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Mountain Agrarian Systems

Agronomic diagnosis and identification of factors limiting upland rice yield in mountainous areas of northern Vietnam

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Abstract

In mountainous areas of northern Vietnam, upland rice remains a crop of major importance, but yields are extremely low and variable. An iterative, multi-scale agronomic diagnosis, based on analysis of variability in farmers' fields, was conducted in a village selected for being representative of biophysical conditions in Bac Kan Province. This diagnosis focussed on interactions between factors and processes, and aimed to identify major constraints to rice production in order to develop alternatives to the traditional slash-and-burn systems.

Variability between fields in rice yield was explained primarily by slashed forest type (5 classes were identified) and number of years of cultivation. Within fields, rice yield variability was largely explained by soil structure (porosity, compaction, bulk density) and partly by soil chemical characteristics. All these factors are, at different scales, indicators of soil regeneration/degradation status. Forest and soil regeneration is limited by short fallow duration (decreasing in the present context of rapidly increasing population pressure) and by intensive buffalo grazing. Soil degradation is caused by erosion after forests are slashed and burned. As a result, poor soil structure and shallow rooting (limited by physical and chemical soil conditions) lead to very poor water use efficiency. In addition, weed infestation is a major constraint to upland rice production in these conditions.

As a consequence, for improvement of (or design of alternatives to) these systems, research priority should be given to development of techniques or systems that increase water use efficiency and facilitate weed control. Until soils have been rehabilitated and protected, and weeds controlled, "classical" research on topics such as fertilisers or varieties will bring hardly any improvement in the traditional systems.

Key words: upland rice, slash-and-burn, variability, agronomic diagnosis, Vietnam.

1. Introduction

Upland rice remains a crop of major importance in the mountains of northern Vietnam (Denning and Xuan, 1995; Pandey and Minh, 1998). It is usually cultivated on acid, ferralitic soils on steep slopes (20 to 40 degrees) after slashing and burning forests. In this traditional extensive system, yields are extremely variable, but remain low on average (around 1t/ha). Yields also rapidly decrease with time, which makes these systems unsustainable under the current population pressure observed in these areas (Jamieson et al., 1998; Castella et al., 1999). The Vietnamese government has banned these traditional slash-and-burn systems because they are regarded as a major cause

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of deforestation. So far, no real alternative has been proposed to farmers for securing food sufficiency, even for the very short term, and some farmers do not have any choice other than growing rice on the slopes (Bal et al., 1997; Bal et al., 2000). It is now extremely urgent to propose to farmers simple, low-input, sustainable agronomic practices and cropping systems, enabling long-term settlement on fields after forest clearing. Developing such practices requires understanding of agronomic processes and identification of the main factors limiting rice yield, at various scales.

Thus, the objective of this study was to establish a rapid but sound and clear agronomic diagnosis of upland rice cultivation under traditional farmers' conditions. It aimed to identify and rank the main factors limiting upland rice yield (at various scales) to enable development of technical innovations recognising fields' constraints and potentialities, and considering farmers' objectives and production means (land, labour and capital).

2. Materials and methods

In order to understand agronomic processes in real farm conditions, the study used an iterative, multi-scale analysis of variability, followed by extracting information from the variability. The rationale behind this approach is that an observed situation is the result of interactions among various factors and processes. Variability indicates differences in the relative importance of interacting factors, and/or the intensity at which the various processes took place, and high variability is due to a strong influence of some factor(s) and/or a high intensity of some process(es). Thus when variability is high, it should be easier to identify and understand the causal factors and processes, because they are of high amplitude. Also, factors are not isolated, but should be studied as they interact in real conditions.

Ban Cuon village (Cho Don District, Bac Kan Province) was selected for its high variability, representing within a single village the major biophysical conditions found in the province. Four main landscape units were identified, which influenced the present land use: (1) Irrigated rice is grown in low-land valleys, (2) houses and garden are located on colluvial terraces, (3) on the slopes, upland rice is cultivated on red or yellow ferralitic, acid soils developed from schists (acrisols for the FAO classification), whereas (4) maize is grown on brown soils developed from karsts (cambisols). Located at 22°10' N latitude and 105°35' E longitude, this area enjoys a subtropical climate, with a warm, rainy season (April to September) and a rather cold dry and dry season (October to March) when monthly minimum temperature can fall below 10°C. The average annual rainfall is 1800 mm.

In 1998, after a survey of farmers' fields in the village, 37 upland rice fields were selected and precisely characterised (type of forest that had been cleared, year of clearing, cropping system, soil characteristics, slope, etc.). Cropping practices also were monitored carefully in these fields over one cropping season. Sampling was conducted in order to cover a high diversity of situations: vegetation type before beginning rice cultivation (5 classes) x cultivation date (1 to 4 years of cultivation) x soil type (red or yellow) x rice variety. Sowing date was not considered, because little variation has been observed in the village (as in most other villages, farmers try to group their sowing in space and time). Soil chemical analyses (pH, Al, C, N, P2O5, K, clay content, etc.) were made to characterise the two main soil types identified (yellow or red).

At harvesting, yield components (plant, tiller and panicle density, number of filled or empty grains per panicle, weight of 1000 grains, weight of straw and yield) were measured in 10 to 40 samples of 1m² with a grid sampling (mesh of 10 x 10 m, number of samples per field being a function of field size). Thus, a total of 700 samples were analysed. For each sample, slope was measured, and scores were given (0 to 4) to characterise the intensities of weed infestation, erosion, insect attack, diseases, symptoms of Al toxicity, etc.

Analysis of spatial variability of yield components and correlation between yield and cropping conditions (at sample and at field levels) led to elaboration of hypotheses about causes of variability, and thus about possible factors limiting rice growth and yield. These hypotheses were then tested in 1999 in specific studies on:

- Frequency analysis of rainfall (1980 to 1995 for Bac Kan Province)

- Distribution, frequency and abundance of various weeds species (Stevoux et al., 2000).
- Influence of physical and chemical soil characteristics on plant rooting, plant growth and yield. In two fields (one each of red and yellow soils), yield components and rooting depth, soil chemical properties (same measurements as in 1998) and physical properties (bulk density, porosity and resistance to penetration) were measured in 6 sample sites per field.
- Soil compaction by penetrometer measurements in various situations (forests before clearing, upland rice field after 2 years of cultivation and after five years of cultivation, cassava field after 5 years of rice cultivation, old pasture), with 3 replications per situation.

At the same time, yield and field characteristics were monitored in 30 fields, to enlarge the 1998 sample and to take into consideration the year-to-year variability. In 18 of these fields, yield components also were measured. Field characterisation and sampling were improved based on 1998 preliminary results.

In such an iterative process, the initial understanding of major agronomic processes achieved during the first year is refined the following year by detailed studies on domains identified as the most important. Furthermore, this comprehensive understanding makes it possible to identify key factors that should be taken into consideration for the detailed studies. It also provides information for a better characterisation of the various situations, and helps to improve the sampling procedure.

