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NGUYEN THI THU HOAN

SCIENTIFIC FOUNDATION FOR REHABILITATING HEADWATER PROTECTIVE FOREST ON LANDS AFTER SHIFTING CULTIVATION IN CAU RIVER WATERSHED, BAC KAN PROVINCE

Speciality: **SILVICULTURE**

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Scientific Supervisors:

1. Assoc. Prof. Pham Van Dien, PhD.
2. Assoc. Prof. Le Sy Trung, PhD.

Reviewer 1: ……

Reviewer 2: ……

Reviewer 3: ……

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PhD. Dissertation would be found in:

- National Library;
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INTRODUCTION

1. Necessity of the study

Cau river watershed - Bac Kan province locates on the territory of four districts and towns: Cho Don, Bach Thong, Cho Moi and Bac Kan. The terrain there is high, mountainous, steep and dissected. In watershed area of Cau river - Bac Kan province, an area of 21,996.8 hectares of land is without forest (*Bac Kan province, 2010*). Scientific basis study and synchronization solutions for the rehabilitation operation and development of Cau river watershed protection forest on after shifting cultivation is limited, namely: lack of basis for classifying land standards after shifting cultivation according to natural rehabilitation potentials; lack of systematic study on protective role of vegetation cover on lands after shifting cultivation; lack of comprehensive silvicultural measures system and suitable trees for forest rehabilitation activities on farmlands after shifting cultivation in headwater areas. In order to address those shortcomings, ***"Scientific foundation for rehabilitating headwater protective forest on lands after shifting cultivation in Cau river watershed, Bac Kan province"*** is absolutely necessary.

2. Research Objectives

- Can analyze the current situation and characteristics of natural rehabilitation of flora carpet on lands after shifting cultivation as a basis for building the classification of rehabilitation capacity in the study area.

- Can assess the protection capacity of flora carpet on lands after shifting cultivation, can classify rehabilitation potential of forest on lands after shifting cultivation through forest time natural rehabilitation, and propose some silviculture solutions for forest rehabilitation on lands after shifting cultivation in the watershed protection area.

3. Significances of the study

3.1. Scientific significance

Determining the quantitative relationship between rehabilitation potential of wood trees on lands after shifting cultivation with combination

of factors such as soil conditions, shifting cultivation time and forest time natural rehabilitation.

3.2. Practical significance

Proposing an index on number of year required for forest rehabilitation on post- shifting cultivation land. The index indicates 03 groups of afftected objects with corresponding specific impact solutions to shorten the rehabilitation time.

4. New scientific findings

Classifying lands after shifting cultivation in accordance with natural rehabilitation potentials of the flora carpet, building an index on number of year required for forest rehabilitation on post-shifting cultivation land.

Proposing suitable silvicultural measures for each target group of lands after shifting cultivation in Cau river watershed protection area.

5. Dissertation structure

The Dissertation includes 135 pages typed in A4 size divided in 3 chapters excluding introduction, conclusion and recommendations (Chapter 1: Literature review, Chapter 2: Object, scope, content and research methods, Chapter 3: Results of research and discussion).

The Dissertation has 35 tables and 31 figures (excluding the appendix for illustration), gets reference from 148 documents, in which 99 documents are in Vietnamese, and 49 documents are in foreign languages.

CHAPTER 1. LITERATURE REVIEW

Most of the national and international studies have proved that the acquired research findings are relatively systematic in various fields:

- *Concept of forest rehabilitation*: there are many different concepts, in general, although most of the concepts show that forest rehabilitation is a progress of re-establishing the forest ecosystems or reversing the degradation process.

- *In term of forest regeneration and rehabilitation features*: The research reflects rules of tropical forest regeneration, natural ability of tropical forest rehabilitation and rules of regenerating and restoring

vegetation on lands after shifting cultivation that are extremely complicated and long-term. That process occurs when impact of exploiting or cultivating definitely disrupts original structure of forest.

- *Factors affecting regeneration*: the research clarifies the factors affecting the natural regeneration features at tropical forests such as group of ecological factors with human interaction and group of ecological factors without human interaction.

- *Water permeability and retention of soil*: It is demonstrated that the most popular method in researching soil permaebility in Vietnam is using O-rings permeability testing (or pipe ring).

- *Characteristics of soil erosion*: Studies of soil erosion have been caried out for a long time in many different land objects by researchers. Universal Soil Loss Equation (USLE) method of Wischmeier and Smith is widely used in the evaluation of erosion. The equation has clarified the role of each factor affecting erosion.

- *Classification of affected objects and proposal of silvicultural solutions:* the division of affected objects was based on basic elements in structure of the forest stand as well as characteristics of regeneration tree layer such as density, growth targets in diameter and height, etc. then, they were inducted into corresponding business objects. Silvicultural solutions for specific objects are also studied and recommended by many authors and are institutionalized in legal documents such as QPN14-92 (1993), QPN 21-98 (1998), QPN13-91 (1991) Regulations.

In addition to research achievements, studies on forest regeneration and rehabilitation potential for lands after shifting cultivation are extremely limited, particularly the protective forest in Cau River watershed, Bac Kan province, lack of studies on features and rules of regeneration as behavior of density increase, height growth, annual increase of the species, the coverage of vegetation, etc. of land plots. The foundations to propose forest rehabilitation solutions for each different forest object, different eco-regions are not sufficient in scientific and practical basis.

Features of researched area: general evaluating characteristics of watershed area and 3 researched communes, the research results are summarized in the Dissertation from page 35 to page 44.

CHAPTER 2
OBJECTS, SCOPE, CONTENT AND METHODOLOGY

2.1. Objects of the study

Objects of the study are divided into 03 types of lands which have not ever been covered by forest after shifting cultivation including: grassland, shrub land, and regenerating woodtree land. Cultivation period is estimated from 5 to 9 years and forest rehabilitation period (from the end of shifting cultivation to the second investigation in 2013) fluctuates between 2 and 11 years.

