Effects of long-term fertilization and mulch on soil fertility in contour hedgerow systems: A case study on steeplands from the Three Gorges Area, China

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Abstract The use of contour hedgerows is widely advocated to sustain crop production and reduce soil loss on steeplands in the Three Gorges Area of China. However, little is known about the effects of soil management on soil fertility within these systems, or about the spatial gradients in soil nutrients that may develop in terraces formed behind the vegetative barriers. Therefore, we carried out a study on the effects of various long-term soil management practices on soil fertility and spatial variation of fertility between hedgerows. At a site in the Three Gorges Area, China, we applied five treatments to a contour hedgerow system: control (no fertilizer and manure); chemical fertilizer (CF); chemical fertilizer and mulch (CF + MU); pig manure (PM); and mulch, pig manure, and chemical fertilizer (CF + PM + MU). Soil samples were collected from the topsoil horizon (0–20 cm) of the selected five treatments in 2006 after 11 crop cycles, and physical and chemical properties

were analyzed. The results showed that chemical fertilizer clearly improves nutrient status of the topsoil, while pig manure also increased the amount of soil organic matter. This increase in organic matter was associated with an increase in soil aggregate stability, a reduction in bulk density, and reduced penetration resistance of the soil. Mulch with pig manure and chemical fertilizer was the best management practice for improving soil quality and crop yields in the Three Gorges Area. Further, mulch and pig manure addition also decreased the magnitude of the spatial variation, but did not offset the soil fertility gradients because tillage resulted in significant movement of soil. More favorable soil properties were found at the lower positions within each alley, regardless of the management practice applied.

Keywords Soil physical properties · Soil chemical properties · Fertility gradient · Crop yield · Contour hedgerow

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Introduction

Approximately 800 million people worldwide depend directly on steeplands for their sustenance (Drees et al. 2003). Of the total area of 62,640 km² in the Three Gorges Area, 52.1% has gradients of between 7° and 25°, and 37.5% has gradients of more than 25° (Zhou 2001). After construction of the Three Gorges

Dam, many farmers resettled in the surrounding mountain areas. The steeplands with slope gradients of greater than 20%, which were largely forested, have been widely cleared for cultivation. Thus, many of the steeplands are subject to catastrophic mass movement and slumping, leading to increased land degradation, accelerated erosion and nutrient loss, and loss of sustainable production. It was reported that annual soil loss in the Three Gorges Area is approximately 157 million tons, 46.2% of which comes from cultivated steeplands (Du et al. 1994). Most soils are less than 50 cm thick, and A- and B-horizons or even C-horizons are absent (Du et al. 1994). Steeplands management is a key factor determining ecological sustainability in this area. If this problem is not adequately addressed, not only will the well-being of the local people suffer, but also the functionality of the Three Gorges Dam and Reservoir will also be undermined due to siltation and eutrophication.

The contour hedgerow system is a simultaneous agroforestry system in which rows of trees or shrubs are planted along contours at 3–6 m intervals within the slope field. Crops are produced in the alley-like spaces between the hedgerows (Sun et al. 2008). Hedgerows can reduce the generation of runoff, and can intercept eroded sediments from the upper slopes so that soil fertility can be conserved (Lal 1989a). Xu et al. (2000) reported that runoff and soil loss from contour hedgerow systems were only 24.8% and 16.9%, respectively, of that from agricultural steeplands under traditional management in the Three Gorges Area. Furthermore, hedgerows can be clipped two to three times a year, and clippings can be used as green manure so that less external nutrient input is required (Isaac et al. 2003). In contour hedgerows, terraces form naturally over time as soil moves from the upper part of the alley and accumulate on the lower side of the alley next to the hedge. Shen (1998) and Zhao et al. (2004) reported that bio-terraces can form on 15–25° slopes after 4–7 years by planting hedgerows. The cost of bio-terraces is only 3–17% of that of engineered terraces, and they are also much more stable (Sun et al. 2008). However, due to the limited soil depth in the Three Gorges Area, this type of terrace is often associated with high spatial variability in soil fertility and crop responses. This is attributed to the movement of topsoil from the upper part down to the buffer-strips of the terraces,

which exposes infertile subsoil near the upper part of the terrace (Dercon et al. 2003).

