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Improvement of water use efficiency under contour cultural practices on highland slopes in Thailand

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Abstract

The effects of selected contour cultural practices on soil and water conservation and crop water use efficiency were compared under a rainfed highland agricultural system. The field trial was conducted during 2000 and 2001 on a 35% hill slope (latitude 19°33'47" N, longitude 98°12'9" E, altitude 780 m) in Maehongson province, Northern Thailand. A completely randomized design, with four treatments and three replicates, used a cropping sequence of maize, followed by lablab bean, was conducted from May 2000 to April 2002. The treatments were (i) conventional contour planting, CC, (ii) contour ridge cultivation without mulching, CR, (iii) contour ridge cultivation with polythene sheet + straw mulch, INCOPLAST or CRP and (iv) alley cropping with mango-hedgerow tree and ground surface cover with Graham Stylo, AL. Soil water stored within 1700 mm was monitored every 2-3 weeks by neutron moisture meter. Runoff and erosion were measured after every rain storm. Soil sampling and analysis were conducted one month after sowing and one month before harvesting maize. Crop development was measured as total dry biomass at different growth stages and maize and lablab bean yields were harvested as total dry-matter and yields.

Results obtained during the two experimental years (2000-2001) showed that alley cropping (AL) was the most effective treatment in decreasing runoff and erosion, while CRP was the second best at erosion control. However, CRP had the highest rate of runoff and erosion under high intensity rainfall during the early growing season. Generally, CRP protected the soil surface from the splash erosion and had better soil physical properties, leading to the highest crop water use efficiency, and had the highest growth rate of Lablab bean. Crop yields under CRP and AL were relatively high and comparable compared with either CC or CR during the dry seasons of both years.

Keywords: Alley cropping, INCOPLAST, soil loss, runoff, water use efficiency, soil water evaporation

Introduction

Many strategies can improve crop water use efficiency under tropical/subtropical rainfed-highland farming systems. Practical methods to decrease runoff and erosion include contour ridge cultivation, alley cropping along the contour and mulching with crop residues and polythene. In South China, contour ridge cultivation with polythene sheets increased maize yield by ~30% compared with contour ridge without mulching. However, this practice caused more runoff and erosion, compared with straw mulch (Fullen *et al.,* 1997). Hence, integrated contour cultivation, plastic and straw mulch treatment (INCOPLAST) was introduced in field and plot studies in South China in 1998. All contour ridge cultural practices are labour intensive, requiring annual reconstruction of ridges, and do not necessarily sustain soil productivity.

For over 20 years, sustainable crop production on sloping land has focussed on erosion control using hedgerow barrier technology. The gradual development of terraces in these systems catches up with mechanically constructed terraces within 4-5 years and is less laborious and costly than mechanical terrace construction (Kiepe, 1995). Furthermore, in Northern Thailand, alley cropping systems have been accepted as the most practical and economical strategy to reduce soil erosion, maintain soil fertility and suppress weeds. Many studies have shown that erosion rates associated with alley cropping are <50% than conventional systems (Boonchee *et al.*, 1997).

Studies on changes in water use efficiency under contour cultural practices on highland slope farming systems was carried out as a subproject of the four-year (1999-2002) 'Sustainable Highland Agriculture in South-east Asia (SHASEA)' Project. The main aims of the overall project were to develop the best strategies to improve crop production for sustainable highland agriculture. This subproject was carried out in Northern Thailand, to evaluate the effects of different contour ridge cultivations on soil and water conservation and sustainable crop production. This paper presents field results obtained in 2000 and 2001, which compared the effects of four contour cultural practices on crop water use efficiency through changes in (i) soil properties, (ii) runoff and erosion and (iii) available soil water storage.

Materials and Methods

Location and experimental design

The experimental plots were located on a 35% hillslope (latitude 19°33'47" N, longitude 98°12'9" E, altitude 780 m) in Maehongson province, Northern Thailand. The plots were established and used for alley cropping experiments during 1988-1994 by the co-operative project between the Department of Land Development (DLD) and the Thai-German Highland Development Project (TG-HDP). The DLD used the plots for upland rice and general crop production during 1995-1998.

