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Effects of intercropping and nitrogen application on nitrate present in the profile of an Orthic Anthrosol in Northwest China

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Abstract

Accumulation of nitrate in soil increases the risk of nitrate leaching and hence ground-water nitrate pollution. The impact of intercropping on nitrate accumulation in soil has been little studied in China. This field study integrated wheat (*Triticum aestivum*)/maize (*Zea mays*) and maize/faba bean (*Vicia faba*) intercropping systems to assess effects of intercropping on nitrate accumulation in the profile of an alkaline soil under various application rates of N and P fertilizers in 2000. The study was conducted in Gansu Province, China. Grain yields of wheat were significantly enhanced by P fertilizer and intercropping. In the maize/faba bean system, grain yields of maize were enhanced by N fertilizer while those of maize intercropped with wheat were improved by both N and P fertilizers. Grain yields of faba bean were not affected by fertilization or cropping system. Nitrate accumulation in soil was positively related with application rates of N fertilizer. The amounts of NO_3^- present in soil after wheat harvest was greatest under wheat planted alone, followed by intercropped wheat, faba bean planted alone, intercropped faba bean, maize intercropped with faba bean, and least under maize intercropped with wheat. Amounts of NO_3^- in soil after maize harvest was in the order of wheat or faba bean planted alone, intercropping wheat and faba bean, maize intercropped with faba bean and wheat. The results suggest that intercropping decreases the accumulation of nitrate in the soil profile. The study also showed that combined application of organic materials and N fertilizer decreased nitrate accumulation compared with application of N fertilizer alone.

Keywords: Wheat; Maize; Faba bean; Intercropping; Nitrate

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1. Introduction

Intercropping has been practiced in China for 2000 years. Wheat/maize and maize/faba bean systems were introduced to Gansu Province in the 1960s and they proved to be an efficient way to resolve the conflict between ever increasing population and gradually decreasing area of arable lands. Though there are many studies about cereal/cereal and cereal/legume cropping systems, most of them are focused on the complementary and competitive interactions above-ground between crops in maize/cowpea (Watiki et al., 1993), wheat/maize and wheat/soybean intercropping systems (Li et al., 2001a,b); and positively below-ground interactions between intercropped species (Li et al., 1999, 2003a). Previous studies showed that there were significant yield advantages of intercropping both for faba bean/maize intercropping systems, with land equivalent ratio values of 1.21–1.23 based on total (grain + straw) yield and 1.13–1.34 based on grain yield (Li et al., 1999). For wheat/maize intercropping systems, land equivalent ratio values were 1.21–1.58 based on grain yields (Li et al., 2001a).

There has been a rapid increase of fertilizer application in recent years to achieve high yields. The average rate of N application in China is 180 kg N ha^{-1}, while that in North China is 500 kg N ha^{-1}. In the irrigated area of Northwest China, the application rates of N fertilizer application average 450 kg N ha^{-1}, which would increase the risk of ground-water nitrate pollution. On the other hand, nitrate accumulation in the soil profile would reduce the utilization efficiency of applied nitrogen fertilizer. Intercropping faba bean with oats or spring wheat could reduce the nitrate accumulation in soil profiles (Stuelpnagel, 1993). Intercropping maize with ryegrass is also an effective way for increasing N uptake under conditions of high N application (Zhou et al., 2000).

Previous studies investigated yield advantage and interspecific interactions on nutrient uptake in wheat/maize or wheat/soybean strip intercropping (Li et al., 2001a,b; Li et al., 2003a,b). The Objective of this field study was to examine whether wheat/maize and faba bean/maize associations, two popular intercropping systems, could decrease nitrate accumulation in soil profile under N and P fertilization.

