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LOW INPUT TECHNOLOGIES FOR REHABILITATION OF DEGRADED RED SOILS IN SOUTHERN CHINA

Working paper series: no. 3

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PREFACE

In early 1992 the Agricultural Department of the Royal Tropical Institute (KIT) was selected by the Asian Development Bank (ADB) to support the planning and implementation of the "Red Soils Development" Project in Hunan Province (the People's Republic of China).

The initial aim of the Project was to establish six demonstration sites (between 10 and 15 ha each) in the rural environment, and on highly degraded uplands and slopes. At each site a range of low input technologies to protect and/or to reclaim degraded uplands were to be established.

An interdisciplinary team of national and international experts designed the plans for the various sites in close consultation with the authorities (Provincial Department of Agriculture, as well as local leaders from the respective counties, townships and villages) and the local population. As a result the scope of the Project was widened to include also production (fruit trees) aspects and more costly protection technologies, like terracing. To accommodate this range of technologies small watersheds or major parts thereof, were selected as demonstration sites.

The six sites were established during the winterseason of 1992/93; subsequently the performance of the various protection and production technologies were monitored by the Project till October 1995.

The Project had to face a number of rather unique challenges, including the introduction of low input technologies (minimising labour and material inputs) on very marginal soils and in very densely populated areas. Because of the latter factor, local organisational issues (with respect to investments, maintenance responsibilities, distribution of future revenues, etc.) were complex and had to be resolved ideally before starting field implementation. The present working paper will deal mostly with the technical aspects; a second paper with the organisational issues.

The combination of national and international experts, covering both a wide range of disciplines (technical, biological and socio-economic), as well as different perspectives on rural development has proved very beneficial to the implementation of the Project.

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LOW INPUT TECHNOLOGIES FOR REHABILITATION OF DEGRADED RED SOILS IN SOUTHERN CHINA

B. Haagsma[1)], Wang De Shen[2)], Yu Tai Wan[3)], W.A. Stoop[4)]

ABSTRACT

Agriculture in the Southern Provinces of China involves predominantly intensive and permanent, rice-based farming systems. Due to high population pressure the availability of paddy land is between 0.05 and 0.1 ha/capita. Consequently the demand for the adjacent uplands -generally unfertile red soils- is also steadily increasing. However, these uplands are often seriously degraded due to erosion, as evidenced by totally bare and gullied areas where trees have been uprooted in the past.

Under the conditions of small and fragmented farm holdings and mostly poor farmers, the implementation of land and water conservation measures on these red soil uplands is both essential and complex. Farmers are focused primarily on maximizing production through labour inputs. Their interests in implementing conservation measures tend to be limited primarily to those areas where the production of commercial crops is feasible. Large scale conservation and rehabilitation of degraded uplands will undoubtedly require additional incentives from the (local) authorities, since the production potentials of these lands are obviously very limited.

In this context a number of cheap and simple, mostly low input techniques were tested and demonstrated to rehabilitate degraded and gullied lands, and to protect other marginal uplands that are currently under tea-oil, or that can be developed as fruit tree orchards.

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TABLE OF CONTENTS

1 INTRODUCTION

The "Red Soils Development" Project in Hunan Province of the People's Republic of China started in early 1992 with funding by the Asian Development Bank (ADB, 1991). Project implementation was the responsibility of the Provincial Agricultural Department with assistance from a joint Chinese-Dutch, interdisciplinary, team of experts.

The objective of the Project was to establish six, on-farm, demonstration sites (each 10 to 15 ha). Low input technologies for the reclamation of eroded (bare and gullied) lands and for the protection of marginal uplands were to be emphasized.

During implementation the team of experts was confronted by a rather unique set of conditions, that had not been appreciated adequately at the time of Project formulation. These conditions applied to:

- **technical aspects** including a lack of knowledge and experience with low input technologies for the reclamation of seriously degraded and gullied uplands;
- **socio-economic aspects** of implementing these technologies in a densely populated rural environment, where farm holdings are very small and fragmented, and farmers are generally very poor; and
- **institutional and organizational aspects** of the implementation, which under the above socio-economic conditions become exceedingly complex.

This paper will focus on the agro-ecological conditions as encountered in the moderately sloping upland areas of Southern China, and on the technical aspects of mostly low input technologies for land reclamation and conservation. The paper describes the approaches followed in designing and developing the various technological alternatives, the performance of the technologies, and the modifications that were subsequently introduced to improve performance. A second paper (Harteveld et al.; in preparation) will deal in detail with the socio-economic and organizational issues.

