Effects of Contour Hedgerows of Nitrogen Fixing Plants on Soil Fertility and Yields of Sloping Croplands in a Dry Valley of the Jinsha River, China

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Introduction

The contour hedgerow system is an agroforestry model in which nitrogen-fixing trees and shrubs are planted closely in double rows between alleys along contour lines in association with annual crops, pastures, or livestock, in some form of spatial arrangement or temporal sequence. The system has also been called 'alley cropping' (Kang et al. 1990; Nair 1993), and has been investigated extensively in tropical regions since the 1980s. It has been developed as an alternative soil conservation and fertility management technique with low external cash, labour, and chemical fertiliser requirements. Contour hedgerow intercropping can provide the physical barriers needed for water and soil conservation, and a biomass source for continuous supply of nitrogen and organic matter.

The contour hedgerow system was introduced to China in the early 1990s because of its potential value in establishing sustainable farming based on local resources. This paper reports the results of a long-term experiment sponsored by the Chengdu Institute of Biology, Chinese Academy of Science, ICIMOD, and the Government of Ningnan County to examine the impact of contour hedgerows on soil fertility and crop production in the Hengduan Mountains of south-western China.

Materials and Methods

Site description

The study was carried out at two sites: Tanguanyao and Masangping. Tanguanyao is located in Pisha Town of Ningnan County, southwest Sichuan; its elevation is 1150m, and it represents a low elevation agro-ecological area in the dry valley of the Jinsha River. A ustic ferrisol (Chinese Soil Taxonomy Research Group 1995) with an organic matter content of 8.0 g/kg and total nitrogen of 0.41 g/kg in 1991 was used for this study. Masangping is located in Liutie Township of Ningnan County at 1450m, and represents the middle mountain agro-ecological area of this region. The soil has a clay-loam texture, and had an organic matter content of 11.1g/kg and total nitrogen of 0.53 g/kg in 1994.

Experimental Design (Field and Laboratory Methodology)

Fifteen soil erosion plots (five treatments with three replicates) were established at Tanguanyao and Masangping in 1995 and 1996, respectively. The five treatments used were (1) control (farmer's up and down practice without hedgerows and with fertiliser); (2) T2 (*Leucaena leucocephala* hedgerow + crops without fertiliser); (3) T3 (*Leucaena leucocephala* hedgerow + crops with fertiliser); (4) T4 (*Tephrosia candida* hedgerows +

crops with fertiliser); and (5) T5 (*Leucaena leucocephala* hedgerows + mulberry trees + crops with fertiliser).

Peanut was grown in all the plots at Tanguanyao from 1995 to 2000 except that maize was grown in 1998. Maize was cultivated from 1995 to 2000 at Masangping, except that peanut was grown in 1998. Superphosphate was used on peanut, and urea on maize in the fertilisation treatments at the two sites at a rate of 30 kg/ha. The soil used for the trial was 30-210 cm deep and classified as an ustic luvisol (Chinese Soil Taxonomy Research Group 1995).

Soil sampling and nutrient analysis

Topsoil (0-30 cm layer) from all the plots was sampled after harvest of the crops at the end of the rainy season. Soil samples were ground to pass through a 1-mm sieve to determine organic matter, total N, available P, available K, cation exchange capacity, exchangeable Na (natrium), K (potassium), Ca (calcium), and Mg (magnesium). Organic matter was determined by the wet digestion procedure; total nitrogen was determined after digestion by the micro-Kjeldahl method; available K by the ammonium acetate extraction method (Jones 1973); available P by the Olsen method (Oslen 1954); and CEC by CH_3COONH_4 exchange. The soil exchangeable base was determined by CH_3COONH_4 exchange and atomic absorption spectrophotometer/flame photometer after CH_3COONH_4 exchange.

Results and Discussion

Changes in organic matter (OM)

As shown in Table 1, the organic matter (OM) content of plots with contour hedgerow treatments exceeded that of controls by 87% to 132% at Tanguanyao (9 years after hedgerows established), and by 81% to 155% at Masangping (6 years after hedgerows established). The results indicated a favourable effect of contour hedgerow intercropping on the improvement of soil organic matter.

Table 1: **Organic matter content under different treatments (g/kg)**

Site	Year	Control	T2	T3	T4	T5
Tanguanyao	1991	8.00	8.00	8.00	8.00	8.00
	1996	7.75	7.76	8.12	9.36	8.95
	1997	7.18	9.08	9.48	9.37	8.61
	1998	6.59	9.89	10.99	9.20	8.87
	1999	6.80	10.34	12.00	9.68	9.48
	2000	5.34	10.91	12.42	10.18	10.00
Masangping	1994	11.10	11.10	11.10	11.10	11.10
	1997	12.99	18.22	17.52	15.61	20.21
	1998	11.16	15.76	15.80	13.91	15.23
	1999	9.32	15.71	15.01	13.10	14.46
	2000	6.74	16.69	17.21	13.88	10.40

Changes in total nitrogen (TN)

At both sites, total N in hedgerow intercropping plots increased considerably compared to the controls (Table 2) by 85%-292% at Tanguanyao, and by 104%-181% at Masangping.