2.2. Scope of the study

The study focuses on 03 communes: Nong Ha and Cao Ky commune - Cho Moi district and Ra Ban commune - Cho Don district - Bac Kan province. Time of study is from 01/2011 - 12/2014.

2.3. Content of the study

2.3.1. Evaluating the situation and characteristics of the terrain and pedology of lands after shifting cultivation.

2.3.2. Evaluating the characteristics of vegetation cover rehabilitation on lands after shifting cultivation.

2.3.3. Evaluating the protection capacity of vegetation cover on lands after shifting cultivation.

2.3.4. Classifying the potential of forest rehabilitation on lands after shifting cultivation.

2.3.5. Recommending some solutions of headwater forest rehabilitation techniques on lands after shifting cultivation.

2.4. Methodology of the study

2.4.1. Viewpoints of research methodology

The research methodology of the study is to follow the laws of the tropical forest regeneration and rehabilitation, analyze factors affecting forest regeneration and describe the forest rehabilitation

potential with group of elements that has important impact, by mathematical equations. Besides, assessment of protective functions of forest vegetation through water permeable and retentive function as well as erosion risk is combined. From those scientific bases, the classification of affected objects according to the number of years of forest rehabilitation required is built to meet the criteria of being forest on lands after shifting cultivation in protection area of Cau river watershed, Bac Kan province.

2.4.2. Methods of data collection

2.4.2.1. Methods of collecting secondary data

2.4.2.2. Interview method: the criteria on origin of cultivation fields, years of shifting cultivation, years of forest rehabilitation, human impacts on vegetation cover, rehabilitation solutions, and choice of crops in forest rehabilitation, etc. are determined by interview method.

2.4.2.3. Experimental investigation Methods

- Methods of plots disign: Arranging standard plots (SP) that are semi-locating to observe twice, 3 years apart to assess vegetation covers' changes: Number of SP: 36 plots, area: 400 m^2, in a SP, there are 5 sub-plots with an area of 25m^2 used to investigate/ study regenerating trees. A typical SP is set as 3 slope levels (15-25 degrees, 26-35 degrees, and >35 degrees) x 3 positions (the foot, the middle and the top of the slope)

- Investigations on the SP: To measure quantity and classify the height, name, origin, quality of regeneration plants. Regeneration plants are investigated twice, the first time in early 2011 and the second one in late 2013. Therefore, the period between two times of measurements is about 3 years. Shrubs, vegetation, and coverage of vegetation are surveyed.

- In term of ecological factors affecting forest regeneration and rehabilitation: Group of geographic-topographical factors: position (in the foot, middle, top), slope. Group of botanical factors: coverage of shrub and vegetation. Group of soil factors: soil depth, soil porosity, soil moisture, etc. Group of socio-economic factors: impact of grazing, mining, etc.

- Researching land under forest canopy to determine surface soil’s moisture. Analyzing soil samples in terms of physics, chemistry indicators:

there are 18 soil samples analyzed at Land Analysis Division - Institute of Life Sciences - College of Agriculture and Forestry - Thai Nguyen University.

- Researching water permeability of forest soil: Use pipe ring for measuring water permeability of forestland on 18 Sps.

- Researching soil retention characteristic through determining capacity of moisture retention in farmland.

- Researching the possibility of soil erosion through equations of Wischmeier W.H. and Smith D.D (1987).

2.4.3. Data processing methods

- Calculating rate and species composition, density, and quality of generated tree species (counting the percentage of good, bad and medium trees).

- Diversity potential of wood tree species is presented by 6 indexes like Number of species(S), Number of trees (N), and diversity index (d,J', H' and 1-λ').

- Quantity and size of generated trees are identified through experimenting many kinds of correlation function, the chosen function is:

NTS_2_13 = a + b.Z

HTS_2_13 = A + B.Z

In which: Z = (SD.P).A_PHR_13/A_CTNR

(SD.P): combination of soil depth (SD, cm), soil porosity (P,%), A_PHR_13: number of years for forest rehabilitation, A_CTNR: number of years for cultivation). a, b, A, B are parameters of correlation equation respectively.

-The number of years for forest rehabilitation based on density of generated tree species (n_{ct_N},year):

$$n_{ct\_N} \geq \frac{400 - a}{b} . \frac{A\_CTNR}{SD.P}$$

- The number of years for forest rehabilitation based on average height of generated tree species: (n_{ct_H}, year):

$$n_{ct\_H} \geq \frac{4 - A}{B} \cdot \frac{A\_CTNR}{SD.P}$$

Condition: A_CTNR > 0, (it means only applicable for lands after shifting cultivation).

- Calculating indicators about shrubs, vegetation: coverage of shrubs and vegetation (CP, %), determining thickness of vegetation by Drude method.

- Analyzing physical and chemical properties in the laboratory

- Calculating water permeability of soil: initial water permeability speed (Vo, mm/minute) during the first 5 minutes, and calculating stable absorption speed (Vc, mm/minutes).

- Calculating water retention of soil through targets of the smallest porosity and humidity of fields, average humidity of wilting trees, etc.

- Determining quantity of potential soil erosion through nomogram of Wischmeier W. H. and Smith D. D. (1987).

A = 2.47.R.K.LS.C.P (tonnes/ha/year)

- *Calculation and data analysis application*: Specialized software as Excel [110], R statistical software and PRIMER IV are used to calculate the statistical indexes of the Dissertation.

CHAPTER 3

RESULTS AND DISCUSSIONS

3.1 Current status and characteristics of topography and soil properties of lands after shifting cultivation in the research area

3.1.1. Overview of shifting cultivation and bare land in the research area

In the research area, it can be seen through fieldwork study that land for shifting cultivation consist of 2 groups: fixed milpas and non-fixed milpas.

Lands after shifting cultivation has some types like grassland, scrubland, and regeneration tree land.

