THE DEVELOPMENT OF SUSTAINABLE CROPPING SYSTEMS IN THE HIGHLANDS OF SOUTH-EAST ASIA: GENERAL LESSONS FOR DEVELOPMENT PROJECTS

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Abstract. Soil conservation in the highlands of South-East Asia is essential for sustainable agro-environmental development. The effectiveness of soil conservation treatments developed in runoff plots was investigated in farmer-managed plots on a natural catchment. This was achieved by the development and scientific evaluation of modified and novel cropping practices in a representative highland catchment in Yunnan Province, China. Wang Jia Catchment covers 40.1 hectares near Kedu, in Xundian County, north-east Yunnan (25^o28'N, 102^o53'E). The initial project consisted of an evaluation of the effects of modified cropping practices on maize productivity and soil properties. This programme was extended to investigate ways of increasing the productivity of maize, wheat and soybean on fragile slopes in a sustainable and environmentally-friendly way. The approach incorporates modified and novel agronomic and soil conservation measures, with the evaluation of their agricultural, environmental and socio-economic impacts using multidisciplinary approaches. This European Union funded project involved an international research team from Belgium, China, Ireland, Thailand and the U.K. Five co-ordinated work packages were implemented. Involving: (1) Background agricultural and environmental assessment of Wang Jia Catchment. (2) Implementation and evaluation of modified and novel cropping systems for wheat, maize and soybean in the catchment. (3) Cost-benefit analyses of the socio-economic impacts of the changed cropping practices. (4) Comparative scientific evaluation of the cropping techniques in the highlands of northern Thailand. (5) Dissemination of project outcomes and establishment of training programmes for best practice in highland rural development. The lessons of the Project for promoting sustainable agro-environmental development in tropical and subtropical highlands include: (1) Recognizing the importance of both 'north-south' and 'south-south' co-operation in development projects, (2) Integrating local people as full partners in the research programme, (3) Matching the different 'time horizons' of the different stakeholders and (4) Developing multidisciplinary teams, including biophysical scientists and

socio-economists.

Key words: China, mulch, sustainability, Thailand, Yunnan.

INTRODUCTION

Agro-environmental systems in the highlands of South-East Asia are under considerable pressure. Crop yields on sloping land in South China have decreased due to soil erosion and it is possible that in 50-100 years most topsoil will have been removed (Fullen *et al.*, 1998). Rapid industrialization and urbanization, coupled to continuing demands for increased food production, are putting further pressure on land use. This is encouraging agricultural intensification and greater use of these fragile areas. More effective soil conservation is therefore essential for sustainable increases in productivity on these hillslopes.

The outlined project is an integrated and holistic attempt to increase the productivity and sustainability of cropping systems in the highlands of South-East Asia by the **SHASEA** (Sustainable Highland Agriculture in South-East Asia) Research Team. It involves the participation of scientists from many different disciplines (agriculture, biology, economics, geology, hydrology and soil science), from different West European and Asian countries, working alongside local farmers and their families in South-East Asia. Attention has particularly focused on the effects of cultivation and conservation treatments on crop productivity and soil erosion rates on the subtropical arable red soils of the Upper Yangtze basin in the Central Plateau of Yunnan Province, China.

AN INTEGRATED STUDY OF WANG JIA CATCHMENT: PHASE 1

To contribute to the development of appropriate soil conservation strategies, a runoff plot study at Yunnan Agricultural University (YAU; Lat. 25°08'N, Long. 102°45'E, elevation 1930 m) evaluated the effectiveness of various soil conservation measures. Various cropping treatments were applied to maize (*Zea mays*) grown in 30 erosion plots at three different slope angles. A treatment programme has been maintained for each cropping season since 1993. Throughout each season, measurements were taken of runoff and erosion rates, crop yield and yield components and soil thermal and hydrological regimes. Results strongly suggest the benefits of straw mulch and contour cultivation in conserving soil, water and nutrients (Fullen *et al.*, 1997, 1999; Barton 1999; Milne, 2001; Milne *et al.*, 2004; AN Tongxin, 2002).