The hedgerow system can increase total N in an alley because large amounts of prunings are used as mulch and the nitrogen content in hedgerow prunings is relatively high.

Table 2: Total nitrogen content under different treatments (g/kg)						
Site	Year	Control	T2	T3	T4	T5
Tanguanyao	1991	0.41	0.41	0.41	0.41	0.41
	1996	0.56	0.75	0.74	0.77	0.84
	1997	0.61	1.14	1.26	1.34	1.07
	1998	0.68	1.19	1.29	1.42	0.98
	1999	0.67	1.28	1.35	1.45	1.04
	2000	0.41	1.51	1.57	1.61	0.76
Masangping	1994	0.53	0.53	0.53	0.53	0.53
	1997	0.47	0.91	0.84	0.79	0.82
	1998	0.46	0.92	0.97	0.77	0.80
	1999	0.45	0.92	1.07	0.79	0.80
	2000	0.43	1.15	1.21	0.88	1.07

Changes in available P

The available P contents of hedgerow treatment plots were higher than controls at both sites, and available P content of hedgerows plus P fertiliser was higher than that of hedgerows without P fertiliser or controls (Table 3). However, long-term observation of the trend in available P is necessary.

Table 3: Available phosphorous content under different treatments (mg/kg)						
Site	Year	Control	T2	T3	T4	T5
Tanguanyao	1998	3.62	3.96	4.04	3.40	3.98
	1999	3.66	3.12	3.78	3.88	3.72
	2000	1.42	1.35	3.74	2.61	2.33
Masangping	1998	1.84	3.34	2.22	2.38	2.68
	1999	1.34	2.67	2.16	2.06	2.96
	2000	0.68	1.83	2.24	2.52	2.74

Changes in available K

The available K under hedgerow treatments increased continuously or remained nearly constant, whereas it decreased in controls (Table 4). In 2000, available K in the hedgerow plots increased by 84%-183% compared to controls at Tanguanyao, and by 56%-77% at Masangping. This shows that pruning can improve the content of exchangeable K in topsoil efficiently under the hedgerow inter-cropping system. Hedgerows also develop deep root systems that may take up leached and available K from the deep soil beyond the root systems of crops. The total K of *Leucaena leucocephala* and *Tephrosia candida* prunings (dry matter) was 29.1 g/kg and 17.1 g/kg, respectively, the K absorbed by hedgerows may be returned to alley topsoil through pruning decomposition.

Table 4: Available potassium content under different treatments (mg/kg)						
Site	Year	Control	T2	T3	T4	T5
Tanguanyao	1997	242.1	259.6	241.9	230.1	276.5
	1998	190.3	338.6	373.2	200.2	246.8
	1999	156.5	349.5	378.8	262.0	244.0
	2000	139.9	397.3	313.0	277.1	258.4
Masangping	1997	222.0	267.4	259.2	273.2	358.0
	1998	216.3	315.7	379.9	290.3	304.6
	1999	214.9	383.2	333.4	345.0	318.6
	2000	207.8	366.9	339.4	336.5	324.9

Changes in cation exchange capacity (CEC)

The CEC of hedgerow treatments was generally higher than that of controls (Table 5), but the difference was not statistically significant. Further research and long-term observation is needed to understand the causes of the changes in CEC.

Table 5: CEC under different treatments (mg/kg)

Site	Year	Control	T2	T3	T4	T5
Tanguanyao	1997	123.7	144.0	135.3	139.0	141.3
	1998	108.0	105.5	99.0	109.0	123.0
	1999	91.0	97.5	98.0	104.0	106.0
	2000	75.5	93.4	106.1	97.02	102.8
Masangping	1997	151.5	155.7	202.6	158.7	181.6
	1998	115.0	120.0	126.0	121.0	134.0
	1999	108.0	111.5	106.0	110.0	107.0
	2000	101.5	129.7	155.1	138.9	130.8

Changes in exchangeable bases of topsoil

Soil recalcification is very common because of the dry and hot climate. The hedgerow system seems to have had no effect on the recalcification that took place in topsoil at Tanguanyao. However, recalcification seemed to be strengthened by the hedgerows at Masangping. Exchangeable Mg and K were also increased under the hedgerow system at the two sites, whereas there was no difference in exchangeable Na between hedgerow systems and controls.

Table 6: Exchangeable bases in topsoil under different treatments (mmol/kg)

	Sites	Control	T2	T3	T4	T5
Exchangeable Ca	Tanguanyao	64.53 ns	69.75 ns	68.58 ns	77.64 ns	65.00 ns
	Masangping	82.06 b	76.72 b	109.20 a	86.92 b	94.29 ab
Exchangeable Mg	Tanguanyao	21.52 b	24.92 ab	28.51 a	26.59 a	25.25 ab
	Masangping	32.01 b	46.14 ab	57.51 a	44.63 ab	46.39 ab
Exchangeable K	Tanguanyao	2.67 b	4.01 a	3.91 a	3.60 a	2.84 a
	Masangping	6.97 b	16.85 a	15.02 a	13.08 a	13.81 a
Exchangeable Na (ns)	Tanguanyao	1.68	1.75	1.46	1.84	1.52
	Masangping	1.88	1.64	1.92	3.08	2.71

Note: Figures in the same row followed by the same letter(s) are not significantly different at p ? 0.05 by the Duncan Multiple Range Test.

