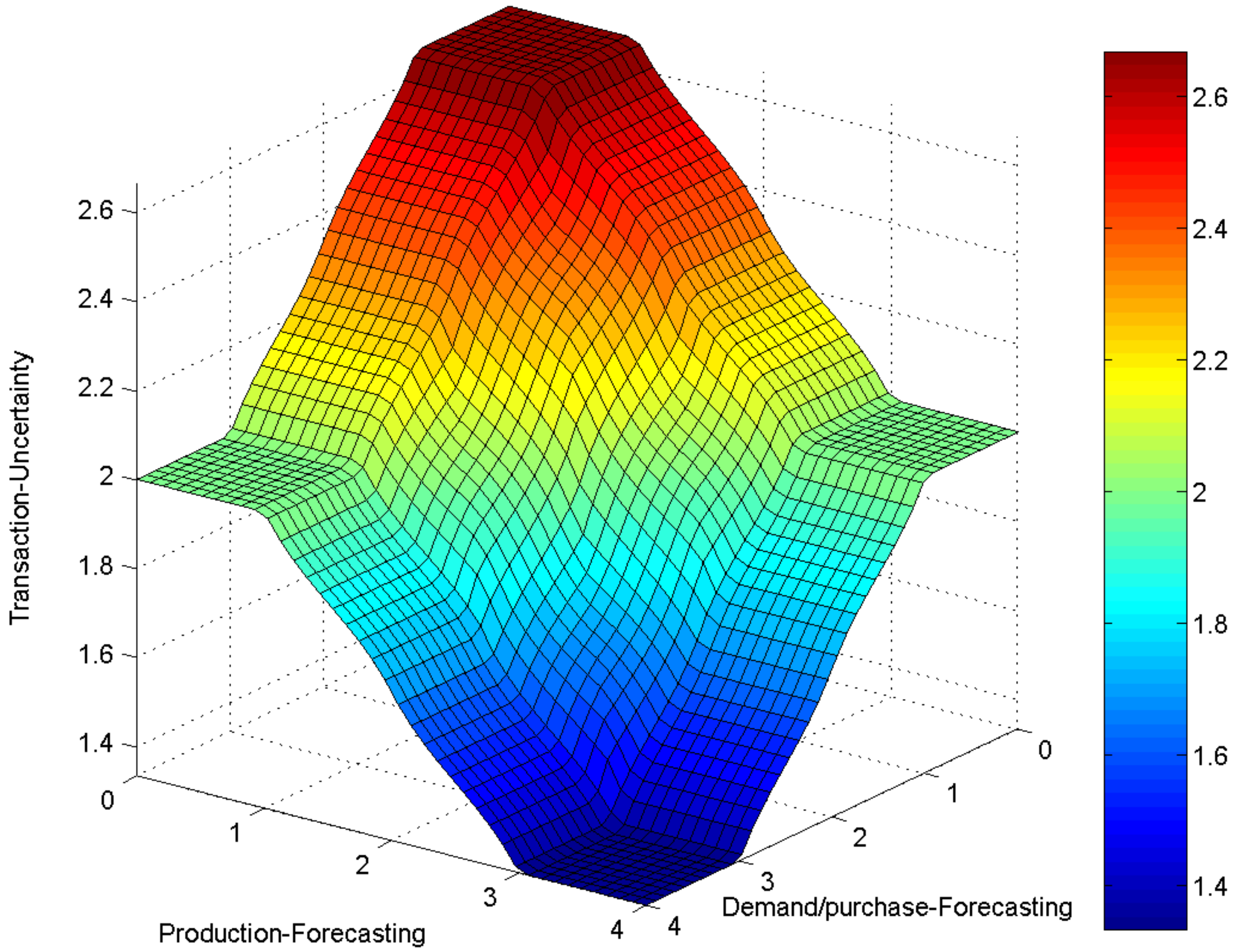

FIGURE 6. Surface Response of three-dimensional mathematical model representing the possible answers when the variable "Production Innovation" is set to "Medium".