The experiment is a completely randomized design consisting of 12 plots with 3 replicates of 4 treatments. The treatments are: (i) conventional contour planting as the control, CC, (ii) contour ridge cultivation, CR, (iii) contour ridge cultivation with polythene sheet mulch on the ridge and rice straw mulch in the furrows, INCOPLAST or CRP, (iv) alley cropping with mango-hedgerow tree and surface cover with Graham Stylo (*Stylosanthes guianensis*), AL. The cropping sequence consisted of maize (*Zea mays*), followed by lablab bean (*Lablab purpureus*).

Plot preparation and crop sowing

Twelve 6x40 m (240 m^2) plots were constructed on the 35% slope, with concrete collection tanks at the down-slope end. Plots were prepared in May, 2000 and 2001. Each double ridge was 780 mm wide and 250 mm high, with 780 mm spacing and was constructed according to methods used in South China. Double ridges in six cultivated plots were prepared along the contour. In the CRP treatment, the ridges and furrows in three plots were mulched with polythene sheets and rice straw, respectively (INCOPLAST). The other three plots had contour double ridges without mulch (CR treatment). The alley cropping plot was prepared by dividing each of three cultivated plots into four sections of 10 m length down the slope. Each section comprised of 9 m lengths of the main cash crop and 1 m width of mango hedgerow tree with ground surface cover of Graham Stylo (*Stylosanthes guianensis*), planted in 1999. The conventional contour planting or control (CC) was prepared in the plots with peach trees without any ground surface cover. This CC is similar to the farmers' traditional practices.

Maize (Hybrid variety No. 888) was sown in each plot on 10-15 and 15-20 May, 2000 and 2001, respectively, at the sowing rate of 4 seeds per pit, with 450 mm plant spacing. Fertilizer was applied as a seed-bed in each sowing pit as 5.356 kg Urea and 5.356 kg 15-15-15 mixed fertilizer per plot (8+8 g pit^{-1}, or 227+227 kg ha^{-1}) for both experimental years. Maize seedlings were removed, leaving only 2 plants per each pit, 10 days after emergence. The second fertilizer was applied 45 days after sowing at the same rate for both years. Lablab bean was sown on the same row of maize between maize pits with the same spacing as maize, by direct drilling or pitting using a hand hoe and without fertilizer application. The sowing date was two weeks before maize harvesting for both years.

Measurement and calculation

Soil sampling and field measurements of soil properties were conducted twice, one month after sowing and one month before harvesting maize. The composite and eight undisturbed soil samples were taken from each plot at 0-150 and 150-300 mm depths. Measured soil properties included bulk density (BD), field capacity (FC), aeration porosity (AP), stable aggregates based on total soil mass (SAT), mean weight diameter of stable aggregate (MWD), steady infiltration rate (IR), soil pH, total nitrogen (N), extractable phosphorus (P), extractable potassium (K) and organic matter content (OM). For these, standard analytical methods were employed.

Runoff and erosion were measured after each rain-storm throughout both growing seasons. Runoff from each plot was firstly collected into a 200 L capacity sedimentation tank, to trap coarse sediments. Overflow was trapped in the second 200 L side tank. Runoff depth in each tank was measured and then thoroughly mixed with a physical agitator. A 300 mL aliquot of the soil suspension sample was taken from each sedimentation tank and evaporated, to calculate sediment lost per litre of runoff and thus total sediment amount.

Soil water content (θ) was measured every two to four weeks by neutron moisture meter down the soil profile up to 1.5 m depth. Measurements were taken at 200 mm depth increments once a month during the growing season and total stored soil water (TSW) calculated as equivalent depth of water (mm) within the 1.7 m soil depth.

Maize yield was harvested as total above-ground dry biomass from two rows of 1.8 m length for each section of sub-plots. Total plant sample (32 plants plot^{-1}) were dried at 55°C for three days. Seed and cob yields were calculated both as dry weight per unit sowing area and per plot. Maize yield was also harvested from the whole plot. Maize was harvested as total dry biomass, seed and cob and seed on 20 and 30 September 2001. Lablab bean was harvested during 5-10 March 2000 and 3-5 March 2001. Water use efficiency of lablab bean was calculated by dividing total dry biomas and yields by the actual crop evapotranspiration throughout the dry growing season.

Results and Discussion

Effects of cultural practices on soil properties

Only soil physical analyses obtained during 2000-2001 are reported. CRP, (INCOPLAST) had the lowest bulk density values (BD) and the highest values of aeration porosity (AP), stable aggregates (SAT), mean weighted diameter (MWD) and steady infiltration rate (IR), compared to the other treatments for both experimental years (Table 1). These surface soil (0-150 mm) physical properties varied with maize growth stage and rainfall conditions.

