Applying the linear mathematical model to determine the structure of agricultural land use in Bac Ninh Province

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Abstract

Nowadays, the linear mathematical model has been being applied widely in socio-economic issues. In the field of land management, this model has been being utilized diversely in many aspects. The objective of the research is applying the linear mathematical model to determine the structure of agricultural land use for restructuring agriculture toward improving the value added, connecting to the commodity production. The research results showed that the rate of the commodity land such as vegetables, winter plants, flowers - ornamental plants have increased strongly which is suitable to the agricultural development direction and is the basis for reasonable land use orientation in Bac Ninh province. However, this is just a master orientation in the provincial level. It is necessary to apply the more detailed model for determining the detailed land use structure of each type of plants in the commune, district levels of the province.

Keywords: *Linear mathematical model, structure of agricultural land use, Bac Ninh*

1. Introduction

In the land use in each country, the conversion of the agricultural land use purposes to the non-agricultural land use purposes for serving the socio-economic development goals is considered the indispensable needs and also the challenges for land use, agricultural households' living and food security in rural areas (Do Nguyen Hai, 2000). Especially, in the developing countries that have the economy based on agricultural production, if the conversion of the agricultural land use purposes to the other purposes is not planned, control in a good way and if the reasonable agricultural land use orientation is not determined, they will cause the direct and disadvantage effects to the human life and the environment of rural areas (Munroe and Müller, 2007; Omrani *et al*., 2015). These also effect directly on many other issues such as solving jobs and ensuring the income of rural households (DFID, 2002; Tran Trong Phuong, 2012). Besides, land resource used for the purpose of agricultural production is the main source of food, creates income and social justice for the majority of poor people in rural areas (ILC, 2012; Đo Van Nha, Nguyen Thi Phong Thu, 2016).

The linear mathematical model has been being applied widely nowadays in many aspects. Utilizing the linear maths will minimize the human's subjective point of view and becomes one of the important support tools for decision-makers. Following the goals of industrialization and urbanization in Bac Ninh in the period 2010 – 2020, more than 15.000 ha agricultural land will have to converse to non-agricultural purpose (Bac Ninh People's Committee, 2013; Bac Ninh People's Committee, 2014). From the reality and the needs of socio-economic development, it has been bringing big challenges for the agricultural land use in the province. Therefore, it is necessary to build the agricultural land use orientation which is reasonable, effective and, besides, meets the requirements of industrialization, urbanization and restructuring agriculture. Determining reasonable, effective land use structure is very necessary (Nguyen Xuan Thanh, 2018), however, it is raised a question of how the balance between the market demand, food safety and natural suitability of land is solved? For solving that, it is useful to apply the linear mathematical model to determine the structure of agricultural land use for satisfying the balance between the development goals of Bac Ninh province. The objective of the math is that land use types must achieve the maximum added value and the rate of products with certain constraints as the suitability of land, the diversity of land use types, and other provincial development constraints that need to be achieved.

2. Methods

2.1. The study site selection

Based on the current agricultural land use and characteristics of farming system, Bac Ninh Province is divided into three zones, including: (Zone 1) agricultural zone; (Zone 2) industrial zone; (Zon 3) urban zone.

2.2. Method of secondary data survey

This method was used to collect the available data in some departments of the province, including: Department of Natural Resources and Environment, Department of Agriculture and Rural Development, Department of Statistics, and Department of Planning – Financial.

The purpose of the method is to collect data on land use, land use type, land structure in department of natural resource management; crop system, crop productivity in the department of agricultural and rural development; the data on socio-economic development of the province in the department of statistics; the data on household income, household investment in the department of planning and financial.

2.3. *Method of primary data survey*

The investigated households were drectily participated in the production activities in three zones of the province. In total, 385 households were investigated in three districts. The main collected data include the types of crops, area and productivity of each crop, cost and labour use.

2.4. *Method of comparison*

The method was used to compare some results of land use, economic data in the research area. Specifically, some criteria were used to compare, including: Present status and the change of agricultural land use, efficiency of agricultural land use.