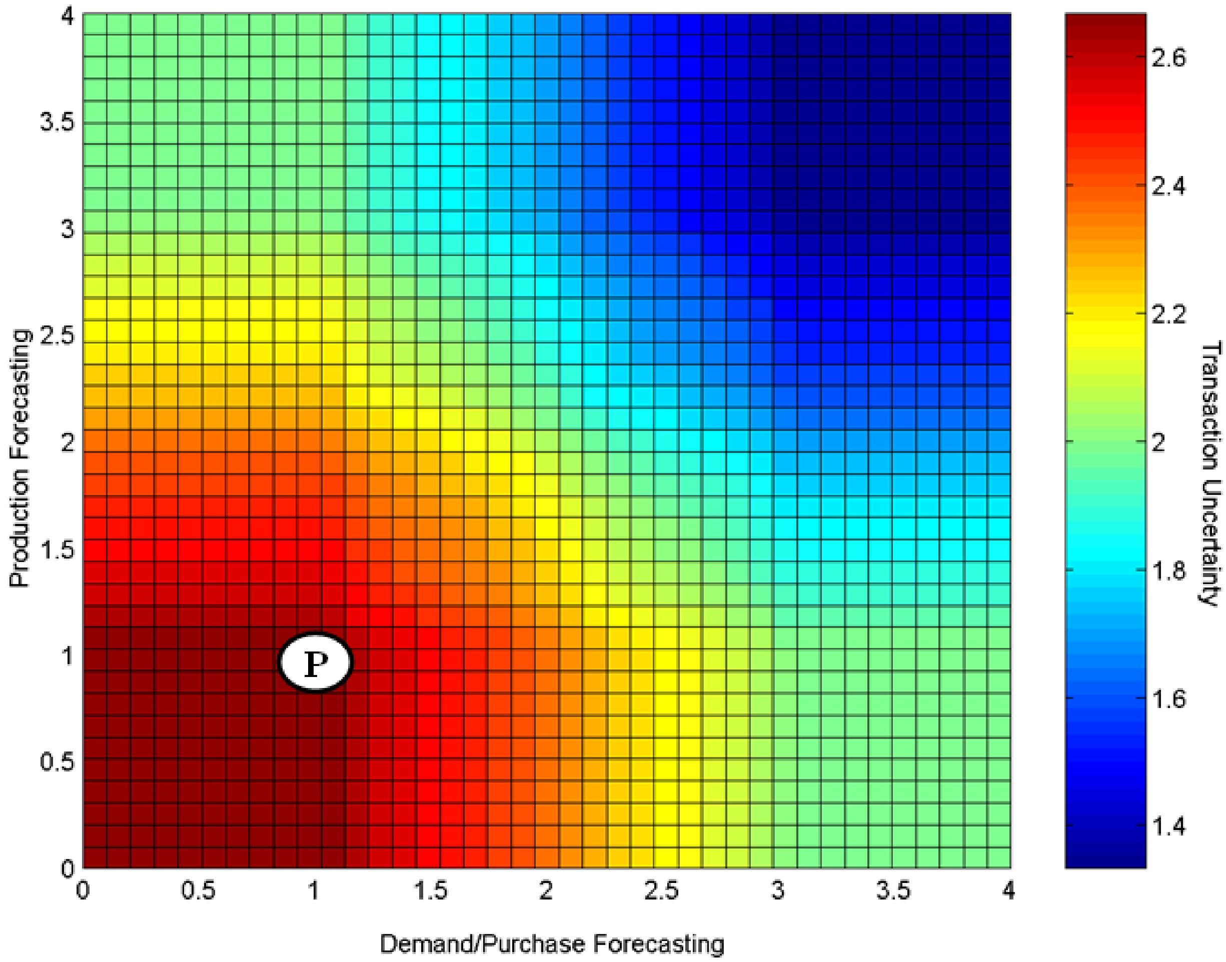

FIGURE 7. Contour map of the system when the variable "Production Innovation" is set as "Medium".

From Figures 7 and 8 it is possible to identify the region on the “Demand/purchase Forecasting" × "Forecast production" that establish values for the "Transaction uncertainty", when the "Production Innovation" is set to "Medium". Thus, such figures represent the results when “Production Innovation" is set to 2.

The other situations of this model, which comprise situations where the "Production Innovation" is 1 or 3 can be determined directly in the computer system implemented in Matlab fuzzy.

In order to use this figure for practical results, “Transaction uncertainty ” should be observed in the Contour map (Figure 7). The map shows that there is a high “Transaction uncertainty ” (u.t.) when “Demand/purchase Forecasting" (d.f.) is high (above 2.5) and “Production Forecast" (p.f.) is high (above 2.5). From the other hand, when d.f. is low (below 1.5), u.t. is also low. The other complementary regions represent medium value for u.t. (between 1.8 and 2.2).

One of the interviews with cassava growers was used for the other simulations and resulted on low “Demand/purchase Forecasting”, low “Production Forecasting” and medium “Production Innovation” (1, 1 and 2). This particular situation was identified as P spot. Figure 8 represents a simulation of fuzzy rule-based system for values at point P indicated in Figure 7.