2. Materials and methods

2.1. Study area

The field experiments were conducted in 2000 at the Baiyun experimental site of the Institute of Soils and Fertilizers, Gansu Academy of Agricultural Sciences. The site (38°37′N, 102°40′E) is located 15 km north of Wuwei city, Gansu Province, at an altitude of 1504 m above the sea level and with the relative humidity of 53%. Annual mean temperature is 7.7 °C. The average cumulative temperature above 10 °C per year is 3016 °C and that after wheat harvest is 1350 °C. The frost-free period is 150 days. The duration of sunlight is 3034 h and total solar radiation is 5988 MJ m^{-2} $year^{-1}$. The precipitation is 150 mm with an evaporation capacity of 2021 mm. The area is classified as typical arid climate area. The site has been described in some detail in a previous paper (Li et al., 2001a,b). The soil in the experimental site was an alkaline (pH 8.8) Orthic Anthrosol (Institute of Soil Science, CAS, 2001) and contained 19.1 g organic matter, 1.18 g total N, 17.3 mg Olsen-P, and 233 mg exchangeable K kg^{-1} dry soil. Soil NO_3–N concentrations before crop sowing were 14.8, 7.0, 4.5, 5.8 and 2.7 μg g^{-1} for 0–20, 20–40, 40–60, 60–80 and 80–100 cm of soil layers, respectively. The NH_4–N concentrations in soil for the above different layers were 1.2, 0.8, 1.2, 1.4 and 0.8 μg g^{-1}. Proportion and

Table 1
Particle distribution of an Orthic Anthrosol by soil depth (Soil Survey in Gansu, 1993)

Soil layers (cm)	Proportions (%) of soil particles (nominal size, mm)					Texture
	>2.0	2.0–0.2	0.2–0.02	0.02–0.002	<0.002	
0–20	2.75	41.5	23.5	22.5	12.5	Sandy loam
20–60	1.75	29.0	27.8	27.0	16.2	Sandy clay
60–130	3.20	26.0	29.4	27.8	16.8	Sandy clay

distribution of soil particles in the soil profile are presented in Table 1 (Soil Survey in Gansu, 1993).

2.2. Cropping system × fertilization

The experimental design was a split–split-plot with three replicates in which the main plot was N (0, 100, 200, 300 and 400 kg N ha^{-1}, as NH_4NO_3). The sub-main-plot treatments were P (0 and 33 kg P ha^{-1}, as triple superphosphate). Sub-plot treatments included sole spring wheat (*Triticum aestivum* cv. "8354"), sole faba bean (*Vicia faba* cv. "Linxia Dacandou"), maize (*Zea mays* cv. "Zhongdan No. 2")/wheat intercropping, and maize/faba bean intercrop as shown in Fig. 1.

All plots had an area of 41.5 m^2. Sole wheat consisted of 16 rows while sole faba bean was made up of eight rows. Maize in both maize/wheat intercrop and maize/faba bean intercrop included two rows. Five rows of wheat and three rows of faba bean constituted the intercropped system with maize (Fig. 1). Plant density was 675 splant m^{-2} for sole wheat and 12.5 plant m^{-2} for sole faba bean. The intercropped area of wheat and faba bean occupied three-seventh of wheat/maize and three-fifth of maize/faba bean, respectively. The density was therefore 288 plant m^{-2} 2 for intercropped wheat and 7.5 plant m^{-2} for intercropped faba bean. Accordingly, the densities of maize intercropped with wheat and with faba bean were 7 and 5 plant m^{-2}.

Seeds were sown on 20 March for wheat and faba bean and 9 April for maize. Crops were harvested on 15 July, 1 August and 25 September for wheat, faba bean and maize, respectively. The residues of wheat and faba bean were left in the soil. All P fertilizers and 100 kg N ha^{-1} (no N fertilizer for N_0 treatment) were uniformly broadcasted and plowed into soil before sowing. The rest of the designed fertilizer rates were top-dressed at the stem elongation stage of wheat for sole wheat and sole faba bean, and at the pre-tasseling stage of maize for intercropping treatment. Irrigation was carried out on 24 April, 20 May, 15 June, 10 July, 1 August and 3 September for all plots, respectively, with each irrigation being 70 mm.