2.5. Method of the linear thematical model

The linear themantical model is used to ditermine the land area with the general model:

$$Z_j = \sum_{i=1}^{n} c_{ij} X_i \rightarrow \text{Max}$$

With the constrain: : $\sum_{j=1}^{n} a_{ij} X_i \ (\leq, =, \geq)\ b_i$ and $X_j \geq 0$

In which: X_i (ha): Area of Land Use type.

Z_j : Objective function of the model.

c_{ij} : Coeficient of each variable in the function.

a_{ij} Coeficient of each variable in the function.

b_i : The value of the constrain.

Based on the actual condition of the province, the variable were determined: $X_{i\_j\_k\_v}$

In which: i: The group of soil (i=1÷18 ; 18 groups of soil)

J: Land suitability (j=1,2 ; level of suitability: S1 and S2)

k: Land Use Type (k=1,2,3,4,5 ; 5 Land Use Types)

v: Zone in the province ((v=1,2,3 ; 3 zones in the province)

For example: *$X_{1\_2\_1\_1}$ – Area of soil group 1, Soil suitability S_2, LUT_1, Zone 1.*

The objective function was determined as follows: $Z_{t\_v} = \sum_{i=1}^{18} \sum_{j=1}^{2} \sum_{k=1}^{5} \mathbf{c_{t\_k\_v}}\ \mathbf{X_{i\_j\_k\_v}} \rightarrow \text{Max}$

In which: t – number of objective (t = 2 ; 2 objectices including economic and social)

$c_{t\_k\_v}$ Coeficient of each variable in the function with each LUT

Constrains: - Constrain 1: Soil group

- Constrain 2: Land Use Type
- Constrain 3: The demands of the local development
- Another constrain: $X_{i\_j\_k\_v} \geq 0$ (i=1,...,18 ; j=1,2 ; k=1,2,3,4,5 ; v=1,2,3,3).

3. Resutls

3.1 Current land use in Bac Ninh Province

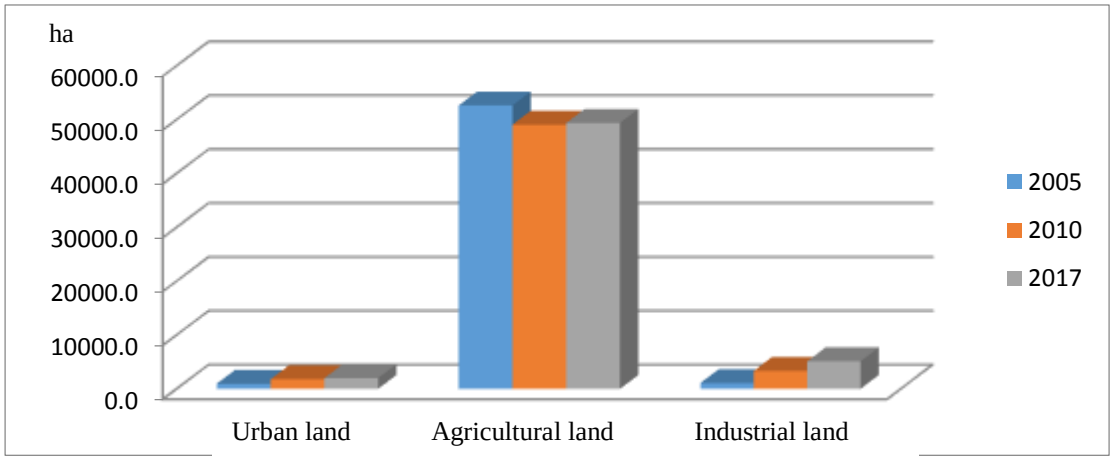

Fig 1. Land use change in Bac Ninh from 2005-2017

***Source**: Statistics department of Bac Ninh*

The current land use in Bac Ninh has changed significantly to meet the purpose of industrialization and urbanization. Especifically, in the period from 2005-2017, urban land increased 1.034,05 ha, industrial land also increased 4.053,0 ha. Non-agricultural land increased everagely 308,46 ha/year. On the contrary, from 2005 to 2017, agricultural land in the province decreased roughly 3.246 ha, in which rice crop land decreased the largest, after that was the another anual crop land.