Land area without forests accounts for a significant area. Grassland has 470.44 ha, accounts for 18% of land without forests, bare land with shrubs has the area of 457.4 ha, equivalent to 17%. 1,543.45 ha is area of bare land with regeneration woodtree (Accounting for 58.8%). Bare land accounts for 20.38% of forestland, but most of the land is shift-cultivated or fallow, the land is eroded with large slope and dispersion, which is difficult and challenging for forest rehabilitation and development.

3.1.2. Characteristics of topography and soil properties of lands after shifting cultivation

- Topography: Most of forestland's area is in the height from 300-600m, slope from 25 - $\leq 35^0$ accounting for 19.8% of total area of the 3 communes. Thus, at the research area, the topography with large slope has the highest percentage. This is sensitive area with high risk of erosion.

- *Soil layer's thickness / soil depth:* The result shows that soil layer is about from 45-110cm depending on condition. Thus, the soil layer is from thin to thick.

- *Natural weight of soil*: According to Katrinski (Cited by Nguyen The Dang and partner, 2007), natural weight of standard plots shows that soil is from a bit compressed to firmly compressed.

- *Density and humidity of soil*: Density of soil ranges from 2.3-2.60 (g/cm^3). Soil's porosity is from a little porous to medium porous, all of 03 lands have humidity range from 14.8-26.4%.

- *Soil texture: R*esults of analysis of particle level of 18 soil samples show that rates of clay particles are from 14.23-32.28%, silt particles are from 17.87-34.06%, fine sand particles are from 8.58-43.31% and coarse sand particles are from 12.0-29.79%.

- *Content of humus:* (OM%) changes from 1.45 in bare land to 4.65 in land having regenerating wood trees, which indicates that content of humus of grassland and shrubland are low.

3.2. Characteristics of rehabilitation of vegetation on lands after shifting cultivation in protection area of Cau river watershed - Bac Kan province

3.2.1. Characteristics of rehabilitation and regeneration of vegetation

3 years of research shows that density of generated tree species on bare lands after shifting cultivation increases proportionally through fallow period, which proves that the regeneration potential after shifting cultivation is quite good. Specifically, with grassland, the density increases from 80 to 320 trees/ha after 3 years. On 1 SP, there are usually from 1-2 kinds of generated tree species deriving from buds of cut trees (but still alive), the density is 133 trees/ha formerly, after 3 years the density of generated tree species increases to 169 trees/ha.

With shrubland, after 3 years, the density ranges from 427 to 844 trees/ha, the number of species increases significantly from 16 to 37 species.

With regeneration wood tree land, the average density is 440 trees/ha, species composition tends to slow down (increases by 10 species). Average height of regenerating trees after 3 years also has a remarkable increase in SPs and ranges from 09 - 55.5 cm depending on density of generated tree species and feature of each SP.

3.2.2. Species composition development of regenerating trees

- *Grassland:* After 3 years, the number of generated tree species increases by 3 species. Time natural rehabilitation is short; most of grasses and shrubs thrive well. However, there is appearance of some kinds of photophilic trees that can endure adverse soil conditions like *Melia azedarach, Macaranga denticulate, Oroxylum indicum, Broussonetia papyrifera, Rhus* chinensis…

- *Shrubland*: After 3 years, there is a significant increase in the number of species from 16 to 37 species. Because some species have small quantity, they are not enough to be written into species composition formula. The generated tree species appear after 3 years are *Trema orientalis, Archidendron clypearia, Microcos paniculata, Schefflera heptaphylla and other kinds of photophilic trees.*. The density of regenerating trees has the significant change in slope level, showing

through the rule that is if the slope is high, the density of regenerating trees decreases. Slope level from 15 to 25 degrees makes an increase of 533 trees/ha, while slope level from 25 to 35 degrees increases by 374 trees/ha and from more than 35 degrees, there is an increase of 347 trees/ha.

- *Regeneration woodtree land:* Species composition of regeneration tree and composition coefficient of each species has differences over time. The longer recovering time is, the more diverse species composition is. After 3 years, some kinds of regeneration wood trees that have long life like *Peltophorum pterocarpum, Fagus sylvatica, Machilus bonii Lecomte, Melia azedarach Linn, Cratoxylum formosum, etc.* increase.

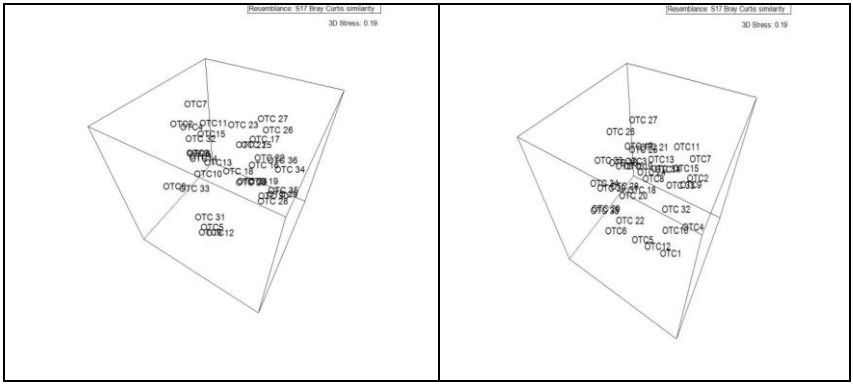

Figure 3.3. Analysis of Nonmetric multi-dimensional scaling of regenerating standard plots between two times of survey

The grouping of standard plots (SPs) based on rehabilitation features between two times of the investigation is unclear (figure 3.3), dispersed SPs do not form distinct groups, so the difference of regeneration tree species between two times of surveying has not yet led to a distinct subgroup. Principal component analysis in the SPs of regeneration tree species between two times of the investigation (Figure 3.4) shows that there is a difference of tree species between two times of the investigation. Based on Priciples Component (PC1) and (PC2) values, generated tree species form 04 different groups.

