CAFEi2016-162

Structural equation modelling development on land and water use change in rice production at Sumani Watershed, Indonesia

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Abstract

Rice production is determined by several factors related to climatologycal, hydrological, agricultural input, technology and social economic condition. Those factors are related and it is difficult to describe how production would be improved. Sumatera Barat is a rice supplier province in Sumatera Island, Indonesia. Sumani Watershed is a primary rice producing region and more development and investment are required in Sumatera Island. Structural Equation Model (SEM) is a family of statistical technic for estimating and testing causal relationship. In this research, SEM was applied to identify the key factor and constrains in rural development area. The model was simulated base on the heterogeneous agricultural condition of each sub districts in Sumani Watersheds. The result show the key factor that affected the increasing rice production in sumani watershed is irrigation system through technical irrigation system and semi-technical irrigation. Irrigation system affected cropping index around 69 % and it effected yiel around 64%. The constraints in rice production in Sumani watershed are the pest issues and farmers poverty. The investments in all factors that effected the rice production are required. But result shows the improvement irrigation system is a substantial factor to increase rice production by significantly increasing cropping index and yield.

Keywords: irrigation, agricultural management, rice production, structural equation modelling.

INTRODUCTION

Background

Rice is a substantial commodity in the most Asian countries. More than 90 % of the world's rice is produced and consumed in Asian with the main challenge is to provide sufficient affordable food for growing and urbanizing populations and to alleviate rural and urban poverty under increasing pressure on land, water, and labour resources that threaten the sustainability of the rice production base (Comprehensive Assessment of Water Management in Agriculture, 2007). To meet the increasing demand of rice in coming decades, productivity irrigated area become a key factor in sustainability of rice production through adequate investment with intensification approach on development of rural area.

The intensification approach in order to increase land productivity and cropping index will determine by hydrological aspect, technology, agricultural input, and agricultural infrastructures. Where soil fertility cannot be maintained by means other than the fallow, yields and the return on labour will decline with intensification. As this proceeds, greater nutrient input is required. More crops also require more water, so supplementary and eventually full irrigation maybe needed. As cropping more intensive and the diversity of crops is reduced, weed, pest and disease problem become more acute, require further inputs (Evans, 1998).

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Based on Binswanger and McIntire (1987) and Smith et al. (1990) improved access to market can also induce intensification. It also increase returns to inputs, providing an incentive to apply higher levels of inputs. The process of intensification can be substantially accelerated, achieved at lower levels of land scarcity, by making appropriate technologies available. If technical advance is large enough to give the region a comparative advantage in the production of a crop, farmers will be anxious to market it as cash crop (Smith et al., 1990). Therefore the comprehensive evaluation and assessment of the existing condition of the factors that influence paddy production is a substantial step for a proper decision making and future investment.

Structural Equation Modelling (SEM) is a powerful statistical approach for analysis of complex datasets with multiple mutually inter correlated dependent and independent variable, and SEM widely used in the social science and behavioural science and recently become commonly applied in natural science (Lamb et al., 2011). Regardless of the specific variable the researcher uses, SEM is confirmatory technique where analysis typically involve testing at least one priori theoretical model, and it test the entire theoretical model in one analysis (Shadfar and Malekmohammadi, 2013). SEM allows a researcher to test multiple potential networks involving latent and observed variables (Lamb et al., 2011). Researcher can choose several variables that directly or indirectly measure and it can be logically or theoretical explained. Therefore, SEM can be used as a tool to evaluate the complex relationship of several factors that determine rice production related to climatological, hydrological, agricultural input, practice/management technology and social/economic condition.

Research Objectives

- To develop structural equation model tool to evaluate the complex relationship of several factors that determine rice production in Sumani Watershed
- To identify the key factors that influence paddy production for a proper decision making and future investment.

