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Impact of erosion prevention methods on yield and economic benefits of maize production in northwest Vietnam

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Abstract
Participatory experiments were conducted in farmers' fields in three villages in Son La and Lai Chau provinces to assess production and economic impacts of mini-terraces, mulch, and intercropping with legumes (live mulch). Maize production was statistically significantly increased in all erosion management treatments with the highest average increase of 1.04 T/ha recorded when mulch was used on mini-terraces. Use of mulch on slopes produced an average increase of 0.66 T/ha while intercropping maize with legumes (black beans) increased average yield by 0.5 T/ha. Basic economic analyses were conducted during participatory evaluation of experiments to compare existing farmer practices with experimental erosion management practices. Income and profitability depended on the level of inputs used and access to the market. In Ta Ngao village where market access was minimal and normal farmer practice was shifting maize production with no inputs, the use of mini-terraces and mulch together with high doses of fertilizer resulted in 150% increase of production but did not lead to significantly higher profitability because of high input costs. In Na Ot, farmers had better access to the market and used low doses of fertilizers, resulting in moderate yields and profitability. In these circumstances, the increase in production that can be attributed to the use of mulch and cultivation on mini-terraces was not proportional to the increase in labor inputs, so profit was lower than in the farmers' fields even though yield and income was higher. In Ban Bo, farmers were well-connected with the markets and practiced high input cultivation. Here, improved crop management and intercropping with legumes resulted in significantly improved production and increased profit of farmers involved in the project. Although results demonstrate that erosion prevention methods did increase maize yields, the small increase in profitability indicates that they will not provide sufficient stimulus for farmers to adopt them.

Highlights
- Minimum tillage combined with the use of mulch was the most cost-effective production method incorporating erosion prevention in all environmental and socioeconomic maize production situations in northwest Vietnam
- Erosion prevention treatments increased maize yield but increase in economic returns were minimal
- Economic benefits from erosion prevention treatments do not provide sufficient stimulus for farmer adoption so outreach strategies must be developed to raise farmer awareness of the impacts of erosion on long term sustainability of farming

- Participatory evaluation enabled researchers to understand farmers' perspectives on the benefits and drawbacks of the various treatments and the applicability of the treatments for integration into prevailing farmer practices.

Keywords
maize, mulch, mini-terrace, erosion, participatory evaluation, upland farming, Vietnam

Introduction

Socioeconomic impacts are primary drivers for land use and land cover change, which in turn determine the structure, function, and dynamics of most landscapes (Wu and Hobbs, 2002). Since the 1990s, production of maize has been the major driver of land use change in Vietnam's northern highlands. Between 1990 and 2004, maize production in Vietnam increased more than five-fold from a total output of 671,000 tons to more than 3.4 million tons, a five-fold increase. The total area planted to maize expanded from 432,000 to 990,000 ha during the same period, primarily in the highland areas. A rapid increase in the use of improved varieties/hybrids and fertilizers, supported by strong government policy, enabled yields to increase on average from 1.5 to 3.5 t/ha, with many farmers in low lands recording yields between 4-6 T/ha. This dramatic change has had a significant impact on the incomes and employment of farmers in many rural areas of Vietnam, with many households in the North West now receiving as much as 70% of their household income from the production of maize for the animal feed industry (Thanh *et al*, 2004, Dao *et al*, 2004).

The growth of the maize market has led smallholders to expand production onto steep slopes to continue to meet livelihood needs. However, the combination of intense rainfall concentrated 80% during the four to five month long rainy season and high soil erodibility make upland fields prone to erosion and maize production unsustainable (Nguyen and Klinnert 2001, Le et al. 2003, Ha et al, 2003, Vezina et al., 2006, Le and Ha, 2008).

Alongside the development of maize production, Vietnamese scientists have conducted many research projects to address erosion problems on sloping lands, most notable of which was research supported by the French organization, Centre de coopération internationale en recherche agronomique pour le développement (CIRAD), which resulted in development of cultivation systems appropriate for mountainous areas of Vietnam (Système Agricole de Montagne (SAM)). Technologies developed include mulch-based direct sowing, mini-terraces, intercropping with legumes, and diversification and rotation of crops (Le et al. 2003, Ha et al, 2003, Le and Ha, 2008).