The team recognized that further progress required full evaluation of the applicability of techniques developed in plot studies to actual field conditions. The research team achieved this by the development and scientific evaluation of modified and novel cropping practices in a representative highland catchment in north-east Yunnan, 60 km north-east from Kunming. The selected catchment, Wang Jia (25°28'N, 102°53'E) covers 40.1 hectares near Kedu, in Xundian County and serves as a teaching, research and extension facility. The catchment has an altitude of 2044-2191 m and has 27.3 ha of sloping cultivated land, 1.1 ha of sweet chestnut trees, 0.4 ha of rocky land, 9.5 ha of forest trees and 1.8 ha of barren hills.

Phase 1 of the Wang Jia Project consisted of an evaluation of the effects of modified cropping practices on maize productivity and soil properties. In 1998, 15 plots were established in a randomized block design, with five treatments and three replicates. The plots were planted with maize and the treatments were: (1) traditional cultivation + downslope planting; (2) traditional cultivation + contour planting, (3) traditional cultivation + contour cultivation + straw mulch, (4) minimum tillage + contour cultivation + straw mulch and (5) traditional cultivation + contour cultivation + polythene mulch. Results in 1998 and 1999 confirm significantly higher maize productivity on areas covered by plastic mulch (HUANG Bizhi, 2001).

THE WANG JIA STUDY: PHASE 2

Phase 1 of the Project provided invaluable preparatory data for Phase 2. It was imperative that the full socio-economic implications of changed cropping strategies were assessed. Preliminary cost-benefit analysis of plot data suggested that increased crop yields could increase farm incomes by ~10% per year ($180 per hectare) and thus provide a significant stimulus to the rural economy. There is a strong need to evaluate the effectiveness of any suggested soil conservation strategy within the appropriate socio-economic context. Therefore, Phase 2 aimed to increase the productivity of wheat, maize and soybean grown on hillslopes in sustainable and environmentally-friendly ways. These twin goals of increased productivity and sustainability were achieved by the development and scientific evaluation of modified and novel cropping practices. Full environmental and socio-economic assessments of these developments were also carried out, covering physical, chemical and ecological impacts, the conservation of natural resources, levels of inputs and losses, management of wastes, returns for stakeholders, poverty alleviation, income augmentation and rural development. The catchment is being used as an experimental area and training model for sustainable agricultural development in the South China highlands.

A project team was assembled to provide multidisciplinary analyses of the complex agro-environmental problems. The **SHASEA** team consists of scientists from Belgium, China, Ireland, Thailand and the U.K. Results from the plot studies have been used to develop and test novel cropping techniques. This on-going programme has established experiencing-sharing links with the local community (farmers, villagers and township officials), which was crucial to incorporating *'end users'* in the research programme and to *'bottom-up'* development. The participative research strategy, with the sharing of experience between European and Asian partners, facilitated a holistic approach, which is essential to the long-term success of this programme. The Project aimed to disseminate information to the international research community, regional training agencies, local agricultural and conservation services and village communities. The team believes the interchange of research information between China and Thailand will be beneficial for sustainable development in the highlands of South-East Asia.

Five co-ordinated work packages were implemented: (1) Background agricultural and environmental assessment of the highland catchment. (2) Implementation and evaluation of modified and novel cropping systems for wheat, maize and soybean in the catchment. (3) Evaluation of the socio-economic impact of the changed cropping practices. (4) Comparative scientific evaluation of the cropping techniques in the highlands of northern Thailand. (5) Dissemination of project outcomes and establishment of training programmes for best practice in highland rural development.

Work Package 1 (Agricultural and Environmental Assessment of Wang Jia Catchment) was co-ordinated by Gembloux Agricultural University (Belgium) and particularly focused on catchment geomorphopedology. The research support infrastructure included an integrated irrigation system, catchment flume, upgraded access road, Delta-T Weather Station and gully check dams. A land management plan was designed and implemented, in consultation with local farmers. This included afforestation of upper areas with pine, prickly ash and sweet chestnut trees, while arable cultivation was concentrated on the gentler slopes of the mid-catchment. A total of 11,037 sweet chestnut seedlings, 4,076 prickly ash seedlings and 24,150 pine seedlings were transplanted into forest gaps in August 2000. Irrigation facilitated a good wheat crop during the dry winter season and assisted early spring growth of maize, thus encouraging the rapid development of crop cover, which protects the soil from erosive monsoon rains.