MATERIALS AND METHODS

Research Location

Research location is Sumani Watershed located in Solok Regency (latitude 00^0 32’ 14’’ to 01^0 46’45” S, longitude 100^0 25’ 00” dan 100^0 41’ 41” E), Sumatera Barat, Indonesia. Sumatera Barat Province contributed approximately 3.2 % of national paddy production with average productivity around 4.9 ton/ha (BPS, 2013). Compare to Java Island, more development and investment are required. Sumani watershed is a primary rice producing region. Total area of the watershed is 57090 ha, and around 30 % is paddy field. Administratively, around 90 % Sumani watershed lies in Solok Regency and the rest in Solok City. Rice is not only the staple food in this area but also the cash crop. Rice is exported to another province and another island. In 2013, Agriculture contribute around 45.23 % of Gross Regional Domestic Product (GRDP) of Solok Regency (BPS of Solok Regency, 2014).

Data collection

Climatologycal, hydrological, agricultural input, practice/management technology and social/economic data was collected for each Sub Districts of Solok Regency that lies in Sumani Watershed. There are 6 Sub Districts; Lembang Jaya, Danau Kembar, Gunung Talang, Bukit Sundi, Kubung, and X Koto Singkarak. The period of data is from 2004-2014. The detail variable is explained in the Table1 and correlation matrix of variables can be seen in Appendix1.

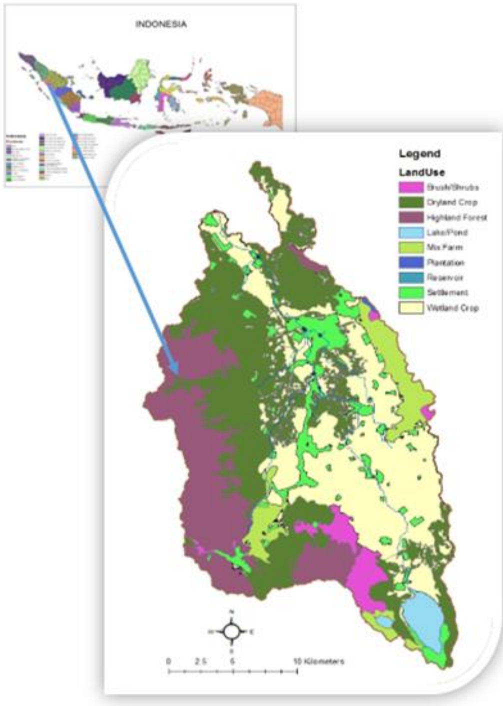

Figure 1. Sumani Watershed (research location).

Table 1. Factors that determine rice production in Sumani watershed.

Categories	Variables
Climatological and Hydrological	Precipitation, temperature, evaporation, discharge
Agricultural	Fertilizer, yield, cropping index, paddy field area, harvested area, planted area, irrigated area
Social/Economic	Population, Number of farmers organization, number of market, number of Rice Milling Unit, number of poor family, rice price, consumption per capita, export
Technology	Thresher, hand tractor, hand sprayer, fumigator

Data Source: Statistical Agency of Solok Regency and Water Resources Management Agency of Sumatera Barat

Structural Equation Model (SEM)

The basic building blocks of SEM analyses, which follow a logical sequence of five steps or processes; model specification, model identification, model estimation, model testing and model modification. Model Specification involves using all of the available relevant theory, research, and information to develop a theoretical model. Model specification directly involves deciding which variable to include and not include in theoretical structural equation model. Model identification refers to whether a set of unique parameter estimates can be identified. Model estimation involves estimating the parameters in the hypothesized structural equation model by deciding estimation technique. Maximum likelihood is an estimation technique for multivariate normality assumption, there are no missing data, no outliers and continuous variable data. Model testing is the next crucial step in interpreting result for the hypothesized structural equation model. If model-fit indices are not acceptable, model modification need to be execute by adding or deleting paths to achieve a better model to data fit (Schumaker and Lomax, 2010).