2 BACKGROUND INFORMATION

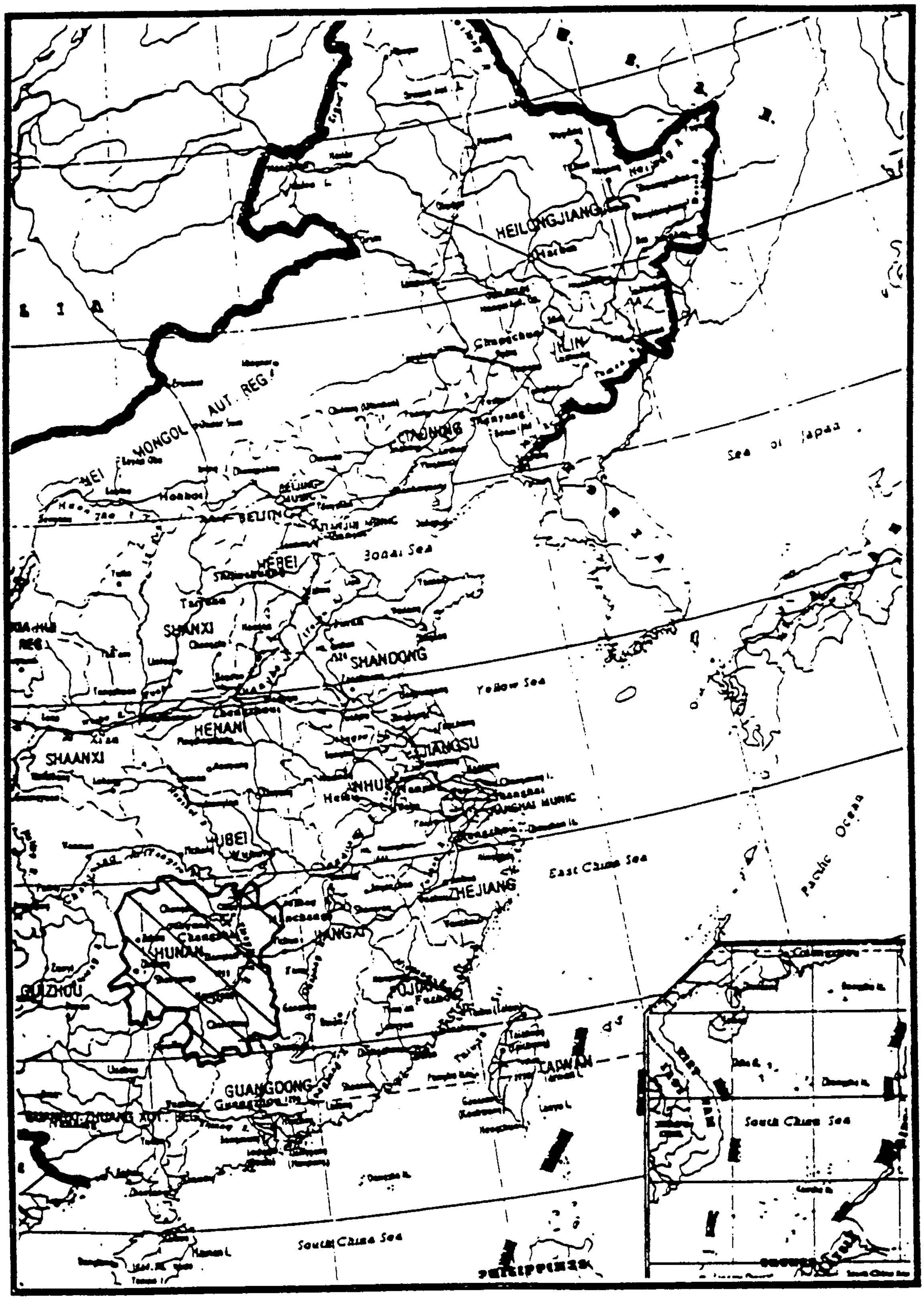
2.1 The physical environment: physiography, climate and soils

Hunan province is located in Southern China (figure 1) and consists predominantly of low to middle high mountains, which are separated by dissected basins. The altitude of the basins ranges from 50 to about 300 m. Since ancient times the basins are used for agriculture and are densely populated. The Project is located in the basin area, that is drained by a network of rivers with the Xiangjiang river as the largest.

The climate is humid subtropical with a continental northeastern monsoon during winter and a maritime southeastern monsoon, causing high temperatures and heavy rainfall during the summer. The annual rainfall ranges from about 1100 to 1500 mm; about half is concentrated in the major monsoon months April, May and June. Droughts are common in July, August and September when potential evapotranspiration is generally high and exceeds rainfall. The winters are cool with average minimum temperatures of 2°C in January, and occasionally frost periods; the summers are very hot with average maximum temperatures of 33°C. Spring and autumn are characterized by abrupt changes in temperatures. The seasonal distribution of rainfall and temperature allows the cultivation of sub-tropical and temperate crops.

The predominantly red soils of the uplands occur on rolling hills, slightly undulating terraces along the rivers and broad plain valleys. The slopes are convex with gradients from 5 to 30%. The soils are derived from the following major parent materials: shales/slates, limestone, purplish shales, red quaternary clay and sandstone. The red clay soils generally have good physical properties in terms of structure, porosity and infiltration, yet their fertility is poor. The acid soils are deficient in phosphate and exchangeable cations, but also extremely high in aluminum (see also Table 2). Where erosion has removed the topsoil a dense, strongly mottled and infertile subsoil with poor internal drainage is exposed (Kaufmann and Chen, 1992; Chen et.al., 1993)

Figure 1: Map of eastern China, including Hunan Province



2.2 Local land use and socio-economic conditions

The farming system is characterized by intensive, permanent, mixed farming, with high-yielding paddy rice as the dominant crop. Two rice crops are harvested annually with an average yield between 5 and 6,5 tons/ha/crop. On the upland fields a wide variety of crops is cultivated; during fall and spring time these may include: wheat, rapeseed and various vegetables; during the summer and fall season: soybean, cotton, watermelon, sweet potato, maize, and vegetables. Crop management standards are very high. Most crops are grown on terraced fields; the total area of rainfed crops is, however, rather limited. Fields are small and scattered, and generally located on the lower slopes or in depressions, where the moisture and soil conditions are most favourable.

Tea-oil (*Camelia olifeira*) is the major crop on the marginal upland slopes. This bush produces oilseeds that constitute an important cash crop for small farmers. Tea-oil and slashpine are the two species most adapted to the unfertile, acid red soils.

Paddy land is allocated to village households according to household size; the area per capita is about 500 m^2 only. Uplands are usually distributed among the residents of the village under the "responsibility system", which involves a formal contract; upland availability is 1000-1500 m^2/capita.

Labour is relatively abundant in relation to the available land, which leads to intensive cultivation methods and low marginal returns to labour. Off-farm employment is actively looked for during slack periods, but opportunities are limited.

2.3 Erosion: past and present

The hill tops and slopes in the densely populated basin area used to be covered with a mixed, broadleave, evergreen forest. However, at present many hills are totally degraded as a result of deforestation during the "Great Leap Forward" campaigns (1957-1960). At that time large quantities of fuelwood were required for the commune-based iron melting industries. The indiscriminate cutting of trees and serious soil disturbances caused by uprooting, in combination with the heavy monsoon summer rains, has resulted in bare, seriously gullied lands (photos 1 to 4). These eroded areas are confined mostly to the low, isolated hill tops near villages.

Photo 2: Renai Chun site in May 1992 before project interventions.

