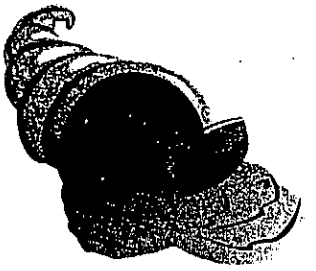

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Improving crop productivity and agro-environmental sustainability on fragile slopes in the highlands of South China and Thailand

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ABSTRACT

The effectiveness of soil conservation treatments developed in research plots on controlled slopes is being investigated in farmer-managed plots in a natural catchment. This is being achieved by the development and scientific evaluation of modified and novel cropping practices in a representative highland catchment in Yunnan Province, China. The selected catchment, Wang Jia (25° 28' N, 102° 53' E) covers 57.2 hectares near Kedu, in Xundian County, north-east Yunnan. The initial project consists of an evaluation of the effects of modified cropping practices on corn productivity and soil properties. This programme has now been extended to investigate ways of increasing the productivity of corn, wheat and soybean on fragile slopes in a sustainable and environmentally-friendly way. The approach incorporates modified and novel agronomic and soil conservation measures, to evaluate the agricultural, environmental and socio-economic impacts of these measures using multi-disciplinary approaches. This European Union funded project involves a collaborative research team from Belgium, China, Ireland, Thailand and the U.K. Evaluated effects include physical, chemical and ecological impacts, the conservation of natural resources, management of wastes, returns for stakeholders, poverty alle-

viation, income augmentation and rural development. This holistic approach has not been attempted previously in the region. The catchment is being used as an experimental area and training model for sustainable agricultural development in the South China highlands. A parallel study, restricted to scientific evaluation of agronomic and physico-chemical impacts, is being carried out in plot studies at Pangmapa, in the highlands of north Thailand, testing the broader applicability of the cropping practices being developed for South-East Asia. Five co-ordinated work packages are being implemented: (1) Background agricultural and environmental assessment of Wang Jia Catchment. (2) Implementation and evaluation of modified and novel cropping systems for wheat, corn 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. This project aims to inform the international research community, regional training agencies, local agricultural and conservation services and village communities.

Key Words: China, contour cultivation, plastic mulch, straw mulch, Thailand, Ultisols, Yunnan

INTRODUCTION

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.

The project commenced in 1990 and has developed in several identified phases. Attention has particularly focused on the effects of cultivation and conservation treatments on crop productivity and soil erosion rates on the subtropical arable Ultisols of the Upper Yangtze basin in the Central Plateau of Yunnan Province, China. Practical outcomes from the project include scientific validation of agricultural techniques which can promote greater crop yield, while conserving soil and water resources. These include mulching methods using both straw and plastic and contour cultivation techniques. These have been integrated into a novel design, called *INCOPLAST (Integrated Contour Cultivation, Plastic and Straw Mulch Treatment)*, which improves corn yield and conserves soil and water resources.

First Phase of the Project: Field Surveys

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 ero-

sion and there is the risk that in 50-100 years most topsoil will have been removed (Fullen *et al.*, 1998). Indiscriminate agricultural intensification is accelerating this degradation of a vital natural resource. Rapid industrialisation and urbanisation, coupled to continuing demands for increased food production, is putting further pressure on land use and is forcing greater use of these fragile areas.

Moreover, an estimated average of 2400 million tonnes of sediment are eroded from the Yangtze basin each year (Wen, 1993) and these high rates are of increasing concern, especially considering the potential impact on the Three Gorges (*Sanxia)* Dam in the middle section. Sedimentation within the proposed reservoir could impair its efficiency. Hence, soil conservation must be an integral component of the management of the Upper Yangtze basin. More effective soil conservation is therefore essential for sustainable increases in productivity on hill slopes.

Field studies facilitated assessments of the scale and severity of these agro-environmental problems. Commencing in 1990, field surveys were carried out in diverse environments within Yunnan Province, both in cool montane environments of the upper Yangtze basin (Dongchuan and Huize Counties) and arable subtropical uplands (Kunming district, Chenggong, Lunan, Xundian, Yiliang and Yuanmou Counties). These included the sub-Himalayan system of North Yunnan, the agricultural Central Plateau and especially problematic erosion areas, such as Tu Lin. These surveys led to practical suggestions for integrated multidisciplinary assessments of agro-environmental problems (Fullen *et al.*, 1996, 1997, 1998, 1999; Barton *et al.*, 1998).