Finally, this approach allows rapid achievement of reasonably reliable results (although not conclusive), or at least, the elaboration of strong hypotheses in the domains of major importance. These strong hypotheses can immediately be used to set priorities for the research programme and provide useful tracks for improvement of, or development of alternatives to the traditional slash-and-burn systems.

3. Analysis of between-fields variability of upland rice yield

3.1. Preceding vegetation type, number of cultivation cycles, and rice yield

Preceding vegetation was classified into five classes, according to forest condition before clearing for rice cultivation:

- Type 1: Old pasture, usually more than 20 years of intensive grazing. No trees.
- Type 2: Young forest (less than 10 years old), or bamboo forest, or 10 to 20 years old forest heavily grazed by buffaloes. Few (less than 5 / 100 m²), small (no more than 10 cm in diameter) trees.
- Type 3: 10 to 20 year old forest moderately grazed by buffaloes, or more than 20-year-old forest heavily grazed. Some (5 to 10 /100m²) small trees, a few (less than 5/100 m²) medium trees (20 –29 cm in diameter)
- Type 4: 10 to 20 year old forest not grazed, or more than 20-year-old forest moderately grazed. Some (5 to 10 /100m²) small and medium trees, a few (less than 5/100m²) big trees (30 - 50 cm in diameter)
- Type 5: More than 20-year-old forest, not grazed. Many medium and big trees, and some very big trees (over 50 cm in diameter)

These classes reflect the differences in forest regeneration conditions before clearing/cultivation, from nil (intensive pasture) to rich (old forest). The sample also reflects the present situation. At present, types 2 and 3 are dominant in the research area, because most types 4 and 5 have been reclaimed between 1990 and 1998. Furthermore, the rare old forests that remain usually are on steep slopes (over 30 degrees on average). Type 1, although usually located on gentle slopes (below 20 degrees) is rarely cultivated by farmers because these heavily grazed soils have poor productivity and because areas of this type often are communal lands.

Figure 1 presents rice yield, for each class of preceding vegetation, as a function of number of years of cultivation. It shows that:

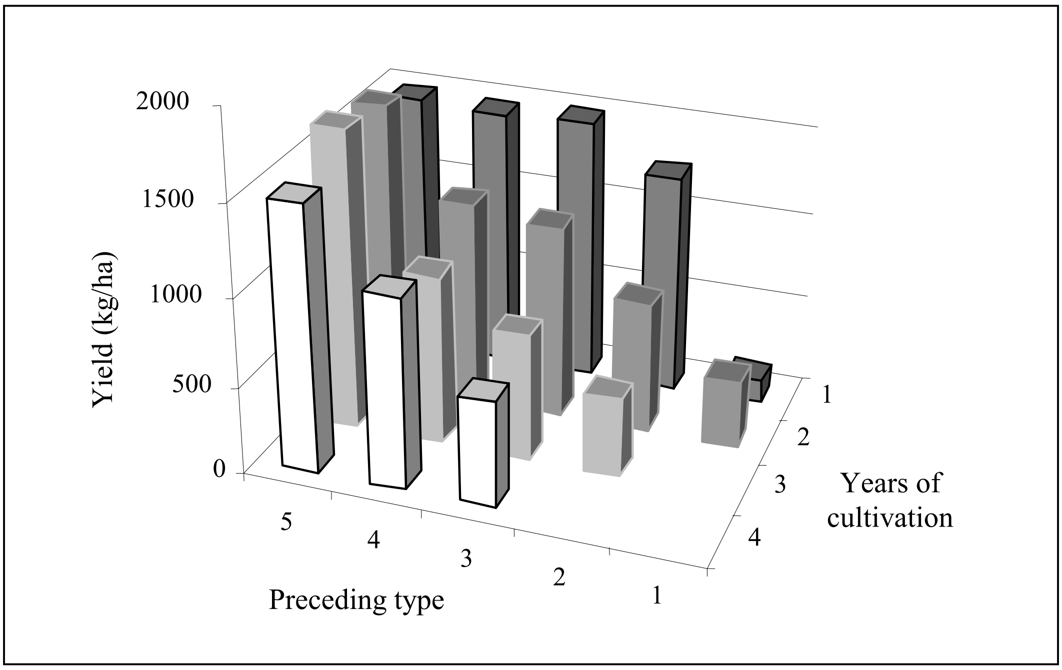

Figure 1: Average yield (kg/ha) as a function of preceding vegetation type and years of cultivation. Missing years in types 1 and 2 are due to abandonment of fields by farmers.

- Preceding vegetation and number of years of cultivation both have a strong impact on rice growth and yield. The multiple regression equation (both variables significant, with an R^2 of 0.70) is:
  Yield (kg/ha) = 461.2 + 309.4 (Preceding type) – 188.2 (Year of cultivation)
- Yield is rather low on average: less than 1.5 t/ha the first year, less than 1.1 t/ha the second year, less than 900 kg/ha the third year, and most fields have to be abandoned after 3 only to 4 years of cultivation (farmers usually abandon cultivation when rice yield is below 500 to 600 kg/ha).
- Yield following vegetation type 1 is extremely low, and the only farmer in the village trying to cultivate this degraded type of field gave up after 2 unsuccessful years.
- Yield in type 2 is very variable in the first year, with a modest average level below 1.3 t/ha, and then decreases sharply from the second year onwards, which obliges farmers to abandon their fields after 3 years.
- Yield in type 3 is higher than in type 2 the first year (1.5 t/ha on average), but also rapidly decreases. Fields usually are abandoned after 4 years.
- For type 4, yield in the first year also is rather high (1.5 t/ha), and the rate of yield decrease over time is slower than for type 3.
- For type 5, yield remains above 1.5 t/ha for more than 4 years.

3.2. Weeds and rice yield

At field level, weeds (either differences in weed pressure, or differences in weed control) seem to have a strong impact on rice yield. Figure 2 gives yield as a function of average weed infestation at harvesting for the 67 fields studied in 1998 and 1999. It shows that yield sharply decreases when weed infestation increases. It also shows that weed infestation is correlated to preceding vegetation type: old forest fields (types 4 and 5) have lower weed pressure than poor forest fields (types 1 to 3).