2.3. Data collection and analysis

The plants in the microplots were harvested at maturity and the yield and biomass were recorded. Soil in each subplot, regardless of cropping systems, was sampled from 0 to 100 cm at the N_0P_{75}, $N_{200}P_{75}$, $N_{400}P_{75}$ treatments, in depth intervals of 0.20 m when crops were harvested on 15 July for wheat, 1 August for faba bean and 25 September for maize, in each subplot of cropping systems. The concentration of NO_3^- in soil was determined using ACS (TRAACS2000) after 1 M KCl extraction (soil to extract ratio is 1 to 2) for 30 min according to the procedure of Emteryd (1989).

Total amount of NO_3^- (kg ha^{-1}) presented in soil profiles (0–100 cm) were calculated according to the

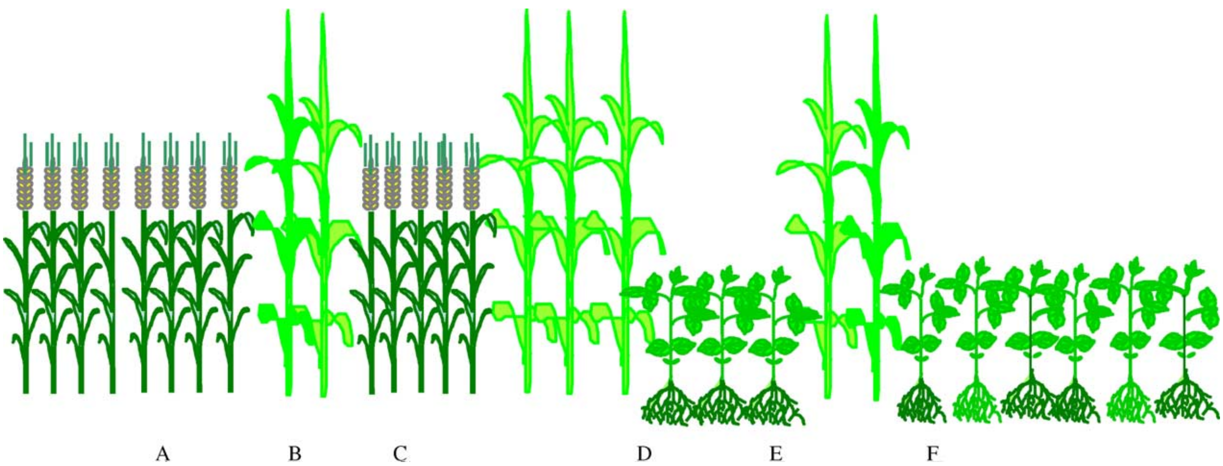

Fig. 1. Arrangement of wheat, maize and faba bean: (A) sole wheat; (B) maize intercropped with wheat; (C) wheat intercropped with maize; (D) faba bean intercropped with maize; (E) maize intercropped with faba bean; (F) sole faba bean.

equation (Emteryd, 1989):

$$Y = \sum T_i \mathrm{BD}_i [\mathrm{NO}_3^-]_i \quad (1)$$

where T_i is the thickness of each layer in cm, BD_i the bulk densities in g cm^{-3} and $[NO_3^-]_i$ the soil NO_3^- concentration in mg kg^{-1}. The bulk density was 1.33 g cm^{-3} in top soil (0–20 cm) and 1.40 g cm^{-3} in deeper soil layers (20–100 cm).

Statistical significance of difference between treatments was analysed by analysis of variance (ANOVA) and LSD (least significant deviation) multiple comparison (SAS institute, 1985).

3. Results

3.1. Grain yield

The grain yield of wheat was not influenced by N fertilizer, but increased by P fertilizer and intercropping (Table 2). Compared with P_0 treatment, the average grain yield of wheat that received 75 kg P ha^{-1} was 13% higher. In general, intercropping with maize evidently enhanced the grain yield of wheat regardless of N and P fertilization, the average grain yield of wheat under intercropping was 1.2 times as much as that of monoculture. In contrast to wheat, application of N and P fertilizers and cropping system had no obvious effects on the grain yield of faba bean (Table 2).