The main results achieved included the improvement of the existing topographic map to produce a digitized catchment map, georeferenced in the UTM projection system, which is the base document for all thematic maps produced, such as the land use and plantation maps. The representativeness of Wang Jia Catchment was evaluated by comparing its geomorphological and land use characteristics with those of the whole mountainside south of Kelang village, in which it is included. The comparison between hypsometric curves, slope classes, SPOT satellite image interpretation (coloured image composition, image classification, vegetation index) showed that Wang Jia is indeed representative of the Kelang mountainous area. A detailed catchment land use map was built up from observation by field survey and aerial photographs. Lithological and geomorphological surveys were also carried out, including catchment geology and geomorphology. This included an assessment of erosion and an investigation of soil physical properties, especially water availability for plants. Soil identification and soil fertility evaluation allowed a synthesis in the form of a catchment geomorphopedological sketch map and associated table legend. Reference plots ensured a link with socio-economic data gained at the farm level in Work Package 3.

A digitized 1:50,000 topographic map was prepared and in 2000, new field observations led to improved map accuracy. A land cover map was prepared using a multispectral SPOT 4 image. A map of potential runoff was calculated according the method of the U.S. Natural Resources Conservation Service. These maps were also used to produce maps showing plant water availability. Erosion features were identified in the field and located on the topographic map. An assessment of sheet erosion, based on the Universal Soil Loss Equation, shows that sheet erosion is unacceptably high. A quantitative evaluation of the effectiveness of soil conservation practices was conducted on three representative slopes.

The study shows that, due to erosion on convex and steep linear slopes and to accumulation in concave positions, soils are young and show strong evidence of rock heritage. This is indicated by the dominant illite/chlorite clay mineral assemblage, a silty texture and a yellowish brown colour in soils on slopes where sandstone and shale outcrops. Many of the soils have a reddish hue, however, often reflecting the influence of carbonate parent rock. From upstream to downstream and from top- to downslope, the colluvial mixing increases, the texture becomes finer, the soil colour darker (except in the catchment outlet) and soil pH increases. This has a direct impact on relatively high soil potentialities, plot fertility ranging from dystric (low fertility status) to eutric (high fertility status).

Mineralogical analyses of the Wang Jia soils identified the influence of three main lithologies, namely shale, sandstone and dolomitic limestone/dolomite (dolostone). Shale outcrops in the northern and eastern part of the catchment and are locally interbedded in the dolomitic limestone in the mid-catchment and with thin beds of sandstone. Sandstones outcrop mainly in the southern and uppermost part of the catchment. Fifty four soil samples, representing 19 soil profiles from the catchment and different landscape units were analysed for pH (H_2O and $CaCl_2$), exchangeable H, Al, Mn and Fe, exchangeable bases (Ca, Na, K and Mg), total C and total N. From these data, the soil cation exchange capacity, % base saturation, % H+ saturation and C/N ratios were calculated. In many parts of the catchment, soil pH was relatively high, often approaching or even exceeding 7, and had full base saturation. The most acidic soils were found mainly in the upper catchment. Six benchmark soil profiles were also sampled from the various landscape units of the catchment. Profiles 1 and 2 were sampled from the upper catchment. Both soils are of a yellowish brown colour and tend to be acidic in reaction towards the surface, with a pH of <5.5 and base saturation of <50%. They were classed as Inceptisols (Dystropepts) and from the mineralogical data it was concluded that they showed little evidence of intensive weathering. Profiles 3, 4 and 5 occurred mainly in the intermediate sector of the catchment. The soils are now more reddish in colour and have a higher pH with higher levels of base saturation, depending on the nature of the parent material. Profile 6 occurs in the lower catchment, near the outlet and Kelang village. The soil is yellowish brown to yellowish orange, has a pH always >7 and is fully base saturated throughout. The clay mineralogy is identical to that of Profiles 4 and 5.

Work Package 2 (The implementation and evaluation of modified and novel cropping systems) was co-ordinated by YAU and several field experiments were established on maize and soybeans. These include:

(1) Investigation of different cultivation techniques, including use of contour cultivation, straw mulch, vetiver grass, minimum tillage, plastic mulch and a novel combination of mulching techniques and intercropping.
(2) Investigation of alternative cropping strategies, including the use of different cash crops and perennial crops, fallow areas and different rotations, leading to the development of a catchment management plan for improved productivities, increased economic return and improved sustainability (WANG Shu Hui, 2003; LI Yong Mei, 2004).

