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ORIGINAL ARTICLE

Soil nitrate–N residue, loss and accumulation affected by soil surface management and precipitation in a winter wheat-summer fallow system on dryland

Gang He · Zhaohui Wang · Fucui Li · Jian Dai · Xiaolong Ma · Qiang Li · Cheng Xue · Hanbing Cao · Sen Wang · Hui Liu · Laichao Luo · Ming Huang · Sukhdev S. Malhi

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Abstract Soil nitrate–N residue after harvesting crops and nitrate–N loss during the following fallow season is serious concern for the agricultural environment in dryland. A 6-year-long, location-fixed field experiment was conducted to determine the effects of plastic film mulch (PM), straw mulch (SM), green manure (GM) and straw mulch plus green manure (SGM) on the nitrate–N residue, loss and accumulation in a winter wheat-summer fallow system. Compared with the bare fallow, average grain yield was increased by 6 % with PM, whereas decreased by 7, 5 and 5 % with SM, GM and SGM, respectively. Average total N uptake was decreased by 13 % with SM, but not affected by PM, GM and SGM. Average nitrate–N residue at wheat harvest was decreased by 35, 32 and 18 % with PM, SM and SGM, respectively, but not affected by GM. Average soil water recharge was increased by 12 % with PM, and not affected by SM, whereas decreased by 20 and 16 % with GM and SGM, respectively. For the PM, SM, GM and SGM, the average nitrate–N loss from top soil was decreased by 51, 53, 50 and 34 %, respectively, and the average nitrate–N accumulation in deep soil was decreased by 56, 45, 31 and 39 %. Above results revealed that increasing the yield decreased soil nitrate–N residue, and nitrate–N loss and accumulation was restricted by the decreased nitrate–N residue and soil water recharge. Overall, PM is a preferable measure for the decreased nitrate–N residue, loss and accumulation, at the same time increased the yield in dryland.

Keywords Grain yield · Total N uptake · Soil water · Plastic film mulch · Straw mulch · Green manure

Introduction

Approximately 40 % of the earth's land area is dryland, and farming in drylands feed about 40 % of the world population (Stewart and Liang 2015). The Loess Plateau in China is a typical dryland farming area, where winter wheat is one of the main food crops and usually sown in late September and early October

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G. He · Z. Wang · F. Li · J. Dai · X. Ma ·
Q. Li · C. Xue · H. Cao · S. Wang · H. Liu ·
L. Luo · M. Huang
State Key Laboratory of Crop Stress Biology in Arid
Areas, Northwest Agricultural and Forestry University,
Yangling 712100, Shaanxi, China

G. He · Z. Wang (✉) · F. Li · J. Dai ·
X. Ma · Q. Li · C. Xue · H. Cao · S. Wang ·
H. Liu · L. Luo · M. Huang
Key Laboratory of Plant Nutrition and the Agri-environment in Northwest China, Ministry of Agriculture/
College of Natural Resources and Environment,
Northwest Agricultural and Forestry University,
Yangling 712100, Shaanxi, China
e-mail: w-zhaohui@263.net

S. S. Malhi
Department of Renewable Resources, University of
Alberta, Edmonton, AB, Canada

at the start of the autumn, then harvested in late May and late June of the following year before the summer fallow coming. Annual precipitation here is around 200–600 mm and water from precipitation is the sole source for crop production due to the absence of surface and underground water, and thus water shortage is usually the limiting factor for crop growth. Hence, increasing soil water recharge from precipitation and its storage in soil is an effective approach for improving crop production in this region (Deng et al. 2006). Also, the soil organic matter content is low, i.e., usually less than 11.0 g kg^{-1} (Guo 1992), and thus low soil fertility is another factor that constrains crop production. In order to harvest more grain, increasing application of nitrogen (N) fertilizer is used widely as an effective measure. However, a higher N fertilizer input usually leads to nitrate–N residue in soil (Cui et al. 2008). Furthermore, nitrate–N residue can leach down into the deep soil or loss by other ways during the summer fallow, when 50–60 % of the annual precipitation occurs. Therefore, efforts to harvest more rainfall to increase soil water storage and the optimization of N management to achieve higher crop yield have always been considered key steps in the sustainable development of dryland agriculture.

The N fertilizer rate is one of the major factors that affects soil nitrate–N residue (Giletto and Echeverria 2013), and decreasing the N application rate is an effective measure for decreasing nitrate–N residue. However, our previous study showed that decreasing the N application rate did reduce nitrate–N residue, but also decreased the grain yield (Dai et al. 2015). When nitrate–N residue was decreased to the limit value, 55 kg N ha^{-1} in top 100 cm soil layer at winter wheat harvest, the grain yield was lowered by 32 % compared to the maximum, and when the grain yield was maximized, nitrate–N residue was as much as 223 % greater than the limit (Dai et al. 2015). To increase the crop yield and thus crop N uptake at a specific N application rate while decreasing nitrate–N residue, other factors or management strategies should be considered, such as water use in dryland. Recently, mulching the soil surface with plastic film has been used widely in dryland crop production, which has been shown to improve available soil water and then increase the crop yield and total N uptake. As Liu et al. (2014) reported, that plastic film mulch respectively increased the grain yield and total N uptake of maize by 60 and 41 %, and this should result in less nitrate–N residue in soil.