The Yunnan Agricultural University Erosion Plot Study (1993-96)

To contribute to the development of appropriate soil conservation strategies, a runoff plot study at Yunnan Agricultural University University (Lat. 25° 08' N, Long. 102° 45'E, elevation 1930 m) is evaluating the effectiveness of various soil conservation measures. Cropping treatments, typically employed in local agronomic practices, were applied to corn (*Zea mays*) grown in 30 erosion plots at three different slope angles, cultivated both parallel and perpendicular to the contour, thus simulating a range of agricultural conditions on arable slopes (Fig. 1).

These treatments were maintained for each cropping season from 1993 to 1996. Integrated measurements were taken throughout each season of runoff and erosion rates, crop yield and yield components and soil thermal and hydrological regimes.

Plot data from the 1993-96 cropping seasons (May to October) suggest several suitable soil conservation measures. The average rank order of treatment effectiveness in diminishing erosion rates was: 1) straw mulch, 2) intercropping, 3) no tillage, 4) polythene mulch and 5) conventional tillage. The mean erosion rate on the straw mulch plots was 22% of the mean conventional tillage rate (Table 1). Erosion rates were generally lower on plots where contour cultivation was used (Table 2). The mean contour cultivation erosion rate was 69% of the mean downslope-oriented rate. Therefore, straw mulch and contour cultivation seem particularly suitable soil conservation measures (Barton 1999, Fullen *et al.*, 1998, 1999).