Unfortunately, even though effective erosion prevention methods were developed, scaling up of developed production systems is slow and challenging (Le et. al. 2003). In 2009, the Australian Center for International Agricultural Research (ACIAR) funded the project "Improved market engagement for sustainable upland production systems in the North West Highlands of Vietnam." The project's objective was to develop a market-driven farming system that would utilize developed soil cultivation methods that minimize erosion. In 2010, a total of 13 small-scale participatory experiments were conducted as part of this project. Experiments were conducted in farmers' fields in eight villages in Son La and Lai Chau provinces. Objectives of the experiments were to assess a range of proven erosion prevention methods, in terms of the yield, the amount of labor required to implement them and profitability. This paper will present results with economic analysis for three locations, representing the different levels of market access and socioeconomic context. In Ta Ngao (Sin Ho district, Lai Chau province), farmers belong to Hmong minority group and practice subsistence farming; in Na Ot (Mai Son district, Son La province), farmers belong to Thai minority and practice low-input farming and trade the primary product (maize) through local collectors (basic market engagement); and in Ban Bo, farmers belong to majority Kinh (Viet) ethnic group and practice high input farming with their primary product (maize) used as an input for their own large-scale pig production.

Methods

Data presented in this paper were collected within three different components of the overall research process; diagnostic phase, applied experimental phase and participatory evaluation. Information on socio-economic, ethnic, and gender-specific context and agricultural production and marketing practices was gathered in the diagnostic phase of the project. Maize yield related to different cultivation practices was measured in field experiments. Feasibility of the tested cultivation practices in the context of the current farmers' production practices and socioeconomic realities was assessed within the participatory evaluation component.

Diagnostic phase

Diagnostic research was performed by mixed research teams that consisted of agricultural and marketing experts from the Center for Agrarian System Research and Development (CASRAD), Northern Mountainous Agricultural and Forest Science Institute (NOMAFSI), and Plant Protection Research Institute (PPRI).

In each village, data collection activities were conducted over five days and consisted of a community meeting at the beginning and the end of the research process, village mapping and transect walk, focus group discussions on market engagement and on resource management, and interviews with individual farmers, farmer leaders, extension officers, and traders engaged in the village. The farmers involved in community meetings were selected by the community leader to represent the social structure of the village. Focus groups and individual farmers that were interviewed were drawn from the farmers that attended the community meetings.

The initial community meeting was conducted with approximately 20-25 farmers, representing about 25% of households in the village. This meeting introduced the project and the research team, mapped out enterprises undertaken in the village, identified/prioritized constraints and explored possible solutions. A transect walk conducted after the meeting with village leaders and a few farmers allowed observations to be made on built-up areas, agricultural land, and infrastructure and initial mapping to be cross-checked and modified.

On the second day, two separate focus group discussions were conducted, each with six to eight farmers (both men and women) from the same ethnic group, but with different socioeconomic status One focus group discussed engagement with markets and also usually included a village trader, while the other group discussed natural resource management. After group discussions, interviews were conducted with 15 individual farmer families to collect data on individual farmer households. Interviews with farmers included demographics of farmers' families, land use and farm enterprises, agricultural production, gender task distribution, market engagement and where they source information on agricultural production and marketing. At the end of the process the final community meeting was held to seek feedback on the needs and opportunities identified in previous activities and to formulate recommendations for research topics to be included in the applied research phase of the project.

Experimental phase

The field experiments reported in this paper were conducted in Ta Ngao and Ban Bo villages in Lai Chau province and Na Ot village in Son La province. Details of the villages are provided in Table 1. Experiments were conducted in the fields of 5 farmers from each village who showed greatest interest in the diagnostic studies and volunteered to participate in the project. These farmers are subsequently referred to as farmer researchers. Experiments were carried out by researchers from Vietnamese research institutions with active involvement of the farmer researchers. The major objectives of the experiments were to measure the inputs into the different erosion prevention treatments and the resultant maize yield. During the experiments farmers were also able to make visual evaluations of the applied treatments. Erosion control treatments applied varied between locations and were selected in consultation with the participating farmer researchers (Table 1).
All experimental locations are influenced by distinct wet and dry seasons, but the rainfall patterns vary between provinces. Moderate rainfall starts in Lai Chau province in March-April, and in Son La province in April-May. In both provinces very heavy rainfall occurs in June and July and it decreases to moderate levels in August. In Son La, low rainfall persists from September to December, and then the period from January to the start of rainy season is virtually without rain. In Lai Chau, the period from September to January is dryer than in Son La, but low rainfall starts again in February. Farmers have adapted to this rain pattern by growing only one crop of maize per year and all experiments were planned to fit in this farmer practice.

<u>Ta Ngao field experiment</u>

Experimental design

There were two treatments: mini-terraces with addition of mulch and mini-terraces without addition of mulch. Each treatment was applied to an area of approximately 500 m^2 on a slope of around 30^o .Experimental plots were surrounded with farmers' fields where organic material was burned prior to plowing and sowing. For assessment of yield, three randomly selected 2 m^2 areas were harvested from three different locations within the plots and results were used as pseudo-replicates in the statistical analysis.

Mini-terraces were formed from the bottom of the slope upwards using double passes of a plow in the same direction. They were approximately 0.7 m apart with a terrace width of 0.4 m. Stubble from the previous harvest was removed from the area assigned to the treatment without mulch and was added to the treatment area with addition of mulch.

