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RESEARCH ARTICLE

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Improving yield and water use efficiency of apple trees through intercrop-mulch of crown vetch (*Coronilla varia* L.) combined with different fertilizer treatments in the Loess Plateau

Wei Zheng, Yonggang Li, Qingli Gong, Haoqing Zhang, Zhiyuan Zhao, Zhaoxia Zheng, Bingnian Zhai and Zhaohui Wang

Northwest A&F University, College of Resources and Environment, Key Laboratory of Plant Nutrition and the Agri-environment in Northwest China, Ministry of Agriculture, Yangling, Shaanxi 712100, China

Abstract

Improving water use efficiency (WUE) and soil fertility is relevant for apple production in drylands. The effects of intercrop-mulch (IM) of crown vetch (*Coronilla varia* L.) combined with different fertilizer treatments on WUE of apple trees and soil fertility of apple orchards were assessed over three years (2011, 2013 and 2014). A split-plot design was adopted, in which the main treatments were IM and no intercrop-mulch (NIM). Five sub-treatments were established: no fertilization (CK); nitrogen and phosphorus fertilizer (NP); manure (M); N, P and potassium fertilizer (NPK); and NPK fertilizer combined with manure (NPKM). Due to mowing and mulching each month during July–September, the evapotranspiration for IM was 17.3% lower than that of NIM in the dry year of 2013. Additionally, the soil water storage of NPKM treatment was higher than that of CK during the experimental period. Thus, single fruit weight and fruit number per tree increased with IM and NPKM application. Moreover, applying NPKM with IM resulted in the highest yield (on average of three years), which was 73.25% and 130.51% greater than that of CK in IM and NIM, respectively. The WUE of NPKM combined with IM was also the highest in 2013 and 2014 (47.69 and 56.95% greater than applying IM alone). In addition, due to application of IM combined with NPKM, soil organic matter was increased by 25.8% compared with that of CK (in NIM). Additionally, application of IM combined with NPKM obtained more economic net return, compared to other combinations. Therefore, applying NPKM with IM is recommended for improving apple production in this rain-fed agricultural area.

Additional key words: apple orchard; evapotranspiration; soil organic matter; mulching; chemical fertilizer; manure.

Abbreviations used: CK (no fertilization); ET (evapotranspiration); ET_{bm} (ET from late March to early July); ET_{mow} (ET from early July to late September); ET_{tot} (total ET); IM (intercrop-mulch); M (manure); NIM (no intercrop-mulch); NP (nitrogen and phosphorus fertilizer); NPK (nitrogen, phosphorus and potassium fertilizer); NPKM (NPK fertilizer combined with manure); SOM (soil organic matter); WUE (water use efficiency); WUE_{mow} (WUE after mowing); WUE_{tot} (total WUE).

Authors' contributions: Conceived and designed the experiments: BNZ. Performed the experiments: WZ, YGL, QLG, HQZ, ZYZ and ZXZ. Analyzed the data: WZ. Contributed reagents/materials/analysis tools: BNZ and ZHW. Wrote the paper: WZ.

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Correspondence should be addressed to Bingnian Zhai: zhaibingniantg@126.com; bingnianzhaitg@126.com; 270603158@qq.com

Introduction

China is the biggest apple producing country in the world (Liu Y *et al.*, 2013), with a cultivated area of 2.41 × 10^6 ha (46% of the world surface devoted to apple) producing 39.68 × 10^6 t of apples (49% of the world's total production) in 2013 (http://faostat3.fao.org/home/E). In China, the Loess Plateau is a large area of apple production that represents 28.09 and 25.73% of the country's apple cultivation area and total yield, respectively (Yang & Chen, 2013). The apple products of the Loess Plateau area have been exported to more than 30 countries in Europe, North America and Southeast Asia (Li *et al.*, 2008; Yang & Chen, 2013; Qian *et al.*, 2015). However, the Loess Plateau is also the largest dryland rain-fed agricultural area in China, and water resource deficiencies seriously restrict apple production (Huang & Gallichand, 2006). In 2010, the apple yield per hectare in the Loess Plateau (with annual mean rainfall and potential evaporation of 200–700 and 763–963 mm, respectively) was 14.22 t/ha, only 47% of that of the Bohai Coastal area (30.15 t/ha) (with annual mean rainfall and potential evaporation of 550–950 and 450–600 mm, respectively) (Pu *et al.*, 2010; Yang & Chen, 2013; Zhang *et al.*, 2014). Thus, decreasing water loss from evaporation and increasing yield per unit area is a great challenge for improving apple production of the Loess Plateau.

In the Loess Plateau, almost 70% of rainfall usually occurs from the hot summer to early autumn (July–September), and much of this is lost through evaporation due to seasonal high temperatures (Ren *et al.*, 2008). Thus, limited annual precipitation and high evaporation in the hot season are the main constraints for apple production. Additionally, apple trees have more extensive root systems and canopy than annual crops, so apple orchards have higher evapotranspiration and lower available soil water in comparison with local cereal crops (*e.g.* winter wheat) (Huang & Gallichand, 2006). Evaporation during hot summers may cause soil moisture deficits of various degrees in apple orchards when precipitation is limited. Low soil fertility is another constraint. Soil organic matter (SOM) in most apple orchards of the Loess Plateau is usually in the range of 1.0–1.5% due to the application of inorganic fertilizer without organic inputs, which is much lower than that of American apple orchards (> 2.0%) (Chen *et al.*, 2014; Zhao & Tong, 2014). The stability of macro-aggregates and moisture retention capacity are also low due to the application of chemical fertilizer alone (Sarkar *et al.*, 2003). Therefore, development of suitable water management measures and rational fertilization are needed to sustain apple production in the Loess Plateau.