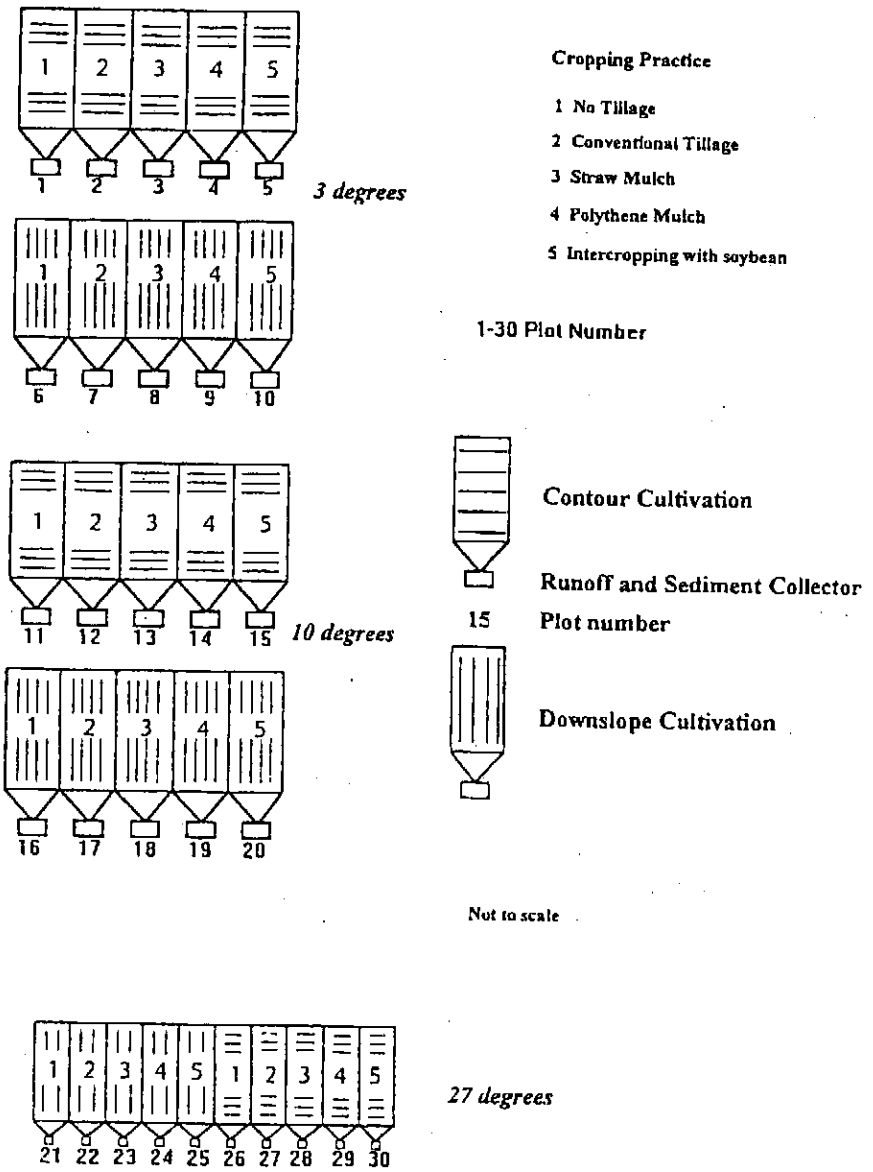

Fig. 1. Plan of the Kunming runoff plots (1993-96)

Table 1. Rainfall and erosion rates on the Kunming plots for the 1993, 1994, 1995 and 1996 cropping seasons

Rainfall/ erosion rate	*1993*	*1994*	*1995*	*1996*	*Mean*
Seasonal rainfall (mm)	576.3	768.3	817.8	619.7	695.5
Intercropping (t ha^{-1})	0.70	3.24	7.65	0.04	2.91
Polythene mulch (t ha^{-1})	0.83	6.98	8.72	0.07	4.15
Straw mulch (t ha^{-1})	0.59	1.36	1.66	0.02	0.91
Conventional tillage (t ha^{-1})	0.73	4.02	11.81	0.07	4.16
No tillage (t ha^{-1})	0.78	4.39	7.95	0.02	3.29
TOTAL (t ha^{-1})	3.63	19.99	37.79	0.22	

Notes: Reported plot values are the means of six individual plots. Cropping season dates May 20-November 2 1993, May 18-October 3 1994, May 18-September 21 1995 and May 18-September 23 1996.

Table 2. Effect of slope and direction of cropping on mean (mean of 1993, 1994, 1995 and 1996) erosion rates (t ha^{-1})

	Surface Treatment					
	Intercropping	*Polythene Mulch*	*Straw Mulch*	*Convent. Tillage*	*No Tillage*	*TOTAL*
Contour cultivation						
3 Degrees	0.68	0.75	0.44	0.96	0.68	3.51
10 Degrees	1.37	2.44	0.94	3.95	3.32	12.02
27 Degrees	3.77	7.15	1.22	4.29	5.93	22.36
Downslope cultivation						
3 Degrees	0.98	2.26	0.47	0.70	0.78	5.19
10 Degrees	4.47	4.71	0.86	4.39	2.74	17.17
27 Degrees	6.18	7.57	1.51	10.67	6.26	32.19

The Yunnan Agricultural University Erosion Plot Study (1997-2000)

The current erosion plot research programme is a replicated study of the most effective treatments (straw mulch and contour cultivation), using conventional cultivation as the control (Fig. 2). To quantify potential erosion rates there are three bare soil plots, one in each block of 10 plots. Data from 1997, 1998 and 1999 seasons confirm that straw mulch and contour cultivation significantly decrease soil erosion rates. The data suggest possible additive benefits of using contour cultivation and straw mulch together (Table 3).