Nitrate–N residue in soil after winter wheat harvest in dryland, such as on the Loess Plateau, will persist during the rainy summer fallow season, and thus there is a potential risk of loss by leaching, bio-immobilization and denitrification (Kettering et al. 2013). Previous research showed that nitrate–N loss ranges among 14–24 kg N ha^{-1} in an N application rate of 150 kg ha^{-1} during the summer fallow in northwest China (Yang et al. 2015). Planting cover crop is considered to be an effective measure for preventing nitrate–N loss during the fallow season (Vos and van der Putten 2004). Indeed, the nitrate–N loss was decreased by 82 % after planting ryegrass as a cover crop in northern France (Constantin et al. 2010). However, the subsequent crop yield was decreased after planting cover crops during the fallow season, especially in dryland. Our previous study showed that the winter wheat grain yield was decreased by 15 % owing to planting soybean in the previous summer fallow (Yang et al. 2014). In addition, straw mulch helped the soil to immobilize nitrate–N and decreased the amount of nitrate–N in soil, thereby decreasing the possibility of nitrate–N loss (Wang et al. 2014). For example, nitrate–N loss was decreased by 5 % with an N application rate of 150 kg N ha^{-1} due to straw mulch during the winter wheat growing season in Denmark (Thomsen and Christensen 1998). However, the effect of straw mulch during the fallow season on nitrate–N loss is still unclear. Mulching the soil surface with plastic film during the winter wheat growing season increased the grain yield due to the decreased soil water loss and increased soil water storage (Chakraborty et al. 2010). In addition to the growing season, our previous study showed that retaining the residual plastic film to continue mulching the ridges during the summer fallow led to a much more soil water recharge, and thus the grain yield increase (Xue et al. 2011; Li et al. 2014). But it is unclear whether it reduces the nitrate–N loss during the summer fallow.

Soil surface managements, such as mulching the soil surface with plastic film or straw or living crop, should have variable effects on nitrate–N residue and loss depending on the mulching measures employed and the specific region. However, it is not known whether these mulching measures can reduce nitrate–N residue and loss on the Loess Plateau dryland, and the effects of different precipitation levels among years are also unclear. Therefore, a 6-year-long, location-fixed field experiment was conducted in dryland of the Loess Plateau to determine: (1) soil nitrate–N residue at harvest affected by grain yield and N uptake of winter wheat under different soil surface managements, (2) soil nitrate–N loss and accumulation affected by nitrate–N residue and soil water under different soil surface managements during summer fallow, and (3) appropriate soil surface managements for decreasing nitrate–N residue, loss and accumulation at the same time increasing grain yield.

Materials and methods

Experimental site

The experiment was initiated in September 2008 and lasted for six consecutive years until September 2014 at Shilipu (35°12′N, 107°45′E, altitude 1200 m), Changwu County, Shaanxi Province, which is a typical dryland and rainfed agricultural area located in the central part of the Loess Plateau, China. In this area, the groundwater table is around 50–80 m, which means that groundwater is unavailable for crop growth. Winter wheat is the major local cereal crop, and sown in late September or early October in early autumn, and harvested in middle or late June in early summer of the following year. The time between harvest and subsequent sowing of winter wheat is the period of summer fallow. At the experimental site, the average annual potential evapotranspiration (1991–2014) is 896 mm, and the average annual precipitation (1957–2014) is 579 mm, about 55 % of annual precipitation occurs in summer fallow. Precipitation and potential evapotranspiration are distributed unevenly over the years. For the six experimental years, the annual precipitation and annual potential evapotranspiration were 513 and 991, 475 and 920, 666 and 932, 722 and 829, 447 and 1025, and 706 and 918 mm in 2008–2009, 2009–2010, 2010–2011, 2011–2012, 2012–2013 and 2013–2014, respectively (Fig. 1). The summer rainfall and summer potential evapotranspiration were 280 and 284 in 2009, 458 and 234 in 2010, 453 and 222 in 2011, 285 and 222 in 2012, 332 and 304 in 2013, and 351 and 294 mm in 2014, respectively. The experimental field had been used for winter wheat production for a long time prior to this experiment. The soil is loess-derived and classified as a silt loam texture according to soil classification system of the United States Department of Agriculture. The basic properties measured in the 0–40 cm soil layer according to the methods described by Bao (2007) are presented in Table 1. The soil N supply capacity was low due to the low soil organic C content. The soil was considered deficient in available phosphorus (Olsen-P) and sufficient in available potassium according to local soil nutrient supply indices (Zhang 2009).