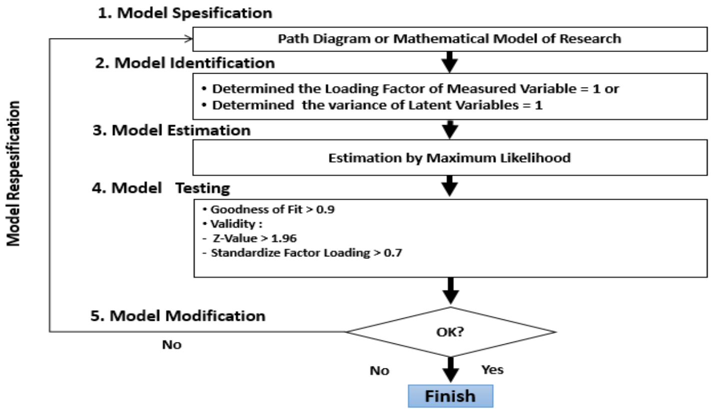

Figure 2. Flowchart of structural equation model.

RESULTS AND DISCUSSION

Data Preparation

Rice production formulated by land productivity/yield, cropping index and area. Crop yield equation is described as formulation of harvest index, machine harvest efficiency, pest factor, and standing live biomass. Harvest index as the growth stage of crop and standing biomass describe the potential plant growth that effected by water, temperature, evaporation, solar radiation and nutrient. Potential crop growth and yield are usually not achieved because of constraints imposed by the plant environment such as stresses caused by water, nutrients, temperature, aeration, and radiation (Williams et al., 2012). Therefore, Climatological and hydrological data such as precipitation, evaporation, discharge and temperature are require as the factors that determine potential plant growth. Climatological data was collected from one climatological station (Saniang Baka). Rainfall data was collected from 6 rainfall stations that located in each sub district and discharge data was collected in one gauge station that located at outlet of Sumani watershed. In addition, agricultural input data such as fertilizer is also require as nutrients that affected potential plant growth. The fertilizers that have been used in research location are Urea, NPK, ammonium sulphate (ZA), phosphate (SP 36) and organic fertilizer.

Machine harvest efficiency is related to technology application that influence yield. In research location, most of farmers use thresher for harvesting tools. The threshers is assumed in good condition and have same capacity and efficiency. Therefore the number of the thresher will affect the harvest efficiency in each sub district. The other technology application in this area are hand tractor. Application hand tractor in land preparation also affect the yield through potential plant growth in aeration process. Majority farmers used hand tractor due to small size of paddy field area. Other technologies related to pest factor are hand sprayer and fumigator. The application of these technology indicate that blast, brown plant hopper, mice, are the pest factor that will influence yield.

The food security for the coming decade depend on productive capacity of irrigated area. Irrigation could contribute 55 % of the total value of food supply by 2050 (Comprehensive Assessment of Water Management in Agriculture, 2007). The conjunctive water use for crop in dry season in irrigated area will increase the possibility to increase yield and cropping index. Therefore the performance irrigated area need to be evaluated through their influence to yield and cropping index. Irrigated area was divided into 4 classification, technical irrigation, semi-technical irrigation, simple irrigation and non-government irrigation. Technical irrigation has high irrigation efficiency due to the irrigation channel and drainage is separated. Moreover it is equipped with a water flow measuring devices at each water diversion. Semi-technical irrigation also has a water flow measuring devices but only at intake, so the efficiency is moderate. Simple irrigation is irrigation system where water distribution is not measured and regulated. While non-government irrigation is a simple irrigation system that is made by farmers with simple construction.

The growing population not only increase demand of food but also increase the land conversion that effect the paddy area. To meet the food demand, intensification is the prominent approach. Therefore the increasing food demand stimulate the increasing cropping index and yield. Another factor that determine food demand are consumption per capita, rice price and income. Consumption per capita can be an indicator of socio-economic condition of the people in the area. Consumption per capita in this area tend to decrease, it is probably due to economic growth that make people more concern on nutritional food and have more ability to access another type of food not only rice. Rice price indicate the availability of rice in the market. Where rice price will higher if stock in the market deficit and it will affect the demand due to consumer ability to buy. Therefore income also an important indicator that determine of demand of rice. Most of the people in this rural area are farmers with low income who has limited access get another source of food except rice, so the number of people who live in poor zone is required to represent income that effected rice demand.