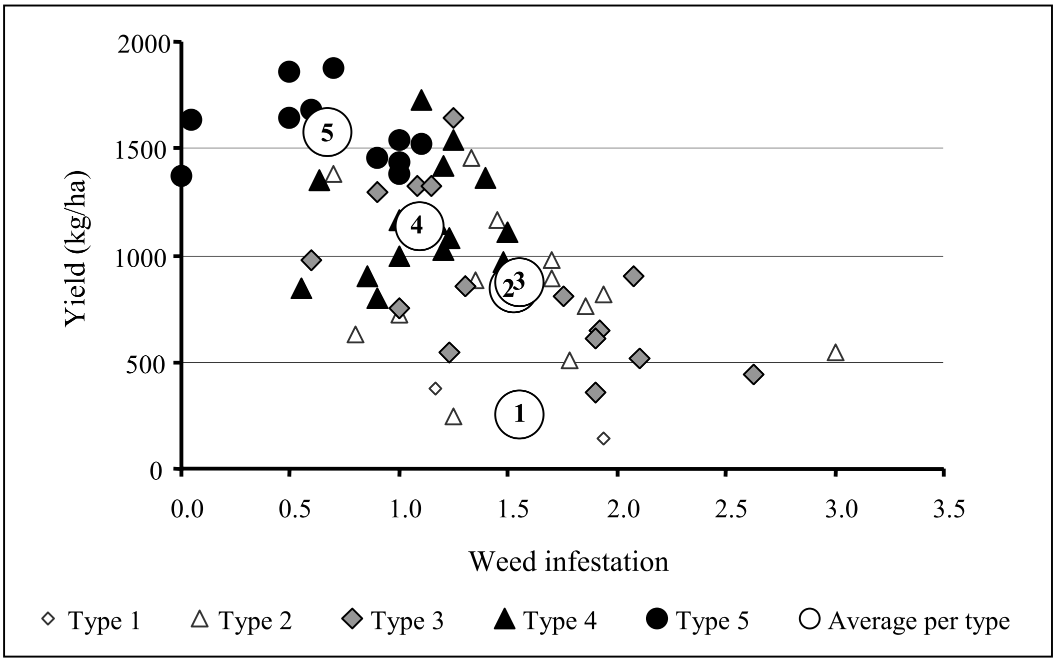

Figure 2: Yield (kg/ha) as a function of average weed infestation at harvesting. N= 67. Symbols indicate preceding vegetation type. Large numerals in circles indicate average values for each preceding vegetation type.

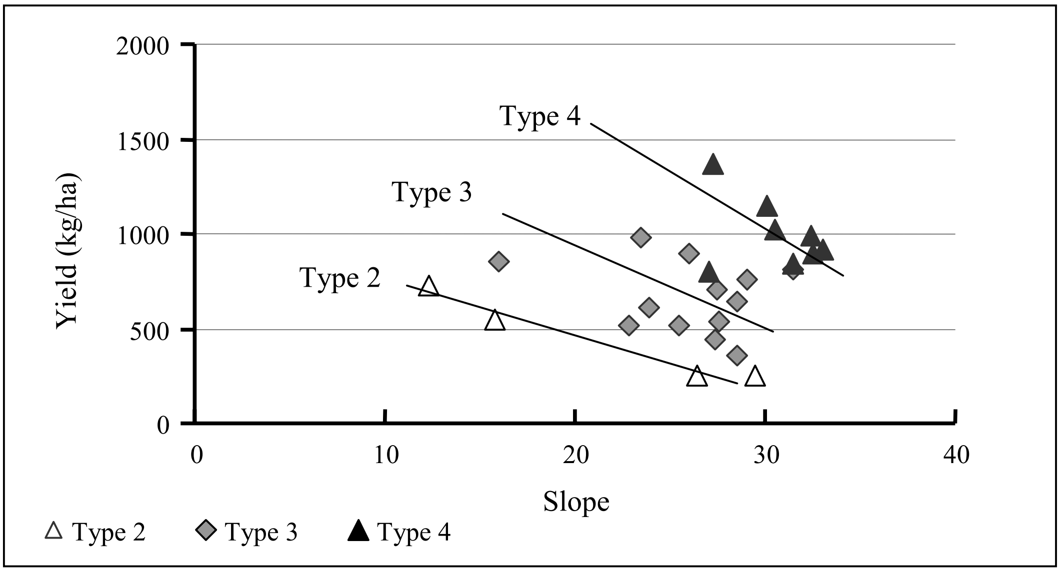

Figure 3: Rice yield (kg/ha) as a function of average field slope (degrees) for fields cultivated 3 and 4 years. N = 25. Symbols indicate preceding vegetation type.

3.3. Slope and rice yield

No correlation between rice yield and average field slope could be observed for fields cultivated for one or two years. For older fields (3 and 4 years old), a trend is detectable within types 2, 3 and 4, showing a decrease of yield when slope increases, especially above 25 to 30 degrees (Figure 3).

Figure 3 also indicates that forest type is correlated with slope. All type 4 forests are found on steep slopes of 30 degrees on average, whereas type 3 forests are on slopes of approximately 25 degrees and type 2 on slopes of "only" 20 degrees on average.

3.4. Agricultural practices and rice yield

Agricultural practices are rather homogeneous in the study area. Land preparation, sowing techniques, and harvesting methods are the same for all farmers. The great majority of farmers neither apply fertiliser nor use herbicides or pesticides. A significant effect of fertiliser could be shown only in 20% of experimental fields (Naudin, 1999).

Most fields were sown within a short period. The rare fields sown earlier had rather low yields, mainly due to damage from rats, birds and insects.

The major differences in cropping techniques are therefore weeding (according to available labour force) and varieties. The impact of varietal choice on yield is difficult to assess, as most farmers select their (many) local varieties according to actual field conditions. Some varieties are used on fertile soils, just after reclamation, whereas others are selected for poor, degraded soils after several years of cultivation. Some also are used on the top of the toposequence, whereas others are for the lower part.

Therefore, it appears that, between fields, preceding vegetation type, years of cultivation and weed pressure are the most important factors explaining upland rice yield. Their impact on yield is much stronger than cropping techniques, which are rather homogeneous. But these cropping techniques, over time, negatively influence field characteristics.

Furthermore, the two main criteria used to characterise average field conditions (preceding vegetation type and years of cultivation) can be regarded as simple indicators of the average soil conditions of the fields (indicators of regeneration / degradation). Within a field, these soil conditions are extremely variable and correlations between soil characteristics and yield should be found. Analysis of within-field soil and yield variability should also indicate which soil characteristics have the strongest impact on rice growth and yield.

4. Analysis of within-field variability of upland rice growth and yield

Table 1 summarises major field characteristics for the two fields selected as representative of major soil conditions where upland rice is grown in the study area. It shows the high acidity, the high aluminium content, and the low N and P availability of these soils. However, large variations exist within fields, some of them explaining yield variations.

4.1. Soil physical characteristics and yield

Figure 4 shows the influence of soil compaction on rice yield. Soil structure, especially in the upper few centimetres, has a strong impact on rice yield. Correlations also were found between porosity or bulk density (0-10 cm) and rice yield (data not displayed).