(3) Implementation of improved water conservation and irrigation management systems.

(4) Implementation of engineering measures to reduce flooding.

(5) Planting of trees (pine, sweet chestnut and prickly ash) and grass strips on steeper slopes to stabilize the soil.

Based on experience gained in field and plot studies, the team designed a composite maize cropping system to maximize both crop yield and soil and water conservation. **INCOPLAST** (Integrated Contour Cultivation, Plastic and Straw Mulch Treatment) combines contour cultivation, straw mulch and plastic mulch. In the field, irrigation water is applied prior to monsoon rains, thereby maximizing yield by early establishment of crop growth. The system is then installed, to both maximize yield (by addition of plastic mulch) and conserve soil, water and associated nutrients (by installation of contour cultivation and straw mulch) (Fig. 1). Ridge morphology is shaped to route water towards the maize roots, beneath the plastic mulch. Experiments proved that soil bulk densities beneath the plastic mulch remained low throughout the growing season, thus promoting easier root penetration, higher infiltration and lower runoff rates.

The **INCOPLAST** technique was first installed in Wang Jia in 1999 and resulted in significant increases in grain yields (WANG Shu Hui, 2003). These positive results encouraged adoption of the technique by local farmers. Crop yield increases are comparable to the significant improvement produced by plastic mulch. However, **INCOPLAST** may offer the added advantages of improved soil, moisture and nutrient conservation and it is thought that these benefits will be particularly apparent in erosive and/or drought periods. The **INCOPLAST** technique was repeated in the 2001 and 2002 cropping seasons and was applied to the runoff plots in the 2000 and 2001 cropping seasons (AN Tongxin, 2002). To enhance soil, water and nutrient retention within fields, experimental plots were bordered with grasses, including vetiver grass (*Vetiveria zizanoides*). Evaluation of the performance of the grass is still in progress but it may be noted that it is near its climatic tolerance limits and so the results will prove valuable for agro-environmental management in the uplands of South China.

Five maize cropping practices were evaluated using plot studies. These were (i) traditional cultivation with downslope planting (D); (ii) traditional cultivation with contour planting (C); (iii) traditional cultivation with double ridge contour planting and polythene mulch (C+P); (iv) traditional cultivation with double ridge contour planting, polythene mulch and straw mulch (C+P+S) (i.e. the **INCOPLAST** treatment) and (v) traditional cultivation with contour planting, polythene mulch and intercropping with soybean (C+P+IS). The main conclusions from these plot studies are summarized below and in Table 1:

1. The control treatment (D) produced maize cob yields in the range 4-7 t/ha, with a mean (three cropping seasons 1999-2001, three replicate plots) of 6.7 t/ha, which is above the average maize yield for Yunnan Province of 3.9 t/ha.
2. The contour treatment (C) produced yields in the range 5-8 t/ha, with a mean of 7.6 t/ha. In most experiments, the mean value was not significantly different from treatment D.
3. The polythene treatment (C+P) produced yields in the range 8-12 t/ha, with a mean of 9.6 t/ha. These yields were no greater than those obtained in a separate experiment for a single ridge system.
4. The addition of straw mulch between the ridges and the use of a double ridge (**INCOPLAST,** C+P+S) compared to a single ridge, as used in a separate experiment, produced no significant additional increases in yield over C+P.
5. Intercropping with soybean (C+P+IS) produced yields in the range 8-10 t/ha, with a mean of 9.3 t/ha, which was not significantly different to either treatment C+P or C+P+S.
6. In a separate experiment using a single ridge, the highest yield for C+P was 10.2 t/ha. Physical measurements suggest that the increased crop response may be partly due to higher soil temperatures and improved soil moisture retention in the early season. Pre-irrigation in advance of the onset of the rainy season, followed by mulching treatment, is particularly beneficial. This enables rapid crop development and thus high crop yields. Furthermore, rapid development of vegetative cover, especially maize canopy closure, is highly beneficial for resource (soil, water and nutrient) conservation. In a separate experiment using erosion plots, the C+P+S treatment was the most effective for soil and water conservation, producing least runoff and soil loss.
7. In terms of increasing maize productivity, the most effective treatments were C+P and C+P+S, with no apparent advantage from using double ridge or straw mulch. For soil and water conservation, C+P+S was significantly more effective than C+P, suggesting the former would achieve the best combined performance of increasing yields and improving soil and water conservation. However, it has not been possible to quantify the magnitude of these conservation benefits under the conditions existing in the catchment. The additional inputs required for C+P+S (**INCOPLAST**), in terms of straw mulch and labour to install the double ridge compared to the single ridge, could only be justified on technical

grounds if achieving improved soil and water conservation was a high priority.