As a perennial legume, crown vetch (*Coronilla varia* L.) is a common intercropping plant in apple orchards with many benefits, including controlling weeds, decreasing soil erosion, fixing atmospheric N_2, increasing soil enzyme activities, and improving the soil micro-ecological environment (Jarvis, 1983; Cardina *et al.*, 1986; Qian *et al.,* 2015). However, intercropping of crown vetch might compete with apple trees for water (Li *et al.*, 2014). Mulch application could help to conserve soil water and decrease evaporation (Sauer *et al.*, 1996; Burt *et al.*, 2005; Monzon *et al.*, 2006; Yuan *et al.*, 2009; Ward *et al.*, 2009). Thus, intercrop-mulch (IM), a process involving intercropping with crown vetch at first and then mowing it (the residues are left on the soil surface as mulch) in the rainy hot season, is recommended. However, the effect of IM on water use efficiency (WUE) in apple production is unclear, especially with regard to differences in water consumption before and after mulch application. In addition, although mulch can significantly decrease evaporation, the WUE can still be very low due to a lack of adequate fertilizer use (Li *et al.*, 2000). Many studies have shown the effects of straw mulch and plastic film or combinations of mulch with varied nitrogen (N) rates on the WUE of cereal crops (Li *et al.*, 2001; Khurshid *et al.*, 2006; Chen *et al.*, 2015; Li *et al.*, 2015). However, little is known about the effect of applying IM of crown vetch with different kinds of fertilization on the WUE of apple trees.

Current apple production in the Loess Plateau can be substantially increased by rational water conservation and fertilization measures. Thus, a field experiment was conducted aiming to: (1) evaluate the combined effects of IM and different kinds of fertilization on soil water storage, evapotranspiration, yield components, yield, and WUE of apple trees under dryland conditions; and (2) find the best combination of these strategies for apple production in the rain-fed area of the Loess Plateau.

Material and methods

Apple orchard description

The experimental site was a typical Loess Plateau area located at the Weibei Dryland Experimental Station of the Northwest Agriculture and Forestry University (109°56′E, 35°21′N; altitude of 838 m), Baishui County, Shaanxi Province, China. The soil of the apple orchard was silt loam (with 8% sand, 67% silt and 25% clay) and classified as Haplustalfs according to USDA system of soil taxonomy. The topsoil had the following chemical characteristics at the beginning of the experiment: pH 8.3, organic matter content 13.02 g/kg, total N 1.03 g/kg (Kjeldahl method), available N 24.90 mg/kg (extracted with KCl and quantified with a flow injection analyzer), Olsen-phosphorus (P) 15.94 mg/kg and available potassium (K) 151.28 mg/kg (extracted by NH_4OAc and determined using a flame photometer). The rainfall distribution is dominated by the monsoon climate. In this region, summer is hot (daily maximum temperatures can reach 39.4 °C in July) and moist, whereas winter and early spring are always cold (daily minimum temperatures can reach −16.7 °C in January) and dry. In average, total annual radiation for this site is 5360 MJ/m^2 and the number of sun hours is 2477 h. There are usually 171 frost-free days each year. Agriculture in this region is completely dependent on natural precipitation.

Experimental design and treatments description

Fuji apple trees (*Malus pumila* Mill.) planted in 2005 on M26 (rootstock) were used as the experimental crop and had a density of 1200 plants/ha. A split-plot design was adopted, with main plots of IM (with crown vetch) and control (NIM, no crown vetch planted) and subplots included five fertilization treatments: no fertilization, CK; N and P fertilizer (NP); manure (M); N, P and K fertilizer (NPK); and NPK fertilizer combined with manure (NPKM). Each treatment was replicated three times. Each sub-treatment replicate contained two rows with 12 apple trees in each row. The surface area of each replicate was about 200 m^2. For IM, crown vetch was sown in each inter-row of apple trees (1.6-m-wide strip) in 2008 at a depth of 1.5 cm with a sowing rate of 6.0 kg/ha. Crown vetch sprouted in late March each year and was mowed (the residues were left on the soil surface as mulch) in early July, August and September. For NIM, no crown vetch was planted and weeds were controlled by mowing. Urea (containing 46% N), calcium superphosphate (containing 12% P_2O_5) and potassium sulfate (containing 50% K_2O) were used as N, P and K fertilizers, respectively. The goat manure contained 35.1% dry organic matter, 0.533% N, 0.309% P_2O_5 and 0.467% K_2O. The fertilizing rates of the sub-treatment groups are shown in Table 1.

Precipitation and air temperature during the experimental period

The data were collected during 2011–2014. However, only 2011, 2013 and 2014 data were analyzed due to loss of fruit from hailstones in 2012. Precipitation (including snow during the winter months) and air temperature were recorded by a weather station placed at the experimental station and shown in Figs. 1A and 1B. Annual precipitation for 2011, 2013 and 2014 was 767.9, 489.6 and 601.5 mm, respectively. According to the inter-annual precipitation distribution, 2011 was defined as a wet year, 2013 was a dry year and 2014 was a normal year (Guo *et al.*, 2012). In addition, precipitation during July–September (after mowing) in 2011, 2013 and 2014 was 469, 316.2 and 341.2 mm, respectively, accounting for 61, 65 and 57% of annual precipitation. In 2013, the annual accumulated temperature was about 4403 °C, which was 7.73 and 2.02% higher than that of 2011 (4087 °C) and 2014 (4316 °C), respectively.