Nitrogen application increased the grain yield of maize significantly when intercropped with wheat. Where 200 kg N ha^{-1} was applied, the yield was 1.9 times as much as that of N_0. Further increasing N application rates did not further increase the yield (Table 3). Phosphorus fertilization enhanced the yield of maize when intercropped with wheat but not when intercropped with faba bean (Table 2). Furthermore, the yield of maize intercropped with faba bean was higher than that of maize intercropped with wheat, especially under N_0P_0 and $N_{100}P_0$ conditions.

Table 2
Grain yields (t ha^{-1}) of wheat and faba bean grown with various application ratio of N and P fertilizers under monoculture and intercropping with maize

N applied (kg N ha^{-1})	P (0 kg P ha^{-1})		P (33 kg P ha^{-1})	
	Monoculture	Intercropping[a]	Monoculture	Intercropping
Wheat				
0	3.96	5.81	4.79	5.57
100	3.76	4.66	4.16	6.27
200	4.80	4.81	4.26	4.74
300	3.54	4.76	4.50	5.37
400	3.48	4.41	5.22	4.74
N fertilizer	NS[b]			
P fertilizer	*			
Cropping	**			
Faba bean				
0	6.71	7.15	8.93	6.54
100	5.20	5.37	5.79	5.72
200	5.37	5.19	6.33	4.63
300	3.65	4.32	5.44	4.74
400	6.03	6.08	8.53	5.98
N fertilizer	NS			
P fertilizer	NS			
Cropping	NS			

[a] Values are yields of intercrop crops on equivalent basis which is comparable land area to sole cropping systems.
[b] NS refers to no significant difference between treatments at 0.05 level.
* Significant difference between treatments at 0.05 level.
** Significant difference between treatments at 0.01 level.

Table 3
Grain yields (t ha^{-1}) of the maize intercropped with wheat and faba bean under different N and P application rates[a]

Rate of N application	Intercropped with wheat		Intercropped with faba bean	
	P (0 kg P ha^{-1})	P (33 kg ha^{-1})	P (0 kg P ha^{-1})	P (33 kg ha^{-1})
0	5.58	7.90	9.31	9.43
100	9.94	12.04	12.97	12.67
200	12.86	12.47	14.39	13.33
300	10.92	13.31	12.53	13.56
400	11.76	11.63	11.53	14.19
LSD (P = 0.05) and significance levels				
N fertilizer	**		*	
P fertilizer	*		NS[b]	
Cropping		**		

[a] Values are yields of intercrop crops on equivalent basis which is comparable land area to sole cropping systems.
[b] NS refers to no significant difference between treatments at 0.05 level.
[*] Significant difference between treatments at 0.05 level.
[**] Significant difference between treatments at 0.01 level.

3.2. Soil nitrate distribution

At the time of wheat harvest where no N was applied, there was no difference in nitrate concentration in soil profiles between intercropping and monocropping, regardless of crop species (Table 4). When 200 kg N ha^{-1} was applied, the nitrate concentration in 80–100 cm under intercropped wheat was significantly higher than that under sole wheat. When 400 kg N ha^{-1} was applied, the nitrate concentration in 40–60 and 60–80 cm of profiles under monocropping wheat was 12.1 and 26.9 mg kg^{-1}, respectively, and significantly higher than that under intercropping. As for faba bean, there was no distinct difference of nitrate

Table 4
Effect of intercrop on nitrate concentration in soil profile (0–100 cm) under N application conditions after wheat harvesting