Main cultivation activities
A local maize variety (name unknown) that develops very tall plants (3.5 m) and has a long growing cycle was sown on April 14, 2010. Two seeds per position were sown in trenches at a depth of 0.05 m with 0.7 m between rows and 0.3 m between sowing positions within the row (0.7x0.3). Fertilizer was added at the time of sowing in the same trenches as seeds but at a depth of 0.08-0.10 m. Time of fertilizer application is shown in Table 1 while the amount, and value of fertilizer applied is shown in Table 4. The first weeding was done on April 30, the second weeding on May 28, and the third and final weeding and soil cultivation when plants had developed 13-14 leaves.

Assessment of yield
Maize was harvested on August 30, 138 days after sowing. Yield was assessed from an area of $2m^2$. In each plot three assessment areas were randomly chosen. Yield data are presented as weight of maize seeds with moisture content standardized at 14%.

Na Ot field experiment

Experimental design
A randomized complete block design was used with three treatments and three replicates. Treatments were: (1) burning of organic material and plowing (conventional farmer practice); (2) mulch applied on soil that was cultivated only by opening one trench every 0.7 m where seeds and fertilizers were applied; and (3) mulch on mini-terraces (as described in Ta Ngao experiment) Table 1. Each plot had an area of approximately 110 m^2, with each block having approximately 330 m^2 making a total experimental area of 1000 m^2. The experimental area had a slope of 30^o.

Main cultivation activities
The maize variety LVN99 was sown on April 18in trenches at a depth of 0.05 m. Two seeds were sown per position with 0.3 m between sowing positions within the row and 0.7 m between rows of (0.7x0.3). Fertilizer was added at the time of sowing in same trenches as seeds but at a depth of 0.08-0.10 m. Time of fertilizer application is shown in Table 1 while the amount, and value of fertilizer applied is shown in Table 6. The first weeding was done on April 28, the second weeding on May 31, and the third and final weeding and soil cultivation on June 10.

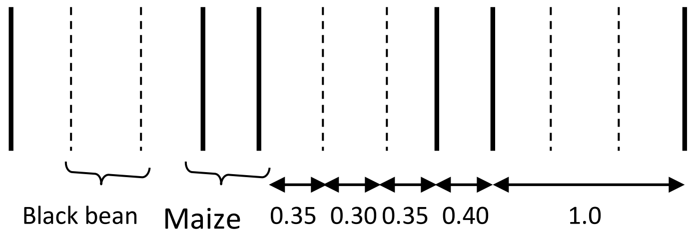
Assessment of yield
Maize was harvested on August 15, 116 days after sowing. Yield was assessed from an area of $2m^2$ in each replicate. Yield data are presented as weight of maize seeds with moisture content standardized at 14%.

Ban Bo field experiment

Experimental design
A randomized complete block design was used with two treatments and three replicates. Treatments were: (1) burning of organic material and plowing and (2) live mulch-intercropping with legumes (black beans) Table 1. Each plot had an area of approximately

170 m^2, with each block having approximately 340 m^2 making a total experimental area of 1000 m^2. The experimental area had a slope of about 8^o.

Main cultivation activities
On April 12, the maize variety KK154 was sown at a rate of two seeds per position in trenches at a depth of 0.05 m. In the treatment where only maize was sown, the distance between rows of maize was 0.7 and the distance between sowing positions within the row was 0.3 m (0.7x0.3). In the treatment where maize was intercropped with black beans, the maize was sown in strips of two rows with a spacing of 0.4 m between rows and 1 m between strips. Black beans were sown in two rows 0.3 m apart into the 1m space between the two maize strips. The number of maize plants per area was the same in both treatments.



Fertilizer was added at the time of sowing in the same trenches as seeds but at depth of 0.08-0.10 m. Time of fertilizer application is shown in Table 1 while the amount, and value of fertilizer applied is shown in Table 8. The first weeding was done on April 30, the second weeding on May 15, and the third and final weeding and soil cultivation was done when plants developed 13-14 leaves.

Assessment of yield
Maize was harvested on August 1, 112 days after sowing. Yield was assessed from an area of 2m^2 in each replicate. Yield data are presented as weight of maize seeds with moisture content standardized at 14%.

Participatory evaluation
Participatory field trial evaluation was conducted over two, two-hour sessions in order to understand the farmers' perspectives of the benefits and drawbacks of the different treatments. Meetings were held in the homes of the farmer researchers, together with their neighbors, the village leader, extension officers, and researchers. The first session was conducted just before harvest and discussion concentrated on production and amount of fertilizers, pesticides, and labor hours used. The second session was conducted after harvest and the inputs and outputs were documented, balance between inputs and outputs discussed, and economic analysis performed. In 2010, participatory evaluation meetings were held in Ta Ngao on April 4 and on September 21, in Ban Bo on August 6 and September 17, and in Na Ot on August 7 and September 16.