FC and AP values tended to increase in 2000, but decreased in 2001, while SAT, MWD and IR values tended to increase from vegetative stage (A) to yield formation stage (B) under most treatments for both years. The highest values of SAT (25.1, 23.9%) and IR (32.9, 53.3 cm h^{-1}) were found under the CRP treatment, indicating better soil structure than other treatments.

Effects of cultural practices on surface runoff and soil loss

Almost all runoff occurred during the rainy season (Figures 1a, 1b), while erosion rates were high during the early to mid rainy season in both years (Figures 1c, 1d). The loosened soil structure after soil preparation in the early growing season was more susceptible to erosion compared to the compacted surface soil. This was largely due to raindrop impact during the mid-late rainy season. Furthermore, the increased canopy development during maize flowering to maturity also helped to decrease erosion during the mid rainy season. However, the high rainfall intensities during the late growing season also caused considerable erosion, due to less canopy cover.

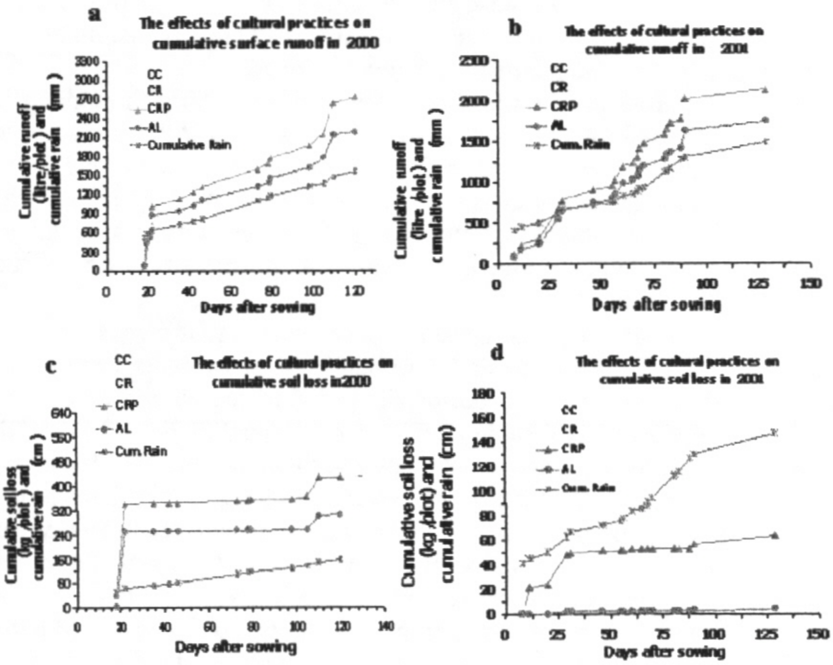

Figure 1 Cumulative surface runoff (a and b) and cumulative soil loss (c and d) as influenced by CC, CR, CRP and AL and growing season rainfall in 2000 (a and c) and 2001 (b and d).

CC tended to yield most runoff and erosion in 2000 (122 m^3 ha^{-1} and 23 t ha^{-1}, respectively). However, these values were not significantly different from CR or CRP. The highest soil loss was from the CR treatment during seedling to flowering stage of maize growth in 2001, due to the loosened soil of the ridges. CRP tended to yield most runoff and erosion under high rainfall intensity (30 mm d^{-1}) during the three weeks after maize sowing in both years. This was caused by cascading of runoff from the polythene sheets, leading to higher runoff. Loosened soil was used to fix polythene sheets on the ridges and was easily washed downslope in the early growing season. Erosion markedly decreased after the loosened soil layer was improved by root development, increased infiltration rate and protected by the crop canopy.

The lowest runoff values (91 m^3 ha^{-1} in 2000 and 72.3 m^3 ha^{-1} in 2001, respectively) and erosion (13 t ha^{-1} in 2000 and 0.16 t ha^{-1} in 2001, respectively) were obtained under AL. This indicates that AL was the most effective cultural practice to conserve soil and water. CRP was able to reduce erosion under low rainfall intensity, but induced high runoff and erosion rates under high rainfall intensity, especially on steep slopes.

Table 1 Mean soil properties on different cultural practices 1 month after sowing (A) and 1 month before harvesting (B) during both growing seasons.