Rice is also a cash crop commodity in Sumani watershed. Improving access to market will increase farmer's income and it also increase farmers ability to access more input for rice production. In this area, rice have been sold in the domestic market. It also has been sold at Rice Milling Unit to private party or exported to other area. Rice milling units are owned and organized by privet sectors or farmers organization. Beside, some farmer's organization also develop agribusiness to increase income. Therefore the existing of farmer's organization also affected paddy production through market stimulation.

Model Specification

Based on theoretical formulation and data collection analysis, the hypothesis of the model was formulated. (1) The increasing rice production have been done through intensification approach, therefore the increasing yield and cropping index determine the increasing rice production in Sumani watershed (2) The direct factors that affect rice production are potential plant growth, production technology and irrigation system, while the indirect factors are demand of rice and market/post-harvest facilities. The path diagram of the model can be seen in Figure 3.

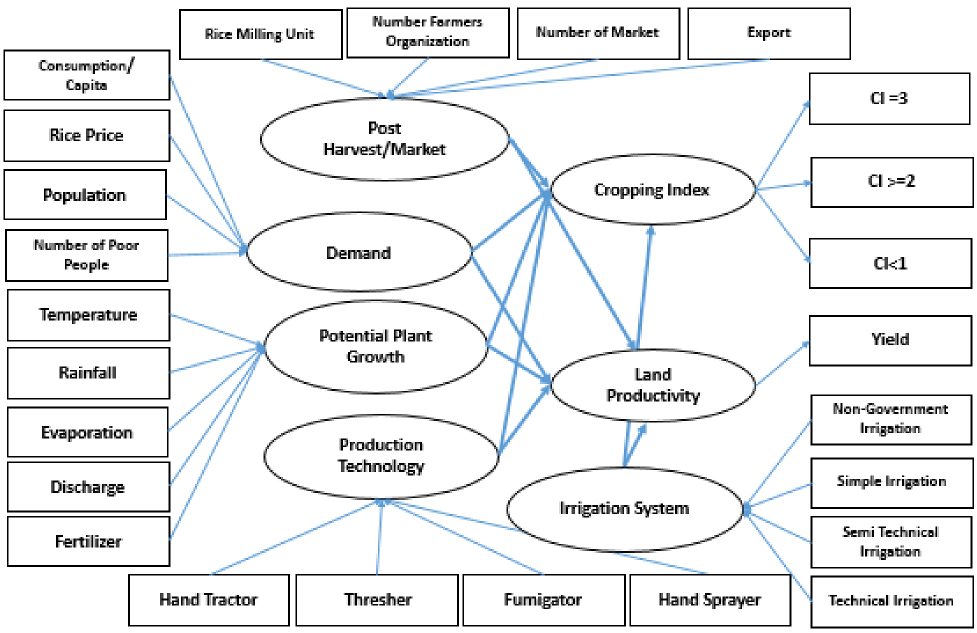

Figure 3. Path diagram of structural equation model.

Model identification

Base on path diagram on Figure2, the model has 25 factor loadings, 25 measurement error, 10 structural coefficients, 5 latent independent variables and 2 equation prediction error variance. A required condition for a model to be estimated is that there are more data points than parameters to be estimated (Ullman, 2006). In the hypothesize model, there are 325 data point which consist 25 variance and 300 covariance. While there are 42 parameters to be estimated. Therefore, model probably is identified.