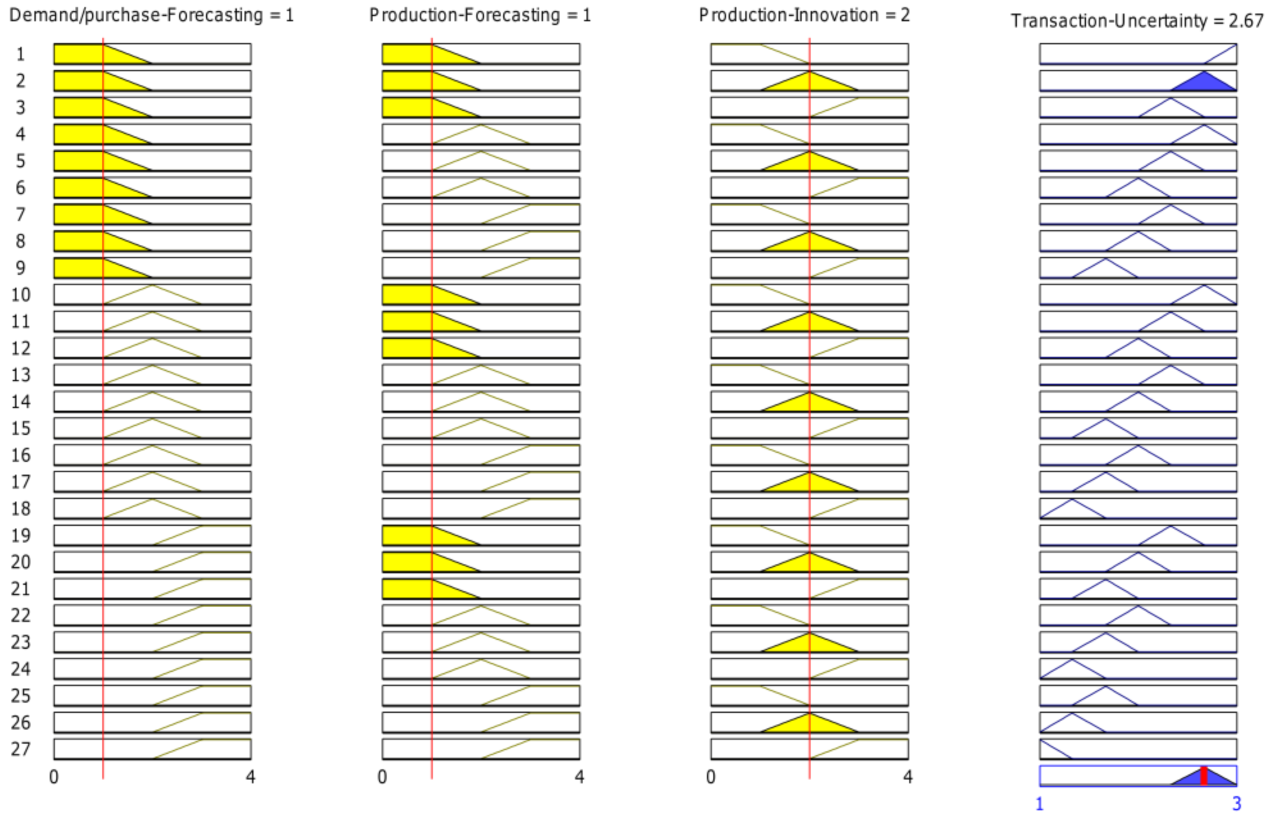

FIGURE 8. Using the inference method of Mamdani to low "Demand/purchase Forecasting" =1, low "Production Forecasting" = 1 and medium "Production Innovation" = 2, resulting in a value of "Transaction Uncertainty " = 2.67.

Visually, this point P is in a high position in relation to other business transactions, and this is also found in calculating their Uncertainty in the transaction Fuzzy, given by 2.67 (Figure 8). Performing an analysis related to membership functions of output variable, P has higher degree of membership in fuzzy set "High" (H), namely a degree of relevance 1, as shown in Figure 9.