Table 1. Curent status and agricultural land use change

Agricultural land use criteria	Code	Area in 2017 (ha)	In comparison with 2010		In comparison with 2005	
			Area (ha)	Increase (+) Decrease (-)	Area (ha)	Increase (+) Decrease (-)
1. Agricultural land	NNP	49.375,94	49.049,1	326,84	52.622,25	-3.246,31
1.1 *Agricultural production land*	SXN	43.534,64	43.283,0	251,64	47.017,86	-3.483,22
1.1.1. Annual crop land	CHN	42.898,99	42.841,5	57,49	46.589,77	-3.690,78
1.1.1.1. Rice crop land	LUA	39.716,92	40.481,1	-764,18	44.003,08	-4.286,16
1.1.1.2. Other annual crops land	HNK	3.182,07	2.360,4	821,67	2.534,45	647,62
1.1.2. Fruit tree land	CLN	635,66	441,5	194,16	428,09	207,57
1.2. *Forest land*	LNP	586,26	625,2	-38,94	607,31	-21,05
1.3. *Aquatic land*	NTS	5.060,38	5.000,3	60,08	4.981,74	78,64
1.4. *Other agricultural land*	NKH	194,66	140,7	53,96	15,34	179,32

Source: Land inventory 2005, 2010 and 2017

According to the change of development purpose, the agricultural land use also has changed towards to decrease gradually the area of 2 rice crops and increase the 3 crops: 2 rice crops – winter crop and vegetable, dry crop. The crop system has also transform towards to increase the commodity crops such as: vegetable, dry cop, fruit tree, flower and ornamental plant. Additionally, many agricultural farms were established in the recemt years, including: aquaculture farm, livestock farm and ecological farm.

Currently, there are 5 main Land Use Types (LUTs) in the province, including: 2 rice crops, 2 rice crops – winter crop, vegetable and dry crop, flower and ornamental plant, fruit tree.

Table 2: Actual main Land Use Types in Bac Ninh Province

No	LUT	Total in province (ha)	Proportion (%)	Area of current Land Use Type (ha)		
				Zone 1	Zone 2	Zone 3
1	2 rice crops	30.341,79	69,70	12.404,42	14.277,65	3.659,72
2	2 rice crops – winter crop	8.745,12	20,09	4.371,02	3.250,00	1.124,10
3	Vegetable and dry crop	3.686,92	8,47	1.373,82	1.150,00	1.163,10
4	Flower and ornamental plant	125,15	0,29	29,67	14,98	80,50
5	Fruit tree	635,66	1,46	198,89	266,10	170,67
	Total	**43.534,64**	100,00	**18.377,82**	**18.958,73**	**6.198,09**

Source: Investigation

The results indicate that agricultural production land in the research was 43.534, 64 ha, in which 2 rice crops were the largest with 69.7%, 2 rice crops – winter crop with 20.9%, vegetable and dry crop with 8.47%, flower and ornamental plant with only 0.29%, and fruit tree with 1.46%.

3.2. Results of the linear thematic model

3.2.1. Objective functions

This is objective that the linear thematic model needs to achieve. Based on the current development conditions, the future agricultural development is to increase the Value added (VA) and to gradually develop towards commodity prodcution. In the research, 2 objectives that the linear thematic model will achieve maximun are to increase value added and the proportion of commodity production of LUT.

+ Objective 1: Total Value Added in each zone is the largest.