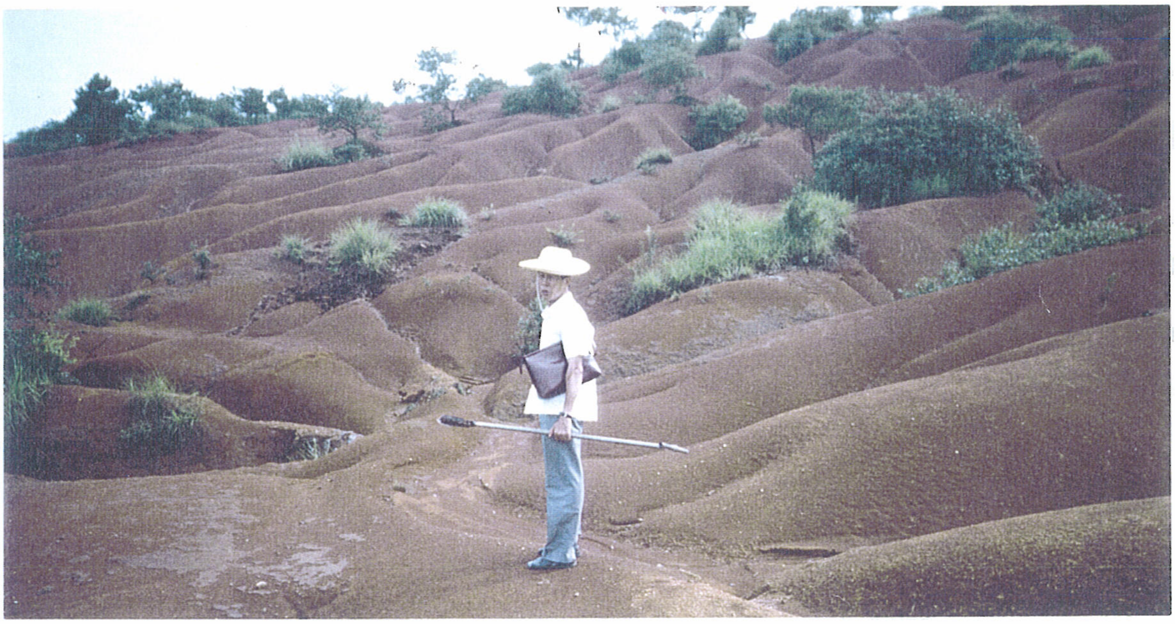


Photo 3: Daling site in May 1992 showing serious gully erosion.

Photo 4: Daling site (overview) in November 1992 before the start of project interventions; the bushes on the slopes are predominantly tea-oil.

Currently, the erosion rates are no longer very high, and most gullies have reached their maximum length of about 150 m (from the hill top to the lower slope). The maximum gully depth is 3 to 4 m, and the cross-section is regular, V-shaped. An important feature is the relative closeness of the gullies: about 100 km gully/km^2! The gullies tend to run parallel, thus reflecting the original tree planting pattern. Consequently each gully drains a small area (at most 1 ha) and the amount of run-off per gully is rather low, as evidenced by some spontaneous revegetation.

Splash erosion is the major on-going process in the bare areas; the splashed-down soil particles accumulate at the bottom of the gully after a rain storm. Next, run-off transports the soil further downslope. Because the red soils have typical, stable soil aggregates, the run-off itself does not cause much additional erosion. However, where farmers have dug diversion drains to protect their lower slopes and lowland fields, run-off concentration readily causes renewed gully erosion.

In addition there are several other local agricultural practices, that lead to bare and sealed soil surfaces, and thus generate considerable run-off and sheet erosion, which interferes with the re-establishment of vegetation. On many of the slopes planted with tea-oil and slash pine all organic materials, such as litter and grass sods, are meticulously collected by local farmers to be used as fuel or for compost preparation. Though other energy sources and chemical fertilizers are available on the market, poor farmers often cannot afford these.

For the project sites the downstream erosion damage mostly remained restricted to the lowland and lower slope fields. Here, the sediments cover the paddy fields with unfertile soil, and fill up the reservoirs and ponds. However, when sediments are carried into to the open water courses, river morphology is affected and increased flooding and siltation of major reservoirs will occur.

3 PROJECT INTERVENTIONS: APPROACHES AND METHODOLOGY

3.1 Project rationale and approach

Originally, the Project envisaged the demonstration of low cost approaches based on agroforestry and sylvopastoral techniques for the rehabilitation of degraded red soils (ADB, 1991). However, the limited availability of land, the surplus of labour and the low levels of farmer income create a powerful drive towards the intensification of upland use. Moreover, the prices for rice, the predominant crop, are low and the availability of extra irrigation water is restricted.

Farmers and local officials, therefore strongly disagreed with the initial aims of the Project, so that its scope was widened to include high and low cost alternatives for land reclamation and conservation, as well as for production. Moreover, instead of strictly demonstrating a set of predetermined (blueprint) technologies, a more flexible "process" approach was adopted, which allowed the modification and fine-tuning of the technologies in response to their field performance (KIT, 1992). As a result the Project and the participating farmers gradually gained experience with different techniques and a divers range of measures were developed, including location specific solutions as well as low and high input alternatives. This approach has contributed to major cost reductions in comparison with many of the initially proposed labour intensive, engineering measures, such as "bunds and ditches" systems and sophisticated constructions of run-off disposal systems.

The following principles were essential in successfully implementing the "process" approach:

- **a step-by-step procedure** involving regular field monitoring and evaluation
- **site-specific adaptation** of every measure, as conditions vary greatly between and within the sites, and
- **flexibility** to change designs readily as new experience and information is obtained.

In addition, the following technical guidelines for the design of soil and water conservation measures (see also CDCS, 1991) were formulated:

1. Minimal disturbance of the soil surface and the existing vegetation.
2. Adaptation to the micro-topography.
3. Stimulation of the natural vegetation by improving soil and moisture conditions.
4. Selection of plant species, adapted to the particular soil conditions (e.g. calcareous or very acid).
5. Maximizing rainfall infiltration.
6. Avoidance of run-off accumulation.