Surface Soil Properties (0-150 mm)	Conventional Cultivation (CC)		Contour Ridge (CR)		Contour Ridge, Polythene + Straw Mulch) (CRP)		Alley Crop (Mango + Graham Stylo (AL)		Lsd Lsd * *(P < 0.05)	
	A = After sowing				B = Before harvesting					
	A	B	A	B	A	B	A	B	A	B
Bulk Density (BD), mg m^{-3} 2000	0.88	0.86	0.84	0.87	0.85	0.90	0.83	0.90	ns	ns
2001	0.81b	0.80b	0.75b	0.75b	0.67a	0.68a	0.80b	0.84b	0.08	0.07
Field Capacity at 0.1 bar (FC), %v/v 2000	34.2	37.1a	33.7	41.5b	31.3	42.0b	32.9	41.0b	ns	3.0
2001	35.0b	32.5b	33.5b	32.1b	29.1a	28.2a	34.8b	34.1b	3.8	3.2
Aeration Porosity (AP) % v/v 2000	28.3ab	25.0b	31.0b	23.6ab	26.0a	21.8a	27.1a	22.4a	2.9	2.1
2001	32.3a	35.3b	35.7b	36.3b	43.7c	42.7c	32.6a	31.6a	*3.4*	3.2
Aggregate stability (SAT) 2000	19.1	18.3a	17.7	17.3a	18.9	25.1b	19.2	22.6b	ns	3.8
2001	17.6a	21.5a	19.4ab	21.2a	21.2b	23.9b	19.2ab	25.4b	2.8	2.2
Mean Weighted Diameter (MWD), (mm) 2000	3.2b	3.6	3.3b	3.7	2.7a	3.9	2.9ab	3.8	0.5	ns
2001	3.9b	3.8	3.3a	3.8	3.6ab	3.8	3.4a	3.7	0.4	ns
Steady Infiltration Rate, (IR), cm hr^{-1} 2000	19.8	25.4a	23.6	24.3a	22.9	32.9b	21.8	27.1a	3.2	4.2
2001	29.2a	38.9a	44.2c	43.4b	48.3c	53.3c	39.0b	42.7b	4.2	4.0

Lsd is the least significant differences of the means for comparison at $P<0.05$ (*)
a-d represent differences between the means

Effects of cultural practices on soil water storage

Water stored within the soil profile to 1.7 m depth during the fallow to crop growing period (maize followed by lablab bean) was affected by cultural practices. Results obtained in 2000 were similar to those obtained in 2001. Figure 3 presents the 2001 results only (January 2001 to March 2002). The soil profile of each plot was filled with rain water to holding capacity during the first two months of maize growth. Rainfall during the flowering to ripening stages (two months after sowing) was insufficient to maintain full storage capacity and there was less stored soil water during the mid to late growing season.

CRP tended to have most stored soil water during both the growing seasons of maize and lablab bean in both 2000 and 2001, due to impeded evaporation. Significantly higher amounts of soil water was stored under CRP during the dry cropping season (lablab bean after maize harvest), a conclusion supported by the soil water evaporation results (data are not presented).

Effects of cultural practices on crops and water use efficiency

Generally, AL and CRP had greater crop development during flowering to yield formation stages, compared with either CC or CR (data not presented). In 2000, maize yields per sowing area were highest on AL (9.5 t ha^{-1}, excluding the hedgerow), compared with CC, CR and CRP (7.6, 6.8 and 7.8 t ha^{-1}, respectively) (Table 2). In 2001, the best maize development and highest yields were obtained from the AL plots. The second best crop yield was from the CRP plots. CC and CR gave the lowest yields. All the practices gave significantly higher dry yields (seed, cob and seed and total dry biomass) than the local farmers' (Figure 3). However, when maize yields were harvested from the whole plots, maize yield (cob+seed) per plot from CRP and AL were almost equal and were significantly higher than both CC and CR. This confirms that AL and CRP were not significantly different in their effect on maize yields.