Crop yields under different treatments

Except for T5, the overall average crop yields in hedgerow intercropping plots between 1996 and 2000 increased by 10-23% compared to controls at Tanguanyao, and by 23-70% at Masangping (Table 7).

The criterion most widely used to assess the desirability of contour hedgerows is the effect of this practice on crop yield. The crop yields under T5 declined by 25-32% compared to controls at the two sites; this was due to shading by the trees interplanted in the alleys. But the income from mulberry was much more than the loss of 25-32% of crop yield.

In 2000, the peanut yield increased by 27% in T3 in Tanguanyao, and the maize yield by 54% in T3 at Masangping. At Tanguanyao, the peanut yield in hedgerow plots without fertiliser (T2) decreased by 11%, while at Masangping crop yields in hedgerow plots without fertiliser increased by 43%. This might imply that P from prunings could not meet the

Table 7: **Crop yields under different treatments (kg/ha)**

Sites	Year	Control	T2	T3	T4	T5
Tanguanyao	1996(peanut)	2846	3144	3287	3474	2922
	1997(peanut)	1926	2236	2733	2086	1276
	1998(maize)	5030	5573	7463	7445	4808
	1999(peanut)	3280	3900	3830	3920	2040
	2000(peanut)	1850	1640	2360	1510	450
	Average*	2476	2730	3053	2748	1672
Masangping	1996(maize)	1390	1503	2097	1623	1733
	1997(maize)	1210	1550	1930	1570	806
	1998(peanut)	872	1055	1089	973	853
	1999(maize)	2780	2930	4510	3080	2470
	2000(maize)	3110	4470	5910	4310	1330
	Average**	2123	2613	3612	2646	1585

*,**: Crop yields in 1998 not included because of different crops

peanut's requirement, but N from prunings could meet the N requirement of maize. As for T4, the decrease in peanut yield at Tanguanyao and increase in maize yield at Masangping could partly be attributed to *Tephrosia* growing better at Masangping than at Tanguanyao. On average, the crops intercropped with and shaded by mulberry trees yielded 48% less peanut and 34% less maize than the controls in two sites. However, the cost of yield loss can be compensated from sericulture.

Discussion

Both above ground parts (such as prunings and leaf litter) and underground parts (such as fine roots turnover and root residues) have impacts on OM and nutrients in alley soil. In the *Leucaena* hedgerow system, 8-14 t/ha of prunings were applied as mulch or green manure into the alley annually, which equals to 3.2-5.6 t/ha of dry matter, containing 133-234 t/ha of nitrogen, 93-163 kg/ha of potassium, 9-16 kg/ha of phosphorous input into its companion alleys. From this perspective, soil organic matter, total nitrogen, and available K are sustainable under hedgerow systems. OM and TN rose fast during the first several years and then improved slowly or fluctuated partly due to the decomposition and addition rates reaching a balance, which may lead to maintaining soil OM and TN at a certain level.

However, soil P is controversial. On the one hand, acidic soil has a high P-fixing capacity, and although legume prunings have a high content of nitrogen and potassium, their phosphorous content is rather lower. In this study, available P was improved by the hedgerow systems, which may be due to the slightly acidic or neutral soil in the study areas having a lower P-fixing capacity. The high rate of OM addition through prunings helps to improve available P.

The results indicate that though hedgerow systems could maintain production of annual crops, the nitrogen and phosphorous supplied by prunings cannot meet the requirements for maximum yields. Middle-level fertilisation is necessary to further improve crop yields.

Future Implications

Contour hedgerows of N_2-fixing plants could keep sloping croplands from deteriorating and efficiently maintain or improve soil nutrients such as organic matter, total nitrogen, and available K. Production of food crops is also improved compared to conventional cultivation. In the long run, the system helps to strengthen food security and environmental sustainability in mountain areas with high populations and diminishing arable land.

As to extension and application of the system to promote sustainable development and food security in mountain regions of China, it is necessary to strengthen demonstration and research work that considers local conditions and resources, and to supply more options to local farmers. Such efforts will require studies of farmers and different models in different regions to meet their needs.

The relationships between the dynamics of soil nutrient pools and hedgerow above and below ground biomass should be quantified in the mid- and long-term. Woody hedgerow species differ from herbaceous manure in the rate and time of addition of organic materials to soil. Hedgerows provide far more lignified materials than herbaceous manure crops, which affects the mineralisation rate of organic carbon and nutrients in organic matter. Hedgerow roots influence soil (especially deeper soil layers), OM, and nutrients all year round. For example, the underground parts of hedgerows are estimated to provide nitrogen at a rate of 25-102 kg/ha per crop season (Saninga et al. 1995). However, their biomass and function are far from clear. More systematic research on underground parts will help to elucidate the functions of hedgerows in the system.

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