Economic analyses presented are based on a combination of recorded and estimated data. At the meetings the research team presented the exact amount and cost of non-labor inputs into experimental trials (recorded data) and then estimated the farmers' labor inputs for each treatment as well as the amount and value of inputs into the farmers own production at the adjoining fields. Long discussions were also held to explain the treatment yields in terms the farmers understood (usually yield of the whole cob) and for researchers to convert farmer estimates of yield in their own fields into standardized units of kilograms of maize seed per hectare (with moisture content standardized at 14%). These discussions were complex because the traditional Vietnamese unit for land area (Sao) is usually 360 m^2, but it does vary from province to province and it is not commonly used by farmers from minority groups.

Statistical analysis
Data from all experiments were statistically analyzed using a mixed model analysis of variance (SPSS v 17) with treatments being the fixed factor and replicates the random factor. Data were checked for compliance with assumptions of normal distribution and variance homogeneity using PP plot and Levene's test for equality of error variances.

If the F test showed significant differences between treatments, Ryan's Q test was used to separate differences between treatment means.

Results

Socio-economic background (Diagnostic study)

Ta Ngao
This village has been inhabited by the Hmong minority group for longer than the current generation can remember. The village has 18 households but historically had 30 households before people moved to lower land. Government assistance allowed farmers to build stronger houses in 1993, install a fresh water storage system in 2006, and connect to the electricity grid in 2008. Farmers grow a local variety of maize and do not wish to introduce hybrid varieties.

Households in Ta Ngao were large, consisting of around 7 family members (Table 2). Education levels of male and female household heads was low while education levels of the second generation have improved significantly and were equal for male and female children (Table 2). Based on average education levels it can be assumed that most adult farmers have difficulties communicating in Vietnamese and they would not be able to read and understand basic written extension materials.

On average, each household had 1.45 ha (SE=0.21 and median=1.40) of agricultural land. The small standard error of mean (SE) and small difference between average and median values indicate that land was fairly equally divided among households. Rice was grown on 58.9%, maize on 40.7%, and temperate fruit on the remaining 0.4% of the cultivated area. All fields were on slopes and the majority (73%) of agricultural land was within 2km of the house.

Overall the work in maize production was fairly equally shared between male and female household members with females doing slightly more work in all tasks except for pest management. Farmers used most of their products to feed their own animals and for their own consumption, so there were no marketing activities (subsistence). Male farmers attended agricultural information sessions and community meetings more frequently than female farmers.

Table 2: Demographic profile of the villages

Village	**Ta Ngao mean/median**	**Na Ot mean/median**	**Ban Bo mean/median**
Agricultural land/household (ha)	1.45/1.4	2.97/2.90	1.20/1.18
No. of household members	7.15/7	4.92/5	4.54/5
No. of children	5.46/5	3.15/2	3.46/4
No. of persons employed outside the farm/household	0.38/0	0.38/0	0.75/0.5
No. of pensioners/household	0.08/0	0/0	0/0
Age of male household head	42.85/42	40.31/39	46.31/42
Age of female household head	39.5/39	38.08/35	42.08/39
Age of oldest child	21.23/20	17.08/18	20.33/19
Age of youngest child	6.15/5	8.46/9	12.55/15
Education of male household head	2.92/0	7.00/5	7.15/7
Education of female household head	0.08/0	5.15/4	5.92/7
Education of male child (highest)	7.38/7	9.00/9	8.67/10
Education of female child (highest)	7.60/6.5	10/10.5	9.30/11.5
Education of lowest educated child	6.36/7	6.70/6	8.25/8

Na Ot

This village has been inhabited by the Thai minority group since 1953. Electricity reached the village in 2002 and a water supply system was established in 2005.

From 1953 to 1992, farmers were producing rice and maize for their own consumption (subsistence). The first surpluses of maize were traded in 1992, but a major boost to maize production and trade came with the upgrade and asphalting of national road 4G. In 2000, the hybrid maize variety LVN was introduced, and together with a significant increase in fertilizer use, resulted in large increase in maize production.

Households in Na Ot were generally smaller than in Ta Ngao with around 5 family members (Table 2). The data indicate that the existence of the villagers almost entirely depends on agricultural production and that children generally leave home after marriage to start their own households. Education levels have been relatively equal between male and female village members for the last two generations; however, the level of education increased significantly from one generation to another and education levels of new generation females was higher than the level of education of new generation males (Table 2). Based on average education levels, it can be assumed that most farmers are sufficiently fluent in Vietnamese and should be able to read and understand basic written extension materials, even though with a median of four years of formal education for female heads of household it is highly possible that some female farmers cannot read and write Vietnamese. Most of the work in maize production was fairly equally shared between male and female household members but male farmers attended agricultural information sessions and community meetings more frequently than female farmers.