8. The increased yields obtained from the use of polythene mulch, with or without straw, were maintained over four years. Therefore, the technique appears to be agronomically sustainable in the short term, but a longer period of monitoring is necessary to determine the long term effects on soil fertility and structure.
9. The relatively high maize yields obtained in this study (more than twice the yield in Yunnan Province) were achieved through the use of high levels of manure and inorganic fertilizers, with irrigation supplied when necessary to offset early season drought. Detailed cost benefit analysis is required to determine if the more labour-intensive techniques and additional inputs required are offset by the value of the increased yield.

The results from two seasons of winter wheat studies, with wheat being grown in the season between maize crops, showed that notable yields were achieved of both wheat grain and straw. This was very valuable for straw mulching needs in the summer. However, results showed that previous crop treatments had no significant influence on the crop.

Table 1. Effects of treatment on maize crop yield (mean of three years 1999-2001)

Treatment	D	C	C+P	C+P+S	C+P+IS
Yield (t/ha)	7.0	7.8	9.6	9.6	9.3
% increase	-	11.4	43.3	43.3	38.8

(D): traditional cultivation with downslope planting; (C); traditional cultivation with contour planting; (C+P) traditional cultivation with double ridge contour planting and polythene mulch (C+P+S) traditional cultivation with double ridge contour planting, polythene mulch and straw mulch (i.e. the **INCOPLAST** treatment) and (C+P+IS) traditional cultivation with contour planting, polythene mulch and intercropping with soybean.

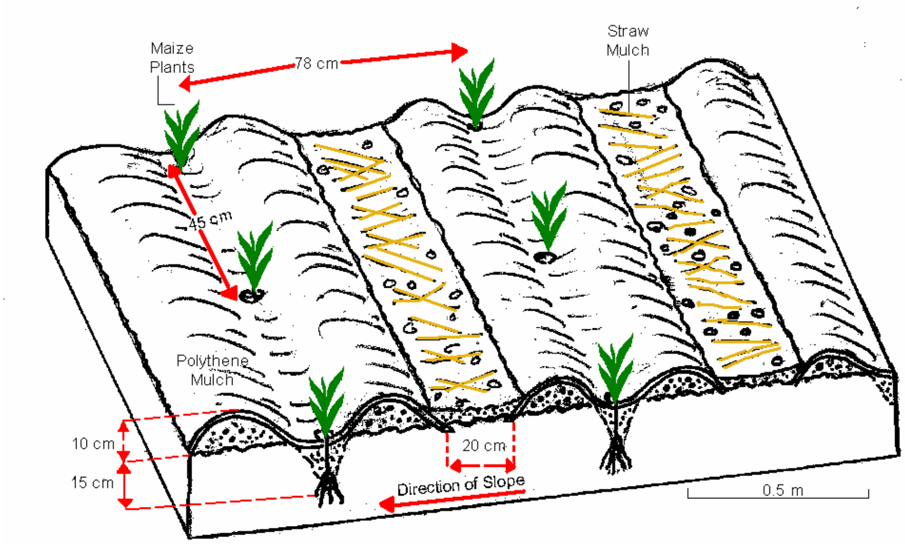

Figure 1. Sketch of the '**INCOPLAST**' (Integrated Contour Cultivation, Plastic and Straw Mulch Treatment) Technique.