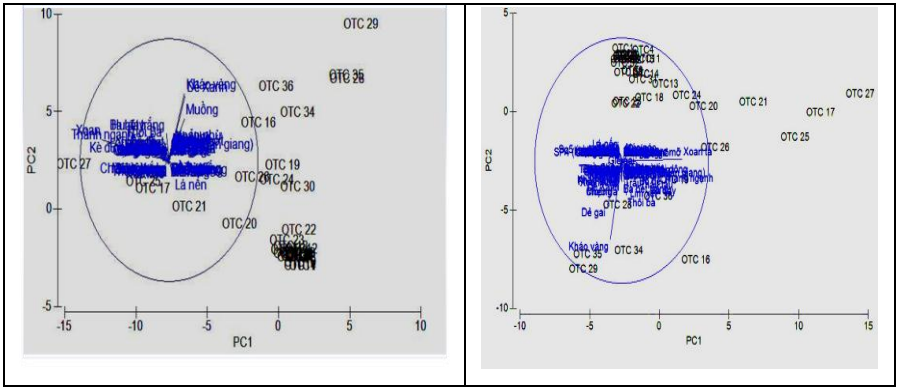

Figure 3.4 a,b. Principal components analysis (PCA) of regeneration plants at two times of the investigation 2011-2013

The difference has been clearly shown when using diagrams to analyze the similarity relationships (Figure 3.5, Figure 3.6). In 2011, there were 9 pairs of generated tree species that had similar levels > 80%, in 2013 there were 12 pairs, it meant that the better forest rehabilitation was, the higher ability to find tree species that appeared simultaneously was.

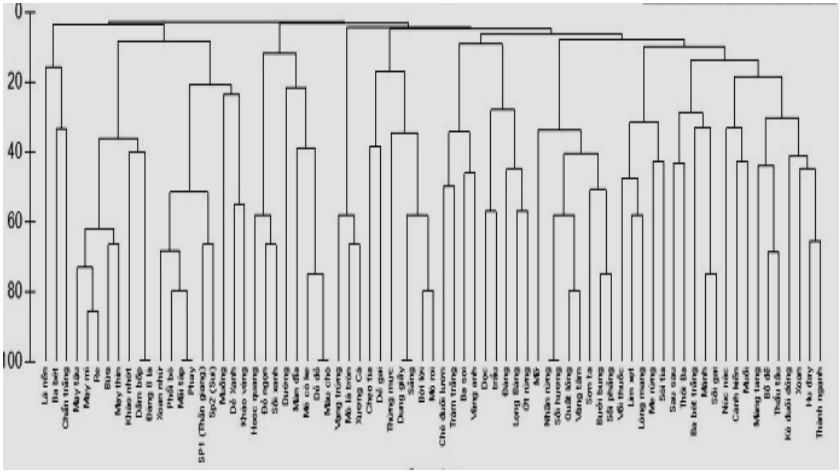

Figure 3.5. Analysis of Cluster relationship among regeneration tree species in 2011

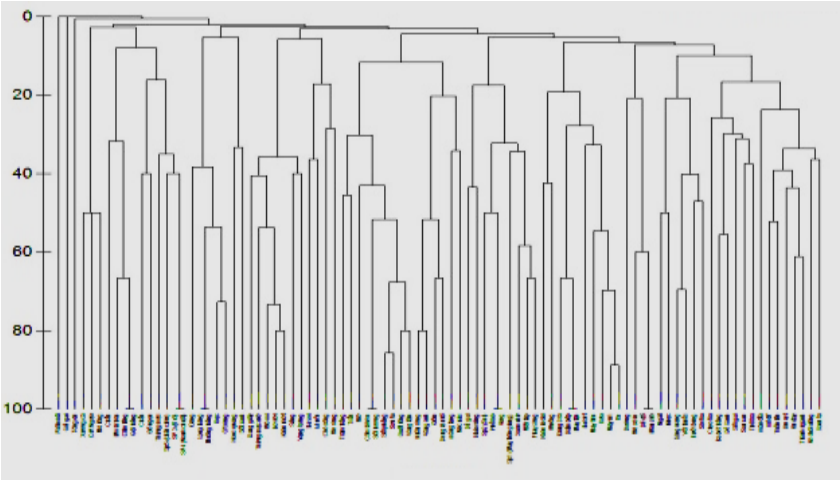

Figure 3.6. Analysis Cluster relationships among regeneration tree species in 2013

3.2.3. Diversity potential of generated tree species species

Table 3.12. Indexes of diversity of regeneration tree species

Indexes	Years	S	N	d	J'	H'	1-λ'
Average values (TB)	2011	7.58	19.64	2.35	0.94	1.56	0.82
	2013	9.47	24.47	2.80	0.93	1.90	0.89
	+/-	+	+	+	-	+	+
Standard error (S)	2011	5.40	16.41	1.19	0.04	0.87	0.27
	2013	5.02	17.70	0.99	0.04	0.66	0.07
	+/-	-	+	-	0	-	-
Coefficient of variation (S%)	2011	71.14	83.56	50.54	4.44	55.78	32.62
	2013	53.03	72.34	35.28	4.61	34.61	7.80
	+/-	-	-	-	+	-	-
Min value	2011	0	0	0	0.82	0	0
	2013	1	1	0.72	0.81	0.00	0.67
	+/-	+	+	+	-	0	+
Max value	2011	17	46	4.62	1.00	2.68	1.00
	2013	18	52	4.30	1.00	2.69	1.00
	+/-	+	+	-	0	+	0

The Dissertation evaluated the ***"Similatity levels"*** of species diversity indexes, classified species diversity indexes (Figure 3.7a) and classified SPs according to the potential of species diversity (Figure 3.7b):

+ Firstly, with similarity levels were 20, 60, 80 and approximately 100% respectively, there are group 1 (6 indicators), 2 (6 indicators), 1 (2 indicators) and 1 (2 indicators).

+ Secondly, there was no difference on subgroup among species diversity indexes at two different times (2011 and 2013). This was correct with all similarity levels.