Measurements and statistical analyses

Soil samples from each treatment (three soil cores per replicate) were collected from 0 to 200 cm deep at 20 cm intervals using an open-faced bucket probe (5 cm diameter). Soil samples were collected three times per year at a distance of 50 cm from tree trunks toward the row space, before sprouting of crown vetch (late March), before the first mowing and mulching of crown vetch (early July) and after apple ripening (late September). However, soil samples were not collected in early July of 2011 due to lack of manpower. Fresh soil samples were taken to the laboratory to determine their gravimetric water content. Soil bulk density was measured according to Li R *et al.* (2013) (Fig. 2). Soil samples from the 0–20 and 20–40 cm soil layers were collected after harvesting in 2014 and used to determine SOM. Three soil cores were collected in each replicate. Prior to analysis of organic matter, soil samples were air dried and passed through a 0.25-mm sieve. The SOM content was determined by potassium dichromate

Table 1. Fertilizer rates applied to the different treatments in the intercrop-mulch and no intercrop-mulch.

Treatments[1]	Basal fertilizers (kg/ha)			Fertilizers (kg/ha) dressed at					
				flowering stage			fruit expansion stage		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
CK	0	0	0	0	0	0	0	0	0
NP	115.2	64.8	0	38.4	21.6	0	38.4	21.6	0
M	191.88*	111.24*	168.12*	0	0	0	0	0	0
NPK	115.2	64.8	100.8	38.4	21.6	33.6	38.4	21.6	33.6
NPKM	57.6 95.94*	32.4 55.62*	50.4 84.06*	19.2	10.8	16.8	19.2	10.8	16.8

[1] CK, no fertilization; NP, N and P fertilizer; M, manure; NPK, N, P and K fertilizer; NPKM, NPK fertilizer combined with manure. '*' represents nutrients supplied by manure.

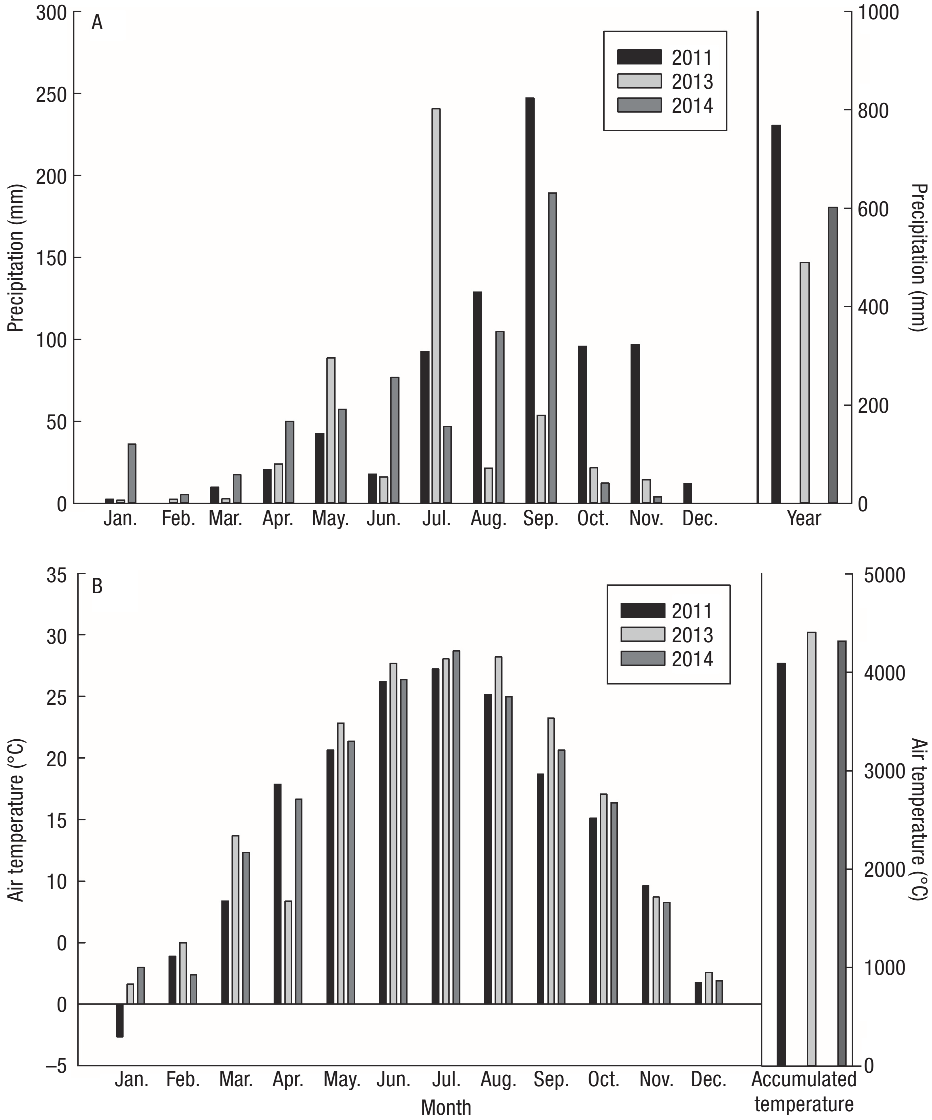

Figure 1. Precipitation and air temperature for 2011, 2013 and 2014: (A) monthly and annual precipitation; (B) monthly mean air temperature and annual accumulated temperature.

oxidation at 170–180 °C, followed by titration with 0.1 mol/L ferrous sulfate (Bao, 2000).