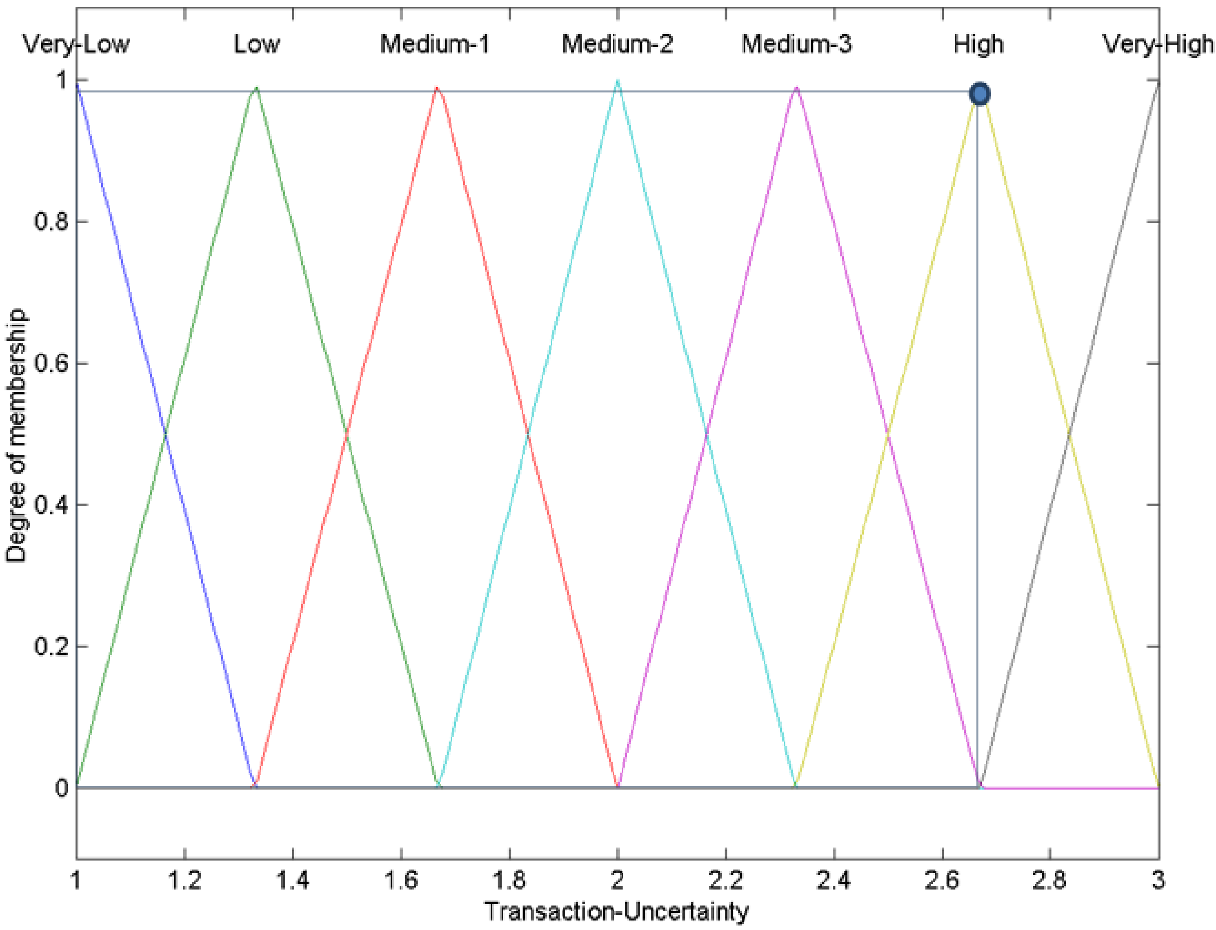

FIGURE 9. Indication of the greater degree of relevance to the fuzzy set "High" of point of “Transaction Uncertainty ” = 2.67.

The interviews were interpreted by means of linguistic variables and were associated to a higher degree of pertinence to the following fuzzy sets: "Demand/purchase Forecasting", "Production Forecasting" and "Production Innovation" (Table 4). This information was used to obtain practical results of the developed fuzzy rule-based system.

TABLE 4. Results of empirical data.

Transaction uncertainty level		Information sharing between grower and dealer regarding		
Grower	Dealer	***Demand/purchase***	***Production forecasting***	***Production innovation***
		Level	Level	Level
1	1	L	L	M
1	2	M	H	H
2	1	L	L	L
2	2	L	L	L
3	1	L	L	L
3	2	L	L	L
4	1	L	L	L
4	2	L	L	L
5	1	H	H	H
5	2	L	L	L
6	1	L	L	L
6	2	L	L	L
7	1	H	L	H
7	2	H	L	H
8	1	M	L	L
8	2	L	L	L
9	1	M	H	H
9	2	M	H	H
10	1	L	L	L
10	2	L	L	L
11	1	L	L	L
11	2	L	L	L
12	1	L	L	L
13	1	L	L	M
13	2	L	L	L
14	1	M	H	H
14	2	M	H	H
15	1	L	L	L
16	1	L	M	M
17	1	L	M	L
17	2	L	L	L
18	1	L	L	L
18	2	L	L	L
19	1	L	M	M
20	1	H	H	L
21	1	L	L	L
22	1	L	L	H
22	2	L	L	M
23	1	M	M	L
23	2	L	L	L
24	1	M	M	H
24	2	M	M	H
25	1	L	M	M
25	2	L	M	M
26	1	L	L	L
26	2	L	L	L
27	1	L	L	L
27	2	L	L	L

The growers 12, 15, 16, 19, 20 and 21 have had commercial transactions with only one dealer, which resulted in only one information input in those cases.

After performing this simulation for all interviews, we found the percentages of first ranking of each question answered (Figure 10), which represented the results of fuzzy rule-based system. Thus, it is possible to observe that a large number of the relationships analyzed have low sharing of information between growers and their dealers on "Demand/purchase Forecasting", "Production Forecasting " and "Production Innovation", with respective percentages of 73%, 68% and 62% for this classification in Low.