Although contour hedgerows were introduced to the Three Gorges Area by the local government as a soil conservation measure in the late 1980s, little is known about the effects of soil management on the soil fertility of these systems, or the spatial gradients in soil nutrients that may develop in the terraces as they evolve behind the vegetative barriers. Long-term experiments provide the best possible means for studying changes in soil fertility and thus, for obtaining valuable information required for formulating future strategies for maintaining soil health. Against this background, this study was undertaken to quantify the changes in soil fertility and its spatial variation in contour hedgerow systems in the Three Gorges Area. These hedgerows have formed under the influence of long-term soil management practices that are commonly used in this area, including the use of chemical fertilizers, organic manure, and mulch.

Materials and methods

Description of the study area

The study was carried out in Wangjiaqiao (31°12'N, 110°42'E), Zigui County, Hubei Province, which is a typical village located approximately 50 km northwest of the Three Gorges Dam (Fig. 1). Wangjiaqiao was chosen as study site because it was representative of villages in the Three Gorges Area, both geographically and socio-economically. Natural resources, land-use patterns, and population densities are typical of the surrounding region. Its annual average temperature is 18°C, with an average summer high of 28°C in July and an average winter low of 8°C in January. Annual precipitation averages 1,016 mm, of which 70% occurs between May and September. The major agricultural crops are rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), rape (*Brassica napus* L.), and soybean (*Glycine max* L.). The local soil type is purple soil (Regosols in FAO Taxonomy, or Entisols in USDA Taxonomy) developed from purple sandy shale. Purple soil is the most common soil type in the Three Gorges Area, and covers approximately 78.7% of the land area (Du et al. 1994; He 2003).

Fig. 1 Location of the study area and photograph of study runoff plot

Experimental design

In 1996, five runoff plots with 0.4 m spacing were laid out within a 240 m² fenced experimental site (Fig. 1). The site is abandoned farmland with a 23–26° slope. Soil depth was less than 20 cm at the start of experiments. The runoff plots were delineated by 10-cm cement ridges projecting aboveground to isolate plot runoff and sediment. A discharge ditch was created at the top of each plot to divert runoff and sediments from the upper slope. At the base of each plot, a volumetrically calibrated tank was positioned to collect runoff and sediment, and was connected with a notch. After the site was prepared, all plots were covered with 20 cm purple soil at a bulk density of 1.3 Mg m⁻³, which was taken at a depth of 0–20 cm from adjacent steepplands and thoroughly mixed before covering the five plots. Table 1 summarizes selected soil properties. Because of financial and resource constraints, plots were not replicated in this study. To minimize problems associated with non-replication, these plots were constructed and managed identically in terms of layout, dimensions, material and location, etc. (Hurlbert 1984).

In all plots, three rows of Vetiver (*Vetiveria zizanioides* L.) were planted along contours at 4 m intervals. Within each plot, three 2 × 4 m² micro-plots were allocated for growing crops. Vetiver is a

Table 1 Selected soil properties before experiment (sampling on March 1996)

Soil properties	Values
Soil organic carbon (g kg ⁻¹)	10.6
pH in H ₂ O (1:1 suspension)	8.06
Total N (g kg ⁻¹)	0.81
Total P (g kg ⁻¹)	0.64
Total K (g kg ⁻¹)	23.8
Available N (mg kg ⁻¹)	49.9
Available P (mg kg ⁻¹)	3.97
Available K (mg kg ⁻¹)	123.5
Bulk density (Mg m ⁻³)	1.31
Sand (g kg ⁻¹)	468
Silt (g kg ⁻¹)	413
Clay (g kg ⁻¹)	119
>0.25 mm water-stable aggregates (%)	37.7