Depth	N_0 (0 kg N ha^{-1})		N_2 (200 kg N ha^{-1})		N_4 (400 kg N ha^{-1})	
	Sole	Intercrop	Sole	Intercrop	Sole	Intercrop
Wheat						
0–20	1.7 c[a]	1.5 c	2.2 b	2.6 ab	2.5 a	2.5 a
20–40	1.5 c	1.4 c	2.6 b	2.4 b	3.0 ab	3.5 a
40–60	1.3 b	1.4 b	3.4 b	2.8 b	12.1 a	3.5 b
60–80	0.8 b	1.4 b	1.9 b	4.6 b	26.9 a	8.9 b
80–100	0.9 c	1.0 c	2.5 c	4.6 bc	8.9 ab	9.5 a
Faba bean						
0–20	1.1 ab	0.8 b	1.5 ab	1.2 ab	1.0 b	2.9 a
20–40	1.2 c	1.2 c	1.6 b	1.5 b	1.5 b	1.9 a
40–60	1.0 b	1.0 b	2.2 ab	1.2 ab	2.6 a	2.7 a
60–80	0.8 b	1.3 b	3.0 b	1.3 b	7.4 a	6.5 a
80–100	1.0 c	1.6 bc	3.2 b	2.6 bc	7.6 a	8.9 a
Maize	With wheat	With faba bean	With wheat	With faba bean	With wheat	With faba bean
0–20	0.8 c	0.7 cb	1.0 ab	1.0 ab	1.2 a	1.1 a
20–40	0.8 c	0.9 cb	1.1 abc	1.1 abc	1.4 ab	1.3 a
40–60	0.7 b	1.0 b	0.8 b	1.1 b	2.0 a	1.7 a
60–80	0.7 b	1.0 b	0.7 b	1.2 ab	2.6 a	2.4 a
80–100	0.6 c	0.9 bc	0.9 bc	2.1 b	2.1 b	3.8 a

[a] Mean values in each row for the same soil depth layer followed by the same letter are not significant at the 0.05 level.

in most layers between monocropping and intercropping, except that the nitrate concentration of upper layers (0–40 cm) under intercropping, where 400 kg N ha^{-1} was applied, was significantly higher than under monocropping. It was noteworthy that the nitrate concentration in 80–100 cm layer under maize intercropped with faba bean increased by 79% compared with the maize intercropped with wheat.

When maize was harvested, the nitrate concentration in 80–100 cm layer under monocropping wheat receiving 400 kg N ha^{-1} was much higher than under intercropping and there was a tendency for the intercrop to have higher nitrate levels above 60 cm. Interestingly, under monocropping wheat, nitrate concentration below 40 cm was significantly lower after maize harvest than after wheat harvest where 400 kg N ha^{-1} was applied for monocropped wheat, indicating the leaching loss of nitrate during absence of the crop, the interval between wheat harvest (15 July) and maize harvest (25 September) (Table 5).

In general, nitrate concentration in the soil profile after maize harvest was higher under monocropped faba bean than under intercropping. For example, nitrate concentration in 0–20, 20–40 and 40–60 cm layers under sole faba bean when 200 kg N ha^{-1} was applied was 1.8, 2.6 and 2.4 times as much as those under intercropping, respectively (Table 5). Compared with wheat harvest, nitrate concentration in the top 60 cm layers under both monocropped and intercropped faba bean receiving 200 kg N ha^{-1} increased significantly over time after wheat harvest and also after faba bean harvest, which might be due to the mineralization of root residue N. When 400 kg N ha^{-1} was applied, nitrate concentration increased with time above 60 cm layer but decreased below 60 cm under both monocropping and intercropping faba bean.

Under maize crop, nitrate concentration in 80–100 cm when intercropped with faba bean was significantly higher than when intercropped with wheat.

3.3. Nitrate in soil profiles

Nitrate accumulation in soil profiles had a positive relationship with rate of N application (Table 6). The average nitrate accumulation in soil profile (0–100 cm) at 400 kg N ha^{-1} was 60 kg N ha^{-1}, which was 2.2 and 4.3 times higher than that of N_{200} and N_0 treatment respectively.