On average, each household had 2.97 ha (SE=0.64 and median=2.90) of land. The small standard error of mean (SE) and small difference between average and median values indicate that land was fairly equally divided among households. Maize was grown on a total of 90% of the cultivated area as a mono-crop. Rice was cultivated on 6%, cassava on 3%, and coffee on 1% of the total area. All maize fields were on slopes while the majority (83%) of rice fields were on the flats. Fields were relatively close to houses with 36.61% of agricultural land being within 1 km of the house and a further 24.51% being between 1 and 2 km from the house. However, sloping topography and poor connections between fields and the main road by unsealed roads has a very significant impact on agricultural production.

Ban Bo
The village has been inhabited by Kinh people since 1978 at its original site and from 1985 at the present site. The village was moved because of lack of water at its original site. Electricity reached the village in 1998 and in 2004 houses were renovated. In 1985, production of the hybrid maize Bioseed 9681 was introduced. Some of the maize crop was sold for production of animal feed but farmers also started raising pigs themselves. Today pigs are the main product and most of the maize produced is used as an input in farmers' pig production.

Households in Ban Bo were similar in size to Na Ot (Table 2). The employment rate outside the farm was the highest of the villages surveyed (Table 2). The data indicate that the existence of the villagers depends on agricultural production even though employment outside the farm is higher than average. Children generally leave home after marriage to start their own household. Education levels have been relatively equal between male and female village members for at least two generations. Many children from the new generation complete 12 years of education and education of female children is now higher than that of male children. Based on the average educational levels it can be assumed that farmers can understand written extension material. Most of the work was equally shared between men and women.

On average, each household had 1.20 ha (SE=0.18 and median=1.18) of land. The small SE and small difference between average and median values indicate that land was fairly equally divided among households. Maize was grown on a total of 57% of the cultivated area as a mono-crop, rice was cultivated on 24%, and tea on 19% of the agricultural area. The majority of the cultivated area was on slopes: 98.95% of maize area and 82.40% of rice areas were on slopes. However in this village, the majority of crops were grown on gentle slopes of less than 20^0 and tea on steep slopes. Most of the fields were relatively close to the houses with 73% of agricultural land being 1-2 km from the house. Large scale pig production with approximately 1,600 pigs raised in the village was the main source of household income. Hybrid maize CP 999 was produced and used to feed pigs. However local maize production does not meet all of pig production requirements and additional maize was bought outside the village.

Field trials

Ta Ngao experiment
There were no significant differences in yield between mini-terraces with mulch (6.29 T/ha) and mini-terraces without mulch (5.19 T/ha) ($F_{1, 2}$ = 9.461, p=0.091) (Table 3). Farmer practice was not part of the experimental design but yield on neighbouring fields was estimated at 2.5 T/ha, less than half the yield recorded in experimental plots.

Na Ot experiment
There were significant differences in yield between treatments ($F_{2, 4}$ = 9.739, p=0.029) (Table 3). Yield of maize grown with mulch on mini-terraces (5.4 T/ha) and where mulch was applied without mini-terraces (5.1 T/ha) was significantly higher than yield of maize grown on soil where plant residues were burned before sowing (4.4 T/ha). There were no significant differences between treatments where mulch was applied. The yield on neighboring fields was estimated at 3.5 T/ha. When compared with the experimental treatment where organic material was burned, yields in farmers' fields was 22% lower and when compared to treatments with mulch, yield in farmers' fields was 31-35% lower.

Ban Bo experiment
There were significant differences in yield between treatments ($F_{1, 2}$ = 34.23, p=0.028) (Table 3). Yield of maize was higher when intercropped with black bean (6.9 T/ha) than when planted as a mono-crop (6.4 T/ha). Yield in experiments was higher than yield in surrounding farmers' fields where production was estimated at 4 T/ha. Results show that intercropping with legumes (green mulch) had a positive impact on maize yield. Total loss of the bean crop due to diseases at the end of the growing season indicates that producing a bean crop during the rainy season may require high use of fungicides.

Economic analysis

Ta Ngao experiment
Economic analysis showed that use of mini-terraces with mulch (MT&M) or use of mini-terraces without mulch (MT) in combination with high use of fertilizers increased production of maize between 2 and 2.5 times in comparison to production on neighboring farmers' fields (Table 4). However, the high cost of inputs offset most of the benefits of higher production so there was only a slight increase in profit (excluding the labor cost) of 438,000 VND/ha (4%) between farmer's own production and production on MT, and a moderate increase in profit between farmer's own production and MT&M of 5,401,000 VND (48%). Addition of mulch onto mini-terraces increased production by 1.1 T/ha and profit by 4,963,000 VND (42%).