Evapotranspiration was calculated using the following formula (Qin *et al.*, 2013):

$$ET = 10\sum \gamma_i H_i(\theta_{i1} - \theta_{i2}) + P_0, \qquad i(1,...,n)$$

where ET is water consumption in a period; $10\sum\gamma_i H_i \theta_i$ is the soil water storage; i is the soil layer; n is the total number of soil layers; γ_i is the soil bulk density of layer i; H_i is the thickness (cm) of layer i; θ_{i1} and θ_{i2} are gravimetric water contents of layer i at the beginning and end of the measuring period, respectively; and P_0 is the precipitation during each measuring period.

Apple fruits were collected from trees in each treatment group at harvest. Nine trees were randomly chosen from each replicate for investigating the fruit number per tree, fruit weight and yield of each replicate. Yield per tree was measured using a scale. The apple yield (t/ha) of each replicate was calculated by fruit weight, fruit number/tree, and tree number/ha. WUE was calculated with the formula $WUE = Y / ET$, where Y is apple yield.

The total cost and yield return was calculated for three years. Seed and sowing costs include the cost of crown vetch seed and sowing. Mowing cost was the cost of crown vetch mowing for IM and weed mowing for NIM. Others costs included the cost of orchard management. All costs were converted from Chinese yuan to Euro (€1 = ¥6.81). Yield return was calculated (¥4 / kg).

SPSS 19.0 was used to conduct analysis of variance. Two-way ANOVA was used for assessing differences among treatments, sub-treatments and their interactions. Least significant difference (LSD) was used for mean separation. The figures were constructed using Sigma Plot 12.0 software.

Results

Soil water storage and evapotranspiration

There were no obvious effects of IM on soil water storage in late March (2013) and late September (2011 and 2013), and significant effects during other periods in 2011, 2013 and 2014. In addition, fertilization significantly affected soil water storage each year, and the interaction effect of fertilization and IM on soil water storage in late March was significant (Table 2). Additionally, over the experimental years of 2011, 2013 and 2014, soil water storage decreased with water consumption by apple trees and crown vetch, and increased at the expansion stage of apple trees in the rainy season (July–September) (Table 3). In IM and NIM treatments, soil water storage of M and NPKM tended to be higher than that of CK, NP and NPK in 2011, 2013 and 2014. The mean soil water storage of IM in late March of 2011 and 2014 was significantly higher than that of NIM with no difference between IM and NIM in late March of 2013. In early July, mean soil water storage of IM was lower than that of NIM in 2013, but it was higher than that of NIM in 2014. However, in late September, the difference in mean soil water storage was significant only in 2014, with that of IM higher than that of NIM.

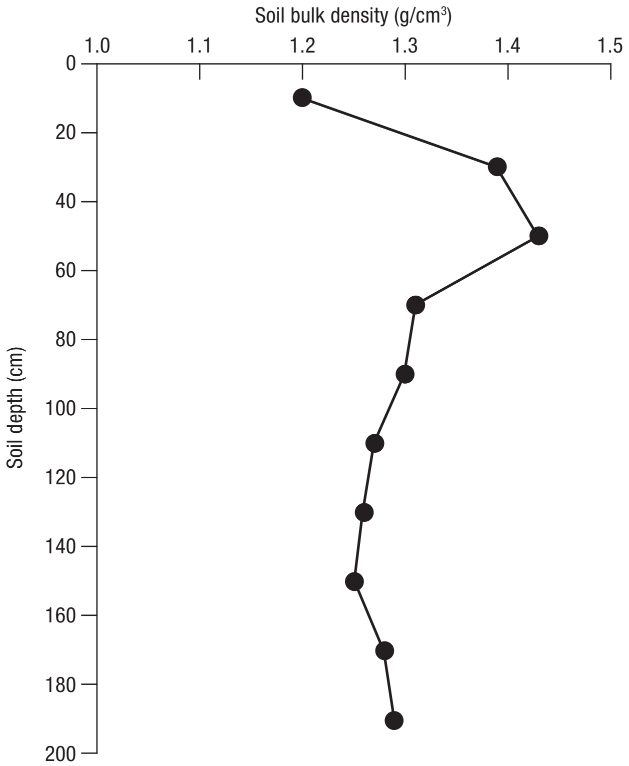

Figure 2. Soil bulk density of each layer (0-200 cm).

The effects of IM on ET_{tot} (total evapotranspiration), ET_{bm} (evapotranspiration from late March to early July) and ET_{mow} (evapotranspiration from early July to late September) were prominent, even though there were no effects on ET_{tot} in 2013 and ET_{mow} in 2014. For fertilization, there were significant effects on ET_{tot} each year and ET_{bm} in 2014. The obvious interaction of IM and fertilization on ET_{tot} (in 2011 and 2014) and ET_{bm} (2014) was also obtained (Table 2). Moreover, the ET_{tot} of the M, NPK and NPKM was higher than that of CK and NP, with the ET_{tot} of NPKM being the highest, although not all differences were significant (Table 3). Additionally, the ET_{bm} of NPKM was higher than that of CK under NIM (2013) and IM (2014). However, there were no significant differences between sub-treatments for ET_{mow}. The mean ET_{tot} of IM in 2014 was significantly higher than that of NIM, with no difference between IM and NIM in 2011 and 2013. Similarly, before the first mowing and mulching (from late March to early July), the ET_{bm} of IM was higher than that of NIM in both 2013 (dry year) and 2014 (normal year). Three periods of mulching (successive mowing and mulching once per month from early July to late September) caused the ET_{mow} of IM to decrease by

Table 2. Analysis of variance of the effects of intercrop-mulch (IM), fertilization, and their interaction on soil water storage and ET (*p*-values are shown).