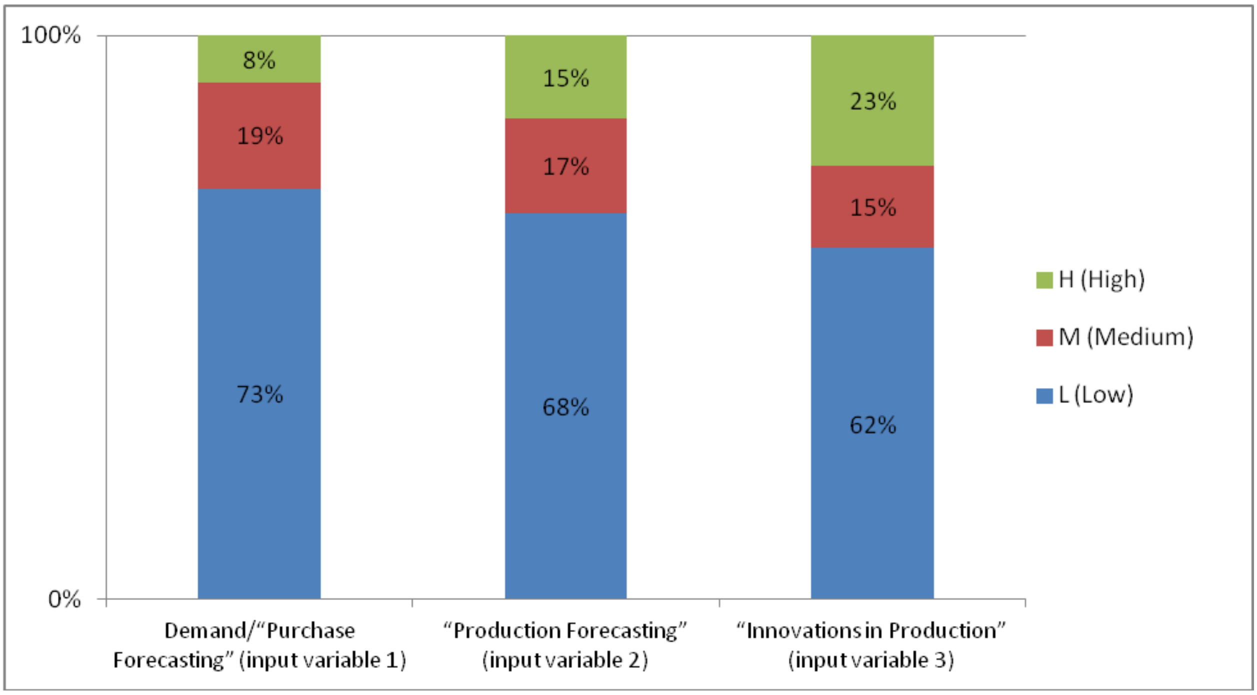

FIGURE 10. Interviews for sharing information between growers and their dealers on "Demand/Purchase Forecasting" (input variable 1), "Production Forecasting" (input variable 2) and "Production Innovation" (input variable 3).

Second, using the system based on artificial intelligence, the overall assessment of the growers (and their dealers) was determined and analyzed by the intelligent classification of transactions (Figure 10). The analysis indicated that the chosen group for evaluating the proposed method has a high number of transactions with Very High uncertainty about commercial transaction (55%) (Figure 11).

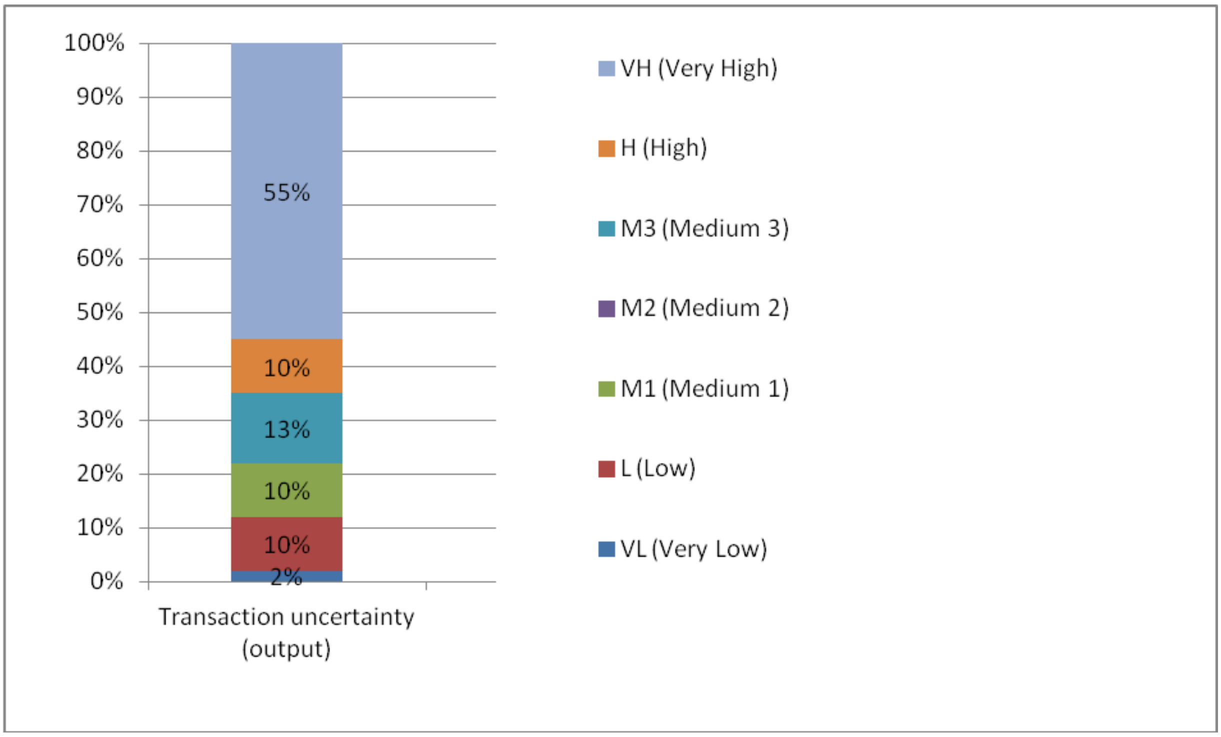

FIGURE 11. Results of simulations of the fuzzy rule-based system, assessing the degree of transaction uncertainty between growers and their dealers.