3.2 Project design: materials and methodology

Six sites representing the major soil conditions (based on the predominant soil parent materials) were selected in the basin area (see table 1). Each site was 10 to 15 ha and consisted of a watershed or part thereof, covering an area from the hilltop and upper slopes to the lower slopes. The soils were sampled and analyzed; the analytical results are presented in table 2.

Table 1: General overview of selected villages / sites

County	Township	Site/village	Soil parent material at site
Hengyang	Qinping	Qing'an	Purplish shale (alkaline)
	Li Ren Xian	Renai Chun	Red clay (acid)
Qiyang	Mao Zhu	Daling	Red clay (acid)
	Juan Pan Tie	Xiang Mu Cheng	Sandstone/red clay (acid)
Yongzhou	Dian Zhi Di	Mao Zhu Yuan	Red clay/shale (acid)
	Jie Li Qiao	Hua Mei Pu	Black limestone/shale (alkaline/acid)

Table 2: Summary and interpretation of soil analyses results

Location		Soil depth	pH	Org. C	CEC	Exchangeable cations				Available		Remarks
						K	Ca	Mg	Al	P	K	
		(cm)		(%)	(cmol/kg soil)					(mg/kg soil)		
Mao Zhu Yuan	(n=5)	0-20	4.4	0.87	13.5	0.20	1.30	0.26	8.51	1.9	140	Low pH; high Al;
		20-50	4.6	0.51	13.3	0.15	0.92	0.18	7.81	1.5	143	low P
Hua Mei Pu	A	0-20	4.6	1.33	16.2	0.32	1.83	0.50	11.21	6.4	280	Low pH; very high Al
	(n=2)	20-50	4.6	0.58	14.1	0.25	1.30	0.30	13.35	2.7	266	
	B	0-20	7.8	2.35	28.4	-	-	-	-	3.4	666	calcareous soil; rich
	(n=1)	20-50	8.1	1.00	24.2	-	-	-	-	2.9	478	
Daling	(n=7)	0-20	4.5	0.66	13.2	0.13	0.79	0.10	6.56	2.2	96	Low pH; high Al; very
		20-50	4.6	0.46	12.5	0.11	0.93	0.13	6.40	1.9	98	low Mg; low K and P
Xiang Mu Cheng	(n=6)	0-20	4.6	0.79	10.7	0.17	0.53	0.14	5.81	2.3	149	Low pH; high Al; low P;
		20-50	4.7	0.47	10.4	0.14	0.43	0.09	6.13	1.7	163	low Ca; very low Mg
Qing'an	(n=4)	0-20	8.1	0.40	18.7	-	-	-	-	2.4	334	Calcareous soil; low P
		20-50	8.3	0.30	18.4	-	-	-	-	1.9	344	
Renai Chun	(n=5)	0-20	4.6	0.62	12.9	0.11	0.33	0.05	9.61	1.5	76	Low pH; very high Al;
		20-50	4.7	0.38	12.5	0.07	0.34	0.04	9.01	1.3	78	very low P, K, Ca; extremely low Mg

Each site was mapped for its topography, soil depth and percentage vegetation cover besides indicating various permanent features (houses, ponds, major gullies etc.). Based on these maps various more or less homogeneous subareas were delineated. Given the specific potentials and constraints of the subareas the Project (in consultation with the local farmers and officials) designed various "technological packages". Each technological package was composed of a set of measures to achieve the production and/or protection objectives.

At each site "protection" and "production" subareas were identified according to their respective potentials. Next, the "protection" subareas were subdivided into *"reclamation"* areas that were totally bare and gullied, and *"conservation"* areas that were mostly in tea-oil, but suffered from sheet erosion due to the local cultivation practices. Production subareas have generally been the lower slope lands with deep soils and a complete (natural) vegetation cover.

To develop and introduce technologies suitable for the different sites and their subareas a "process" approach was followed: various alternatives were tested, evaluated and adjusted through trial and error, and further informal experimentation by farmers was encouraged.

3.3 Project implementation: design of technological packages and organization

For the degraded higher slopes and hill tops, i.e. the "reclamation" part of the "protection" subareas, technological packages composed of low input measures aimed at re-establishing a protective vegetation of mostly grasses and slashpine at minimal costs of labour and inputs, were proposed. For the slightly better areas, i.e. the "conservation" parts, these measures were complemented by planting additional (commercial) trees, including chestnut, ginkgo and improved tea-oil.

The various low input measures proposed by the Project were not known as well-tested technologies. Neither did the local farmers have any previous experience with gully rehabilitation, or the construction of gully checks, nor with the revegetation of bare, degraded areas. Consequently, the various low input measures were developed and fine-tuned during the course of Project implementation.

The technological packages for the better endowed, "production" subareas, were based mostly on a high input, locally developed, technology aimed at establishing fruit trees, such as citrus, persimmon, peach and plums on very acid soils. This technology involved extensive soil preparation through the digging of (contour) trenches that were 0.8 m deep and 1.0 m wide. The soil of the trenched areas is loosened and improved through straw, manure, (rock)phosphate and lime applications during the fall and winter season prior to planting the trees. In subsequent years the trenched strip is further widened and used for intercropping vegetables and other leguminous crops, such as groundnut and soybean. Where the production subareas occurred on sloping lands, the contour trenching technology gradually leads to the creation of backsloping terraces. The details of this technology were described in an earlier paper by Haagsma et al. (1994).

Counter to the local practice the Project insisted on maintaining the natural vegetation between the trenched areas so that the terrace risers were automatically protected against erosion during the land development phase (photo 5). Where the natural vegetation was damaged, as in many of the marginal tea-oil plantings on the slopes, sheet and even rill erosion are already common problems. In such areas additional low input conservation measures, as elaborated for the "protection" subareas, are often required.

The Project was implemented by the Provincial Department of Agriculture in Hunan Province, which organized the actual field implementation through its county level Agricultural Bureaus. The county staff was responsible for day-to-day implementation and supervision of all activities. Site development activities were implemented by the villagers of the various sites; maintenance activities were generally the responsibility of the group of farmers having contracts for lots in the "production" subareas. The contractual and organizational arrangements varied from site to site and will be discussed in a separate paper (Harteveld et.al.; in preparation).