Use of mini-terraces with or without mulch increased labor input (Table 5), so if profit is expressed as profit relative to the labor input, then profit was lower for experimental treatments: 166,510 VND and 129,866 VND per day of work for MT&M and MT respectively, versus 173,077 VND per day of work for farmers own production.

Na Ot experiment

Economic analysis of treatments within the experiment shows that use of mini-terraces with mulch (MT&M) and use of mulch without plowing (M) increased production of maize in comparison to the treatment of burn and plow (B&P) by 0.96 T/ha (22%) and 0.66 T/ha (15%) respectively (Table 6). When treatments within the experiment were compared with production on surrounding farmers' fields, the addition of fertilizer (B&P) resulted in a yield increase of 0.89 T/ha (27%); MT&M in conjunction with a higher dose of fertilizers resulted in a yield increase of 1.85 T/ha (53%); and M in conjunction with a higher dose of fertilizer resulted in a yield increase of 1.85 T/ha (44%).

However, the high cost of inputs offset the benefits of higher production, so profit for B&P was 2,100,000 VND (-16%) lower than profits achieved by farmers from their own fields, and profits from treatments MT&M and M were 1,740,000 VND (14%) and 540,000 VND (4%) higher than farmers' profit respectively. Profit from treatments MT&M and M were 3,840,000 VND (36%) and 2,640,000 VND (25%) higher than profit from treatment B&P.

However, when profits were expressed relative to the number of labor days (Table 7), the much higher labor input in experimental treatments in comparison to farmers labor input in their own fields resulted in lower profit expressed in the experimental treatments (116,849, 112,230 and 107,984 VND per day of work for B&P, MT&M and M respectively vs. 150,292 VND per day of work in farmers own production).

Ban Bo experiment
Farmer researchers contributed to the estimation of the number of work-days used in production of maize in experimental plots (100 days), their own fields (84 days) and the cost of inputs and income from maize sales (Table 8).

Results show that better use of fertilizers and control of pests and diseases in experimental plots increased production of maize by 2.42 T/ha (61%) and resulted in increased profits (excluding cost of labor) of 2,277,000 VND (17%). When B&P experimental plots were compared with plots where maize was intercropped with legumes then intercropping increased production of maize by 0.49 T/ha (8%) and profit by 2,205,000 VND (14%).

There was only a slight increase in labor inputs so profits expressed relative to the labor input for experimental treatments was higher than for farmers own production (164.074 VND and 177.920 VND per day of work for B&P and intercrop treatment respectively vs. 158,452 VND per day of work for farmer production).

Discussion and Conclusions
Participatory evaluation of experiments showed that the use of erosion prevention measures (mulch and mini-terraces) increased yields in all experiments. , However, the economic impact, at least in the transitional period between current practices and more sustainable practices (Hoa et al., 2008), depended on the socioeconomic realities in the community, particularly on existing levels of inputs used by farmers and connectivity with the market.

In Ta Ngao, farmers do not engage in maize trade and their only source of cash income is the sale of a few pigs and medicinal plants collected in the forest. There is strong opposition to selling maize as expressed by the village leader at the evaluation meeting: “You may not understand but Hmong don’t want to sell. If we get a lot of maize we will store it for two years, but we will not sell it.” There is also a strong belief that fertilizers are poisonous for the soil. Low educational levels resulting in limited command of Vietnamese language and inability to read extension materials is one of the major contributors to community persistence in subsistence production. Another very important factor, as shown in our analysis for Ta Ngao, is that shifting cultivation practices in maize production (i.e. opening new production areas by cutting the forest for short term use of land followed by a long fallow period) with no use of external inputs currently remains an economically viable option for farmers. However, population increase in the area and government restrictions on deforestation reduce the availability of land for shifting cultivation. As a result, the duration of the fallow period is becoming shorter, which eventually will make this type of farming unsustainable (Le and Ha, 2008).

It also became apparent through our economic analysis that the use of high doses of fertilizers alone within current farming practice is not economically viable. If higher use of fertilizer was adopted as part of a more comprehensive change in cultivation including use of hybrid varieties and high density planting, then yield increases of three to four times current levels may be possible, justifying higher investments and resulting in increased income for farmers. However, under the current socioeconomic conditions in Sin Ho district, a high level of production intensification is not possible because farmers have neither finances nor labor available to apply high doses of fertilizer, nor the technical knowledge to implement intensive cultivation. However, as yields further decline in existing production systems, the necessity for change will become more urgent. As our results suggest, the production system based on use of mulch, reduced tillage, and moderate use of fertilizers, will soon become a more acceptable option for farmers. Our results also show that the new generation of young farmers, in their late teens are much better educated, literate and fluent in Vietnamese, providing a human resources base that can take up new farming practices and introduce a sustainable system in their communities.