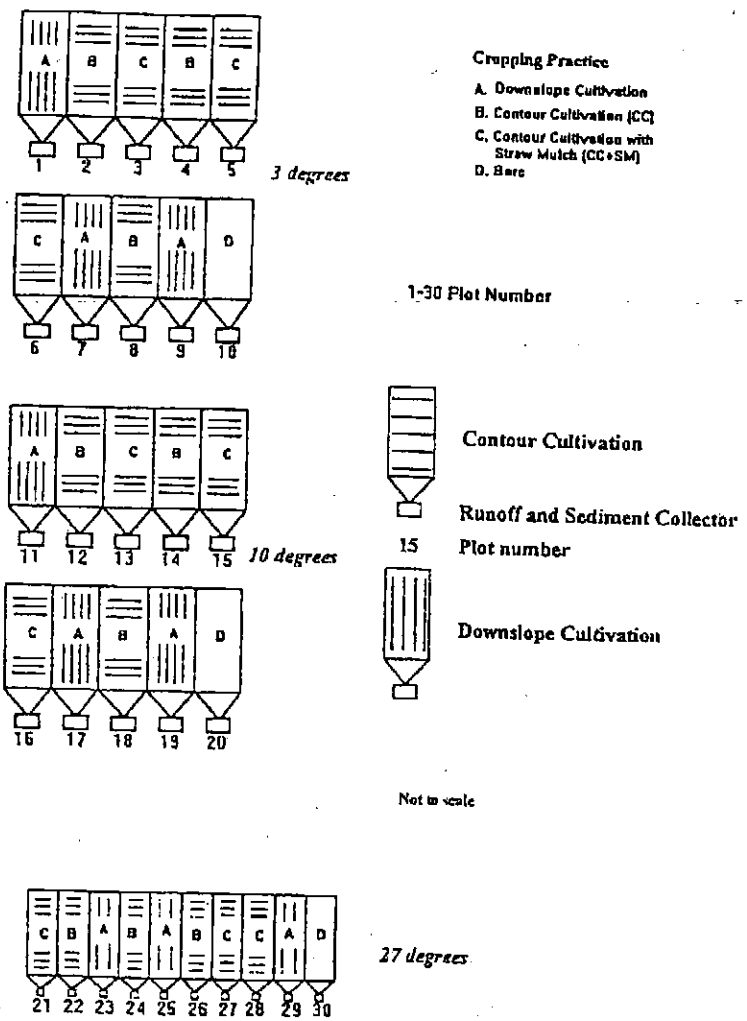

Fig. 2. Plan of the Kunming runoff plots (1997-99)

Table 3. Erosion rates (t ha^{-1}) on the Kunming plots for the 1998 cropping season

Treatment	*Slope I (3.°)*	*Slope II (10.°)*	*Slope III (27.°)*
Down slope	3.07 * 0.80	19.11 * 2.69	6.92 * 0.66
Contour	0.58 * 0.16	8.00 * 2.58	6.28 * 1.73
Contour plus straw mulch	0.21 * 0.10	3.51 * 2.24	0.04 * 0.03
Bare	21.18	79.11	43.4

Notes: Cropping season May 21 to October 7 1998. Precipitation amount 1024 mm. Mean soil loss refers to mean of three replicate plots * standard error of the mean, bare plot unreplicated

Field Studies of Soil Conservation: An Integrated Study of the Wang Jia Catchment: Phase 1

The team recognised that further progress required full evaluation of the applicability of techniques developed in plot studies to actual field conditions. The research team is achieving this by the development and scientific evaluation of modified and novel cropping practices in a representative highland catchment in north-east Yunnan. The selected catchment, Wang Jia, covers 57.2 hectares near Kedu, in Xundian County (Fig. 3) and serves as a teaching, research and extension facility.

The initial phase of the Wang Jia project consisted of an evaluation of the effects of modified cropping practices on corn productivity and soil properties. Fifteen plots were established in a randomised block design, with five treatments and three replicates, in 1998. The plots were planted with corn and the treatments were:

Traditional cultivation + downslope planting (T+D)

Traditional cultivation + contour planting (T+C)

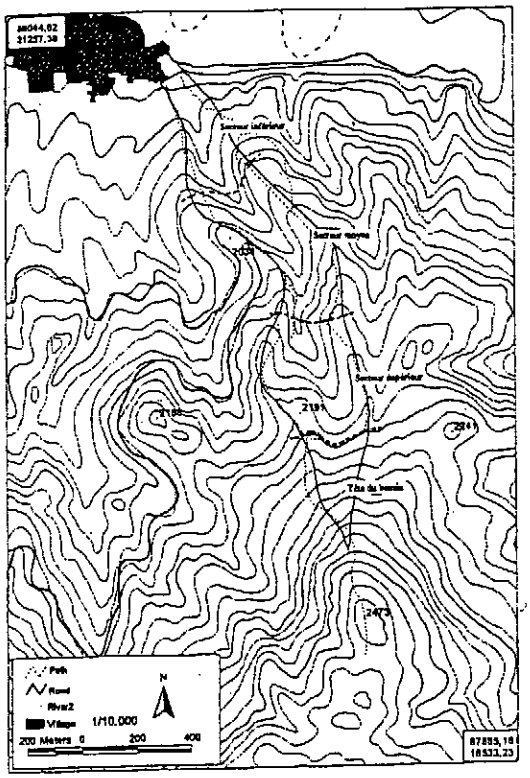

Fig. 3. Plan of the Wang Jia Catchment

Traditional cultivation + contour cultivation + straw mulch (T+C+St)
Minimum tillage + contour cultivation + straw mulch (M+C+St)
Traditional cultivation + contour cultivation + polythene mulch (T+C+P).