Experimental design and management

The experiment tested five soil surface managements each year, as follows: (1) bare fallow (BF, the local conventional practice used as the control), (2) plastic film mulch (PM), (3) straw mulch (SM), (4) green manure (GM) and (5) straw mulch plus green manure (SGM). At winter wheat sowing, the soil surface for PM was formed into alternating ridges and furrows using a plastic film mulch machine, and the ridges were mulched with clear plastic film (thickness = 0.008 mm) and the furrows were left uncovered for sowing, and it was kept in this form during the winter wheat growing season. For BF, SM, GM and SGM, the soil surface was prepared with no mulching and winter wheat was sown in the conventional flat planting. During the summer fallow, for BF, all the crop straw was removed from the field at winter wheat harvest, and the soil was ploughed to a depth of 40 cm about 2 weeks after harvest, then the soil surface was left as bare fallow. For PM, plastic film was still left on the ridge continuously along with all the wheat stubble and crushed straw were returned to the furrow to cover the soil surface. Until the end of summer fallow (2–3 weeks before the next winter wheat sowing), the plastic film was removed from the field. For SM, all the wheat stubble and crushed straw were returned to cover the soil surface during the summer fallow. For GM, all the straw was removed from the field at winter wheat harvest and a widely used local soybean (*Glycine max* L. Merr.) cultivar “Huaidou” was seeded at a rate of 150 kg ha^{-1} as a cover crop. Until the end of summer fallow, the soybean was mowed and chopped into less than 5 cm segments. The SGM is the combination of the SM and GM. At the end of summer fallow, the soil in PM, SM, GM and SGM were ploughed to a depth of 40 cm, at the same time straw or green manure on the