fast growing herbaceous plant with deep and far-ranging roots (up to 2–3 m). It is commonly used to control soil erosion in cultivated fields in tropical and subtropical regions (Greenfield 1989). Wheat (*Triticum aestivum* L.) was grown between October and May, and soybean (*Glycine max* L.) between June and September, as is the normal practice for crop production in this area. Soil management practices, including chemical fertilizers, pig manure, and mulch, were used in this study. Five experimental

treatments are shown in Table 2. N was supplied as urea and P as single superphosphate. Pig manure was sourced from a local farmer. Fertilizer was applied only to wheat each year, following the normal farming practice in the area. Pig manure and single superphosphate were applied as basal fertilizer before plowing in mid October. Urea was applied in three equal applications, the first applied as basal fertilizer before sowing, the second as side-dressing 30 d after planting, and the third as another side dressing 30 d after the first side-dressing. Wheat straw was applied as mulch at 2 Mg ha^{-1} twice each year in May and November. These two mulch applications were approximately the same time as crop sowing in the first and second growing seasons. Pests and diseases were controlled with pesticide, while weeding was carried out by hand. After crop harvest, all above-ground crop residues were removed from each plot.

Soil sampling and analysis

Soil was sampled in bands between two contour hedgerows, which were located every 1.3 m beginning at the lower contour hedgerow. One sample was taken from each band, and three bands were sampled within each micro-plot. The three samples represented lower, middle, and upper slope positions of the micro-plot. Samples were taken at a depth of 0–20 cm, and a total of 45 samples were taken from five plots in October 2006. At each sampling position, soil samples were collected from 5 to 7 points and mixed to get a composite sample. Stones, roots, and large organic residues were carefully removed from the field-moist soil samples. Approximately one quarter, or 500 g of the soil was sub-sampled from

the mixed composite sample, and approximately 200 g of this soil was reserved for aggregate analysis.

Selected soil properties were determined using routine methods (ISSAS 1978; Liu 1996). Soil bulk density (BD) was determined by oven-drying and weighing cores of known volume taken from the undisturbed field soils. Soil structural stability was estimated by the wet sieving method and expressed as percentage of water stable aggregates (% WSA). Soil texture was determined by the hydrometer method. Penetration resistance (PR) was measured for the 0–20 cm depth layer with a blunt-tip pocket penetrometer by digging small pits during sampling. Soil pH was measured using a glass electrode with a soil/water ratio of 1:1. Soil organic matter (SOM) was determined using an oil bath- K_2CrO_7 titration method, total nitrogen (TN) by the Kjeldahl method, and available nitrogen (AN) by the alkaline potassium permanganate distillation method. Total phosphorus (TP) and total potassium (TK) were determined after digesting soil with $\text{H}_2\text{SO}_4\text{--HClO}_4$. Available phosphorus (AP) in soil was determined by extracting samples with $0.5 \text{ mol l}^{-1} \text{ NaHCO}_3$, then determining P colorimetrically using the molybdate blue method. Available potassium (AK) was determined using 1 mol l^{-1} ammonium acetate extraction followed by emission spectrometry.

Biomass and crop yield measurements

All above-ground crop biomass was harvested manually from all micro-plots at the end of each growing season. Grain and straw parts were separated and weighed. Contour hedgerows were pruned three times each year, in May, August, and October. The top

Table 2 Details of treatments. MU, PM, and CF are wheat straw mulch, pig manure, and chemical fertilizer, respectively

Treatments	Average annual fertilizer application (kg ha^{-1})			Mulch (kg ha^{-1})
	N	P	Pig manure ^a	
Control	NA ^b	NA	NA	NA
CF	150	45	NA	NA
CF + MU	150	45	NA	4,000
PM	NA	NA	20,000–25,000	NA
CF + PM + MU	75	22.5	10,000–12,500	4,000

^a N, P, and K concentrations in pig manure were 6.5–7.6, 1.8–2.4, and 3.5–4.6 g kg^{-1} , respectively

^b Not applied

50 cm of the hedge was cut and weighed, and then clippings were placed at the base of hedge as green manure. Three plant samples were collected after the experiment to determine the ratio of clipped to residual parts. Dry matter content of grain, straw, and clippings was determined from 200 g oven-dried samples. Grain yield for the whole plot was calculated based on total land area.