Variation source	Soil water storage (Late Mar)			Soil water storage (Early Jul)		Soil water storage (Late Sep)			ET_{tot}			ET_{mow}		ET_{bm}	
	2011	2013	2014	2013	2014	2011	2013	2014	2011	2013	2014	2013	2014	2013	2014
IM	<0.01	0.397	<0.01	<0.01	<0.01	0.182	0.274	<0.01	<0.01	0.510	<0.01	<0.01	0.647	<0.01	<0.01
Fertilization	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01	<0.01	<0.01	<0.05	<0.01	0.218	0.222	0.083	<0.05
IM×Fertilization	<0.05	<0.01	<0.01	0.080	0.233	0.289	0.138	0.697	<0.01	0.448	<0.01	0.980	0.656	0.140	<0.01

ET_{tot} is the total evapotranspiration from late March to late September. ET_{mow} is the evapotranspiration from early July to late September. ET_{bm} is the evapotranspiration from late March to early July.

17.3% in comparison with that of NIM in the hot rainy season of 2013 (dry year), although there were no significant differences between IM and NIM in 2014 (normal year).

Yield components

There was a significant effect of IM on single fruit weight in 2014 ($p < 0.05$), and no significant effect in 2011 and 2013. Additionally, the impact of IM on fruit number per tree was significant only in 2011 and 2013 ($p < 0.01$); whereas, fertilization markedly affected single fruit weight and fruit number per tree in each year (Table 4). Additionally, there were no significant interactions between IM and fertilization for single fruit weight or fruit number/tree in 2011, 2013 and 2014. In 2014, the single fruit weight of IM was 8.5% higher than that of NIM, while the fruit number per tree of IM was 6.2 and 68.9% higher than that of NIM in 2011 and 2013, respectively (Table 5). The mean single fruit weight and fruit number per tree of NPKM treatment under IM were 20.89% and 42.21% higher than those of CK under IM, respectively; with a similar trend also observed for the NIM treatment (Table 5). Additionally, IM increased single fruit weight in 2014 and fruit

Table 3. Soil water storage during different periods (late March, early July and late September), ET_{tot}, ET_{bm} and ET_{mow} in 2011, 2013 and 2014.

Years[1]	Treatment[2]	Soil water storage (mm) Late Mar.		Early Jul.		Late Sep.		ET_{tot} (mm)		ET_{bm} (mm)		ET_{mow} (mm)	
		IM	NIM	IM	NIM	IM	NIM	IM	NIM	IM	NIM	IM	NIM
2011	CK	403.6c	366.9c	-	-	563.8b	577.2ab	390.3c	340.2d	-	-	-	-
	NP	403.7c	379.6c	-	-	568.1b	554.2b	386.1c	375.9c	-	-	-	-
	M	502.2b	448.8ab	-	-	589.9a	582.0a	462.8b	417.3b	-	-	-	-
	NPK	506.9ab	439.6b	-	-	571.1ab	555.8b	486.3ab	434.3a	-	-	-	-
	NPKM	539.0a	467.9a	-	-	590.9a	583.9a	498.6a	434.5a	-	-	-	-
2013	CK	338.2d	341.7c	319.8c	354.5c	320.7b	306.4c	464.0a	480.9b	147.8a	116.6ab	315.3a	364.3a
	NP	353.9cd	361.7c	321.8c	413.2b	318.5b	356.9ab	481.0a	450.4b	161.4a	77.9b	319.5a	372.5a
	M	428.6ab	425.9b	402.3ab	427.7b	396.5a	371.2ab	477.7a	500.2ab	155.7a	127.6ab	322.0a	372.7a
	NPK	400.6bc	358.0c	375.0b	402.0b	360.8a	321.2bc	485.4a	482.4b	155.0a	85.4ab	330.5a	397.0a
	NPKM	462.0a	482.0a	420.2a	475.2a	385.6a	376.1a	522.0a	551.5a	171.2a	136.2a	350.8a	415.3a
2014	CK	327.1b	313.1c	312.4b	282.0d	461.3b	438.8b	391.5d	400.0ab	199.3b	215.6a	192.3a	184.4a
	NP	471.4a	329.1c	359.8a	311.7cd	495.1ab	472.0ab	501.9bc	382.8b	296.2a	201.9a	205.9a	180.9a
	M	513.3a	380.6b	399.2a	356.2ab	530.1a	483.2a	508.9b	423.1ab	298.6a	208.9a	210.2a	214.2a
	NPK	482.9a	348.3bc	373.5a	340.6bc	513.9a	485.6a	494.6c	388.3ab	293.9a	192.2a	200.7a	196.1a
	NPKM	516.5a	423.0a	392.2a	386.6a	523.3a	503.6a	518.9a	445.1a	308.9a	220.9a	210.1a	224.2a
Mean	2011	471.1A	420.6B	-	-	576.8A	570.6A	444.8A	400.4B				
	2013	396.7A	393.9A	367.8B	414.5A	356.4A	346.4A	486.0A	493.1A	158.2A	108.7B	327.6B	384.4A
	2014	462.2A	358.8B	367.4A	335.4B	504.7A	476.6B	483.2A	407.9B	279.4A	207.9B	203.8A	200.0A

[1] The precipitation from March to September (Mar-Sep) of 2011, 2013 and 2014 was 550.5, 445.6 and 525.7 mm, respectively; the precipitation from July to September (Jul-Sep) of 2013 and 2014 was 316.2 and 341.2 mm, respectively. [2] See Table 1. [3] ET_{tot} is the total evapotranspiration from late March to late September, ET_{tot} = Precipitation (Mar–Sep) + Soil water storage (Mar) − Soil water storage (Sep); ET_{bm} is the evapotranspiration from late March to early July, $ET_{bm} = ET_{tot} - ET_{mow}$; ET_{mow} is the evapotranspiration from early July to late September, ET_{mow} = Precipitation (Jul–Sep) + Soil water storage (Jul) − Soil water storage (Sep). Different uppercase and lowercase letters denote significant differences between main treatments and sub-treatments at $p < 0.05$.