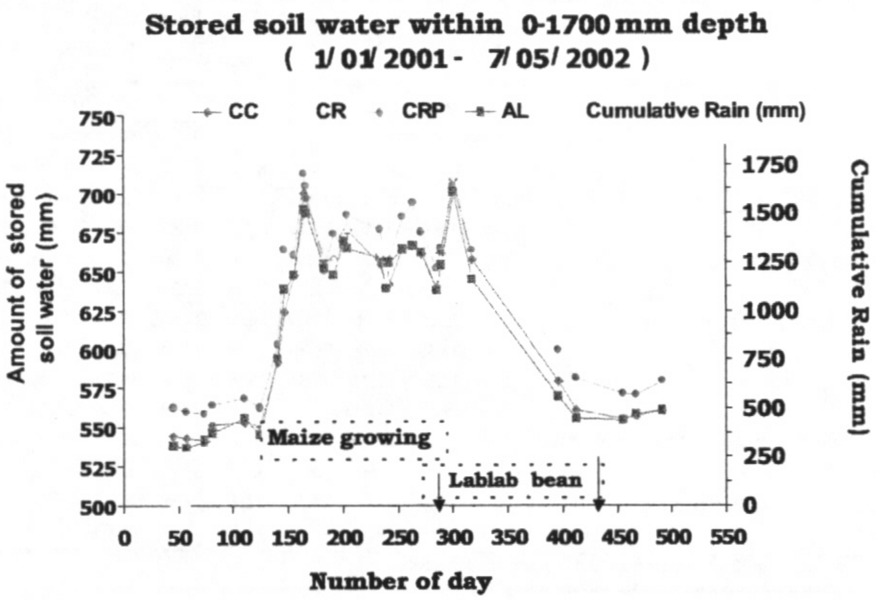

Figure 2 The effects of different cultural practices on crop water use (evapotranspiration, ET) and soil water storage.

Figure 4 shows biomass development of lablab bean grown after maize in 2001. The highest biomass development was on CRP plots, while the least was on CR plots. AL tended to have higher dry matter amounts than CR or CC. These results were similar to those obtained in both 2000 and 2001 (Table 2) and confirmed that CRP and AL were the best and the second best practices, respectively. CR was the poorest practice compared with CC, in terms of improving crop yields during the dry season.

CRP tended to be the best cultural practice during the dry period after the rainy season, due to higher stored soil water within the root zone and decreased evaporation.

Table 2 Mean values of dry weight of total biomass, seed, seed and cob yield of maize and lablab bean on different cultural practices during the 2001 growing season.

Cultural Practices		CC		CR		CRP		AL	
Maize		2000	2001	2000	2001	2000	2001	2000	2001
Dry Seed Yield	(t ha^{-1})	7.6b	6.2a	6.8a	6.7a	7.8b	9.1b	9.5c	9.9c
Dry Cob & Seed	(t ha^{-1})	9.0b	7.5a	8.0a	8.1a	9.2b	11.0b	11.1c	11.9c
Total Dry Biomass	(t ha^{-1})	15.2b	15.1a	13.7a	18.2b	16.0c	23.1c	18.0d	26.9d
Lablab Bean									
Dry Seed Yield	(kg ha^{-1})	182b	272b	149a	224a	251d	376d	213c	320c
Dry Pod & Seed	(kg ha^{-1})	259b	388b	204a	306a	346d	519d	286c	429c
Total Dry Biomass	(t ha^{-1})	1.35b	2.02b	0.74a	1.12a	1.92d	2.88d	1.58c	2.38c

a, b, c and d represent differences between the means

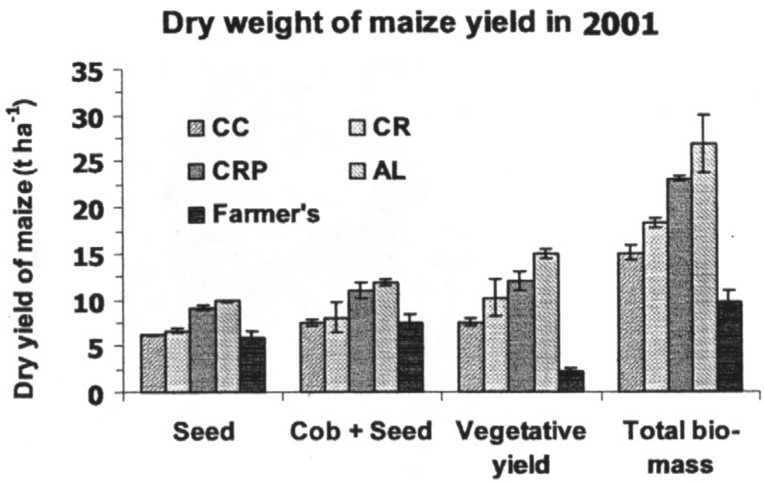

Figure 3 The influences of CC, CR, CRP and AL on dry yields and total dry biomass of maize per unit sowing area, in 2001.