From the quartile of the set degree of uncertainty in commercial transactions between all growers and their dealers (Table 5), it is possible to observe (Figure 12) that 50% of commercial relations are equal to the maximum degree of uncertainty (2.8965), which has a higher degree of pertinence to the Very High set (Figure 13). Besides, 75% transactions present a level of uncertainty higher than 2.3335 (Medium 3 set). Thus, 50% of the growers hold transactions with Very High level of uncertainty, 25% Medium 3 or High. The others were classified between Low and Medium 2 (Figure 13).

TABLE 5. Descriptive Statistics of the degree of uncertainty in commercial transactions between growers and their dealers.

Minimum	**Quartile 1 (Q1)**	**Median**	**Quartile 3 (Q3)**	**Maximum**
1.10	2.3335	2.8965	2.8965	2.8965

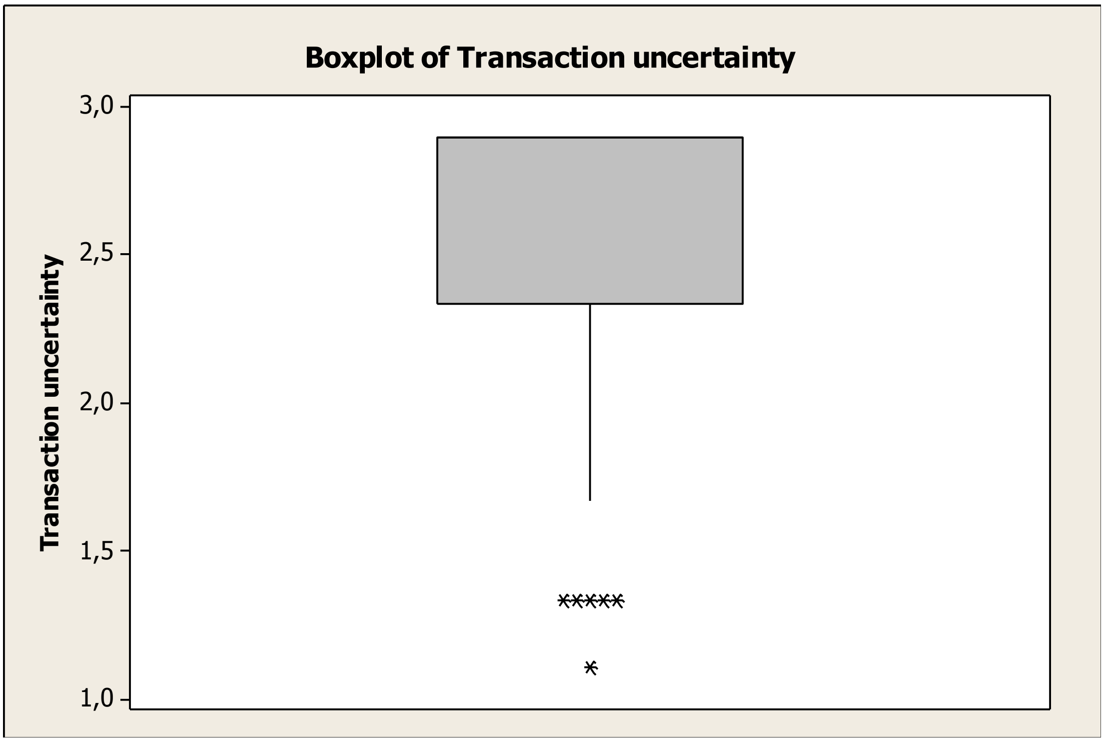

FIGURE 12. Boxplot for data sampling of the degree of transaction uncertainty between growers and their dealers.