Table 1: Field 1 and field 2 characteristics (average of 6 replications per field)

	Field 1	Field 2
Soil type	Yellow ferralitic	Red ferralitic
Preceding vegetation	type 3	type 4
Years of cultivation	3	4
Average slope (degrees)	21.7	30.3
Average pH $_{(KCl)}$	3.78	3.93
Average CEC (meq/100g)	16.8	15.6
Average Exchangeable Al (meq/100g)	4.55	2.96
Average N content (%)	0.27	0.28
Average P_2O_5 content (%)	0.08	0.08
Average K_2O content (%)	1.12	0.29
Average Organic matter Content (%)	5.57	4.72
Average porosity (%)	70.2	67.5
Average bulk density	0.78	0.91
Average clay content (%)	40.3	35.4
Average yield (kg/ha)	545	1010

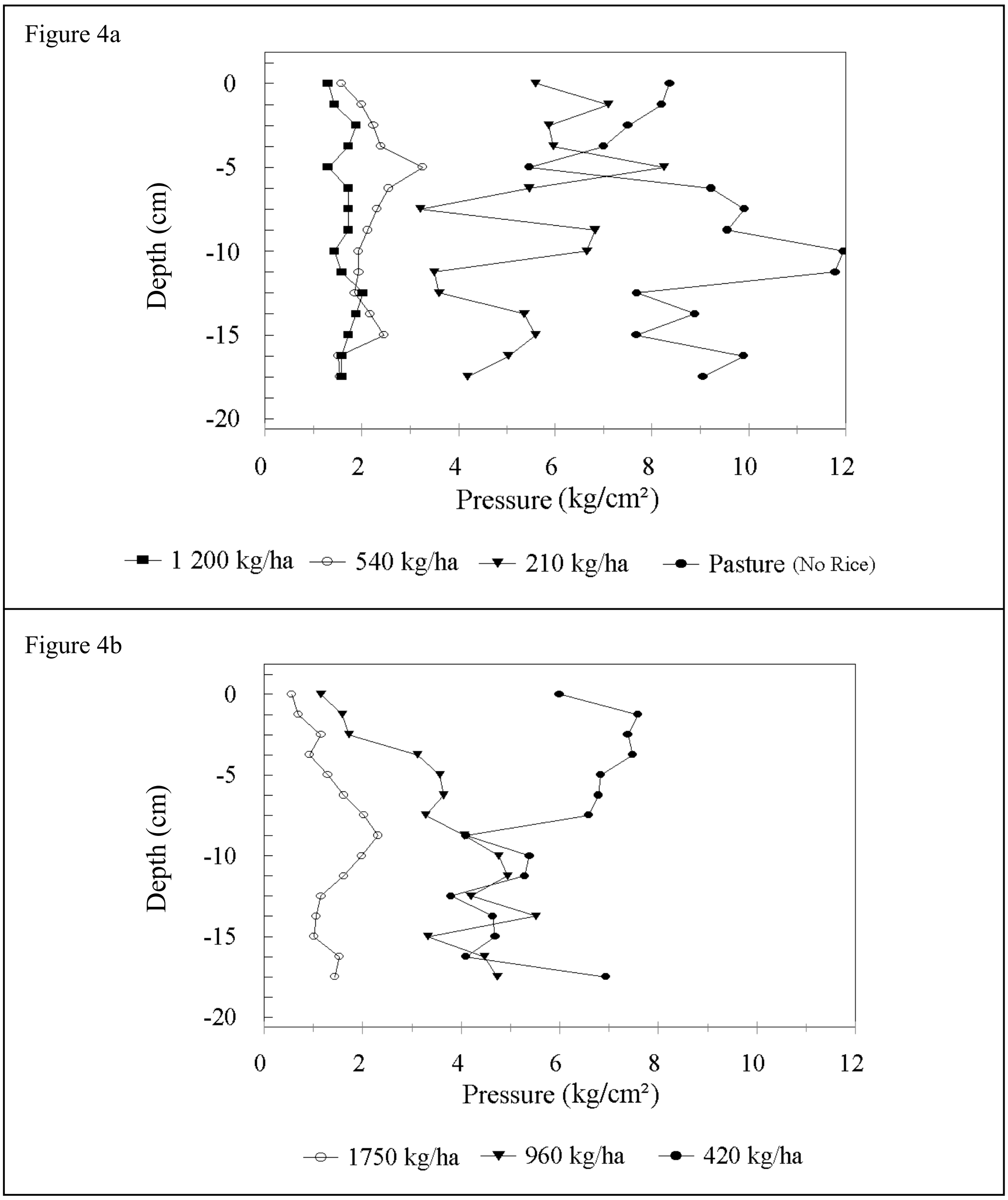

Figure 4: Impact of soil compaction (pressure in kg/cm² required to penetrate soil at various depths) on rice yield (kg/ha). Average of 2 replications. Figure 4a: Field 1; Figure 4b: Field 2.

4.2. Soil chemical characteristics

Although no clear correlation could be detected between rice yield and the major chemical soil characteristics, some trends seem to appear. Yield seems to be positively correlated to N and organic matter (R^2 of 0.45 and 0.40 respectively; data not displayed). The low correlation coefficients measured between rice yield and soil chemical characteristics probably are due to the strong impact of soil physical characteristics on yield.

Some trends also appear between soil chemical and soil physical characteristics (for example C and N content seems to decrease when bulk density increases), and correlations were found between soil chemical characteristics (for example a negative correlation between $pH_{(KCl)}$ and aluminium as shown in Figure 5).

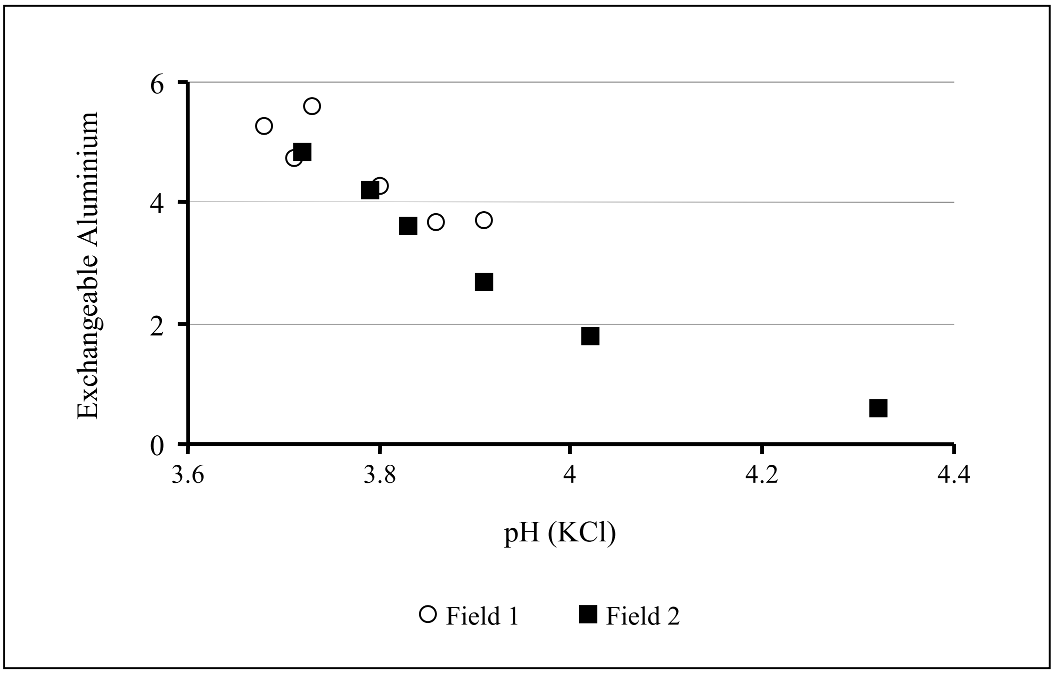

Figure 5: Extractable aluminium (meq/100g) as a function of $pH_{(KCl)}$. Symbols indicate field of sampling.