Table 4. Analysis of variance of the effects of intercrop-mulch (IM), fertilization and their interaction on apple fruit weight, fruit number per tree, yield, WUE_{tot} (water use efficiency from late March to late Sept ember) and WUE_{mow} (water use efficiency from early July to late September) (p-values are shown).

Variation source	Single fruit weight 2011	2013	2014	Fruit number/tree 2011	2013	2014	Yield 2011	2013	2014	WUEtot 2011	2013	2014	WUEmow 2013	2014
IM	0.795	0.491	<0.05	<0.01	<0.01	0.064	<0.01	<0.01	<0.05	<0.01	<0.01	0.108	<0.01	<0.05
Fertilization	<0.01	<0.05	<0.01	<0.01	<0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01	<0.05	<0.01
IM×Fertilization	0.063	0.472	0.889	0.076	0.691	0.846	0.053	0.850	0.953	<0.01	0.836	0.367	0.881	0.823

number per tree in 2011 and 2013. Thus, applying IM with NPKM treatment was much more effective than single application of IM, especially in the dry year.

Apple yield and WUE

IM and fertilization affected apple yield and WUE from late March to late September (WUE_{tot}) and WUE from early July to late September (WUE_{mow}), because the single fruit weight or single fruit number per tree was affected, although the effect of IM on WUE_{tot} was not significant in 2014 (Table 4). The apple yield of IM was 6.5%, 69.5% and 30.3% higher than that of NIM in 2011, 2013 and 2014, respectively. Thus, the WUE_{tot} of IM was 73.3% higher than that of NIM in 2013 (dry year), although this trend was not observed in years with enough precipitation (2011 and 2014). Especially after applying mulch in the rainy season, the WUE_{mow} of IM was increased by 100.4% and 28.1% in 2013 and 2014, respectively, in comparison with that of NIM (Table 6). In addition, the trees subjected to the NPK and NPKM treatments produced higher apple yield than those subjected to the other fertilization treatments, with the highest yield in each year for the NPKM treatment, although differences in the yields of M, NPK, and NPKM under IM in 2013 were not significant. The WUE_{tot} of NPKM under IM was significantly higher than that of CK under IM. The WUE_{tot} of NIM also followed the same trend. In addition, the

Table 5. Yield components of apple for all fertilizer treatments under intercrop-mulch (IM) and no intercrop-mulch (NIM).

Main treatments	Sub treatments[1]	Single fruit weight (g)				Fruit number/tree			
		2011	2013	2014	Mean	2011	2013	2014	Mean
IM	Mean	250.0A	259.2A	252.9A	254.1A	82.2A	57.1A	64.6A	68.0A
NIM	Mean	249.3A	255.8A	233.1B	246.0A	77.4B	33.8B	54.0A	55.1B
IM	CK	227.4c	243.9b	216.6b	229.3d	72.2d	44.5a	56.6b	57.8b
	NP	245.6b	247.6b	234.6ab	242.6cd	80.5bc	49.9a	66.2ab	65.5ab
	M	254.5ab	259.2b	255.5ab	256.4bc	77.2cd	60.9a	56.8b	65.0b
	NPK	259.2a	260.1b	274.9a	264.7ab	85.8b	66.7a	55.6b	69.4ab
	NPKM	263.3a	285.4a	282.9a	277.2a	95.4a	63.4a	87.8a	82.2a
NIM	CK	236.1c	249.2a	199.0b	228.1c	70.8b	17.5c	43.0b	43.8b
	NP	241.3bc	245.8a	219.0ab	235.4bc	79.1ab	26.4bc	55.9ab	53.8ab
	M	242.5bc	256.0a	248.1a	248.9bc	76.6ab	30.4bc	37.5b	48.2b
	NPK	252.0b	264.0a	244.2a	253.4ab	79.6ab	40.4ab	55.4ab	58.5ab
	NPKM	274.5a	263.8a	255.3a	264.5a	80.8a	54.4a	78.3a	71.2a

[1] See Table 1. Different uppercase and lowercase letters denote significant differences between the two main treatments and the five sub-treatments under each main treatment at $p < 0.05$.

Table 6. Yield, WUE_{tot} (WUE from late March to late September) and WUE_{mow} (WUE from early July to late September) of apple under IM (intercrop-mulch) and NIM (no intercrop-mulch) for different fertilizers.