A team of national and international experts has guided the county staff through regular field visits and a series of workshops, in which all parties involved (including farmer, village and township representatives) participated.

4 RESULTS AND DISCUSSION: EVOLUTION OF THE TECHNOLOGICAL PACKAGES

Worldwide there exists little experience with the rehabilitation of seriously gullied land, such as the degraded "badlands" in Hunan (see figure 1). Usually, rehabilitation strategies are focused on the prevention of new gullies, rather than curing the existing ones, because the rehabilitation costs tend to be high, whereas the value of the land for agricultural purposes is low. However, population pressures and demands for agricultural land elsewhere in the world are rarely as high as in China!

At the start of the Project no well tested, low input techniques to treat gullies and to protect uplands effectively were readily available: not at research stations, nor at demonstration farms. Neither had farmers developed their own local techniques. At first only a few relatively costly and labour-intensive techniques were suggested by the local experts. Yet, cheap and simple gully rehabilitation and land conservation techniques are essential in view of the existing socio-economic conditions in the rural areas.

The evolution in the technological measures, including the proposed engineering works as well as the low input alternatives, are described in the following sections.

4.1 Run-off control structures

Initially two systems were proposed and designed to control run-off:

- a "bunds and ditches" system for the protection areas to control run-off and to enhance moisture infiltration; and
- a run-off disposal system aimed at protecting the production subareas.

These designs and their drawbacks, in view of the physical and socio-economic conditions at the various sites, will be reviewed first.

4.1.1 *Bunds and ditches system*

A "bunds and ditches" system was designed initially to control run-off and erosion from the slopes of the protection areas. The contour ditches -dug at 5 m. intervals- were to intercept all run-off and let it infiltrate *in-situ*, thereby increasing the moisture availability for the newly planted trees. In view of the common dry spells during the period of July-September, the shallow soils and the high rates of run-off, this measure was considered essential to achieve successful reforestation.

The contour ditches were designed as short sections with small checks every 3 m. to prevent a lateral flow and thus accumulation of run-off. The number and dimensions of the ditches were based on the once in 20 years probability that rainfall exceeds 150 mm/day. After digging the ditches rows of grasses were to be planted on the upslope side, while trees would be established on top of the downslope bund. The ditches would serve mainly during the initial years; thereafter its function would be taken over by the trees and grasses.

However, infiltration ditches are known to be most suitable under semi-arid conditions with annual rainfall less than 600 mm; under more humid conditions, such as in Hunan, large amounts of run-off and sediments are likely to occur, making this technique ineffective (Hudson, 1992). Other technical weaknesses, high risks and high labour requirements for construction and maintenance, quickly became obvious also. For instance, the volume of soil movement would surpass that of terrace construction. Moreover, the large volumes of loose soil would be rapidly washed down the slope and into the next ditch. Finally, it was considered unlikely that small farmers would ever make such major investments in these marginal lands without additional Government support.

In the end only a few infiltration ditches were dug on a sparsely vegetated slope in just one location. The experience largely confirmed the weaknesses described above. In addition, the irregular topography greatly interfered with the proper lay-out along the contour, leading indeed to overspilling and renewed gully erosion downslope. Moreover, poor soil fertility proved to be a far greater constraint to revegetation than the lack of soil moisture.

4.1.2 *Run-off disposal systems*

In the humid tropics with annual rainfall exceeding 1000 mm run-off disposal systems are a common feature of many conservation programmes. Such system comprises the construction of: interceptor ditches, terrace ditches, and collector drains (often including drop structures). Its proper realization requires an accurate lay-out and close supervision.

Initially, such systems were designed for all sites: the interceptor ditches were to be located at the lower boundaries of the protection subareas, and the ditches on the backsloping terraces of the production subareas would lead into major collector drains. However, serious reservations were raised about the appropriateness of such systems under the prevailing site conditions:

- The very irregular terrain, dissected by many small and big gullies, would greatly complicate the required, accurate lay-out. Irregularities in canal slope and cross-sections would unavoidably, lead to either scouring or sedimentation of the canals.
- The bare surfaces of the protection areas would yield much sediment, that would be deposited in the canal system. Next, the canals would readily overflow causing renewed gully erosion downslope.
- Continuous maintenance of the canal systems, therefore would be required.
- Much of the best land in the already small production areas would be further fragmented by the newly constructed waterways.
- The digging of the disposal system would require huge amounts of labour.

These points were confirmed by field observations on the performance of interceptor ditches constructed by local farmers. Moreover, when the bare, gullied areas are relatively small, and run-off is divided over a dense natural gully system, there is little need for large disposal systems. On the contrary, any attempt to concentrate this run-off through such system may well increase the erosion hazards further downslope.

Following an ex-ante evaluation it was concluded that both the "bunds and ditches" and the "run-off disposal" systems were mostly inappropriate given the conditions at the various sites. Instead, a range of less costly and easier rehabilitative measures were developed for the bare upper slopes (see 4.2) and for the major gullies, while exploiting these as natural drains (see 4.3).

4.2 Soil and Water Management for protection and production sub-areas

Soil and water management measures, emphasizing low input techniques were developed and implemented in both the "protection" and "production" subareas of the various sites. Table 3 provides an overview of the various techniques and their major characteristics.

The designs can be divided into two types: **mechanical** and **biological** structures, according to the predominant construction materials used. For mechanical structures building materials, such as stone, cement, poles and timber are used, whereas grass and soil are basic components of the biological structures. Often the biological structures should be used in combination with mechanical structures (see 4.3.). The following advantages of the "biological structures" were identified:

- very low construction costs, because the building materials -grass sods and soil- are readily available;
- simple design and easy construction;
- the grass vegetation will progressively strengthen the structure;
- the height of the structure increases naturally with the growing grass and as sediments are trapped; and
- maintenance requirements are low and mostly limited to a short period following establishment.

By comparison "mechanical structures" are characterized by:

- high construction costs (on average 5-10 times more expensive than biological structures);
- building materials are not always locally available;
- specific skills and experience are required for design and construction ;
- the structures will deteriorate over time;
- spill-over of sediments once the structure is silted-up, and consequently
- maintenance will be required for indefinite periods.