Zone 1: $Z_{1\_1} = 46{,}65 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_1\_1} + 125{,}60 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_2\_1} + 232{,}99 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_3\_1} + 139{,}04 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_4\_1} + 270{,}50 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_5\_1} \rightarrow Max$

Zone 2: $Z_{1\_1} = 49{,}24 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_1\_2} + 122{,}94 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_2\_2} + 225{,}87 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_3\_2} + 148{,}00 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_4\_2} + 207{,}00 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_5\_2} \rightarrow Max$

Zone 3: $Z_{1\_1} = 52{,}20 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_1\_3} + 154{,}07 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_2\_3} + 228{,}92 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_3\_3} + 288{,}62 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_4\_3} + 171{,}30 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_5\_3} \rightarrow Max$

+ Objective 2: The proportion of commodity production in each zone is optimal (The proportion of the sold agricultural product of each LUT in each zone)

Zone 1: $Z_{2\_4} = 45{,}0 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_1\_1} + 52{,}0 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_2\_1} + 92{,}0 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_3\_1} + 100{,}0 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_4\_1} + 80{,}0 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_5\_1} \rightarrow Max$

Zone 2: $Z_{2\_4} = 49{,}0 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_1\_2} + 54{,}0 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_2\_2} + 82{,}0 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_3\_2} + 90{,}0 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_4\_2} + 75{,}0 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_5\_2} \rightarrow Max$

Zone 3: $Z_{2\_4} = 47{,}0 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_1\_3} + 60{,}0 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_2\_3} + 78{,}0 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_3\_3} + 98{,}0 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_4\_3} + 70{,}0 \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_5\_3} \rightarrow Max$

Table 3: The value of the objective functions ($c_{t\_k\_v}$)

LUT	Value Added (million Đ/ha)			The proportion of sold product (%)		
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3
2 rice crops	46,65	49,24	52,20	45	49	47
2 rice crops – winter crop	125,60	122,94	154,07	52	54	60

Vegetable and dry crop	232,99	225,87	228,92	92	82	78
Flower and ornamental plant	139,04	148,00	288,62	100	90	98
Fruit tree	270,50	207,00	171,30	80	75	70

Source: Investigation

3.2.2. Constrains

+ Constrain 1: The area of soil group

Accorrding to the land evaluation in Bac Ninh Province, there were 82 Land Mapping Units (LMU), however, to reduce the number of varables in the constrain of the linear thematic model, some LMUs having the same level of land suitability with 5 LUTs are aggregated into 1 soil group. The result shows that there are 18 soil groups in the province (Table 4)

The area of LUTs in each soil group is lower than the area of this soil group.

The constrain: : $\sum_{j=1}^{2}\sum_{k=1}^{5} X_{i\_j\_k\_v} \leq d_{i\_v}$

In which: d_{i_v}: The area of each soil group in each zone (18 soil group in 3 zone)

Table 4: Area of soil group (d_{i_v})

Soil group	Land Mapping Unit (LMU)	Area - d_{i_v} (ha)			
		Total in the province	Zone 1	Zone 2	Zone 3
1	9,25,40,41	4.657,91	2.799,45	1.748,36	110,10
2	1	495,38		440,14	55,23
3	67	560,59	355,84	204,74	
4	38	143,66		143,66	
5	6,10,21,22,26,39,42	5.851,12	1.486,46	3.451,47	913,19
6	65,66,68,70	605,82	34,30	502,06	69,46
7	58,6	959,62	564,79	304,77	90,06
8	53	155,54		155,54	
9	13,30,43,54,56,57, 59,61,62,63	3.665,98	1.018,04	2.280,15	367,79
10	69	46,87		21,50	25,37
11	7,8,11,15,23,24,27,28,32, 74,75,76,77,78,79,0,81	15.361,08	8.620,18	4.283,41	2.457,50
12	14,16,29,31,33,44,71	1.492,36	429,00	853,88	209,49
13	2,3	3.045,25	300,21	2.018,92	726,13
14	4	374,53	305,45		69,08
15	52	29,84	29,84		
16	46,47,48	739,18		533,63	205,55
17	5,17,18,34,35,45,49	3.106,96	987,13	1.317,17	802,66
18	19,20,36,37,50,51,55, 64,72,73,82	2.242,94	1.447,14	699,32	96,48
Total		**43.534,64**	**18.377,82**	**18.958,73**	**6.198,09**

Source : Land valuation in Bac Ninh

+ Constrain 2: Area of Land Use Types

The area of each LUT should be lower than the area of land suitability at level S1 and S2 of this LUT. The constrain: : $\sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_k\_v} \leq d_{k\_v}$