Main treatment	Sub treatment[1]	Apple yield (t/ha)				$WUE_{tot.}$ (kg/ha·mm)				$WUE_{mow.}$ (kg/ha·mm)		
		2011	2013	2014	Mean	2011	2013	2014	Mean	2013	2014	Mean
IM	Mean	24.7A	17.8A	19.8A	20.8A	55.6B	36.4A	40.6A	44.2A	53.9A	96.6A	75.2A
NIM	Mean	23.2B	10.5B	15.2B	16.3B	57.9A	21.0B	37.0A	38.6A	26.9B	75.4B	51.1B
IM	CK	19.7d	13.0b	14.4b	15.7c	50.5c	28.1b	36.7b	38.4b	41.3a	74.7b	58.0b
	NP	23.7c	14.6b	19.0b	19.1bc	61.4a	30.3b	37.9b	43.2ab	45.6a	92.4b	69.0ab
	M	23.5c	18.9a	17.2b	19.9bc	50.8c	39.6a	33.9b	41.4b	58.7a	82.0b	70.3ab
	NPK	26.7b	20.8a	18.4b	21.9b	54.8b	42.4a	37.1b	44.8ab	62.3a	91.5b	76.9ab
	NPKM	30.1a	21.7a	29.9a	27.2a	60.4a	41.5a	57.6a	53.2a	61.7a	142.2a	102.0a
NIM	CK	20.0c	5.2c	10.3b	11.8b	58.9ab	10.9c	25.8b	31.9b	14.4c	56.0b	35.2b
	NP	22.9b	7.8bc	14.4b	15.0b	60.9a	17.4bc	37.6ab	38.6ab	21.0bc	79.6ab	50.3ab
	M	22.3b	9.4bc	11.2b	14.3b	53.4c	18.7bc	26.5b	32.9ab	25.1bc	52.4b	38.8ab
	NPK	24.1b	12.9b	16.0b	17.7ab	55.4bc	26.8ab	41.3ab	41.1ab	32.5ab	81.7ab	57.1ab
	NPKM	26.6a	17.2a	24.0a	22.6a	61.1a	31.2a	54.0a	48.8a	41.5a	107.1a	74.3a

[1] See Table 1. Different uppercase and lowercase letters denote significant differences between the two main treatments and the five sub-treatments under each main treatment at $p < 0.05$, respectively.

mean WUE_{mow} of NPKM under IM was the highest (75.86% higher than that of CK under IM).

SOM content

Soil organic matter was significantly increased by seven years of IM application (2008–2014) (Table 7). In comparison with CK under NIM, the SOM (0–20 cm) of CK under IM was increased by 11.8%; the M and NPKM treatments under IM resulted in the highest SOM. Compared with CK under IM, the SOM (0–20 cm) of M and NPKM under IM was 19.1% and 15.8% higher, respectively, and correspondingly 19.5% and 20.3% higher for SOM at 20–40 cm depth. These results suggest that the applications of IM and manure increased SOM.

Table 7. Soil organic matter (SOM, g/kg) at 0-20 cm and 20-40 cm depths in 2014.

Main treatment	Sub treatment[1]	0–20 cm[2]	20–40 cm
IM	CK	15.2c	13.3c
	NP	16.5b	14.6b
	M	18.1a	15.9a
	NPK	15.7c	14.2b
	NPKM	17.6a	16.0a
NIM	CK	13.6c	13.1b
	NP	13.5c	13.3b
	M	16.7a	14.8a
	NPK	13.9c	13.5b
	NPKM	15.8b	14.3a
IM	Mean	16.6A	14.8A
NIM	Mean	14.7B	13.8B

[1] See Table 1. [2] The SOM of 0–20 cm depth at the beginning of experiment (2008) was 13.02 g/kg.

Input, output and net revenue

The average net return of IM was 31.48% higher than that of NIM (Table 8). In addition, the cost of IM was only €110.7 higher than that of NIM. The NPKM treatment had the highest net return of any treatment for both IM and NIM.

Discussion

About 70% of yearly precipitation usually occurs from the middle of the hot summer to early autumn (July–September) in rain-fed dryland apple orchards in the study area; thus, this period has sufficient rainwater resources. However, the high temperature in this period induces a high amount of water evaporation. Additionally, this period coincides with the fruit expansion stage when adequate soil water is imperative. Therefore, decreasing ineffective water evaporation during this period could improve apple tree growth, yield, and WUE.

In the present study, under IM with crown vetch, single fruit weight and fruit number per tree were significantly increased in comparison with the NIM treatment (Table 5). The apple yield and WUE under IM increased by 27.4% and 14.6% during the three years studied, respectively; particularly in the dry year, they significantly increased by 69.5% and 73.3%, respectively, although the increase in WUE was not obvious due to a lack of water stress in 2011 and 2014, during which there was enough precipitation. The yield and WUE of IM were increased due to the application of mulch three times during June–September, which decreased evaporation from topsoil and improved soil water storage. The water stored through mulch applica-

Table 8. Production cost and economic benefit of the different treatments (the cost and economic benefit were the total for three years) (EUR/ha) [1].

Main treatment [2]	Sub treatment [3]	Fertilizer	Seed+Sowing[4]	Mowing[5]	Others[6]	Total cost	Yield return	Net return
IM	CK	0	110.7	991.2	1500	2601.9	27665.2	25063.3
	NP	667.8	110.7	991.2	1500	3269.7	33656.4	30386.7
	M	3489.0	110.7	991.2	1500	6090.9	35007.3	28916.4
	NPK	889.8	110.7	991.2	1500	3491.7	38707.8	35216.1
	NPKM	2190.0	110.7	991.2	1500	4791.9	47988.3	43196.4
NIM	CK	0	0	991.2	1500	2491.2	20851.7	18360.5
	NP	667.8	0	991.2	1500	3159	26490.5	23331.5
	M	3489.0	0	991.2	1500	5980.2	25198.2	19218.0
	NPK	889.8	0	991.2	1500	3381	31130.7	27749.7
	NPKM	2190.0	0	991.2	1500	4681.2	39823.8	35142.6