4.3. Rooting depth and rice yield

Figure 6 indicates that rice yield is correlated to root development, which can have a very strong impact as in field 2 (more than 50 kg/ha increase in yield on average for each 1 cm increase in rooting depth). The poor root development and shallow rooting of rice in these conditions can be explained by:

(i) Physical problems. Low porosity and high compaction prevent development of rice roots, together with

(ii) Chemical problems. In these acid soils ($pH_{(KCl)}$ between 3.7 and 4.3), exchangeable aluminium content is high (often above 4 meq/100g), with an aluminium saturation level often higher than 90%. Symptoms attributed to aluminium toxicity were frequently observed on leaves (as described by Jugsujinda et al., 1978) and roots (as described by Bell and Edwards, 1986). These soils also are low in phosphorus (1.9 to 2.4 mg P_2O_5/100g) and highly unsaturated (sum [K + Mg + Ca] / CEC between 5 and 17%).

4.4. Weeds and yield

Within fields, the impact of weed infestation on yield also was marked (Figure 7). The maximum yield measured in sample sites that were scored as 1 (low weed infestation) was twice the maximum yield measured in sample sites scored as 2 (medium infestation) and five times the maximum yield in sample sites scored at 3 (high weed infestation).

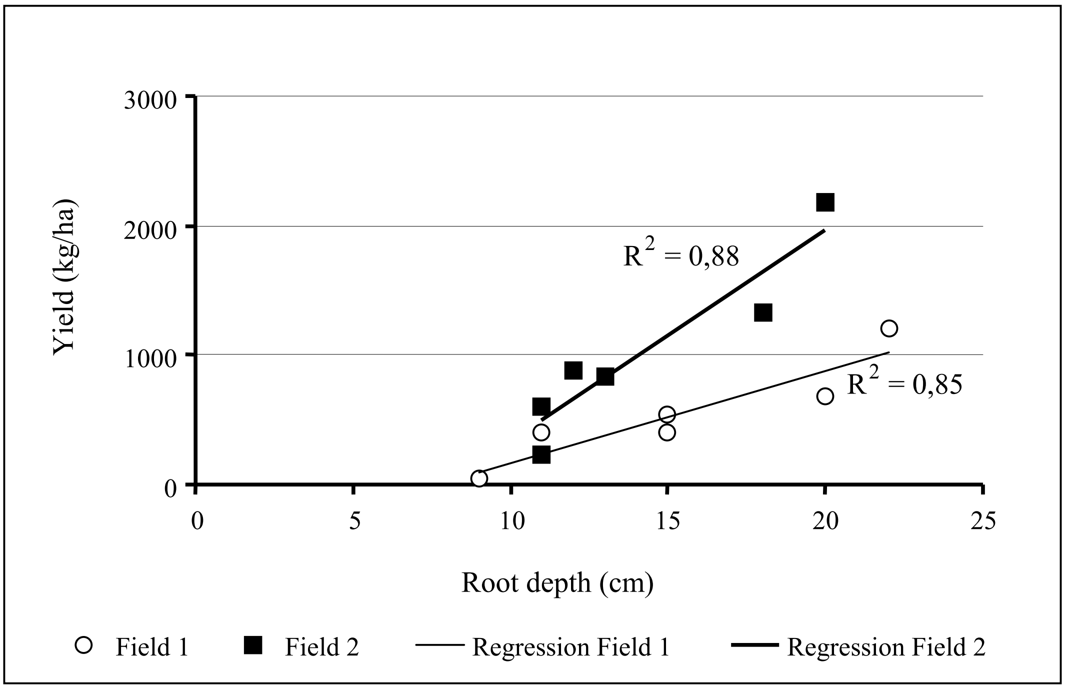

Figure 6: Rice yield (kg/ha) as a function of rooting depth (cm). Symbols indicate field of sampling.

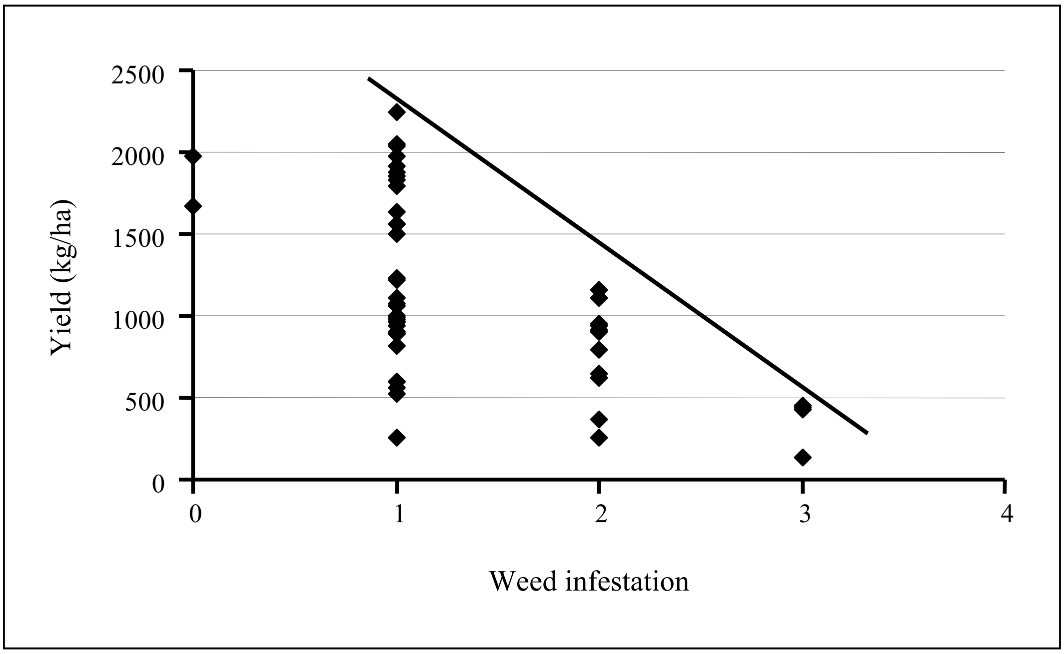

Figure 7: Rice yield as a function of weed infestation at harvesting in field 2. n= 33. The line indicates the envelope curve of yield limitation by weed infestation.

5. Agronomic processes and key factors explaining upland rice yield

Between fields, the major field characteristics explaining rice yield are preceding vegetation type, and number of years of cultivation. Within fields, rice yield is largely explained by soil structure (porosity, compaction, bulk density) and partly by soil chemical characteristics. All these criteria are, at different scales, indicators of soil regeneration/degradation status. In land-use cycles, periods of more or less intensive soil regeneration under forested conditions alternate with periods of rapid degradation under cultivation (slash and burn, erosion, compaction).