Corn was planted on May 20 1998 and harvested on 9 October 1998, during which time 1032 mm of rain was measured at the Wang Jia meteorological station. Results confirm significantly higher corn productivity on areas covered by plastic mulch (Table 4). Periodic measurements were made of soil bulk density, with five replicate soil samples removed from 0-10 cm depth at the beginning, middle and end of the season. The plastic mulch, by protecting the soil from raindrop impact and splash, allowed the soil to retain a lower bulk density (Table 4). The more open, porous structure will be conducive to high infiltration rates and thus low runoff rates, if precipitation is allowed to penetrate beneath the plastic, possibly at the plant pits. These measurements were repeated and corroborated during the 1999 cropping season.

Table 4. Corn productivity and soil bulk density results in the Wang Jia plots in 1998

Treatment	*Grain yield (kg/8 plants)*	*Dry weight of corn (t/ha)*	*Dry weight of corn stem (kg/ha)*	*Dry soil bulk density (g cm^{-3})*
T+D	0.602	4.38	430.7	1.30
T + C	0.680	5.08	456.7	1.35
T+C+St	0.678	4.95	499.1	1.31
M+C+St	0.669	4.91	433.6	1.36
T+C+P	0.760*	5.67*	728.8*	1.23

Notes: Values are overall mean, based on eight plant samples per plot. * denotes difference is significant at $P < 0.05$. Bulk density based on analysis of 15 soil samples per plot.

The Wang Jia study: Phase 2

Phase 1 of the project provided invaluable preparatory data for Phase 2. It is imperative that the full socio-economic implications of changed cropping strategies are assessed. Preliminary cost-benefit analysis of plot data suggest increased crop yields can 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, the next phase of the Wang Jia study aimed to increase the productivity of wheat, corn and soybean grown on hill slopes in a sustainable and environmentally friendly way. These twin goals of increased productivity and sustainability are being achieved by the development and scientific evaluation of modified and novel cropping practices.

Full environmental and socio-economic assessments of these developments are being carried out, covering physical, chemical and ecological impacts, the conservation of nat-

ural resources, levels of inputs and losses, management of wastes, returns for stakeholders, poverty alleviation, income augmentation and rural development.

This holistic approach has not been attempted previously in this region. 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 is proving 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, is facilitating the holistic approach which is essential to the long term success of this programme.

Five co-ordinated work packages are being implemented: (1) Background agricultural and environmental assessment of the highland catchment. (2) Implementation and evaluation of modified and novel cropping systems for wheat, corn 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.

Development and Initial Evaluation of the INCOPLAST Technique

Based on experience gained in field and plots studies, the team designed a composite corn cropping system to maximise both crop yield and soil and water conservation.

The 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 maximising yield by early establishment of crop growth. Then the system is installed, to both maximise yield (by addition of plastic mulch) and conserve soil, water and associated nutrients (by installation of contour cultivation and straw mulch) (Fig. 4).

Ridge morphology is shaped to route water towards the corn roots, beneath the plastic mulch. Experiments have proved that soil bulk densities beneath the plastic mulch remain low throughout the growing season, thus promoting high infiltration and lower runoff rates.

The INCOPLAST technique was first installed in Wang Jia in 1999 and resulted in a significant 48.7% increase in grain yields (Table 5). These positive results have encouraged adoption of the technique by local farmers. These results are comparable to the significant improvement produced by plastic mulch of 53.6%.

However, besides increased crop yield, INCOPLAST may offer the added advantages of improved soil, moisture and nutrient conservation. It is postulated these benefits will