With respect to the biological structures the **timing** for both the construction and for the grass planting proved to be critical. Structures that use soil and grass sods as the principal building materials are most vulnerable during the period immediately following construction when the grass is not yet properly established. Therefore, the winter and early spring, when rainfall is relatively gentle, are the ideal construction periods. The June-August period is characterized by heavy rainfall, which will inflict serious damage to grassed plugs and dams that are built during or shortly before this period.

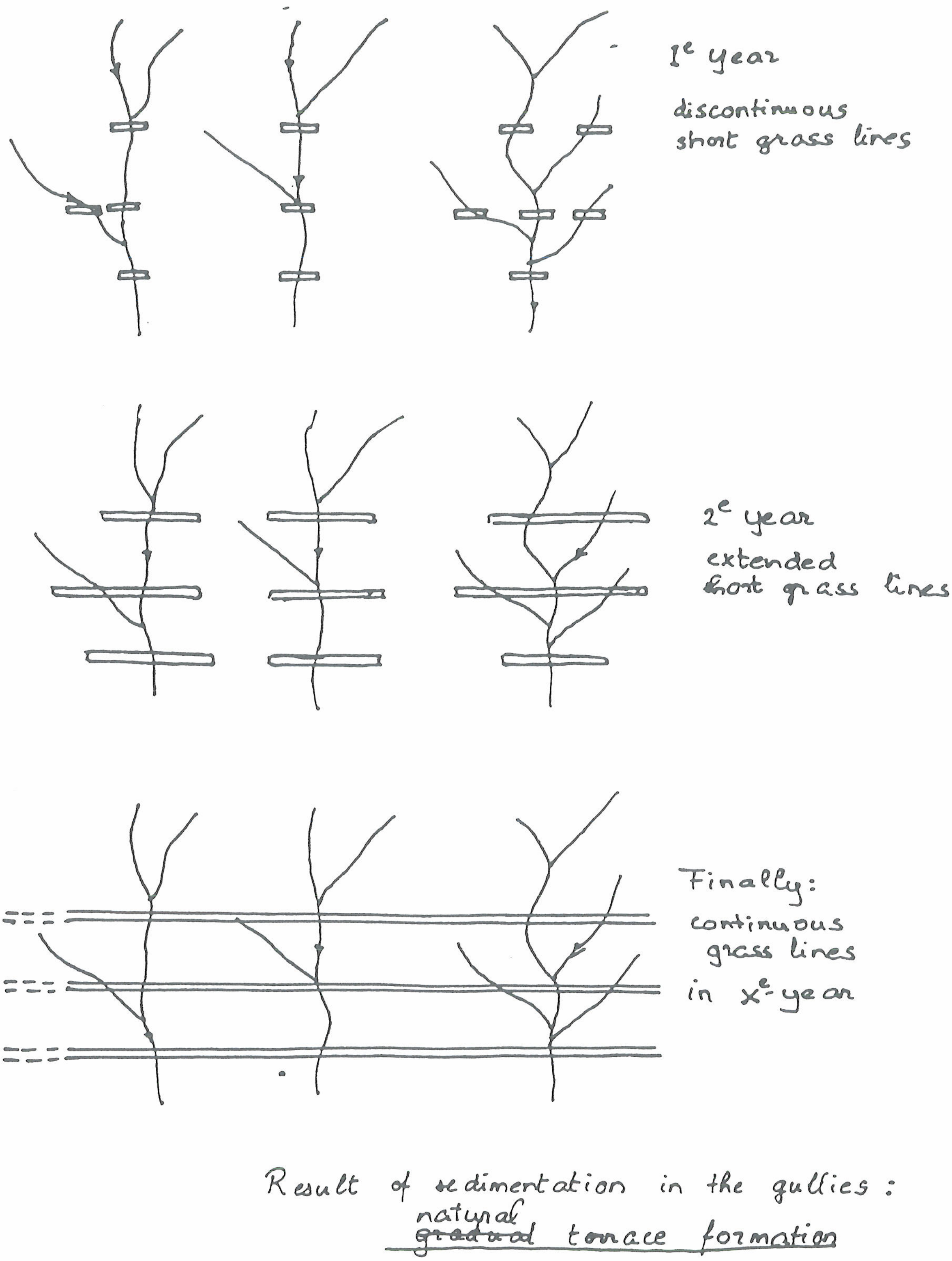
Table 3: Major characteristics of the different gully control structures tested at the various sites (1 Yuan = $ 0.15)

	Mechanical structures				Biological structures			
Gully control structures	**Open stone dam**	**Masonry dam**	**Brushwood dam**	**Pole dam**	**Grass-soil dam and grass dam**	**Rice-straw dam**	**Grass lines**	**Gully plug** (grass)
A. Construction costs								
1. Total Costs (Y)	40-170	340	80	120	7-20	5	5	3
2. Material costs	20-85	240	60	90	0	0	0	0
3. Construction costs	20-85	100	20	30	7-20	5	5	3
B. Construction features								
4. Initial height (m)	1	1-1.5	0.5	0.5-1	1	0.5-1	n.a.	0.3
5. Location	at gully exit; in deep, V-shaped gullies	at gully exit; in deep V-shaped gullies	at gully exit; in wide sections	at gully exit; in wide sections	in every location	minor gullies in terrace risers	wide, flat gully bottom	big rills
6. Amount of run-off	high	high	high	high	moderate	low	moderate	low
7. Timing of construction	year round	year round	year round	year round	winter, early spring	winter, early spring	winter, early spring	winter, early spring
8. Availability of materials	requires transport	requires transport	localized problems	localized problems	no problem	no problem	no problem	no problem
9. Complexity of construction	moderate	high	moderate	high	low	moderate	low	low
10. Specific features	grass can be planted after silting-up	grass can be planted after silting-up	not in hard soil; poles will rot away; additional grass planting	not in hard soil; timber will rot away; additional grass planting	crest height will increase by filtering sediments	must be planted with grass	crest height will increase by filtering sediments	crest height will increase by filtering sediments
11. Durability	high	high	high	moderate	high/moderate	low	high	high

Additional observations:
n.a. = not applicable

The construction of any of the structures does not require specific tools.
Farmers do not have previous experience with these structures.
Rice-straw dam is a temporary measure intended to repair serious damage to terraces by new, fresh gullies; if planted with grasses then its durability increases considerably.
Grass-soil dams and grass lines: use tall growing species for maximum filtering effect on sediments.
Grass lines have not been tested yet, but have been suggested as a measure fit for wide gullies.