In which: d_{k_v}: The area of land suitability at S1 and S2 of each LUT in each zone (including 5 LUTs in 3 zones)

The land suitability at S1 and S2 indecates in the following table:

Table 5: Land suitability *(Unit: ha)*

Zone	Suitability	Land Use Type (LUT)				
		2 rice crops	**2 rice crops – winter crop**	**Vegetable and dry crop**	**Flower and ornamental plant**	**Fruit tree**
Total in the province	S1	5.153,29	11.819,11	1.520,21	299,20	6.178,12
	S2	36.138,41	25.596,61	34.253,12	18.675,26	25.859,91
	S3		2.272,77	4.654,34	1.213,28	3.735,30
	N	2.242,94	3.846,15	3.106,96	23.346,89	7.761,30
	Total	**43.534,64**	**43.534,64**	**43.534,64**	**43.534,64**	**43.534,64**
Zone 1	S1	2.799,45	4.676,06	920,63		3.720,08
	S2	14.131,23	11.237,66	15.864,40	6.168,95	11.188,82
	S3		1.476,97	605,65	390,15	1.876,13
	N	1.447,14	987,13	987,13	11.818,73	1.592,79
	Total	**18.377,82**	**18.377,82**	**18.377,82**	**18.377,82**	**18.377,82**
Zone 2	S1	2.188,50	6.050,30	509,52	299,20	2.257,88
	S2	16.070,91	10.358,31	14.139,34	10.243,81	10.837,78
	S3		699,32	2.992,69	728,30	1.553,20
	N	699,32	1.850,80	1.317,17	7.687,41	4.309,87
	Total	**18.958,72**	**18.958,72**	**18.958,72**	**18.958,72**	**18.958,72**
Zone 3	S1	165,34	1.092,75	90,06		200,16
	S2	5.936,27	4.000,64	4.249,38	2.262,50	3.833,31
	S3		96,48	1.055,99	94,83	305,97
	N	96,48	1.008,21	802,66	3.840,76	1.858,65
	Total	**6.198,09**	**6.198,09**	**6.198,09**	**6.198,09**	**6.198,09**

Source : Land valuation

Table 6: Total area of suitablity of LUTs (d_{k_v}) (Only 2 levels: S_1 and S_2) *(Unit: ha)*

v \ k	Land Use Type (LUT)				
	2 rice crops	**2 rice crops – winter crop**	**Vegetable and dry crop**	**Flower and ornamental plant**	**Fruit tree**
Total	**41.291,70**	**37.415,72**	**35.773,34**	**18.974,46**	**32.038,03**
Zone 1	16.930,68	15.913,72	16.785,03	6.168,95	14.908,90
Zone 2	18.259,41	16.408,60	14.648,87	10.543,01	13.095,66
Zone 3	6.101,61	5.093,40	4.339,44	2.262,50	4.033,47

Source : Land valuation

+ Constrain 3: Local development demands

Together with the constrain on land suitability, to achieve the development purposes, the area of some LUTs need to be zoned in the province to meet the need of food security, vegetable, flower and ornamental plant demands.

The area of each LUT is more than the develoment demands : $\sum_{i=1}^{18} \sum_{j=1}^{2} X_{i\_j\_k\_h} \geq d_{k\_v}$

In which: d_{k_v}: the area of each LUT in each zone to meet the need of the local development demands.

The local development demands based on the master plan, the reconstruction program of agricultural sector in Bac Ninh Province. The demands show in the table 7:

Table 7: Local development demands on the area of LUTs (d_{k_v})

No (y)	Local development demands	Minimum area (ha) – d_{k_v}			
		Total	Zone 1	Zone 2	Zone 3
1	Area of rice crop	34.200	16.000	17.200	1.000
2	Area of winter crop	8.445,4	4.500	3.500	445,4
3	Area of vegetable, dry crop	2.650	1.300	1.200	150
4	Area of flower and ornamental plant	193,8	45	38,8	110
5	Area of fruit tree	690,5	350	265,5	75