Model estimation and model fit

Several model were tested but only two model are discussed in this paper, the first model and the best model. The initial model estimations showed improper solution result. It was shown by loading factors > than 1, negative variance estimations or Heywood case. The first estimation result showed that export and fumigators have factor loading > 1 and rice milling unit, rice price, thresher, hand tractor, discharge, rainfall, fertilizer have negative factor loading. While land productivity and cropping index have negative error variance. Therefore the first model need to modify.

Model modification

Based on the first simulation result, respesification of the model by deleting or adding measurement variable need to be done. The result of the respesification can be seen in Figure4.

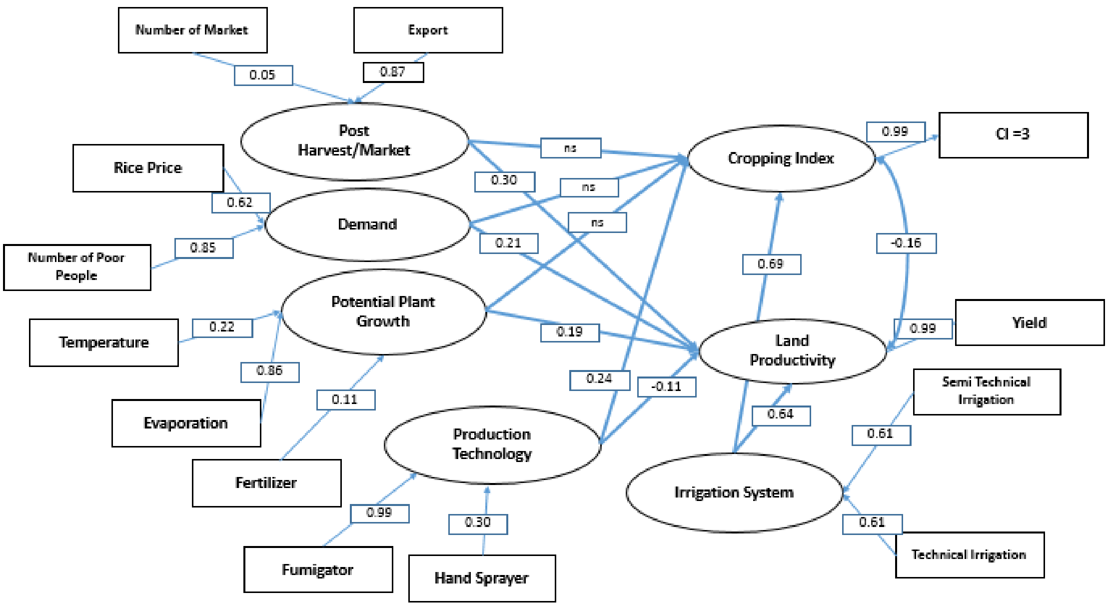

Figure 4. Path Diagram of structural equation model after respesification.

The goodness of fit indicators showed that the model has good fit index. Such as GFI = 0.975, CFI = 0.980, and RMSEA = 0.12. There are several measure variable that have factor loading less than 0.7, but due to the model has a good fit and theoretical prove, researcher decide to keep the variables. The structural equation can be seen in table 2.

Table 2. Structural Equation Model

Structural Equation
Cropping Index = 0.69 Irrigation System + 0.09 Production Technology
Land Productivity = 0.64 Irrigations System + 0.21 Demand + 0.30 Post Harvest/Market + 0.19 Potential Plant Growth – 0.11 Production Technology

The result shows that cropping index is effected by irrigation system and production technology. Irrigation system affected cropping index around 69 % through technical irrigation and semi technical irrigation. While production technology affected cropping index around 24 % through fumigator and hand sprayer. Irrigation system also effected yield around 64% and production technology effected yield negatively around 11%. Moreover, yield also effected by demand around 21%, post-harvest/market around 30 % and potential plant growth around 19%.