Figure 2: Evolution of grass gully plugs/grass lines into continuous grass lines on land with an irregular topography with shallow gullies



▵ Photo 5: Xiang Mu Cheng site: Persimmon trench/terrace plantings in October 1994 (19 months after planting); terrace risers remained protected by the original natural vegetation and tea-oil shrubs.

◃ Photo 6: Daling site: contour grass strips (local grasses) without superphosphate (foreground) and with superphosphate fertilizer (background) in October 1993 (6 months after planting grass and applying phosphate).

▹ Photo 7: Mhao Zhu Yuan site: Slashpine in October 1994, 19 months after planting and with 100 g superphosphate/tree mixed in the planting hole.

On the severely gullied upper slopes and hill tops without hardly any vegetation (the "reclamation" areas) several low input protection measures were implemented. These involved tree plantings (mostly slashpine for firewood) in combination with (contour) grass lines and gully plugs, as discussed in the next section.

4.2.1 *Gully plugs*

Initially, gully plugs, as simple earthen barriers of 0.3 m high, and located at regular 3 m intervals in the rills and minor gullies, were considered an adequate measure to enhance moisture infiltration and sedimentation. It was anticipated that these plugs would become starting points for a spontaneous revegetation. However, despite run-off retention no natural revegetation occurred on the very infertile soils, whereas the heavy summer rainfall did cause serious damage.

In response the plugs were strengthened successfully with sods of local grasses, together with a minimal P-fertilizer application (100 kg/ha superphosphate) and a shallow soil preparation. Local creeping grasses proved very effective in starting the revegetation process. However, how much time such natural revegetation may take and how it will affect the rate of run-off is as yet unknown. The construction of gully plugs involves a minimum of soil disturbance and labour. Under average field conditions, with 600-700 plugs/ha, the costs of construction would amount to about US$ 250/ha. Where the gullies are deeper, the gully plugs can be raised and be built successfully as grass-soil dams (see section 4.3. and table 3).

If, a more intensive utilization of the "badlands" is planned for the future, one may chose the location of the gully plugs in such a way, that these follow the contour. In subsequent years the gully plugs could be extended and where necessary strengthened to become eventually a continuous contour grass line (see figure 2). In any case regular maintenance is essential to avoid that run-off bypasses the plugs and causes renewed erosion.

4.2.2 *Contour grass lines*

Contour grass lines, often with Vetiver grass, are a well known biological measure for erosion control on gentle and moderately steep slopes (NRC, 1993). By establishing vegetative barriers along the contour, the run-off will be slowed down thereby promoting infiltration and sedimentation. A major result is the gradual and natural formation of terraces.

Vetiver grass was widely used by the Project, but the local experience with it was very limited. So its use was mostly of an experimental nature. A major constraint was the very irregular topography which interferes with the correct establishment of grass line plantings on the contour. Other problems were:

- the grass was often planted without any soil preparation;
- the grass slips were spaced too widely apart;
- inappropriate planting positions were chosen, where the grass has no impact;
- maintenance, including the periodic cutting of the grass to enhance tillering and additional slip planting in weak spots, was often neglected.

On these very infertile soils, a minimal P application and soil preparation as a shallow trench of 0.2 x 0.2 m were essential measures for successful establishmentf (photo 6). Some of the local grasses, that are adapted to the very acid soil conditions, might be promising alternatives for Vetiver. Among these grasses both the tall, erect types and the creeping types provide interesting opportunities to control erosion and run-off.

Whether contour grass lines are indeed the most appropriate erosion control measure, for seriously degraded and gullied lands needs to be questioned. For these areas the planting of firewood trees in combination with grassed gully plugs seems the best initial option, because soil disturbances will be minimal. For non-eroded land with a regular topography, i.e. most of the "production" subareas, contour grass lines on the terrace edge would contribute to stabilizing the terraces.

4.2.3 *Slash pine planting*

Slash pine is well adapted to the acid soils and the seedlings developed remarkably well even under very difficult conditions. The survival rate of the planted trees was improved even further by some simple measures:

- instead of rigidly following a prescribed grid, planting distances should be adapted to the local topography, so that very unfavourable positions on steep gully sides, or on top of narrow ridges are avoided;
- a superphosphate application of 100 g/tree in the planting hole greatly enhanced initial growth;
- timely preparation of planting holes during the winter season, and timely planting of seedlings during the early spring was crucial in ensuring that the trees can profit from the spring rains and will survive the dry summer season.

The above measures are the minimum requirements for the successful establishment of a slashpine planting (photo 7). Yet, also other vegetation, such as tea-oil, grasses and shrubs planted on the seriously eroded soils, responded greatly to these measures.

4.3 Gully rehabilitation

The major function of gully checks is the trapping of sediments thereby reducing the deposition of sediments into the cultivated fields and in the reservoirs and ponds. At the start of the project only a very narrow range of gully rehabilitation techniques was available: cemented or open stone dams in combination with Bamboo planting. Although open stone dams are a well tested and widely used technique, there were serious doubts whether it would be suitable for the red soil areas, given the limited availability of stones and the high construction costs involved. Obviously, the choice of techniques had to be broadened.

In most of the sites a range of gully rehabilitation measures were used to treat an entire gully. These existed of:

- gully plugs composed of sods of creeping grasses on the upper slopes and in minor gullies (see 4.2);
- grass-soil dams with both creeping and erect growing grass species in the middle slope sections where gullies are deeper (photo 8); and
- one or more stone (open or cemented) dams (photo 9), pole dams (photo 10), or brushwood dams at the end of the gully or where run-off tends to accumulate.