Calculation of soil deterioration indices

The soil deterioration index (Adejuwon and Ekanade 1988) was calculated on the assumption that each individual soil property under the different treatments had once been the same as the reference soil (at the start of experiments). The difference between mean values of individual soil properties under the five treatments compared with base values of reference soil properties was calculated, and was expressed as a percentage of the base value for each individual property. These percent values were then averaged across all soil properties to calculate the soil deterioration index.

Statistical analysis

All data were analyzed using SPSS software. One-way analysis of variance (ANOVA) was carried out for each soil property among the different treatments or position of micro-plots to determine significance among differences ($P < 0.05$). When necessary, data were log-transformed prior to statistical analysis to achieve normal distribution of data. Mean values were compared using least significant difference (LSD).

Results and discussion

Soil properties

Soil responses to different management practices are shown in Table 3. Among the 14 soil properties tested, 9 properties were significantly affected by mulch, chemical fertilizers, and pig manure. These properties included bulk density (BD), penetration resistance (PR), percentage of >0.25 mm water stable aggregates (% WSA), soil organic matter (SOM), total N (TN), total P (TP), available N (AN), available P (AP), and available K (AK). The

remaining five properties (pH, clay, sand, silt, and TK) were excluded because they failed to meet the screening criteria. A similar screening approach was used by Sharma et al. (2005).

Soil organic matter

Soil organic matter (SOM) was significantly ($P < 0.05$) affected by long-term application of chemical fertilizer, pig manure, and/or mulch (Table 3). Both PM and CF + PM + MU treatments resulted in significantly higher SOM (17.12 and 16.47 kg kg⁻¹, respectively) than all other treatments. Further, the SOM content in control and CF plots was the same as the initial SOM level (10.6 kg kg⁻¹) (Table 1), while the SOM content in CF + MU, PM, and CF + PM + MU treatments reached new equilibria that were 26.3, 61.5, and 55.4% higher, respectively, than the initial SOM level. Generally, intensive cropping causes a decline in SOM over time (Lal 1989b). In the present study, however, the SOM status in unfertilized plots showed no decline even after 11 years of cropping, apparently because of the low SOM equilibrium (10.6 kg kg⁻¹) in the experimental soil at the initiation of experiments in 1996. The hedgerow clippings may have helped to maintain the SOM level in control and CF treatments. In the PM and CF + PM + MU treatments, direct addition of organic matter from the farmyard manure increased the organic matter content (Benbi et al. 1998).

Soil physical properties

The percentage of >0.25 mm water stable aggregates (% WSA) in CF + PM + MU and PM treatments was about twice that of the control (Table 3). The % WSA was significantly higher when mulch was applied instead of chemical fertilizer (46.7 versus 36.6%, $P < 0.05$). Formation of water-stable aggregates was greater after addition of pig manure than after addition of chemical fertilizers (49.9 versus 36.6%, $P < 0.01$). Therefore, enhanced soil aggregate stability was consistent with greater input of organic matter. The organic matter stabilizes the aggregates by forming and strengthening bonds among clay domains and between quartz particles and clay domains (Tisdall and Oades 1982; Albiach et al. 2001). Moreover, mulch on the soil surface can decrease erosion, reduce evaporation, protect against raindrop impact, and increase