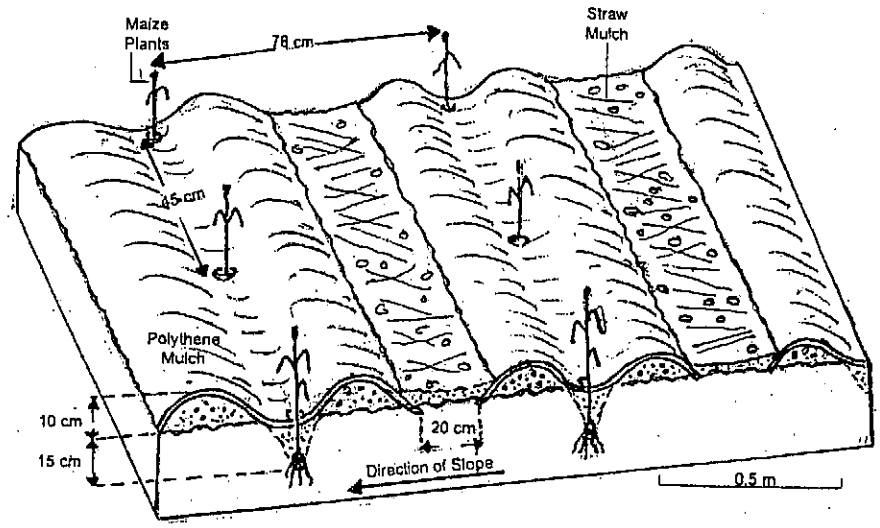

Fig. 4. Sketch of the 'INCOPLAST' *(Integrated Contour Cultivation, Plastic and Straw Mulch Treatment)* Technique

Table 5. Corn yield on plots at Wang Jia in 1999

Treatment	*Fresh cob yield (kg/plot)*	*Fresh Stem weight (kg/plot)*	*1000 grain weight (g)*	*Grain yield (kg/ha)*	*Increasing percent vs.D*
D	44.1	51.0	293.7	7263a*	0
C	47.3	53.2	312.3	8077.5a	11.2
C+P	60.3	68.5	325.3	11157b	53.6
C+P+S	61.6	74.1	312.2	10801.5b	48.7
C+P+IS	55.9	61.2	322.9	10192.5b	40.3

Notes: This experiment is situated in the middle part of the catchment. Five treatments were replicated three times; in total 15 plots were designated. Five cropping practices for corn were used as different treatments, in summer 1999: Traditional ploughing, downslope cultivation of corn, no mulch (D).

Traditional ploughing, contour cultivation of corn, no mulch (C). Traditional ploughing, contour cultivation of corn, polythene mulch (C+P). Traditional ploughing, contour cultivation of corn, wheat straw and polythene mulch (C+P+S). Traditional ploughing, contour cultivation of corn, wide and narrow spacing, polythene mulch, intercropping with soybean in wide spacing (C+P+IS).

* The same letter denotes no significant difference using Analysis of Variance (ANOVA) at $P < 0.05$.

F-ratio = 11.25.

be particularly apparent in erosive and/or drought periods. The INCOPLAST technique will be applied to the runoff plots in the 2000 cropping season.

Table 5 shows the biomass yield for the different treatments. The mulched treatments increased crop yields. The increase ranged from 40.3 to 53.6% for grain yields compared with Treatment D, which had the lowest yield. The yield of 'contour cultivation' was also low, but increased by 11.2% compared to Treatment D. For the 1000 grain weight and

fresh stem weight, the mulched treatments were more productive than non-mulched treatments. Traditional downslope cultivation was very poor, followed by traditional contour cultivation.

To enhance soil, water and nutrient retention within fields, experimental plots have been bordered with vetiver grass (*Vetiveria zizanoides*). Evaluation of the performance of the grass is in progress and yielding valuable results. As a tropical grass, vetiver grass is near its climatic tolerance limits and so the results will prove valuable for agro-environmental management in the uplands of South China.

Extending studies to the Highlands of South-East Asia: The Pangmapa Study

A parallel study to the Wang Jia project is scientifically evaluating the agronomic and physico-chemical impacts of improved agronomic techniques and is being carried out in the highlands of north-west Thailand. This sub-project is testing the broader applicability of the cropping practices being developed for South-East Asia. The experimental site is located near Jabo village, Pangmapa District, Maehongson Province (19° 33' 47" N latitude, 98° 12' 9" E longitude, altitude 783 m). The experimental site consists of 18 plots each measuring 6 x 40 m on slopes ranging from 30 to 35% (19-23 degrees). Sub-plots are divided into four sections of 10 m length down the slope and cropping treatments were established in 1999.

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) have been modified and adapted to Thai agronomic conditions. These modified and novel techniques will be applied to 12 of the Bangmapa plots during the 2000-2002 cropping seasons. The team believe this interchange of research information between China and Thailand will be beneficial for sustainable development in the highlands of South-East Asia.

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