Such a combination of measures, which was strongly favoured by the local farmers, was more effective and economic in handling the increasing amount of run-off in the gully, than the original design of a series of open stone dams in combination with Bamboo plantings for the entire gully. The use of brushwood and pole dams proved less suitable, because of the limited availability of materials, the complexity of the design and the relatively rapid deterioration of the materials.

The construction costs for the stone dams are considerable; for instance, for a 150 m long gully, and a dam spacing of 5 m, the total costs for some 30 dams would amount to some 3,000 Yuan. However, a combination of various measures: 1 stone dam, 15 grass-soil dams and 15 gully plugs, reduces the total costs to about 300 Yuan (see Table 3).

Photo 8: Daling site: the use of "grassed earth dams" to reclaim gullied red soils (May 1994).

Photo 9: Xiang Mu Cheng site: the use of "open stone dams" to stabilize and/or reclaim gullied land (September 1994).

Photo 10: Mao Zhu Yuan site: the use of a "pole dam" to stabilize a large gully; silted up area above the dam should be planted to slashpine/timber trees to stabilize the gully further (October 1994).

The gully checks installed by the Project indeed silted up rapidly due to the simultaneous land preparation activities on the adjacent slopes. Therefore, gully rehabilitation was implemented in stages; the trapping capacity of the gully checks was gradually increasing by:

- planting grass in front of the silted-up dams;
- raising the height of the dam; and
- building additional dams.

The trapping of sediments by the gully checks has had some additional effects. Firstly, silted-up dams contribute much to the reduction of the erosive energy of run-off; secondly gullies become more stable, and the dams stronger after silting up; thirdly, the silted-up gully checks provide additional opportunities for planting trees (photo 10).

Usually, gully rehabilitation is carried out in a **upslope-downslope** sequence. However, because run-off quantities are relatively limited even in bigger gully systems, a reversed procedure, **downslope-upslope**, might be possible and be more attractive to farmers. The construction of only one open stone dam at the end of the gully without the immediate backing by upstream checks had several advantages:

- the downslope fields are protected.
- all sediments are concentrated at one gully check,so that a new spot where vegetation can be planted is formed readily;
- greater flexibility because labour use and investments can be spread out over the years according to the rate of sedimentation; once a gully check is silted up a next one may be constructed upslope.

More systematic trials and monitoring would be required to verify under which conditions such a reversed sequence is viable.

4.4 Environmental impacts

At the various sites the slopes and the adjacent paddy fields and farm reservoirs constitute rather closed systems. Erosion damage therefore was mostly restricted to local farms and off-site impacts seem negligible. The precise impacts of the conservation measures in the protection areas on the adjacent production areas and other neighbouring areas are, however, very difficult to assess. Yet, before the Project started, there was no production from most of the protection areas. Presently some vegetation has recovered and there are prospects for firewood, timber, and fodder grasses production in the future. Likewise gully rehabilitation has been successful through a number of cheap and easy techniques. Whether these investments can be recovered from future revenues is yet uncertain. In any case these revenues will be marginal in comparison with those from the fruit tree production areas. This implies, that farmers are likely to request additional incentives from the (local) government to protect and reclaim the degraded uplands.

Strictly, the conservation measures at the various sites will have two types of environmental impacts: *on-site* and *off-site*. The former refers to the direct local impacts mentioned above, while the latter refers to impacts on areas further downstream, outside the sites. In the first case the farmers are the sole beneficiaries, in the second the society-at-large benefits. A clear identification of the impacts is also important in determining by whom the conservation measures should be financed and subsequently, who should be responsible for maintenance.

4.5 Factors affecting implementation

Implementation of the Project and of the various interventions discussed above was greatly influenced by a number of typical factors. At first the field staff felt rather uneasy about the "process" approach and the farmer participation in design and planning activities, since traditionally there has been a strong emphasis on standardized, blueprint solutions (Stoop, 1993). Moreover, the quantity of work, rather than its quality, was nearly always considered the most important achievement. Consequently, the proper timing of interventions such as the optimum periods for planting vegetation and for constructing various biological anti-erosion measures, as well as timely maintenance and repair operations were often considered of secondary importance. Likewise, the local monitoring and evaluation procedures, in particular detailed field observations, were often inadequate in meeting the needs of the "process" approach.

Yet, over the years the Project's results have increasingly aroused the interests of farmers as well as (local) officials. Moreover, these results have stimulated farmers to initiate also their own trials, by testing various local grass species, other than Vetiver, for their use in gully control works and in vegetative recovery of bare lands.

5 CONCLUSIONS

For the reclamation and conservation of the (degraded) red upland soils in Hunan Province technical guidelines for a range of soil and water conservation measures have been developed (KIT, 1995). Poor soil fertility (soil acidity, Al-toxicity and P-deficiency) was a more serious constraint in regenerating soils, than was soil moisture availability. Soil improvement measures that enhance fertility, especially with respect to phosphate, will generally improve vegetation growth and thereby also the moisture retention capacity of the soils. Under the prevailing rainfall conditions infiltration ditches and water retention bunds, which intercept and concentrate run-off with the objective of reducing moisture deficits, are redundant.

In addition, run-off disposal systems should be used only as a last resort in view of their vulnerability, and excessive construction and maintenance requirements. To dispose of the excess run-off it is most efficient to rely on the natural drainage system of major gullies, which can be improved -where necessary- by gully rehabilitation measures.

The gully control and rehabilitation measures tested offer a range of techniques for different field conditions. Generally, brushwood and pole dams will have limited use. Costs are high and building materials are often not easily available. Open stone dams and masonry dams are also costly. In either case the local experience to construct these structures was limited, which resulted in unnecessary damage and additional repair costs. Therefore, stone dams, though widely used by the Project, should be restricted to a few strategic places inside the major gullies.

The prevailing climatic conditions favour the application of biological soil and water conservation measures. The various biological gully control methods have shown promising results and can be widely applied. This refers in particular to grass-soil dams and grassed gully plugs. Contour grass lines, however, have a more limited use in most protection areas, because of the highly irregular terrain, which makes the proper establishment of contour lines very difficult. Their full potential therefore cannot be realized under such conditions. Grass lines were found to be more appropriate for the production areas in stabilizing the edges of the terraces.

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