This indicate the irrigation system is the key factors that effected rice production in Sumani watershed. But in this watershed only 29 % of paddy area are irrigated with technical and semi technical irrigation system. Therefore, the irrigation improvement still need to be done to increase yield and cropping index. Post-harvest/market and demand only effected yield, it means majority farmers in this area manage paddy field for self-consuming and sell the surplus. It was caused by small holder's farmers and farmers aging factors. Therefore these factors cannot stimulate cropping index due to the limited return input. The pest control also become a major concern that effected rice production, where the production technology through fumigator and hand sprayer effected the increasing cropping index but effected yield negatively. It is also explained by small holder's farmers. When pest issues occur and decrease the yield, farmers will force to increase cropping index.

CONCLUSIONS

The following conclusions can be drawn from the study:

- All the hypothesis in this research are accepted and can be explained by the simulation result, therefore structural equation model can represent the real situation in Sumani Watershed.
- The factor that has significantly affected rice improvement in sumani watershed is irrigation system through technical irrigation system and semi-technical irrigation. The constraints in rice production in Sumani watershed are the pest issues and farmers poverty.
- The increasing rice production in Sumani watershed in Sumani watershed respectively low, therefore the investments in all factors that effected the rice production are required. But result shows the improvement irrigation system is a substantial factor to increase rice production by significantly increasing cropping index and yield.

Literature cited

[BPS] Statistical Agency of Solok Regency. (2004-2014). Solok Regency in Figures. Indonesia: Solok Regency.

Comprehensive Assessment of Water Management in Agriculture. (2007). Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. London: Earthscan, and Colombo: International Water Management Institute. 515-549.

Evan, L.T. (1998). Feeding the Ten Billion: Plants and Population Growth. United Kingdom: Cambridge University Press. 196-227.

Lamb, E., Shirtliffe, S., and May, W. (2011). Structural equation modeling in the plant sciences: An example using yield components in oat. Can. J. Plant Sci. *91(4),* 603-619 http://dx.doi.org/10.4141/CJPS2010-035 http://www.nrcresearchpress.com/doi/pdfplus/10.4141/cjps2010-035.

Schumacker, R. E., and Lomax, R. G. (2004). *A* beginner's guide to structural equation modeling. Psychology Press. Third Edition. New York: Taylor & Francis Group. 1-11.

Shadfar, S., and Malekmohammadi, I. (2013). Application of Structural Equation Modeling (SEM) in restructuring state intervention strategies toward paddy production development. Int. J. Acad. Res. Bus. Soc. Sci. *3(12),* 576. http://dx.doi.org/10.6007/IJARBSS/v3-i12/472

Smith, J., Barau, A. D., Goldman, A., and Mareck, J. H. (1994). The role of technology in agricultural intensification: The evolution of maize production in the Northern Guinea Savanna of Nigeria. Economic development and cultural change, *42(3),* 537-554.

Ullman, J. B. (2006). Structural equation modeling: Reviewing the basics and moving forward. J. Pers. Asses. *87(1),* 35-50.

Water Management Resources Agency. 2004-2014. Climatological and hydrological data of Saniang Baka Station. Bukittinggi, Indonesia: Water Management Resources Agency.

Williams, J. R., Izaurralde, R. C., and Steglich, E. M. (2008). Agricultural Policy/Environmental eXtender Model: Theoretical documentation version 0604. BREC Report, *17*.