Figure 5 shows that AL and CRP gave equal values of crop water use efficiency (WUE) in 2000, while the lowest WUE value was under CC. In 2001, the highest WUE values during the dry period was under CRP. AL gave the second highest WUE-value, while the lowest was CR. These results corroborated the improved soil properties (Table 1), the decreased runoff and erosion (Figure 2) and the higher stored soil water during the dry period (Figure 2). All these conditions might support better lablab bean development under CRP, leading to the highest yields and water use efficiency.

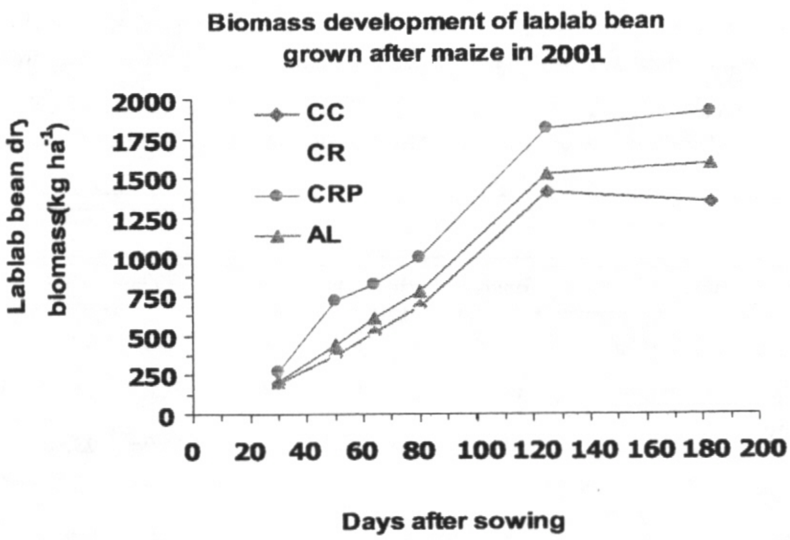

Figure 4 The influences of CC, CR, CRP and AL on the development of total dry biomass of lablab bean in 2001.

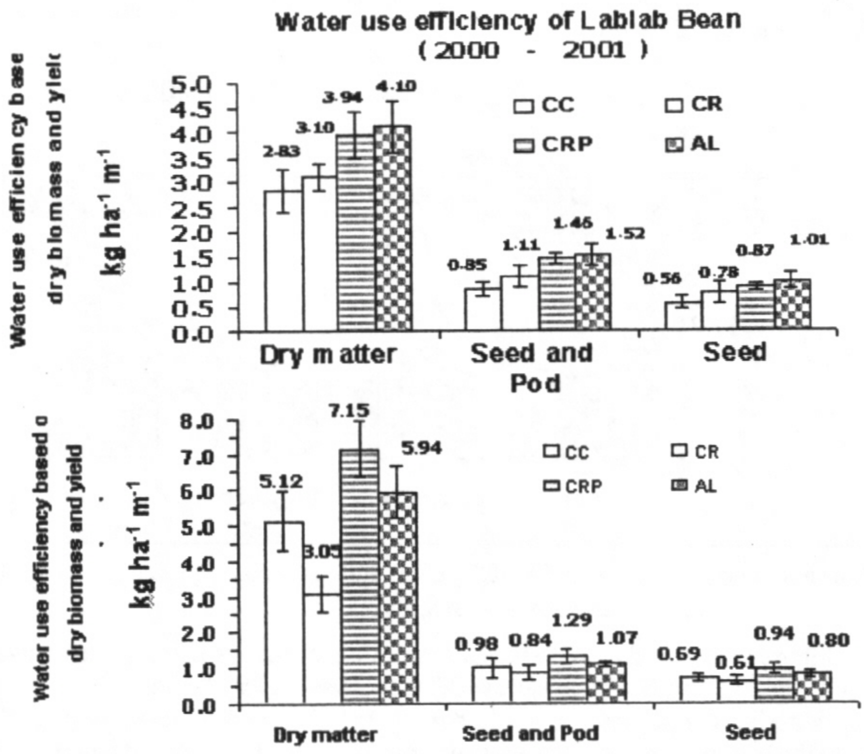

Figure 5 The influences of CC, CR, CRP and AL on water use efficiency, based on total dry biomass and dry yields of lablab bean in (a) 2000 and (b) 2001.