Table 3 Effects of soil management on selected soil properties

Soil properties	Control	CF	CF + MU	PM	CF + PM + MU	ANOVA <i>P</i> value
Bulk density (Mg m^{-3})	1.34a	1.30ab	1.26bc	1.24c	1.22c	0.04
Penetration resistance (kg cm^{-2})	1.81a	1.56b	1.17cd	1.38bc	1.07d	0.002
>0.25 mm WSA (%)	25.2c	37.7b	47.7a	49.9a	51.4a	0.003
Soil organic matter (g kg^{-1})	9.65c	11.67b	13.39b	17.12a	16.47a	<0.001
Total N (g kg^{-1})	0.64d	0.84c	0.92bc	0.95b	1.12a	<0.001
Total P (g kg^{-1})	0.55c	0.76b	0.85ab	0.82b	0.92a	0.002
Available N (mg kg^{-1})	44.7d	54.4c	62.6b	58.7bc	78.3a	<0.001
Available P (mg kg^{-1})	3.28c	4.78b	6.34b	9.58a	9.26a	0.005
Available K (mg kg^{-1})	115.2c	131.7b	138.9b	143.0ab	155.5a	0.03

MU, PM, and CF are wheat straw mulch, pig manure, and chemical fertilizer, respectively

Same letter(s) on same rows indicates non-significant difference ($P < 0.05$, LSD)

aggregate stability (Layton et al. 1993). The ability of soil organic matter to promote the formation of water stable aggregates has a profound effect on soil physical properties (Haynes and Naidu 1998). The bulk density (BD) in the control was significantly higher than in CF + MU, PM, and CF + PM + MU treatments (by 0.08, 0.10, and 0.12 Mg m^{-3} , respectively; Table 3). Bulk density did not differ significantly among CF + MU, PM, and CF + PM + MU treatments. The reduction in BD could be attributed to higher organic matter content of the soil, better aggregation and a consequent increase in the volume of micropores, and increased root growth in the manure-treated plots (Schjonning et al. 1994). Alongside the change in soil bulk density, the penetration resistance (PR) also decreased from 1.81 kg cm^{-2} in the control to 1.07 kg cm^{-2} in the CF + PM + MU treatment. Treated mulch had the lowest penetration resistance, and the PR of CF + MU and CF + PM + MU was 1.17 and 1.07 kg cm^{-2} , respectively. This may be partly attributed to the high soil moisture in the soil profile resulting from the reduced surface runoff and soil evaporation after mulch application. Soil moisture is the dominant factor influencing the force required to push a penetrometer into the soil, with PR increasing as the moisture content decreases (Shaw et al. 1942).

Soil chemical properties

Compared with the control, the other treatments showed significantly improved nutrient status in

the topsoil, with the highest values in the CF + PM + MU plot (Table 3). Mulch had no significant effect on accumulation of total N, while available N was 8.2 mg kg^{-1} higher in the CF + MU treatment than in the CF treatment. The major influence of treatments on soil N was probably related to the amount of fertilizer and pig manure applied (Table 2). Nitrogen, as nitrate or ammonium, is highly soluble and moves rapidly in runoff and in soil solutions, and thus available N increases with mulch. Total P did not differ between CF, CF + MU, and PM treatments, because P is relatively immobile in soils and does not move far from the application site (Cai et al. 1996). Although the differences were not significant, Table 4 shows high N and P concentrations in the mulch treatment. Straw mulch was rich in phosphorous and nitrogen; therefore, the amount of N and P in the soil is likely to increase. The high available P concentration was associated with greater input of organic matter. Levels of available P increased in the following order CF < CF + MU < CF + PM + MU < PM. Organic amendments can directly affect P availability via three mechanisms: (1) they can adsorb to soil minerals, and compete with P for adsorption sites; (2) they can complex with surface-bound aluminum or iron to form soluble organic-metal compounds substituting for, and releasing, previously adsorbed P; or (3) adsorb to soil particles at nonspecific adsorption sites, increasing the surface negative charge of the particle and resulting in reduced electrostatic attraction of P to the soil surface (Traina et al. 1986; Ohno et al. 2007).