5.1. Forest and soil regeneration

Forest and soil regeneration occur during fallow/forest periods. During these periods, various processes lead to:

- Improvement of soil structure: development of light soil structure and increase of porosity by the actions of roots, micro-organisms (fungi, etc.) and meso-fauna (insects, worms, etc.).
- Increase in organic matter by accumulation and decomposition of vegetal biomass produced by trees (which also improves soil structure)
- Recycling of nutrients absorbed by tree roots from deep within the soil profile

However, intensity and length of regeneration vary in space and time. The main factors explaining these variations are:

- Reduction of fallow/forest periods due to increasing population pressure. In 1998, the human population density of the area was twice as high as in 1994 (47 and 22 inhabitants per km² respectively). At present, the only patches of forest older than 20 years are located on extremely steep slopes (over 45 degrees), usually on soils developed from karsts. In 1998 and 1999, the last forests to be opened for cultivation (before it was banned) were 15 to 20 years old.
- The high pressure of buffaloes on the forest. In Ngoc Phai commune, with over 30 buffaloes or cattle per km² of total land, insufficient areas of (low productivity) pasture, and free grazing practices, most animal feed is taken from the regenerating forests (Tran Quoc, 1999). Such animal density is representative of the entire district of Cho Don, and it is increasing rapidly. Farmers show a growing interest in livestock raising thanks to new market opportunities (Tran Quoc, 1999). Grazing by cattle can strongly reduce forest and soil regeneration, by consumption and exportation, by tree destruction, and last but not least, by mechanical compaction of soils by hooves. Differences in soil compaction level between type III forest and pasture (type I) shown in Figure 8 reflect this impact of buffalo grazing on soil structure.
- This impact of buffalo grazing has a spatial structure: Buffaloes preferentially graze on the less steep slopes, and start grazing from pasture areas or valley bottoms. Thus, their impact on forests often is stronger in the bottom part of toposequences, and decreases towards the upper part of the toposequence, with preferred paths concentrated in areas where slopes are not too steep.
- The number of cycles of slashing and burning also seems to have an impact in the long run, by modification of tree species. Bamboo species progressively replace other trees as trees seed bank in the soil becomes scarce or depleted.

5.2. Soil degradation

Slashing and burning for cultivation starts the process of soil degradation. Burning leads to a substantial loss of organic matter. But, more important, erosion processes can start as soils are cleared at the beginning of the rainy season and are no longer covered and protected by vegetation. This land preparation also "prepares" soils for erosion when heavy rains occur. Although land preparation, and erosion, remain limited to the top few centimetres, these are the most important centimetres of soils, owing to good structure and high organic matter content. These processes of erosion are stronger and faster on steeper slopes, which partly explains why after 3 to 4 years of cultivation, rice yield is negatively correlated to slope.

Furthermore, land preparation with a simple hoe, parallel to soil surface, also leads to deterioration of soil structure and creation of an impermeable plough pan (Le Bourgeois, 1999).

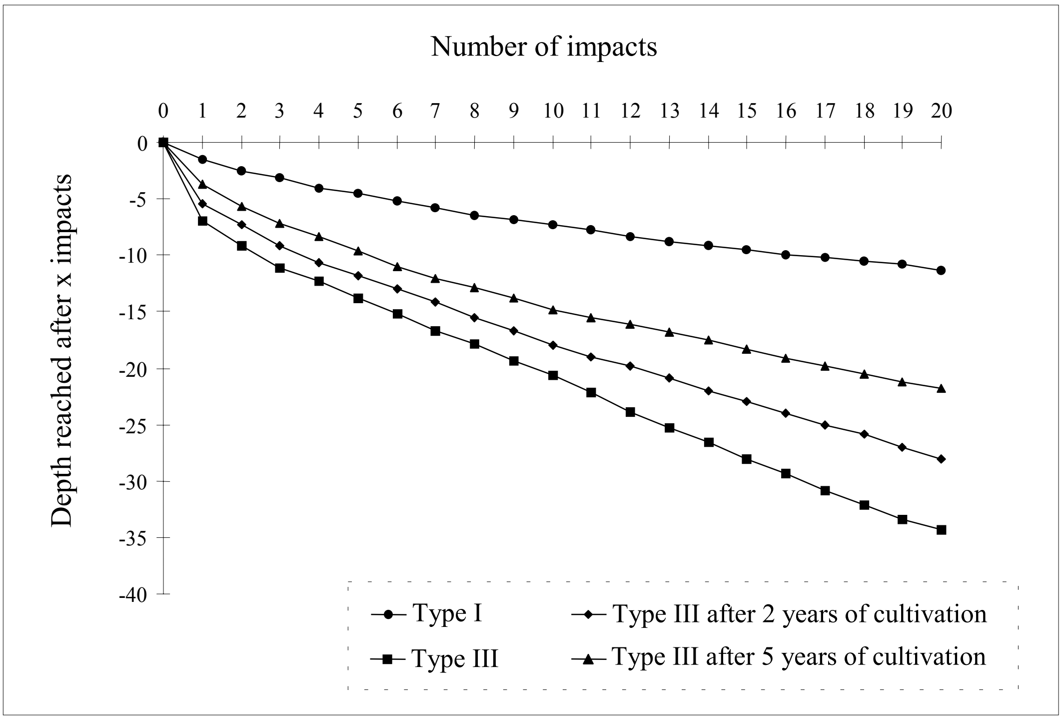

Figure 8: Soil compaction measured by penetrometry on red ferralitic soils: Depth (cm) reached after x drops (1 kg dropped from 1m, surface of 0.78 cm²). Average of 3 replications.

5.3. Water use efficiency

In such poorly structured and compacted soils, with low porosity, run-off is substantial and water infiltration is limited. This leads to very low water reserve.

Furthermore, because of shallow rooting, only a small part of the soil water is available to rice plants, which makes useful water reserve very low. Field observations in the study site indicate that after 4 to 5 days without rainfall, upland rice started to suffer from water stress, and presented rolled, dry leaves. Periods of more than 5 successive days on which rainfall was lower than evaporation were observed 7 and 8 times between June (sowing) and October (flowering) in 1998 and 1999, respectively.

Frequency analysis of rainfall (1980 to 1995) for Bac Kan province also shows that the risk of drought is high after 15th September (Figure 9), which often coincides with the period of rice flowering. In 1999, for instance, a period of 17 successive days with no rains occurred in September. Together with poor plant growth and insect attack, this drought stress at flowering explains the high percentage of empty grains: 32 % on average, but only 25 % for the well structured soils (type 5) versus 36 % on poorly structured soils (type 2).

5.4. Weeds

Water availability to plants probably also is limited by weeds. At all growth stages, competition between rice and weeds has a negative impact on rice growth. Thus in the study area, the rates of tillering, production of panicles, and grain filling are related to weed infestation. Weed competition can be extremely high, and weeding represents more than half of the time spent in agricultural labour (Naudin, 1999). It is a major cause of field abandonment, as even 100 person - days/ha is not always sufficient to control weeds adequately (Stevoux et al, 2000). Here again, preceding vegetation type and number of cultivation cycles are the main field characteristics explaining weed infestation level.