Cropping system significantly affected nitrate accumulation in the soil. The amounts of nitrate in

Table 5
Effect of intercrop on nitrate concentration in soil profile (0–100 cm) under N application conditions after maize harvesting

Depth	N_0 (0 kg N ha^{-1})		N_2 (200 kg N ha^{-1})		N_4 (400 kg N ha^{-1})	
	Sole	Intercrop	Sole	Intercrop	Sole	Intercrop
Wheat						
0–20	2.0 b[a]	1.9 b	2.7 ab	1.9 b	3.9 ab	5.0 a
20–40	1.8 b	1.8 b	3.2 b	3.5 b	2.9 b	5.5 a
40–60	1.0 c	1.1 bc	2.3 bc	2.0 bc	3.7 ab	6.0 a
60–80	0.8 b	2.1 b	2.4 b	2.4 b	10.0 a	8.2 a
80–100	1.1 b	1.3 b	3.1 b	1.4 b	8.7 a	3.2 b
Faba bean						
0–20	1.9 b	1.6 b	3.6 a	2.0 b	3.3 a	2.0 b
20–40	1.4 c	1.9 c	7.7 a	2.9 bc	4.5 b	2.8 bc
40–60	1.2 c	1.8 c	4.1 b	1.7 c	3.5 b	10.3 a
60–80	1.4 c	1.3 c	3.6 b	2.8 bc	5.4 ab	6.0 a
80–100	1.0 c	1.0 c	2.7 bc	2.0 c	4.5 a	4.3 ab
Maize						
0–20	1.5 ab	0.8 c	1.4 ab	1.3 b	1.5 ab	1.9 a
20–40	1.1 b	0.9 b	0.9 ab	1.2 ab	1.4 a	1.4 a
40–60	1.0 b	0.5 b	0.6 b	0.5 b	2.1 a	2.0 a
60–80	1.0 b	0.4 b	0.7 b	0.4 b	2.4 ab	3.5 a
80–100	1.6 bc	0.8 c	2.2 bc	2.9 b	2.2 bc	6.8 a

[a] Mean values in each row for the same soil depth layer followed by the same letter are not significant at the 0.05 level.

Table 6
Amounts of nitrate accumulated (kg N ha^{-1}) in soil profiles (0–100 cm) under various cropping system applied with 0, 200 and 400 kg N ha^{-1}

Cropping system	N_0 (0 kg N ha^{-1})	N_2 (200 kg N ha^{-1})	N_4 400 kg N ha^{-1})
After wheat harvest			
Sole wheat	17.6	41.9	132.0
Intercropped wheat	18.6	47.2	78.2
Sole faba bean	13.9	31.9	56.2
Intercropped faba bean	16.4	21.9	63.6
Maize Intercropped with wheat	9.6	12.5	25.6
Maize Intercropped with faba bean	12.3	17.9	28.7
N fertilizer (N)	**		
Cropping (C)	**		
N × C	**		
After maize harvest			
Sole wheat	18.3	43.5	86.3
Intercropped wheat	22.7	35.6	75.3
Sole faba bean	19.0	61.5	63.5
Intercropped faba bean	21.4	31.4	69.9
Maize intercropped with wheat	16.9	16.9	29.6
Maize intercropped with faba bean	9.6	14.9	39.4
N fertilizer (N)	**		
Cropping (C)	**		
N × C	**		

** Significant difference between treatments at 0.01 level.

0–100 cm soil profile under monoculture wheat was the highest, followed by intercrop wheat, monoculture faba bean, intercrop faba bean. Nitrate accumulation in the soil profiles was much lower under maize than under other crops due to the longer growth period of maize.

During 75 days between wheat harvest and maize harvest, the amounts of nitrate presented in soil profiles decreased in the monoculture wheat plots receiving 400 kg N ha^{-1}. Generally, 46 kg NO_3–N ha^{-1} was lost in the soil profile. The amounts of nitrate in other treatments did not change with time significantly.