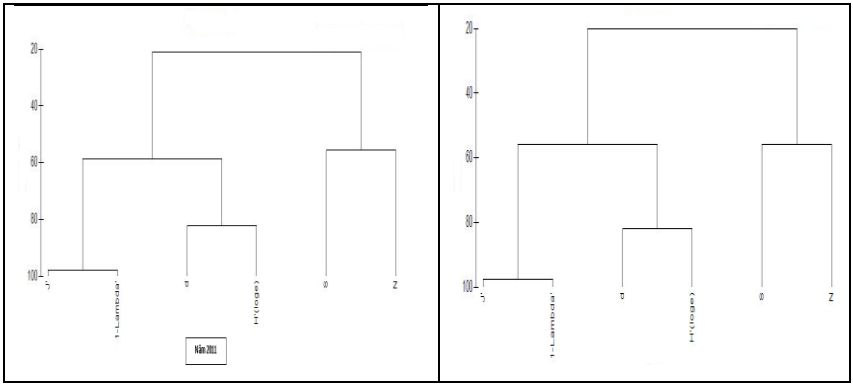

Figure 3.7a. Classification of species diversity indexes in 2011 and 2013

However, if we base on the six species diversity indexes to classify SPs, there will be difference between subgroup between two times of investigation (2011 and 2013).

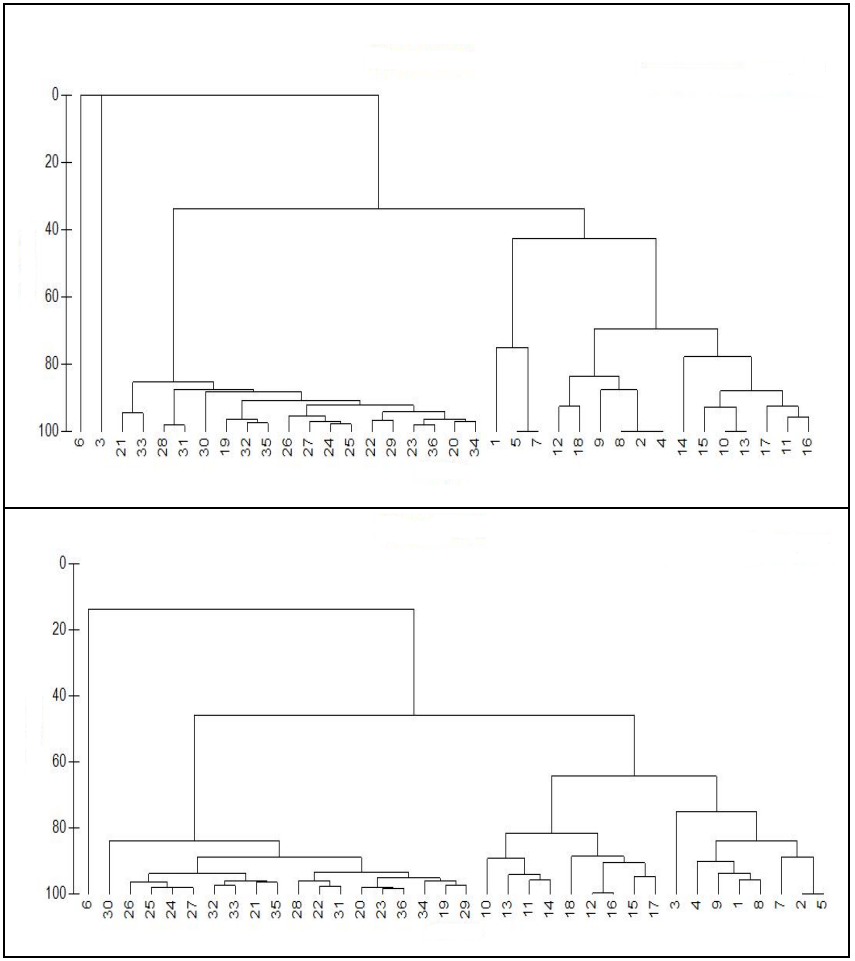

Figure 3.7b. Classtification of SPs based on potential of species diversity

One more issue is that generated tree species appear differently in both species composition and number of individuals on SPs. In order to solve this issue, based on PC1 and PC2 values (figure 3.4), species were classified into 4 groups: Group 1: PC1 > 0 and PC2 > 0, Group 2: PC1 > 0 and PC2 < 0, Group 3: PC1 < 0 and PC2 > 0, group 4: PC1 < 0 and PC2 < 0, each group corresponds to specific number of regeneration tree species.

3.2.4. Classification of generated tree species based on height

Table 3.14. Classification of generated tree species density based on height

Unit: Tree/ha

Height (m)	Grassland		Shrubland		Regeneration woodtree land	
	2011	2013	2011	2013	2011	2013
Level I (>0,2-0,5m)	89	169	71	213	618	529
Level 2 II (0,5-1m)	36	98	151	311	587	862
Level III (1-2m)	9	27	134	62	542	671
Level IV (2-3m)	0	9	71	160	604	413
Level V (3-4m)	0	0	0	62	173	436
Level VI (4-5m)	0	0	0	36	129	164
Level VII (>5-6m)	0	0	0	0	67	85
Total (tree/ha)	133	302	427	844	2720	3160

Results of evaluation and test of regeneration tree distribution based on height showed that number of trees tended to steadily decline when the heights grew, in all studied subjects.

3.2.5. Quality of generated tree species and rate of prospective generated tree species

Quality of generated tree species: With different time natural rehabilitation s, rates of regeneration tree qualities are different: Rate of good and medium (quality) trees rose along with long fallow period, which is favorable for taking advantage of natural regeneration for reforestation after shifting cultivation.

Rate of prospective generated tree species: Density of generated tree species HTS-2-2013 increased compared to it in 2011, indexes on height of generated tree species increased over time natural rehabilitation. After 3 years, height of prospective generated tree species rose, with average level reached by 0.3m/year, which was relatively fast.