Conclusion

CRP maintained or improved soil properties. CRP could not prevent runoff under intense rain during the early growing season. Most soil water was stored under CRP and least under AL. AL had least runoff and erosion, due to the hedgerow barrier, which indicated it was the most conservative method. AL and CRP had equal highest maize yields.

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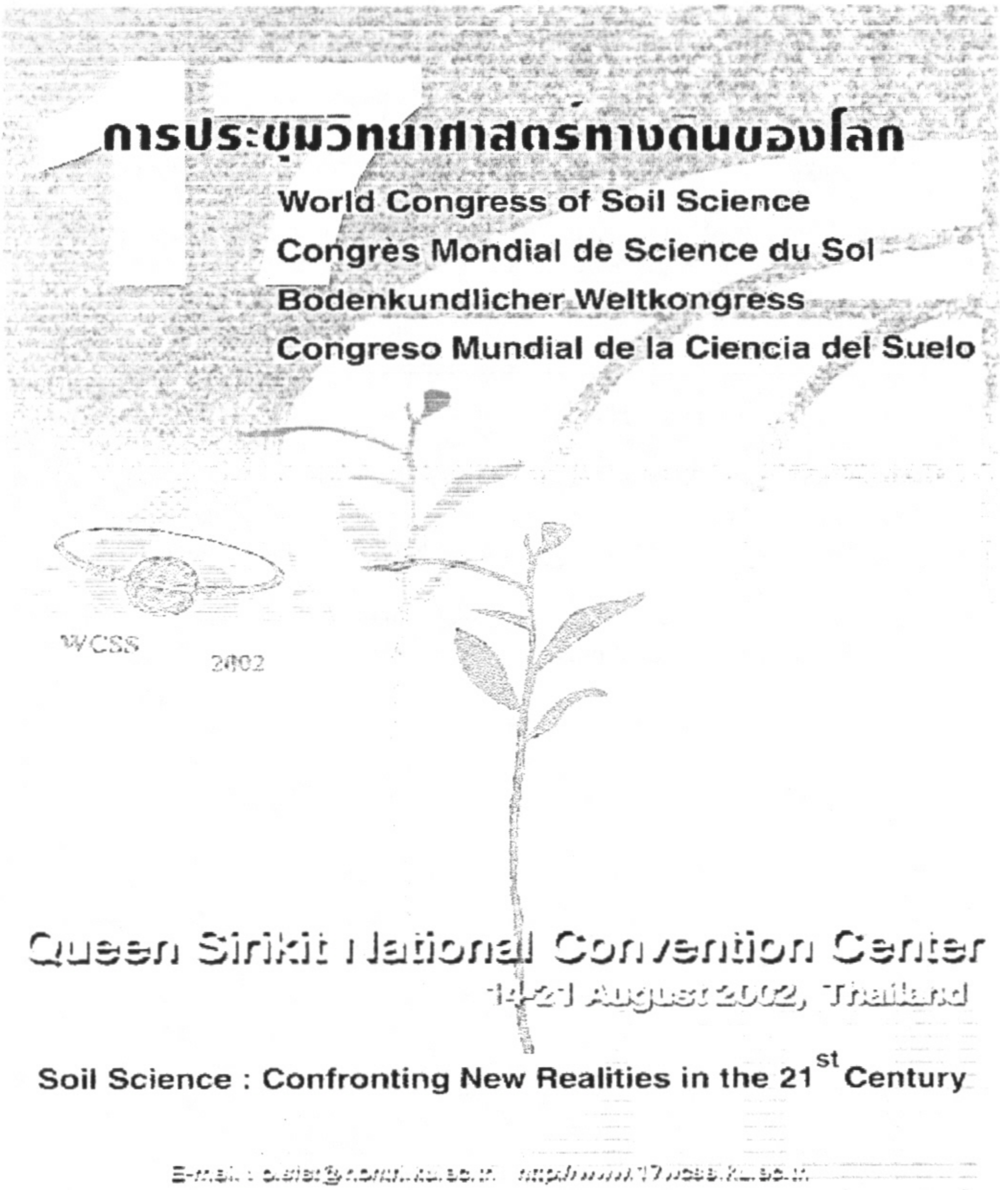
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