4. Discussion

4.1. Yield advantages for wheat/maize and faba bean/maize intercropping systems

Previous studies have shown the yield advantage in legume/non-legume intercropping systems. For example, when wheat intercropped with field bean, total grain yield of intercrops per unit land increased by 40% compared with sole crops (Haymes and Lee, 1999). The advantage in the legume/non-legume systems can be attributed to the enhanced growth of the non-legume components by legumes (Fujita and Budu, 1996). In previous studies, yield advantage of faba bean/maize intercropping was observed, with land equivalent ratio values of 1.21–1.23 based on total (grain + straw) yield, and 1.13–1.34 based on grain yield (Li et al., 1999). Furthermore, the yield advantage has also existed in intercropping systems without legumes, for instance, wheat/maize intercropping system (Li et al., 2001a), where land equivalent ratios are 1.21–1.58 based on grain yields.

The present study combined wheat/maize and faba bean/maize systems and confirmed the yield advantage in both intercropping systems. More importantly, this study demonstrated that maize was not responsive to P fertilizer when intercropped with faba bean, while P fertilizer could significantly improve the grain yield of maize intercropped with wheat. In the faba bean/maize system, faba bean via N_2 fixation could secrete H^+ (Tang et al., 1997). This acidification of the rhizosphere could enhance dissolution of P in high pH soils (Hinsinger, 2001) and thereby increase the availability of soil P to maize plants. In previous studies, Li et al. (2003a) also showed that faba bean enhanced P uptake by maize when intercropped. By contrast, in the wheat/maize system, wheat plants were seemingly unable to activate soil fixed P. Olsen-P in soil was 17.3 mg kg^{-1}. The reason for this is probably the greater competitive ability of wheat for N nutrients than maize (Li et al., 2001a).

4.2. Species diversity and nitrate residue in soil profile

Among the different cropping systems, the strips under wheat accumulated the highest amount of nitrate in the soil profile. In 2-year continuous cropping, wheat yield did not respond to N application (data not shown), resulting in low N use efficiency. The lack of yield response to N fertilizer was probably due to high indigenous N in soil or cropping history. Wheat also had less biomass compared with other crops and thus might have lower N demands. Moreover, the soil at the trial site of this study had an alkaline pH which could favor nitrification.

Herridge and Bergersen (1988) reported that more nitrate remained in soil following a legume than after a cereal. This might be due to less nitrate being taken up by the legume and increased mineralization under a legume crop (Peoples and Craswell, 1992), or due to added N from legume crop roots to soil. Under conditions of this study, these phenomena were not observed. The amount of nitrate accumulated in soil profiles under faba bean was similar to or even less than those under wheat. Malhi et al. (2002) found that cropping systems could influence the accumulation and distribution of plant nutrients in the soil profile, especially for nitrate N. In low cropping diversity where crop sequence was fallow or green manure–wheat–wheat–fallow or green manure–canola–wheat for 6 years, there was a greater nitrate–N accumulation compared to diversified annual grains where crop rotation was lentils (green manure) fallow–wheat–field pea–barley–sweet clover (Malhi et al., 2002). Previous results of the same experiment (Li et al., 2003b) showed that N uptake was increased to 152–175 kg ha^{-1} for intercropped wheat from 79 to 115 kg ha^{-1} for monocropping wheat at different N rates of application. Similar trends were observed for maize (Li et al., 2003b). This is mainly because of nitrate residue in soil profile probably.

In general, the nitrate accumulated was lower under intercropping than under monoculture of faba bean or wheat. This might be due to the complimentary root distribution of wheat/maize and faba bean/maize or the increased time of plant uptake of N by wheat/maize intercropping system. In the faba bean/maize system, maize roots are distributed in both the profiles of maize and faba bean. Thus, maize could utilize the nitrate in the strip of intercropping faba bean (Li, 1999).

5. Conclusions

Both wheat/maize and faba bean/maize intercropping had significant yield advantages, compared to correspond monocultue cropping systems. Most importantly, intercroppings of wheat/maize and faba bean/maize reduced nitrate accumulation in soil, thereby decreasing the potential risk of nitrate pollution of ground water, compared to corresponding monocropping wheat, faba bean and maize. This has implications for sustainable agriculture and environmental protection.

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