3.2.6. Rehabilitation of quantity and size of generated tree species on lands after shifting cultivation

There was a large variation in density and height of prospective generated tree species, with 0-880 trees/ha and 0-4.5 m respectively. Average value of density and height of prospective generated tree species as well as standard error (STC), coefficient of variation (S,%), minimum value (min) and maximum value (max) showed that some forest plots had been able to reach the standard for completing the reforestation phase.

SPs with similarity levels ranged from 40-45% could be placed in one group. With similarity levels from 80% or more, in both cases namely including and not including elements of terrain and soil property, the SPs were divided into 4 groups.

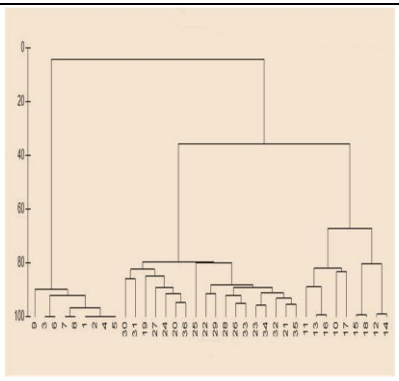

Figure 3.12a. Classification of SPs based on quantity and size of generated tree species (not including elements of terrain and soil property)

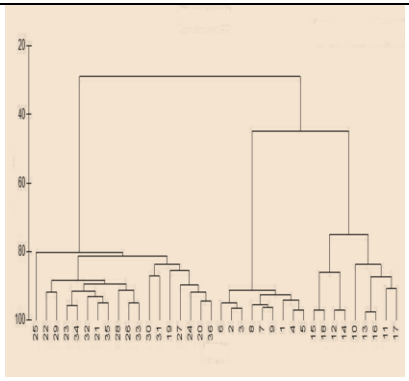

Figure 3.12b. Classification of standard plots based on quantity and size of generated tree species (including elements of terrain and soil property)

The above results showed that setting SPs helped researcher to satisfactorily grasp fluctuation of elements that reflected potential of reforestation on lands after shifting cultivation.

3.2.7. Fluctuation of shrubs and vegetation

Shrub layer in the bare land thrived, increased by 0.17m/year in average, rates of shrubs and vegetation coverage grew at 11.4%, but in grassland and shrubland only. Shrub layer in land with regeneration woodtrees mitigated since the development of generated tree species layer increased shade and decreased coverage of shrubs and vegetation.

3.2.8. Factors affecting natural rehabilitation

- Effects of several land factors to density of generated tree species: Depth of soil layer and soil porosity had nonlinear relationship with exponential function. Evaluation results were consistent with conclusions of Nguyen Tien Ban (1996), Nguyen Van Truong (1983) who stated that the more degradation of land was, the longer the chain goes up and the longer time natural rehabilitation was.

- Effects of slope and terrain: when the slope increased and the terrain was from the foot to the top, density of generated tree species tended to decrease, and so did other factors such as coverage of shrub and vegetation, level of rich composition, and quality of generated tree species. Research results of Pham Ngoc Thuong (2002), Bui Dang Pho (2006), Le Trong Cuc, Pham Hong Ban (1996), Pham Ngoc Thuong (2003), Le Dong Tan (1999) also showed similar conclusions.

- Additionally, the Dissertation also assessed effects of natural factors to the natural rehabilitation such as shrub and vegetation, distance to forest wall, and social factors in the studied area.

- By establishing links between NTS_2_13 and HTS_2_13 with factors that had serious affect to the natural rehabilitation, the project had built a scatter chart (figure 3.18) and selected the following correlation equation:

$$NTS\_2\_13 = -87.077 + 0.09926.Z \quad r = 0.872, F = 108.63$$

$$HTS\_2\_13 = 1.759 + 0.00323.Z \quad r = 0.851 \; F = 89.31$$

With $Z = (SD.P).A\_PHR\_13/A\_CTNR$

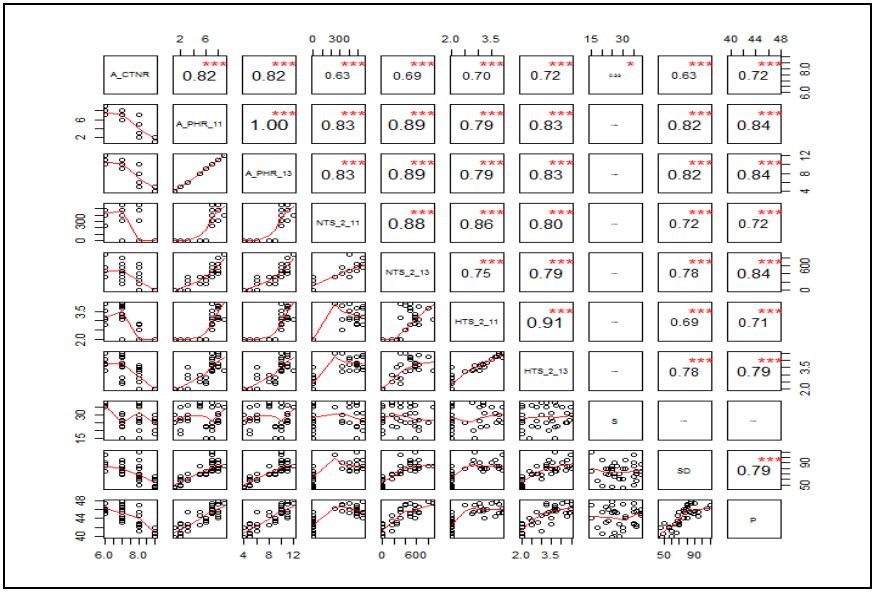

Figure 3.18. Scatter chart of relationship between quantity and size of generated tree generated tree species with important factors

3.3. Protection capacity of forest vegetation on lands after shifting cultivation

3.3.1. Features of soils' water permeability and retention

- Speed of initial water permeability and stable water permeability

Speed of initial water permeability of 03 states of bare lands was from 5.08mm/min to 6.4 mm/min, stable permeability was from 2.68-3.11mm/min. In comparing with gradation of Tran Cong Tau, et al. (1986), the above water permeability is the best. That result was also close to research results of Pham Van Dien (2009), Do Thi Lan (2011), and Vo Dai Hai (1996).