In Na Ot, farmers are connected to the market through local collectors and use low amounts of fertilizers in their fields, resulting in moderate yields and profitability of their crops. Under such circumstances, application of high amounts of fertilizer on experimental fields did not result in proportional increases of income and led to lower profitability of production in the experimental treatment that had cultivation practices similar to farmer practices. It can be concluded that increased investment in only one production component, in this case fertilizers, does not result in increased profitability if other factors in the cultivation system remain unchanged. It can also be concluded that the increase in maize production attributed to the use of mulch and cultivation on mini-terraces was not proportional to the increase in labor input. This means that even though profit increased, profit expressed per day of work in the experiment was lower than in farmers' fields. Adoption of more sustainable production systems is not limited by lower profit per working day, rather the limiting factor is lack of available labor. In these circumstances, reduced tillage with use of mulch is the most viable option for sustainable production, providing that low inputs production of organic material for mulch can be developed. Results of the diagnostic study showed that farmers, based on their own experiences, have awareness about the effects of deforestation on water shortage through more rapid runoff, and therefore have restricted cultivation on steep slopes. They have also started the process of reforestation on land previously used for maize production. These results indicate that farmers do change their practices when they are convinced that current practices are unsustainable and when solutions to the problem are achievable within their limited resources.

In Ban Bo, farmers are well connected to markets and they have the financial means for intensive production. Consequently, they use hybrid maize varieties and significant amounts of fertilizer but without substantial increases in yield (4 T/ha in comparison to 3.5T in Na Ot), resulting in only moderate profitability of their crops. In these circumstances,, more frequent use of smaller quantities of nitrogen fertilizers, mulching, and pest and disease management significantly improved production in experimental fields and increased profits of farmers involved in the project. The socioeconomic realities of Ban Bo farmers enables them to search for ways to intensify their production on fields located on gentle slopes (up to 15^0) by producing two crops instead of one crop per year. Two crops are possible with earlier sowing of maize hybrid varieties with a shorter growth duration, better use of fertilizers and use of mulch.

Our results showed that in each of these three communities there is both the need for change and the human capacity for that change. However, the new sustainable farming system should be different in each community and the approach to and speed of the change will need to be different too. The simple approach of introducing better varieties and increasing fertilizer use, which was successful in the lowlands (Thanh et al., 2004), has very limited potential to improve production in the mountainous areas (Le and Ha, 2008). A more complex system (Hoa et al., 2008), that based on our results includes reduced tillage and mulching with inputs tailored (from low to high) in accordance to community socio-economic realities, is necessary. The government needs to organize financial assistance in the form of small household loans, and provide information and technical services through the extension network. However, improvement of the extension service capacity is necessary to effectively facilitate the participatory processes required to enable farmers to make gradual changes towards sustainable production in such a diverse and complex socio-economic and environmental context.

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Table 1: Details of experimental locations and experimental treatments

Village	**Ta Ngao**	**Na Ot**	**Ban Bo**
District	Sin Ho	Mai Son	Tam Duong
Province	Lai Chau	Son La	Lai Chau
Nearest town (distance from village)	Sin Ho (21 km)	Mai Son (37 km)	Sin Ho (12 km)
Distance to provincial capital	85 km	57 km	42 km
Distance and direction from Hanoi	650 km NW	300 km NW	530 km NW
Location (Latitude and Longitude)	22 ^{o} 17’ 36” N, 103^{o} 15’ 22” E	21^{0} 03’ 50” N, 103^{o} 59’ 56” E	22^{0} 17’ 04” N, 103^{o} 40’ 33” E
Elevation	1519 m	730 m	600 m
Experimental design	Semi-replicated	Randomized complete block with 3 treatments and 3 replicates	Randomized complete block with 2 treatments and 3 replicates
Treatments	• Mini-terrace + mulch • Mini-terrace	• Burning of organic material and plowing • Minimum tillage and mulch • Mini-terrace and mulch	• Burning of organic material and plowing • Burning of organic material, plowing and intercropping with legumes
Maize variety	Local unknown	LVN99	KK154
Date of sowing and 1st fertilizer application	14 April	18 April	12 April
Date of 2nd fertilizer application	30 April	28 April	30 April
Date of 3rd (and 4th) fertilizer application	28 May	31 May (10 June)	15 May
Date of harvest	30 August	15 August	1 August

Table 3: Yield of maize in Ta Ngao, Na Ot and Ban Bo.