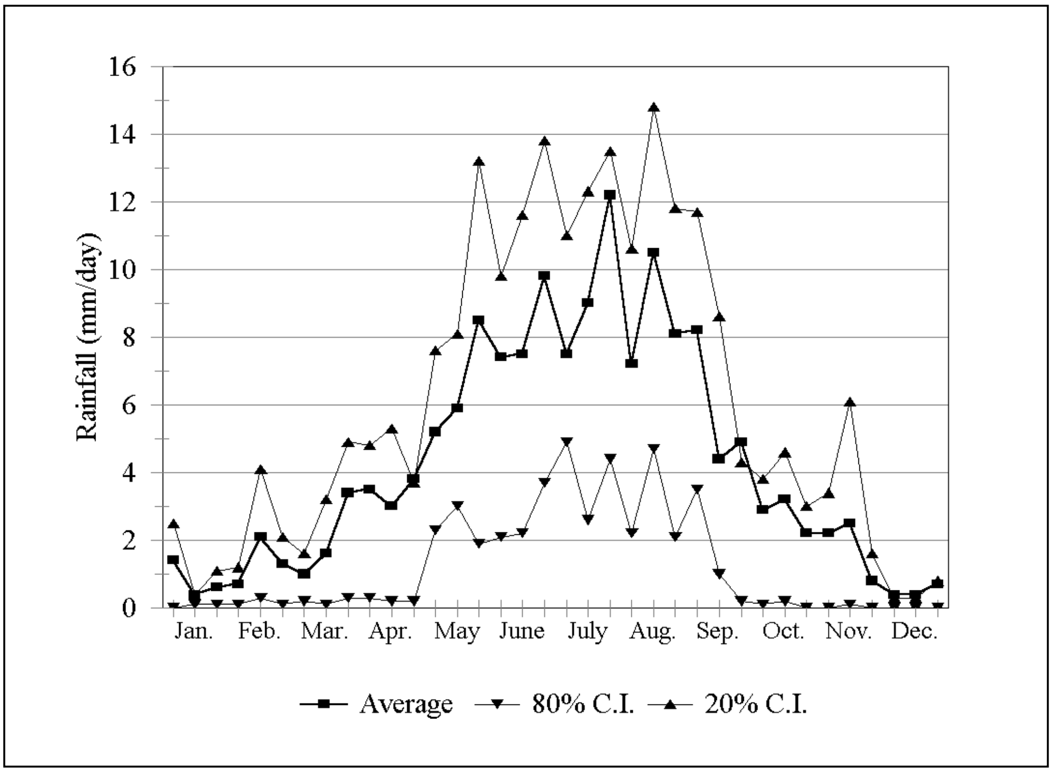

Figure 9: Frequency analysis of rainfall. Average curve, 80 % and 20 % confidence intervals. Bac Kan Province 1980-1995. Source: Bac Kan Meteorological Office.

5.5. Synthesis

Figure 10 is a synthetic diagram of major factors and processes interacting and explains rice growth and yield in the traditional systems of slash and burn. Main factors limiting upland rice growth and yield in the traditional systems of slash-and-burn as conducted in the study area are:

- Poor water use efficiency, due to high run-off, poor soil structure (compaction, and low porosity), and shallow rooting (due to unfavourable physical and chemical soil characteristics).
- Weeds competition

These two major problems are less important in the first year after clearing, especially where forest could regenerate properly, thus restructuring soils and reducing stocks of weed seeds (De Rouw, 1991). This regeneration is correlated mainly to length of fallow period (positively) and grazing by fallow period (positively) and grazing by buffaloes (negatively). However, these problems rapidly increase with time and cultivation, as erosion processes take place and changes in ecological conditions favour weed development.

In addition (and in relation) to these two major problems, mineral nutrition can be a limiting factor because of poor availability in soil and poor rooting, together with diseases (weak plants are more sensitive to diseases) and chemical toxicities (as aluminium toxicity symptoms indicate).

Finally, pests (insects, rats and birds) can greatly reduce yield. Concentration of cultivation in space and the narrow sowing time window can be seen as the farmer's answer to these problems. These traditional practices limit pests impact on rice yield.