[1] Values were converted from Chinese yuan to EUR (€1 = ¥6.81). [2] See Table 5. [3] See Table 1. [4] Seed + sowing costs include the cost of crown vetch seed and sowing. [5] Mowing cost was the cost of crown vetch mowing for IM and weed mowing for NIM. [6] Others costs were the costs of orchard management.

tion surpassed or at least compensated for the water consumed in crown vetch growth. However, Du *et al.* (2015) found that apricot yield decreased due to water competition between erect milk vetch and apricot in an intercrop-mulching system, even though the mulch was applied after mowing, probably because mulch was applied too late (in autumn) to be effective for seasonal fruit growth as apricots had already ripened (in July). In the present study, successive monthly mowing and mulching during July–September would substantially restrain the competition capacity of crown vetch and decrease water evaporation in the hot rainy season. Especially in the dry year, mowing and mulching significantly decreased ET_{mow} by 17.3% in comparison with that of CK (Table 3). Thus, more water was stored for apple tree growth and WUE_{mow} in the rainy hot summer was significantly increased (Table 6). Additionally, although growth of crown vetch would consume some soil water before mowing (from late March to early July) and so compete for soil water with apple trees and increase ET_{tot}, the apple yield still increased. A possible explanation for this observation was the adaptive spatial complementarity of the two root systems, which may have prevented water competition (Fetene *et al.*, 2003; Morlat & Jacquet, 2003). Monteiro & Lopes (2007) found that the water depletion that was observed in the sward treatments at bloom time may have induced death of vine roots in the upper layers and development of a deeper root system to explore deeper layers. Li *et al.* (2011) also reported that apple roots extended more into deep soil layers, while fine roots extended more deeply into soil layers than thick roots did, and white clover fine roots extended more into surface soil layers in the apple-white clover intercropping system. After mowing and mulching from July-September, IM treatment can result in more water storage for fruit growth in comparison with NIM. Taken together, these results indicate that IM increased apple yield, showing that there is great potential for decreasing evaporation and increasing apple yield and WUE through IM with crown vetch if crown vetch is well managed and competition with apple trees prevented.

Although IM of crown vetch can decrease evaporation and store more water for transpiration of apple trees, adequate fertilization is still needed in combination with IM to increase WUE. In our experiment, soil fertility was improved after applying IM with NPKM for seven years. The SOM of NPKM (with IM) at depths of 0–20 and 20–40 cm was increased by 15.8 and 20.3% in comparison with that of CK under IM, respectively (Table 7). Thus, single fruit weight and fruit number per tree were obviously increased. Therefore, apple yield for NPKM (with IM) was increased by an average of 73.25% in the three studied years; the WUE_{mow} of NPKM (with IM) was also significantly increased by 75.86% in comparison with that of CK (with IM). These results suggest that NPKM fertilization supplies sufficient available nutrients for tree growth and improves soil fertility in the long term, in comparison with NPK fertilization (Lönhárd-Bory & Németh, 1990; Zhao *et al.*, 2014). As a result, we suspect that apple trees subjected to NPKM treatment likely had larger canopies (Li TT *et al.,* 2013), while soil water, which was conserved by mulch, was efficiently used for transpiration, so apple yield and WUE_{mow} increased. Previous research had reported that intercropping might decrease yields because of nutrient competition (Du *et al.,* 2015). In our experiment, NPKM treatment improved soil fertility more than other fertilization treatments. Therefore, NPKM treatment was more effective than other treatments as a means of mitigating nutrient competition between crown vetch and apple trees. In addition, due to the manure addition, which could improve the mean weight diameter of aggregates, total porosity, and water holding capacity (Karami *et al.*, 2012; Liu CA *et al.*, 2013), NPKM fertilization could induce water storage more effectively than chemical fertilizer alone, mitigating water competition between crown vetch and trees. As a result, NPKM fertilization could greatly compensate for nutrient deficiency with IM and applying the two together could result in greater apple yields compared to applying IM with other fertilizers, benefiting farmers (Table 8). In the Loess Plateau, farmers always apply plastic film and straw mulch to decrease the evaporation. However, plastic film does not increase the abundance of soil nutrients and has negative environmental impacts, and both plastic film and straw mulch impose transportation expenses and other costs each year. As a perennial legume, crown vetch can live for several years if well managed and sprout in late March each year after being sown in the first year, and it can form root nodules, control weeds, prevent soil erosion, and improve soil fertility (Wheeler, 1974; Symstad, 2004). As a legume, crown vetch can mitigate nitrogen competition due to its ability to fix atmospheric N_2 via root nodules, compared to other non-legume species, and other similar studies found that nitrogen competition was mitigated by legume grass cover systems (King & Berry, 2005; Messiga *et al.*, 2015). In our experiment, the total net return (for three years) of IM was 31.5% higher than that of NIM, and that of IM combined with NPKM was 72.35% higher than that of IM alone. All of these reasons indicate that IM of crown vetch combined with NPKM is a good practice for apple production, although it may compete for soil water with apple trees before the first mowing and mulching.

In summary, applying IM conserved more soil water in the hot rainy season for transpiration during the fruit expansion stage of apple trees, particularly in the dry year, although the effect was not obvious when enough precipitation prevented water stress. Thus, single fruit weight and fruit number per tree increased, as well as apple yield and WUE. Additionally, in comparison with other fertilization treatments, the water and nutrients consumed by crown vetch were more effectively compensated by NPKM application. Hence, IM with NPKM resulted in the highest yield and WUE of the tested treatments. For these reasons, and considering agricultural, soil and economic factors, IM combined with NPKM is expected to be a beneficial practice for farmers engaged in apple production in the Loess Plateau.

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