	Yield (T/ha)		
	Ta Ngao[1, 2]	Na Ot[1, 2]	Ban Bo[1, 2]
Mini-terrace + Mulch	6.29 **a** (0.24)	5.40 **a** (0.09)	n/a
Mini-terrace	5.19 **a** (0.18)	n/a	n/a
Minimum tillage + Mulch	n/a	5.10 **a** (0.18)	n/a
Burn + tillage	n/a	4.44 **b** (0.12)	6.42 **b** (0.13)
Life mulch (legume intercrop)	n/a	n/a	6.91 **a** (0.20)
Farmers field surrounding the experiment	2.5	3.5	4.0

[1]Values are treatment means with standard error of mean shown in brackets.
[2]Treatments follow by the same letter do not differ significantly ($P \leq 0.05$)

Table 4: Economic analysis of maize production at Ta Ngao

	Value of unit (dong)	Unit	Amount per hectare			Value ('000 dong) per hectare		
			Farmer	*MT+ Mulch*	*MT*	*Farmer*	*MT+Mulch*	*MT*
Variety (local)	Not known	kg	12	17	17		0	0
Biofertilizer Song Gianh	2,700	kg	0	1,000	1,000	0	2,700	2,700
Urea	6,800	kg	0	330	330	0	2,244	2,244
NPK (5:10:3)	3,700	kg	0	500	500	0	1,850	1,850
Phosphate	3,000	kg	0	500	500	0	1,500	1,500
Kaliclorua	14,000	kg	0	240	240	0	3,360	3,360
Pesticide			0	0	0	0	0	0
Labour		day	65	100	90			
INPUT COST						0	11,654	11,654
INCOME	4,500	kg	2,500	6,290	5,187	11,250	28,305	23,342
PROFIT		dong				11,250	16,651	11,688
PROFIT/ LABOR DAY		Dong /day				173.077	166.510	129.866

Table 5: Estimate of labor input per hectare in Ta Ngao

Operation	**Mini-Terraces + Mulch**	**Mini-Terraces**	**Farmer practice**
Slashing organic material	14	14	14
Plowing the whole field	0	0	12
Cultivating to make a row	12	12	4
Sowing + fertilizing at sowing	21	21	10
Weeding and “earthing up”	10	10	10
Fertilizing	3	3	0
Mulching	10		0
Harvesting	30	30	15
Total	**100**	**90**	**65**

Table 6: Economic analysis of maize production at Na Ot

	Value of unit (dong)	Unit	Amount per hectare				Value ('000 dong) per hectare			
			Farmer	*Burn + Plow*	*MT+ Mulch*	*Mulch*	*Farmer*	*Burn + Plow*	*MT+ Mulch*	*Mulch*
Variety (LVN10)	38,000	kg	17	0	0	0	646			
Variety (LVN 99)	60,000	kg	0	17	17	17		1,020	1,020	1,020
Manure	350	kg	100	0	0	0	35			
Urea	6,800	kg	50	300	300	300	340	2,040	2,040	2,040
NPK (5:10:3)	3,300	kg	100	0	0	0	330			
Phosphate	3,100	kg	0	500	500	500		1,550	1,550	1,550
Kaliclorua	14,000	kg	0	150	150	150		2,100	2,100	2,100
Pesticide								300	300	300
Labor		day	85.5	92	130	124				
INPUT COST							1,351	7,010	7,010	7,010
INCOME	4,000	kg	3,550	4,440	5,400	5,100	14,200	17,760	21,600	20,400
PROFIT		dong					12,850	10,750	14,590	13,390
PROFIT/ LABOR DAY		Dong /day					150.292	116.849	112.230	107.984

Table 7: Estimate of labor input per hectare in Na Ot

Operation	**Mini-Terraces + Mulch**	**Mulch**	**Burn + Till**	**Farmer practice**
Slashing organic material	14	14	14	14
Plowing the whole field	0	0	15	15
Cultivating to make a row	12	6	4	4
Sowing + fertilizing at sowing	21	21	21	21
Weeding and “earthing up”	10	10	10	10
Fertilizing	3	3	3	1.5
Mulching	10	10	0	0
Harvesting	30	30	25	20
Bringing mulch material from outside	30	30	0	0
Total	**130**	**124**	**92**	**85.5**

Table 8: Economic analysis of maize production at Ban Bo

	Value of unit (dong)	Unit	Amount per hectare			Value ('000 dong) per hectare		
			Farmer	*Burn + Plow*	*Intercrop*	*Farmer*	*Burn + Plow*	*Intercrop*
Variety (KP154)	55,000	kg	17	17	17	935	935	935
Biofertilizer Song Gianh	2,700	kg	0	1,000	1,000	0	2,700	2,700
Urea	7,600	kg	400	330	330	3,040	2,508	2,508
NPK (5:10:3)	3,300	kg	500	500	500	1,650	1,650	1,650
Phosphate	3,100	kg	0	500	500	0	1,550	1,550
Kaliclorua	14,000	kg	0	240	240	0	3,360	3,360
Pesticide							600	600
Labour		day	84	95	100			
INPUT COST						4,690	13,303	13,303
INCOME	4,500	kg	4,000	6,420	6,910	18,000	28,890	31,095
PROFIT		dong				13,310	15,587	17,792
PROFIT/ LABOR DAY		Dong /day				158.452	164.074	177.920