Table 4 Soil nutrient conditions along slope under different soil management practices in a contour hedgerow system

Treatments	Slope position	Organic matter (g kg ⁻¹)	Total N (g kg ⁻¹)	Total P (g kg ⁻¹)	Available N (mg kg ⁻¹)	Available P (mg kg ⁻¹)
Control	Upper	7.75c	0.51c	0.49c	37.63c	2.42b
	Middle	9.36b	0.65b	0.56b	42.88b	3.31ab
	Lower	11.86a	0.76a	0.60a	53.53a	4.12a
CF	Upper	9.56c	0.72c	0.64c	45.72c	4.11c
	Middle	11.92b	0.86b	0.78b	56.10b	4.60b
	Lower	13.54a	0.98a	0.86a	61.41a	5.64a
CF + MU	Upper	12.80b	0.86b	0.79b	58.91b	6.04b
	Middle	13.05b	0.90b	0.86ab	62.68ab	6.37a
	Lower	14.32a	1.01a	0.91a	65.10a	6.54a
PM	Upper	15.69b	0.86b	0.69c	49.71c	7.78b
	Middle	16.29b	0.95b	0.84b	57.92b	8.67b
	Lower	19.38a	1.06a	0.99a	68.58a	12.28a
CF + PM + MU	Upper	15.91a	1.07a	0.85b	75.82b	8.72b
	Middle	16.22a	1.17a	0.93ab	78.94a	9.35a
	Lower	17.28a	1.15a	0.97a	80.22a	9.71a

MU, PM, and CF are wheat straw mulch, pig manure, and chemical fertilizer, respectively

Means within a column for the same treatment with the same letter (a–c) are not significantly different at $P = 0.05$

Available K in all treatments was at sufficient levels according to standards for classification and gradation of soil fertility in China (National Soil Survey Office 1992). Even control and CF treatments that had not received K fertilizer had adequate K levels, possibly because of the release of non-exchangeable K. Some studies in the Three Gorges Area showed that where K inputs were inadequate, the K needs of the crop were largely met from the non-exchangeable K fractions of the soil (Cai et al. 1996). In addition, available K increased in the treatments in which pig manure and straw mulch were added. Both these organic matters were rich in potassium (>20 g kg⁻¹), and the amount of potassium in the soil was likely to increase.

Soil deterioration indices

As the soil deterioration index reflects the percent changes in soil nutrients from their values in reference soil, it can be regarded as an indication of the degree of soil deterioration (or improvement). Values for SOM, TN, TP, and % WSA were included in this calculation according to results of our previous study in the Wangjiaqiao watershed and other studies conducted in the Three Gorges Area (Shi et al.

1999; He 2003; Li et al. 2004). The calculated soil deterioration indices are shown in Fig. 2.

Soils in the control had a significantly lower (i.e., negative) deterioration index (-19.3%) than the other treatments. In contrast, the deterioration indices for soils under CF + MU, PM, and CF + PM + MU

Fig. 2 Soil deterioration index for different treatments in contour hedgerow system (MU, mulch with wheat straw; PM, pig manure; and CF, chemical fertilizer)

treatments were positive (27.2–43.9%), which indicated that soil fertility had been significantly improved under these management practices. The deterioration index in the chemical fertilizer treatment was also positive (8.7%), but was not significantly different compared with the reference soil. These soil deterioration indices clearly showed that soil quality significantly deteriorated when the steeplands were planted in contour hedgerows. The main reason was that there was no input of fertilizer or manure, which resulted in deteriorated soil conditions that were unfavorable for vegetation growth. This resulted in a vicious cycle between soil and vegetation. Therefore, these soil deterioration indices clearly indicated that mulch and fertilizer/manure addition improve soil fertility in contour hedgerow systems.