- *Water penetration process*: Total amount of water was different among different objects. There was a gap of about 40-50mm between grassland and land with generated tree species. Overall, amount of water ranged from 206.32 mm to 255.70 mm. Total amount of penetrated water increased gradually from bad to good vegetation cover.

- *Amount of retention water*: The place with thicker vegetation coverage had more useful water retended, in the research SPs, the amount of water ranged from 73.4 mm to 140.9 mm.

3.3.2. Potential erosion of soil under vegetation cover after shifting cultivation

In accordance with the State Standard No. 579/TCVN -1995 on gradation of erosion levels, the results showed that average grassland erosion was 67.69 tonnes/ha, equivalent to level 3 of erosion, shrubland was 49.67 tonnes/ha/year and land with regeneration wood trees was 36.27 tonnes/ha/year, equivalent to level 2 of erosion.

3.4. Classification of potential of protection forest rehabilitation on lands after shifting cultivation

Table 3.29. Index of years needed for forest rehabilitation to meet requirements of being forest

SD.P	A_CTNR year	n_{ct_N} year	n_{ct_H} year	Δn_{ct} Year	SD.P	A_CTNR year	n_{ct_N} year	n_{ct_H} year	Δn_{ct} year
1800	5	13.6	19.3	5.6	3800	5	6.5	9.1	2.7
1800	6	16.4	23.1	6.8	3800	6	7.7	11.0	3.2
1800	7	19.1	27.0	7.9	3800	7	9.0	12.8	3.7
1800	8	21.8	30.8	9.0	3800	8	10.3	14.6	4.3
1800	9	24.5	34.7	10.2	3800	9	11.6	16.4	4.8
1800	10	27.3	38.5	11.3	3800	10	12.9	18.3	5.3
2000	5	12.3	17.3	5.1	4000	5	6.1	8.7	2.5
2000	6	14.7	20.8	6.1	4000	6	7.4	10.4	3.0
2000	7	17.2	24.3	7.1	4000	7	8.6	12.1	3.6
2000	8	19.6	27.8	8.1	4000	8	9.8	13.9	4.1
2000	9	22.1	31.2	9.1	4000	9	11.0	15.6	4.6
2000	10	24.5	34.7	10.2	4000	10	12.3	17.3	5.1
2200	5	11.2	15.8	4.6	4200	5	5.8	8.3	2.4
2200	6	13.4	18.9	5.5	4200	6	7.0	9.9	2.9
2200	7	15.6	22.1	6.5	4200	7	8.2	11.6	3.4
2200	8	17.8	25.2	7.4	4200	8	9.3	13.2	3.9
2200	9	20.1	28.4	8.3	4200	9	10.5	14.9	4.4
2200	10	22.3	31.5	9.2	4200	10	11.7	16.5	4.8
2400	5	10.2	14.5	4.2	4400	5	5.6	7.9	2.3
2400	6	12.3	17.3	5.1	4400	6	6.7	9.5	2.8
2400	7	14.3	20.2	5.9	4400	7	7.8	11.0	3.2
2400	8	16.4	23.1	6.8	4400	8	8.9	12.6	3.7

SD.P	A_CTNR year	n_{ct_N} year	n_{ct_H} year	Δn_{ct} Year	SD.P	A_CTNR year	n_{ct_N} year	n_{ct_H} year	Δn_{ct} year
2400	9	18.4	26.0	7.6	4400	9	10.0	14.2	4.2
2400	10	20.4	28.9	8.5	4400	10	11.2	15.8	4.6
2600	5	9.4	13.3	3.9	4600	5	5.3	7.5	2.2
2600	6	11.3	16.0	4.7	4600	6	6.4	9.0	2.6
2600	7	13.2	18.7	5.5	4600	7	7.5	10.6	3.1
2600	8	15.1	21.3	6.2	4600	8	8.5	12.1	3.5
2600	9	17.0	24.0	7.0	4600	9	9.6	13.6	4.0
2600	10	18.9	26.7	7.8	4600	10	10.7	15.1	4.4
3400	5	7.2	10.2	3.0	5200	5	4.7	6.7	2.0
3400	6	8.7	12.2	3.6	5200	6	5.7	8.0	2.3
3400	7	10.1	14.3	4.2	5200	7	6.6	9.3	2.7
3400	8	11.5	16.3	4.8	5200	8	7.5	10.7	3.1
3400	9	13.0	18.4	5.4	5200	9	8.5	12.0	3.5
3400	10	14.4	20.4	6.0	5200	10	9.4	13.3	3.9

(Note: Calculated data n_{ct_N}, n_{ct_H} were rounded up)

In order to meet the requirements of being recognised as forest, years for forest rehabilitation were needed to define based on n_{ct_H}.

Table 3.30. Classification of forest rehabilitation potential on lands after shifting cultivation

Years needed for forest rehabilitation (years)	Group	silviculture solutions
≤ 6	1	Forest protection
6 - ≤ 10	2	natural regeneration and forest protection
> 10	3	reforestation

Table 3.31. Classification of SPs in accordance with forest rehabilitation potential

A_CTNR (year)	A_PHR_13 (year)	NTS_2_13 (tree/ha)	HTS_2_13 (m)	SD (cm)	P (%)	n_{ct} (year)	PA1	PA2
9	5	0	0	57	41.9	26.1	3	3
9	5	0	0	48	40.6	32.1	3	3
9	4	0	0	47	39.9	33.3	3	3
9	5	0	0	66	40.9	23.1	3	3