Source: Local development demands

The detail constrains:

- Area of rice crop: $\sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_1\_v} + \sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_2\_h} \geq d_{1\_v}$
- Area of winter crop: $\sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_2\_v} \geq d_{2\_v}$
- Area of vegetable, dry crop: $\sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_3\_v} \geq d_{3\_v}$
- Area of flower and ornamental plant: $\sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_4\_v} \geq d_{4\_v}$
- Area of fruit tree: $\sum_{i=1}^{18}\sum_{j=1}^{2} X_{i\_j\_5\_v} \geq d_{5\_v}$

+ *Another constrain:* The varables $X_{i\_j\_k\_v} \geq 0$ (i=1,...,18 ; j=1,2 ; k=1,2,3,4,5 ; v=1,2,3,4).

3.2.3. Results of the linear thematic model

Solving the thematic model for each zone by making concession, Z_1 (Maximun Value Added) is selected with the main objective, Z_2 (The proportion of commodity production) is selected with the expected achievement ≥ 90%. The modul Solver in Excel software is used to run the thematic model. The results show in the following table:

Table 8: Results of the linear thematic model *(Unit: ha)*

No	Land Use Types	Total (ha)	Proportion (%)	Zone		
				Zone 1	Zone 2	Zone 3
1	2 rice crops	3.875,95	8,90	1.016,96	1.850,81	1.008,18
2	2 rice crops – winter crop	30.777,42	70,70	14.982,93	15.349,24	445,25
3	Vegetable and dry crop	5.308,53	12,19	1.447,13	1.454,38	2.407,02
4	Flower and ornamental plant	2.346,44	5,39	45,00	38,80	2.262,64
5	Fruit tree	1.226,30	2,82	885,80	265,50	75,00
	Total	**43.534,64**	100.00	**18.377,82**	**18.958,73**	**6.198,09**

Table 9: The comparison between the results of thematic model and current area of land use

(Unit: ha)

No	Land Use Types	Total	Zone 1	Zone 2	Zone 3
1	2 rice crops	**-26.465,84**	-11.387,46	-12.426,84	-2.651,54
2	2 rice crops – winter crop	**22.032,30**	10.611,91	12.099,24	-678,85
3	Vegetable and dry crop	**1.621,61**	73,31	304,38	1.243,92
4	Flower and ornamental plant	**2.221,29**	15,33	23,82	2.182,14
5	Fruit tree	**590,64**	686,91	-0,60	-95,67

The results indicate that the area of 2 rice crops decrease 26465.84 ha equivalent to 60.7%. In the contrary, 2 rice crops – winter crop, vegetable and dry crop, flower and ornamental plant, fruit tree increase largely with 22032.30 ha, 1621.61 ha, 2221.29ha, 590.64ha, respectively, almost

from 2 rice crops. Therefore, the area of 2 rice crop decrease significantly, and area of commodity crops, such as: vegetable crop, flower and ornamental plant.

4. Conclusions

Bac Ninh is a flat province which has many advantages of natural and socio-economic conditions for developing agriculture towards commodity. There are 5 main land use types in the whole province, of which the area of land use type for 2 rice crops gets the largest proportion of nearly 70% agricultural land, flowers - ornamental land gets the smallest proportion of 0,29%.

Building the linear mathematical model has had 2 main objectives related to restructuring agriculture is optimizing added value and production rate of commodity. With the development conditions of the province, for optimizing the above objectives, it was necessary to put in certain constrains that are binding on area; binding on land suitability; binding on provincial development goals, of which the minimum area needs to be achieved for the main types of land use.

The results of running the model showed that the area of 2 rice crops decreased 60,7%, the area of 2 rice crops – winter plants increased 55,61%, the area of vegetables increased 3,71%, the area of flowers – ornamental plants increased 5,10%, the area of fruit trees increased 1,36%. Therefore, the area of commodity trees increased outstandingly, the crop land dropped sharply. The results ensured the optimal value added in agricultural production and it is ability to shift gradually to the agricultural production of high value commodity.

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