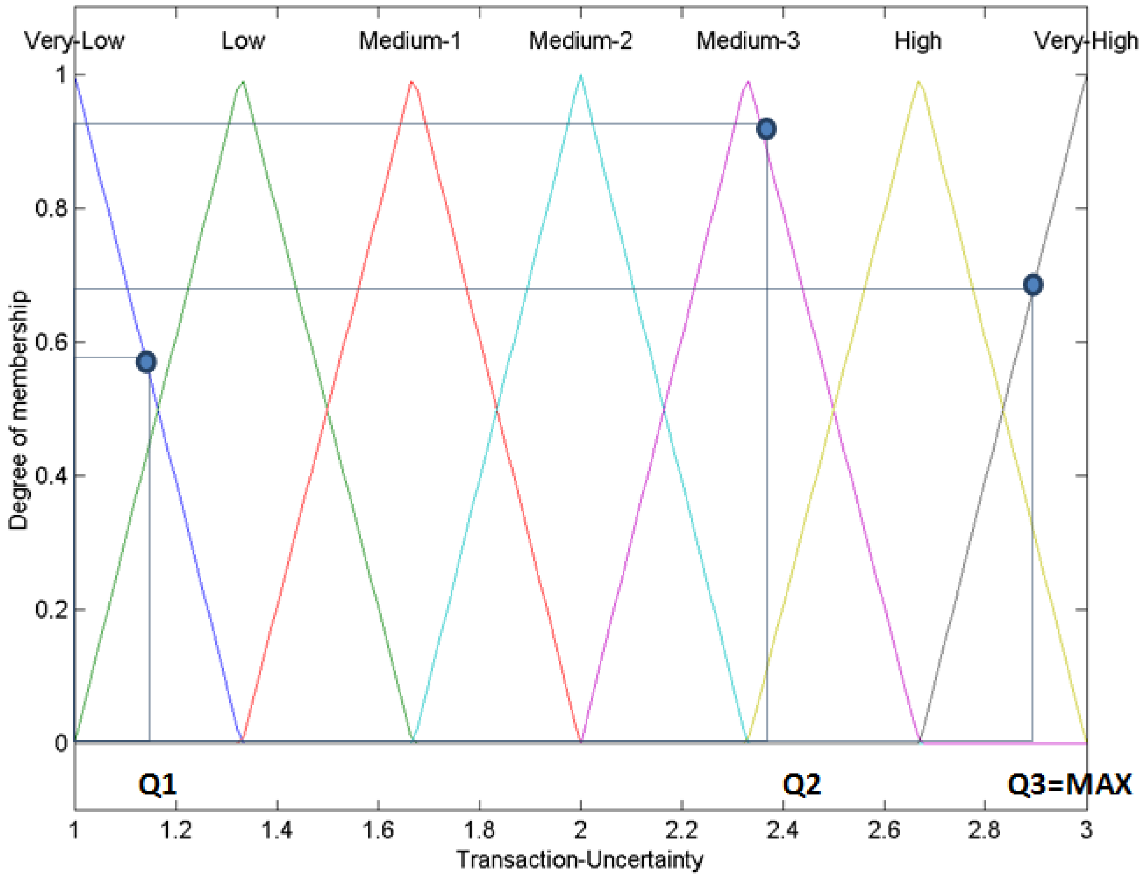

FIGURE 13. Assessment of the quartiles of degree of Transaction Uncertainty between of the growers and their dealers and associations with the respective fuzzy sets.

The different results of the variables analyzed lead to this classification of uncertainty level. Amongst the three information analyzed, the ones under grower control (technological improvements and production level) presented "Low" level of information sharing (62% and 68%). The one out of grower control (demand/purchase) presented a "Very High" level of uncertainty because of the low level of information sharing (73%). "Medium" and "High" level of information sharing were 38% for production innovation; 32% for production forecasting and 27% for demand/purchase forecasting.

The results indicate that the growers tend to focus their attention to technical aspects of production and less to market signs leading to the conclusion that uncertainty derives more intensely from exogenous than from endogenous reasons. This result confirms WILLIAMSON's (1998) statement that uncertainty is related to the difficulty of predicting future situations related to the instability of demand and supply, or to agents' behavior.

It is important to highlight that although the level of endogenous uncertainty is lower than exogenous uncertainty, it still presents a "High" level of uncertainty (55% of "High" level of uncertainty according to artificial intelligence analysis).

CONCLUSIONS

After using the system based on artificial intelligence, it was determined an overall assessment of cassava growers (and their dealers), with the highest degree of membership for the fuzzy feature as High, indicating this level for the transaction uncertainty between growers and their dealers.

The results of this research can be useful to perform simulations of actions that could be implemented in order to reduce the level of uncertainty concerning the transaction between the cassava marketing channel agents, that is, to bring it to a degree level lower than Very High, allowing for transaction cost reduction. The developed fuzzy system consists of an excellent decision making tool for managers to create public policy to improve one of three input variables and thus improve performance of cassava market.

The scientific contribution to the academic community considering the New Institutional Economics is the possibility of measuring uncertainty, which is an important source of transaction costs. Besides, the research contributes to public policy makers because it allows for simulation of situations aiming at reducing the level of uncertainty before they are effectively implemented.

Thus, if the policy makers at Regional Development Offices (of Assis and Tupa) want to propose actions to improve, for example, the behavior of information sharing between growers and dealers regarding demand/purchase forecasting, they can have a prediction system based on artificial intelligence fuzzy result of these actions on the level of uncertainty. So, if half of the growers/dealers improve this particular aspect (demand/purchase forecasting), one can verify that the improvement in the degree of uncertainty will be really effective. Still, one can choose to perform other actions (with lowers costs) that will further improve the production forecast. These actions may occasionally lead to a lower degree of transition uncertainty.

Finally, the methodology for building this mathematical/computational system can be applied to any group of growers/dealers, since the fuzzy rule-based system has been also confirmed by experts in the region where the system was applied.

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REFERENCES

AIMIN, H. Uncertainty, risk aversion and risk management in agriculture. *Agriculture and Agricultural Science Procedia*, Beijing, v.1, p. 152-156, jun. 2010.

ARBAGE, A. P. *Custo de transação e seu impacto na formação e gestão da cadeia de suprimentos: estudo de caso em estruturas de governança híbridas do sistema agroalimentar no Rio Grande do Sul*. Tese (Doutorado em Administração) – Universidade Federal do Rio Grande do Sul, Porto Alegre, 2004.

AZEVEDO, P. F. Nova Economia institucional: referencial geral e aplicações para a agricultura. *Agricultura em São Paulo*, São Paulo, n.47, v.1, p. 33-52, 2000.