A_CTNR (year)	A_PHR_13 (year)	NTS_2_13 (tree/ha)	HTS_2_13 (m)	SD (cm)	P (%)	n_{ct} (year)	PA1	PA2
9	5	0	0	60	40.1	26	3	3
9	4	0	0	45	41.9	33.1	3	3
8	5	0	0	50	42.9	25.9	3	3
8	5	0	0	65	42.7	20	3	3
8	6	0	0	57	42.1	23.1	3	3
7	9	320	2.4	75	44.1	14.7	3	1
7	9	240	2.8	70	43.2	16.1	3	2
7	9	160	2.5	68	43.6	16.4	3	2
8	8	320	2.8	84	45.5	14.5	3	2
8	8	160	2.5	70	42.5	18.7	3	3
8	8	160	3.0	68	44.7	18.3	3	3
8	6	320	2.8	70	45.5	17.4	3	3
8	6	240	3.5	70	42.8	18.5	3	3
8	6	160	3.0	60	41.2	22.5	3	3
6	10	320	4.5	105	46.3	8.6	2	1
6	10	480	4.1	90	47.3	9.8	2	1
6	10	480	3.3	88	45.1	10.5	3	1
7	11	800	4.3	85	47.8	12	3	1
7	11	640	4.4	85	45.3	12.6	3	1
7	11	400	4.5	80	47.1	12.9	3	1
6	12	880	3.3	85	47.4	10.3	3	1
6	11	560	3.8	75	45.6	12.2	3	1
6	10	320	3.7	75	46.1	12	3	1
8	10	560	3.7	110	46.9	10.8	3	1
8	10	640	3.4	95	45.4	12.9	3	1
8	10	400	3.2	80	47.0	14.8	3	1
7	11	560	3.6	90	45.6	11.8	3	1
7	11	480	4.3	95	44.5	11.5	3	1
7	11	560	3.5	80	44.0	13.8	3	1
7	10	640	3.7	80	46.6	13	3	1
7	10	560	3.8	79	46.0	13.4	3	1
7	10	480	4.2	77	45.3	13.9	3	1

Table 3.31 also shows that some forest plots have achieved the recognition of being forest, 01 forest plot needs 0.2 year more to be recognized. The other forest plots need more rehabilitation to become forest.

3.5. Silviculture solutions for rehabilitation of watershed forest on lands after shifting cultivation

3.5.1. By afforestation

- Subject: Afforestation is applied to land without forest after shifting cultivation, or group 3 (Table 3:30) (group needs time for forest rehabilitation > 10 years).

- Some problems need attention in choosing plants, planting density, soil preparation techniques, cover treatment and some other notes, etc.

3.5.2. By zoning off for natural and artificial regeneration

a. Zoning off for natural regeneration

Subjects: Apply to land without forestlands after shifting cultivation in group 1 (with time required for forest rehabilitation is under 6 years) in the classification

b. Zoning off for artificial regeneration

Subjects: Apply to land without forestlands after shifting cultivation in group 2 (with time required for forest rehabilitation is from 6-10 years).

CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

- Results of the study outlined the status and history of shifting cultivation to identify the origin, former shifting cultivation period, fallow

period, characteristics of soils, etc. as bases for analyzing factors affecting the rehabilitation of vegetation cover on lands after shifting cultivation.

- Difference of species composition depends on time natural rehabilitation; the longer time natural rehabilitation is, the more diverse species composition is. Density of generated tree species also proportionally increases through time. The average height of regeneration tree has increased at 0.20-0.3m/year. The factors that have the most influence and truly exist are indicated and as a basis for selection criteria for the classification of forest rehabilitation potentials.

- Ability of permeability, water retention and erosion show that infiltration rates of 3 subjects initially range from 5.08 to 6.74 mm/min, the initial flow velocity is at the best level. The water absorption rate is stable and steadily increases over the states.

- Erosion potentials of grassland are 67.69 tonnes / ha, of shrub land are 49.67 tonnes / ha / year and of recycled timber land is 36.27 tonnes/ha /year equavalent to erosion level II (according to the National Standards).

- The potential for forest rehabilitation on post-shifting cultivation is determined through three indicators, including (1) diversity of regeneration tree species, (2) quantity and size of generated tree regeneration tree, (3) the time required to restore forest to meet the criteria for recognition of being forest; in which criteria (3) has the highest aggregate property, since it depends on a combination of factors such as soil (SD, P), shifting cultivation time (A_CTNR) and reflect of average height of generated tree species. Therefore, it is used to classify potential on forest rehabilitation after shift cultivation in the study area, which is represented by n_{ct_H} indicator. Consequently, the forest rehabilitation

potentials are divided into 03 groups (corresponding with the 03 silviculture solutions for forest rehabilitation).

- The classification of rehabilitation group is used to determine the silvicultural solutions; for watershed protection forest, silvicultural solutions are also proposed based on the protective function of the vegetation cover, and attached with conditions of the practice.

2. Recommendations

- Using classification of potential forest rehabilitation on lands after shifting cultivation to build silvicultural measures applied to forest rehabilitation solutions at Cau river or other neighboring watersheds whose forest rehabilitation object is orginated from shifting cultivation

- Applying the said silvicultural measures together with groups of potential reforestation, potential soil and water retention, soil erosion and specific economic conditions in implementation of local forest development projects.

LIST OF PUBLICATION RELATED TO PhD. DISSERTATION

1. Pham Van Dien, Nguyen Thi Thu Hoan (2015), "Classifying potential of forest rehabilitation on lands after shifting cultivation in Cau river watershed, Bac Kan province", *Journal on Agriculture and Rural Development*, No. 2, pp. 125-134.

2. Nguyen Thi Thu Hoan, Le Sy Trung (2014), "Studying on the water infiltration and retention ability on lands after shifting cultivation in Cau river watershed, Bac Kan province", *Journal on science and technology of Thai Nguyen University*, Vol. 118, No. 04, pp. 9-14.

3. Nguyen Thi Thu Hoan, Le Sy Trung, Le Sy Hong (2014), "Studying on the natural regeneration ability on lands after of shifting cultivation in Cau river watershed, Bac Kan province", *Journal on Agriculture and Rural Development*, 6/2014, pp. 181-186.