Appendix 1. Correlation matrix of measurement variables

Variables	Yield	NPF	Pop	Cons	RP	RMU	NFO	NM	Export	D	T	E	Rain	Fer	Thresh	HT	Fum	HS	TI	STI	SI	NGI	CI1	CI2	CI3
Yield	**1.00**																								
Num of Poor Family (NPF)	0.37	**1.00**																							
Population (Pop)	0.54	0.60	**1.00**																						
Consumption Per Capita (Cons)	-0.03	0.20	-0.08	**1.00**																					
Rice Price (RP)	0.21	-0.29	0.11	-0.53	**1.00**																				
Rice Milling Unit (RMU)	0.39	0.20	0.41	-0.05	-0.10	**1.00**																			
Num of Farmers Organization (NFO)	0.53	0.23	0.65	0.03	0.45	0.25	**1.00**																		
Number of Traditional Market (NM)	-0.28	0.14	0.01	-0.18	-0.06	0.69	-0.03	**1.00**																	
Export	0.84	0.22	0.49	-0.02	0.08	0.75	0.39	0.25	**1.00**																
Discharge (D)	-0.07	0.34	0.02	0.05	0.07	0.07	-0.22	-0.12	0.00	**1.00**															
Temperature (T)	0.16	-0.20	0.00	-0.34	0.37	0.16	0.21	0.13	0.16	-0.31	**1.00**														
Evaporation (E)	0.42	-0.15	0.14	-0.49	0.65	0.13	0.32	0.21	0.29	-0.21	0.24	**1.00**													
Precipitation (Rain)	-0.13	-0.31	-0.31	-0.08	0.06	-0.03	-0.15	0.10	-0.09	-0.18	0.07	0.26	**1.00**												
Fertilizer (Fer)	0.32	-0.09	0.12	-0.07	0.13	0.21	0.18	0.07	0.37	-0.20	-0.01	0.15	0.16	**1.00**											
Thresher	0.02	0.14	0.01	-0.06	0.19	-0.02	0.09	0.08	-0.04	-0.01	-0.01	0.06	-0.03	-0.05	**1.00**										
Hand Tracktor (HT)	0.58	0.08	0.47	-0.38	0.55	0.15	0.53	-0.06	0.45	-0.27	0.43	0.43	-0.17	0.20	-0.06	**1.00**									
Fumigator (Fum)	0.51	0.17	0.55	-0.03	0.26	0.38	0.34	0.01	0.62	-0.08	0.12	0.14	-0.21	0.30	-0.02	0.59	**1.00**								
Hand Sprayer (HS)	-0.54	-0.24	-0.39	-0.11	-0.03	-0.20	-0.31	0.09	-0.45	0.02	0.05	-0.08	0.41	0.04	0.02	-0.35	-0.30	**1.00**							
Technical Irrigation (TI)	0.73	0.71	0.28	0.07	0.02	0.09	0.28	-0.31	0.56	0.01	0.06	0.21	-0.20	0.21	-0.15	0.40	0.16	-0.55	**1.00**						
Semi-Technical Irrigation(STI)	0.71	0.38	0.67	0.14	0.02	0.54	0.52	0.04	0.77	0.00	0.03	0.09	-0.05	0.38	0.02	0.38	0.71	-0.26	0.28	**1.00**					
Simple Irrigation (SI)	0.40	0.32	0.46	-0.13	0.16	0.47	0.31	0.45	0.47	-0.10	0.08	0.17	-0.08	0.19	0.09	0.33	0.62	-0.11	-0.23	0.64	**1.00**				
Non Government Irrigation(NGI)	0.41	0.05	-0.14	0.39	-0.33	0.17	-0.08	-0.16	0.45	0.09	-0.08	-0.11	0.16	0.16	-0.09	-0.05	0.04	-0.24	0.54	0.28	-0.25	**1.00**			
Cropping Index1(CI1)	-0.04	0.10	-0.07	-0.20	-0.04	0.11	-0.04	0.18	-0.02	0.08	-0.08	0.02	0.28	0.19	-0.01	-0.14	-0.26	0.20	-0.03	-0.03	-0.01	0.02	**1.00**		
Cropping Index2 (CI2)	0.64	0.43	0.52	0.17	-0.07	0.23	0.46	-0.15	0.49	0.00	-0.06	0.08	-0.19	0.19	-0.02	0.30	0.19	-0.45	0.60	0.45	0.00	0.50	0.15	**1.00**	
Cropping Index3 (CI3)	0.81	0.27	0.51	0.15	0.02	0.44	0.39	-0.05	0.84	-0.02	0.09	0.15	-0.14	0.31	-0.06	0.46	0.68	-0.45	0.59	0.83	0.47	0.42	-0.30	0.33	**1.00**