CANEPPELE, F. L.; SERAPHIM, O. J. Análise da eficiência energética na indústria madeireira através da lógica fuzzy. *Energia na Agricultura*, Botucatu, v.28, n.2, p. 95-102, 2013.

CANEPPELE, F. L.; SERAPHIM, O. J.; GABRIEL FILHO, L. R. A.; CREMASCO, C. P.; SAVI, A. F. Gains obtained in hybrid systems of energy generation solar photovoltaic and wind power for rural electrification with the use of fuzzy logic controllers based. *Scientific Journal Agricultural Engineering*, Belgrado-Sérvia, v.28, n.2, p.35-44, 2013.

CREMASCO, C. P.; GABRIEL FILHO, L. R. A.; CATANEO, A. Metodologia de determinação de funções de pertinência de controladores fuzzy para a avaliação energética de empresas de avicultura de postura. *Energia na agricultura*, Botucatu, v.25, n.1, p. 21-39, 2010.

BAIMEI, Y.; EUNCHEOL, P.; ZHONG, Q. Fuzzy comprehensive evaluation of industrialized agribusiness selecting agricultural garden district. *Journal of China Agricultural University*, Beijing, v.8, n.6, p 77-80, 2003.

GABRIEL FILHO, L. R. A.; CREMASCO, C. P. C.; PUTTI, F. F.; CHACUR, M. G. M. Application of fuzzy logic for the evaluation of livestock slaughtering. *Engenharia Agrícola*, Jaboticabal, v.31, n.4, p. 813-825, 2011.

LOCATELLI, B.; ROJAS, V.; SALINAS, Z. Impacts of payments for environmental services on local development in northern Costa Rica: a fuzzy multi-criteria analysis. *Forest Policy and Economics*, Amsterdam, v.10, n.5, p. 275-285, 2008.

MASSAD, E.; ORTEGA, N.R.S.; BARROS, L.C.; STRUCHINER, C.J. *Fuzzy Logic in Action*: applications in epidemiology and beyond (Studies in Fuzziness and Soft Computing). Heidelberg: Springer-Verlag, 2008.

MENARD, C. A. New aproach to the agro-food sector: new institutional economics. In: CHAIN MANAGEMENT IN AGRIBUSINESS AND THE FOOD INDUSTRY, 2000, Wageningen. *Proceedings*…Wageningen: Wageningen Pers, 2000.

PEREIRA, D. F.; BIGHI, C. A.; GABRIEL FILHO, L. R. A.; CREMASCO, C. P. Sistema fuzzy para estimativa do bem-estar de matrizes pesadas. *Engenharia Agrícola*, Jaboticabal, v.28, n.4, p. 624-634, 2008.

PONCIANO, P. F.; YANAGI JUNIOR, T.; SCHIASSI, L.; CAMPOS, A. T.; NASCIMENTO, J. W. B. do. Sistema fuzzy para predição do desempenho produtivo de frangos de corte de 1 a 21 dias de idade. *Engenharia Agrícola*, Jaboticabal, v.32, n.3, p.446-458, 2012.

PUTTI, F. F.; GABRIEL FILHO, L. R. A.; SILVA, A. O.; LUDWIG, R.; CREMASCO, C. P. Fuzzy logic to evaluate vitality of catasetum fimbiratum species (*Orchidacea*). *Irriga*, Botucatu, v.19, n.3, p.405-413, 2014.

REYS, M. A.; ARBAGE, A. P.; OLIVEIRA, S. V. Identification of sources of transaction costs: a fuzzy approach for the evaluation of analytical categories. In: INTERNATIONAL PENSA CONFERENCE: economic crisis: food, fiber and bioenergy chains, 7., 2009, São Paulo: Proceedings…São Paulo: school of economics, business and accounting (FEA/USP), 2009.

REYS, M. A.; ARBAGE, A. P.; OLIVEIRA, S. V. Identification of sources of transaction costs: a fuzzy approach for the evaluation of analytical categories. *Organizações Rurais & Agroindustriais*, Lavras, v.12, n.1, p. 11-19, 2010.

TIZZEI, A.; MENEGHETTI, C. R.; CAPPELLI, N. L. UMEZU, C. K. Sistema para estudos de estratégias de controle aplicadas em câmaras frias. *Engenharia Agrícola*, Jaboticabal, v. 31, n.5, p. 868-878, 2011.

VIANA, J. G. A.; SILVEIRA, V.C.P.; ARBAGE, A.P.; MACHADO, J.A.D. 2012. Governance and transaction costs in the sheep production chain in Rio Grande do Sul, Brazil. *African Journal of Business Management*, Nairobi, v. 11, n. 6, p. 4376-4385.

WILLIAMSON, O. E. Transaction Cost Economics: how it works, where it is headed. *De Economist*, Dordrecht, v. 146, n. 1, p. 23-58, 1998.

YANAGI JUNIOR, T.; SCHIASSI, L.; ABREU, L. H. P.; BARBOSA, J. A.; CAMPOS, A. T. Procedimento fuzzy aplicado à avaliação da insalubridade em atividades agrícolas. *Engenharia Agrícola*, Jaboticabal, v.32, n.3, p. 423-434, 2012.