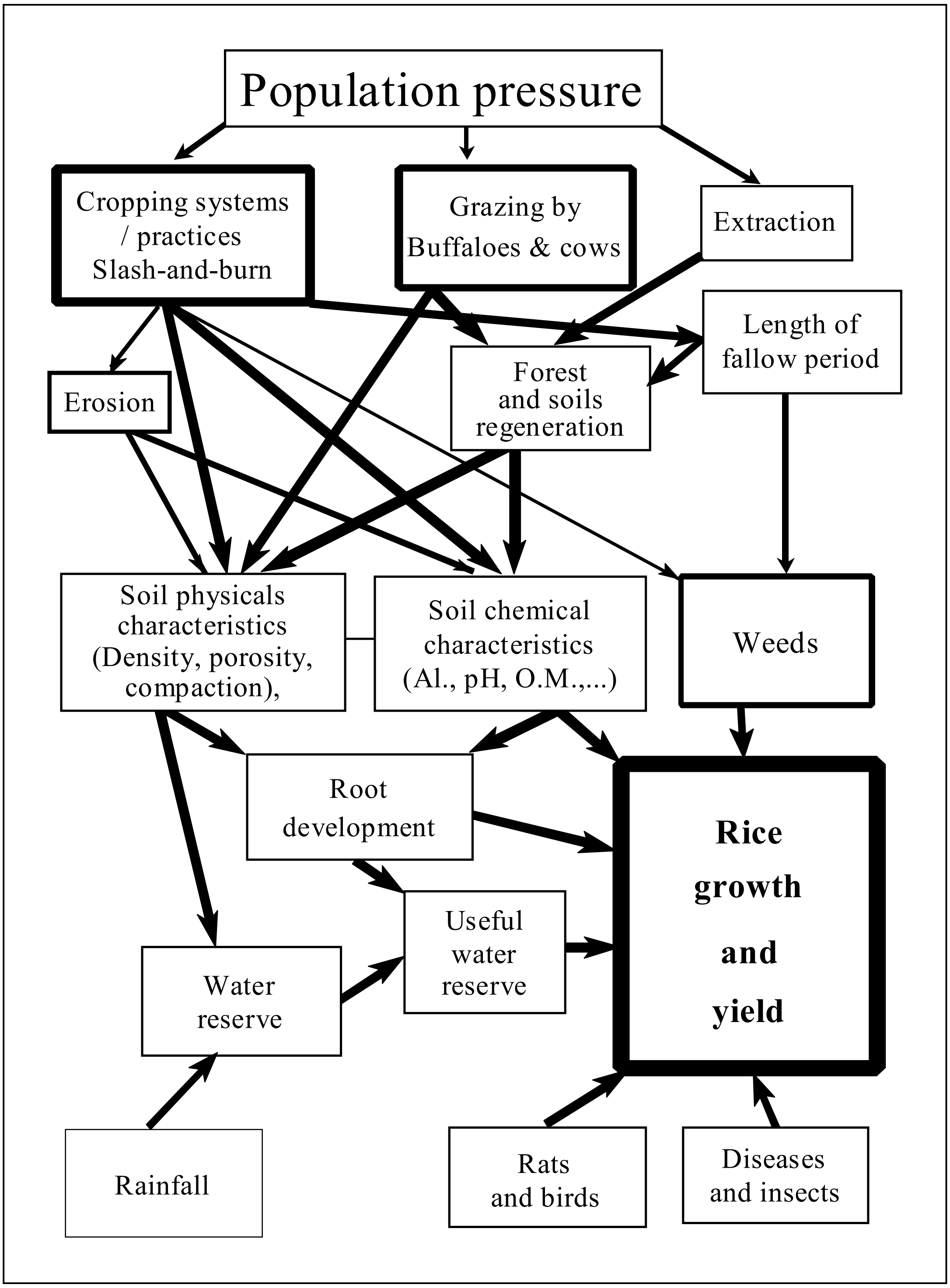

Figure 10: Synthesis of agronomic problems and factors limiting upland rice growth and yield in Cho Don district

6. Discussion

6.1. Correlations between factors and interactions between processes

In traditional slash-and-burn systems, upland rice growth and yield are the results of interactions between various processes, involving multiple factors. Correlations between factors have been observed and/or are well documented, such as a correlation between aluminium and organic matter and/or pHKCl (Pionke and Corey, 1967; Thomas, 1975), a correlation between bulk density and organic matter (Araki, 1993; Da Silva et al, 1997). Dynamic of weeds under slash-and-burn systems (De Rouw, 1991) also are well documented.

These processes interact, but often have different spatial structures and rates, and do not always occur simultaneously. They ultimately can affect positively or negatively rice growth and yield. This is the case, for instance, for soil and forest regeneration processes, which usually are stronger and faster on tops of toposequences and on steep slopes where buffalo grazing is limited, while erosion processes have an opposite effect, leading to accumulation of soil on bottoms of toposequences and/or gentle slopes.

This multiplicity of factors and interactions, the differences in their spatial structure, and the strong impact these factors have on the successive stages of upland rice growth, often lead to highly heterogeneous and even chaotic situations (with no clear spatial structure) and to tremendous yield variability, as observed.

6.2. Methodological aspects

In such conditions, variables or factors can hardly be isolated and/or studied separately. Sampling procedures also can be biased by such complex situations, and several effects can be confounded. For instance, the correlation observed between forest type and slope (well-regenerated forest is now found only on steep slopes) makes it impossible to isolate these two factors in the study area. However, this reflects actual farmers' conditions. The point of such a diagnosis should not be to study individual factors or processes for which references already are available in literature. It is to use collective, extrapolable knowledge to reach a global understanding of the actual situation, with emphasis on understanding the interactions among these factors and processes.

The large number of factors influencing rice growth and yield, their high possible impact, the multiplicity of their interactions, and the tremendous within-field variability also make it difficult to measure clear correlations without using impractically-large numbers of replications. In such a diagnostic approach, one should be satisfied with replicated observations of trends, provided that these trends have been explained, fit in a global model of biophysical interactions, and are not in contradiction with the general background and knowledge of the scientific community.

6.3. Ranking factors

Ranking factors influencing rice growth and yield is an important step in such an agronomic diagnosis. However, in the study area, it can be seen that the importance of various factors influencing final yield varies greatly not only between fields, but also within fields. This high variability makes it difficult to propose a global ranking of these factors. It can only be said that some factors, such as soil physical and chemical characteristics and weeds pressure are of major importance, are more important in field where soil regeneration was poor (vegetation types 1 to 3) or where soil degradation occurred (years 3 and 4), and frequently are the most important factors explaining rice yield. It also can be said that other factors such as damage from pests and diseases locally can have a strong influence on yield.

7. Conclusions

This detailed study, conducted in one village, made it possible to identify major factors to be considered in explaining upland rice growth and yield. It has led to a simple model of interactions among factors and knowledge on general, extrapolable processes taking place in such situations. Furthermore, as the research site was selected for being representative of Cho Don district and Bac Kan Province, it can be expected that these results observed locally can be extrapolated to most conditions of upland rice cultivation in the province. Furthermore, preliminary results indicate that maize cultivation faces similar constraints, but to a lower extent, as maize has a stronger root system and is cultivated on less acidic soils.

This diagnosis also provides critical information on possible ways to improve (or design alternatives to) these systems. Research priority clearly should be given to development of techniques or systems for increasing water use efficiency and facilitating weed control (figure 10). Until soils have been rehabilitated and protected, and weeds controlled, "classical" research on topics such as fertilisers (which probably will be leached or removed by erosion, or will benefit weeds) or varieties (which will not be able to express their potential) are meaningless. They will bring hardly any improvement to these traditional slash-and-burn systems, which have reached a dead-end under current biophysical conditions and population pressure.

Since 1999, a wide range of cropping systems and techniques (over 100), based on direct sowing on vegetal cover have been tested in Cho Don, with very promising preliminary results (Husson et al., 2000). The main principles underneath these techniques or systems are to copy and speed up processes observed in forest ecosystems. Soil structure is rapidly (3 to 18 months) improved by grasses with strong root systems (*Brachiaria sp.* and *Panicum maximum*, which also are good forages for animals) and/or legumes (*Mucuna pruriens*, *Stylosanthes guyanensis*, *Cassia rotundifolia*). Rice is then sown directly into the mulch produced by simply killing these plants with herbicides or cutting them. This mulch protects soil from erosion (soil is permanently covered, and "sewn together" by the dense and deep root system), reduces evaporation, regulates soil moisture and temperature, and completely controls weeds when thick enough. Development of macro fauna and micro flora under this mulch, without any tillage (i.e., no soil perturbation), also aids in soil regeneration (Marinissen and Hillenaar; 1997, Caesar-Ton That and Cochran, 2000). Decomposition of the mulch releases nutrients and organic acids, increases soil organic matter content, and as a consequence, reduces aluminum toxicity problems (Thomas, 1975; Hue et al, 1986). Soil structure is then maintained by crops/forages rotation, including plants with very deep roots (such as pearl millet), which also help recycle nutrients that have been leached, just as trees would in the forest. Moreover, some cover crops can be used as fodder for livestock and consequently reduce livestock's negative impact on forest regeneration.

The best cropping systems tested in fields usually abandoned by farmers after they cultivated for 4 to 5 years, with limited inputs (no fertilisation, no weeding), gave yields over 1.7 t/ha (as compared to expected yields below 500 kg/ha with traditional techniques). These systems provide practical solutions to the major problems identified in this diagnosis and reverse the main processes leading to yield decrease in the traditional systems. The dramatic increase in yield indicates the relevance of this diagnosis. This also shows that such a rapid diagnosis, identifying major constraints of the systems, is an extremely useful tool, provided it is not perceived as the ultimate goal, and remains oriented towards solving farmers' problems.

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