Soil fertility spatial variation between hedgerows

Spatial variation in soil nutrients on terraces was found in various treatments, although the pattern and the magnitude of spatial variation were varied among treatments (Table 4). In general, soil fertility in the lower alley became more favorable compared with the upper alley due to the combined effect of water erosion and tillage practices, and due to the movement of fertile topsoil from the upper part of the alley to the lower part (Agus et al. 1999). There were significant differences in all soil properties along the slope in the control and CF treatments (Table 4). At the lower slope position in the control, organic matter increased by 53.0%, total N by 49.1%, total P by 22.4%, available N by 44.3%, and available P by 70.2% compared with values in the upper slope position. In the CF treatment, organic matter, total N, total P, available N, and available P in the lower slope position were increased by 41.6, 36.1, 34.5, 34.3, and 37.2%, respectively, compared with values in the lower slope position. Although there was a similar trend in soil nutrients along slopes in the control and CF treatments (Table 4), no significant differences were found in soil organic matter, total N, and available P between middle and upper slope positions under CF + MU and PM treatments. In contrast to the other treatments, the CF + PM + MU treatment resulted in the best distribution of soil nutrients along the slope. Soil organic matter and total N did not differ significantly among the different slope positions. Total P, available N, and available P did not

differ significantly between middle and lower slope positions (Table 4).

This study shows that addition of mulch and pig manure can alleviate the magnitude of spatial variations in soil fertility. Despite that fact that some differences were not statistically significant, soil nutrients were distinctly higher in the lower part of the alleys between hedgerows under the CF + PM + MU treatment (Table 4). The problem with the current fertilization practice is that the same dose of fertilizer and pig manure was applied over the whole alley, which resulted in insufficient application to the upper part and excess application to the lower part. In addition, the lower part would likely receive a part of the dose applied to the upper part after the next tillage operation, which would also increase spatial variability in soil fertility. Fertility gradients between hedgerows may also mean that alternative cropping practices could be employed within this soil conservation system (Walle and Sims 1999). The more fertile zone could be used for main crops, and the less fertile zone could be used for the production of secondary crops, for supplemental uses such as mulch or fodder, or fallowed to fit the farmers' needs.

Crop and hedge responses to soil fertility

Average crop yields and hedge production during the study year are shown in Fig. 3. Significantly lower

Fig. 3 Average crop yields and hedge production under long term soil management (MU, PM, and CF are wheat straw mulch, pig manure, and chemical fertilizer, respectively). Vertical bars represent standard errors, and bars followed by different letters are significantly different at $P < 0.05$

grain yields of both soybean and wheat were obtained in the control treatment, indicating the benefits of chemical fertilizer, pig manure, and/or mulch on crop performance. The CF + MU and CF + PM + MU treatments resulted in significantly higher grain yield of wheat compared with the CF treatment, but the difference in seed yield of soybean was not significant except in the control. Although the mean annual precipitation in the Wangjiaqiao watershed is approximately 1,010 mm, it has clear seasonal and interannual variations. The maximum annual precipitation reaches 1,350 mm, while the minimum was only 784 mm during the experimental period. Additionally, 70% of rainfall occurs between May and September. Therefore, water is also a principal factor in determining wheat yield, and mulch can significantly improve wheat yield due to its effects on increasing soil moisture. During the experimental period, hedge growth did not vary significantly among the experimental plots. This is likely because Vetiver grows well even at low soil fertility and under very dry conditions (Greenfield 1989).

Conclusions

The study showed the importance and benefits of long-term application of chemical fertilizer and pig manure alone or in conjunction with mulch. Chemical fertilizer clearly improves nutrient status in topsoil, while pig manure also increases the amount of soil organic matter. This increase in organic matter was associated with improved stability of soil aggregates, reduced bulk density, and reduced penetration resistance of the soil. Our results indicate that chemical fertilizer in combination with pig manure and mulch should form part of soil management practices in this intensively cultivated steep land region. Such management practices will result in better soil fertility and higher crop productivity. Further, mulch or pig manure can alleviate the magnitude of spatial variation, but cannot offset soil fertility gradients because tillage results in significant soil movement. More favorable soil properties were found at lower positions of hedgerow alleys, regardless of the different management practices.

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