EXTENDING STUDIES TO THE HIGHLANDS OF THAILAND: THE PANGMAPA STUDY

A parallel study to the Wang Jia Project scientifically evaluated the agronomic and physico-chemical impacts of improved agronomic techniques in the highlands of north-west Thailand (Panomtaranchagul *et al.*, 2001). This sub-project tested the broader applicability of the cropping practices developed at Wang Jia for other areas of South-East Asia. The experimental site is located near Jabo village, Pangmapa District, Maehongson Province (latitude 19^{o}33'47"N, longitude 98^{o}12'9"E, altitude 783 m) and consists of 12 plots each measuring 6 x 40 m (240 m^2) on slopes ranging from 30-35% (19-23^o). The soils of this experimental site are similar to those of Wang Jia in that they are developed on limestone, have a high pH and are fully base saturated.

During 1999, the **SHASEA** team designed cropping systems based on the best management practices of both Chinese and Thai agriculture. Chinese systems (ridge tillage, contour cultivation, plastic mulch and **INCOPLAST**) were modified and adapted to Thai conditions. These novel techniques were applied to 12 of the Pangmapa plots during the 2000-2002 cropping seasons. The team believes this interchange of research information between China and Thailand will be beneficial for sustainable development in the highlands of South-East Asia.

DISCUSSION

Collation of the experimental data enable several conclusions, which should assist the development of sustainable agro-environmental systems on subtropical highlands, similar in nature to those of Wang Jia Catchment. Where the priority is to increase maize yields on sloping land under conditions where the risk of soil erosion is low, contour planting with single ridge polythene mulch is recommended. Where the risk of soil erosion is higher, or rainfall is likely to be limiting early in the growing season and irrigation water is available for application prior to the application of polythene mulch, the **INCOPLAST** technique is recommended. Where this technique is used, straw must be readily available to be used as the mulching material.

In all cases, the availability of sufficient manure and, in the case of **INCOPLAST**, the availability of sufficient straw, may be major constraints. The availability of sufficient water for early season irrigation will also be a constraint when rainfall in May and June is considerably below average.

The soil and water conservation benefits of polythene mulch/intercropping with soybean have not been evaluated in this study but, if the effects are similar to those of **INCOPLAST**, this practice may be recommended where soybean production is important, without significant reduction in maize yield. However, soybean yield is less reliable than that of maize.

It has been demonstrated that the productivity of maize can be increased, by up to 50% compared to traditional methods, on sloping fragile land, using simple cost-effective technologies, which in parallel plot studies have been shown to improve soil and water conservation. A detailed scientific evaluation has been carried out in Wang Jia Catchment to quantify the effectiveness of these technologies and develop explanations of how the crop responses have been produced.

Improvements in maize cropping practices have been linked to a land management plan to develop a more sustainable agricultural system in Wang Jia Catchment. This plan has included a range of engineering measures to control erosion, the installation of an irrigation system to improve the level and reliability of crop yield, including maize and winter wheat, the planting of trees as cash crops (sweet chestnut and prickly ash) on the steeper slopes, the planting of pine on parts of the upper catchment to return that land to forestry and the development of a monitoring system to evaluate the effectiveness of these measures over the longer term.

The land management plan has been based on a comprehensive survey and description of the biophysical characteristics of the catchment, which has provided a baseline for subsequent change and established the representativity of the catchment in relation to the surrounding area. The catchment has been shown to be representative of the mountainside where it occurs, and the soils at the different sites to be representative of red soils dominated by the influence of limestone and strongly affected by contributions from material further upslope. Such areas are extensive in the highlands of Yunnan Province. The description and analysis of the site is ongoing, as changes to the catchment proceed, and will be developed into a GIS-based land management and evaluation system for subtropical highland catchments, such as Wang Jia.

There are several lessons of the Project for promoting sustainable agro-environmental development in tropical and subtropical highlands, including:

1. Recognizing the importance of both ‘north-south’ and ‘south-south’ co-operation in development projects. A particularly important aspect of the **SHASEA** Project was Chinese-Thai collaboration in developing viable solutions for agro-environmental problems in the highlands of South-East Asia.
2. Integrating local stakeholders as full partners in the research programme. This should include genuine consultation and feedback of research information and stakeholders need to see tangible benefits from the Project.
3. The research needs to address the problem of ‘time horizons’. Farmers usually have short time horizons, while government policy tends to be much longer term (five years plus). Matching these different aspirations poses many challenges to the development of appropriate agro-environmental policies.
4. Multidisciplinary teams must be developed, including biophysical scientists and socio-economists. This can be challenging, due to the different approaches of the disciplines and this necessitates regular dialogue and exchange of research information.

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