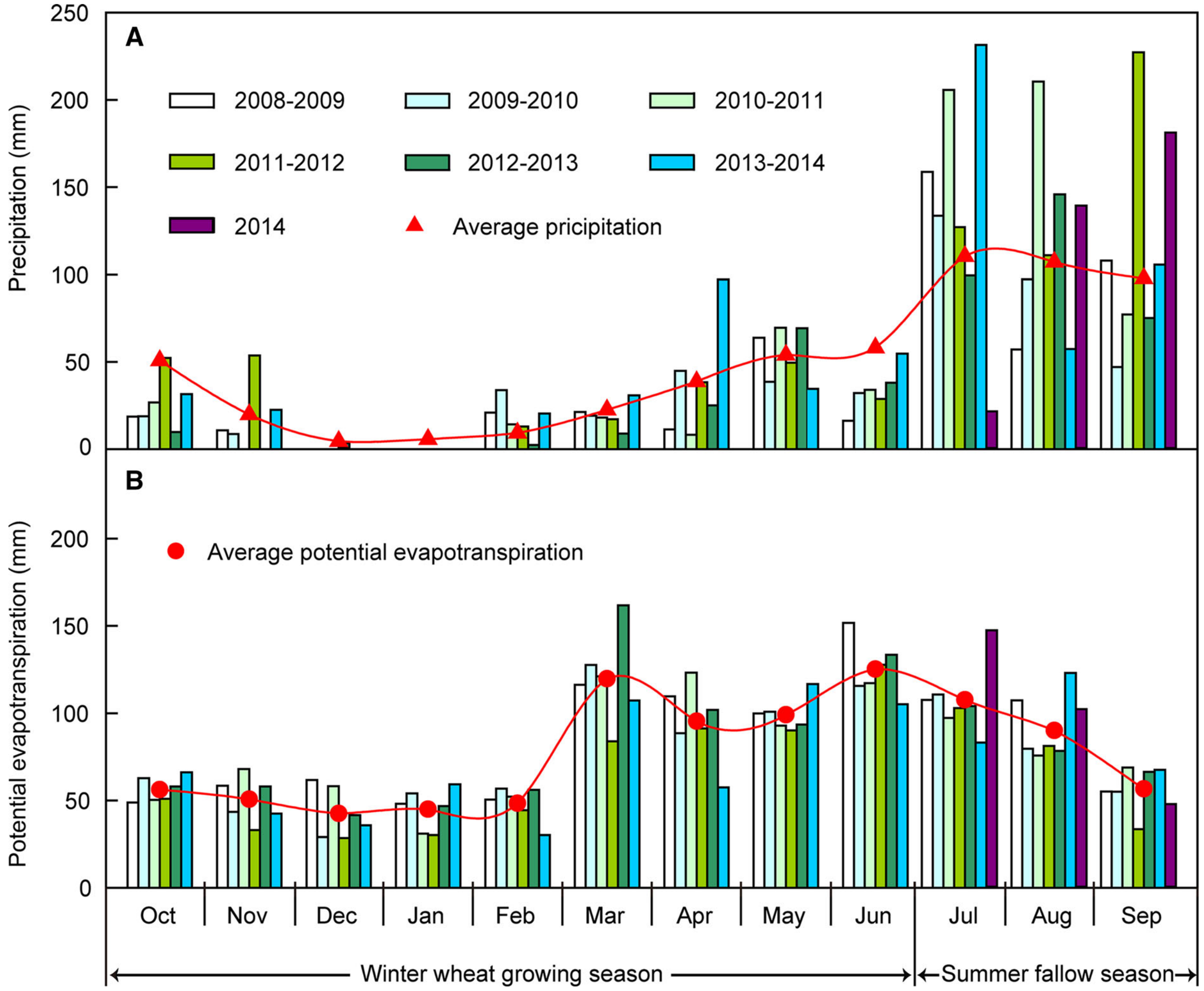

Fig. 1 Distribution of the monthly precipitation (**A**) and monthly potential evapotranspiration (**B**) at the experimental site in six experimental years (2008–2014). Data source of precipitation and potential evapotranspiration (2008–2014): Changwu Agro-ecological Experimental Station on the Loess Plateau at the Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources. Data source of average precipitation (1957–2007) and average potential evapotranspiration (1991–2007): China Meteorological Data Sharing Service System

Table 1 Basic physical and chemical properties of the 0–40 cm soil layer sampled from the experimental field at sowing winter wheat in 2008

Soil layer (cm)	Bulk density (g cm^{-3})	Organic C (g C kg^{-1})	Total N (g N kg^{-1})	Available P (mg P kg^{-1})	Available K (mg K kg^{-1})	pH (H_2O)	Mineral N	
							NO_3^-–N (mg N kg^{-1})	NH_4^+–N (mg N kg^{-1})
0–20	1.4	8.5	0.77	4.5	130	8.2	13.1	2.6
20–40	1.3	6.3	0.58	1.6	122	8.2	8.6	1.8

soil surface was incorporated evenly into soil using a plow. Table 2 shows the average dry matter and N contents of the soybean and wheat straw returned to the soil. Each treatment was replicated four times in a randomized complete block design and the plot size was 22 m × 6 m.

Table 2 Seeding and harvest times for soybean and winter wheat, and return of nitrogen to the soil in the field experiment from 2008 to 2014

Items	2008	2009	2010	2011	2012	2013	2014
Sowing time of soybean	–	27 Jun	1 Jul	30 Jun	2 Jul	16 Jun	29 Jun
Harvest time of soybean	–	23 Sep	11 Sep	1 Sep	3 Sep	1 Sep	5 Sep
Harvest time of wheat	–	22 Jun	28 Jun	27 Jun	30 Jun	14 Jun	27 Jun
Sowing time of wheat	23 Sep	2 Oct	22 Sep	23 Sep	22 Sep	28 Sep	2 Oct
Dry weight of soybean (Mg ha^{-1})	–	1.40	3.18	3.81	4.19	4.00	1.18
N from soybean returned to soil (kg N ha^{-1})	–	42.2	85.5	96.0	114.2	100.3	32.2
Dry weight of wheat straw (Mg ha^{-1})	–	3.85	5.10	3.71	6.21	2.57	10.5
N from wheat straw returned to soil (kg N ha^{-1})	–	16.1	20.5	22.9	32.0	13.4	48.2

The N and P fertilizer application rates were calculated based on the relevant available soil nutrients and the target winter wheat grain yield of the BF using the method proposed by Zhang et al. (2012b). The N and P rates were 138 kg N ha^{-1} and 105 kg P_2O_5 ha^{-1} for all the plots in 2008–2009 and 2009–2010, and 150 kg N ha^{-1} and 105 kg P_2O_5 ha^{-1} in 2010–2011, 2011–2012, 2012–2013 and 2013–2014, respectively. In the first four experimental years, three-fourths of the N fertilizer was applied as basal fertilizer and the remaining N fertilizer was applied as a top-dressing. All the N fertilizer in 2012–2013 and 2013–2014, and all the P fertilizer in each year was applied as basal fertilizer. The basal N and P fertilizers were incorporated into the soil (20 cm depth) using a rotavator around 1–2 weeks before winter wheat sowing. The top-dressed N fertilizer was applied by opening a narrow 10 cm deep furrow between the crop rows when the frozen soil melted in the early spring (20 February 2009, 8 March 2010, 5 March 2011 and 18 March 2012). The N fertilizer was supplied as urea and P fertilizer was supplied as triple superphosphate calcium. Since the soil is sufficient in available K, no K fertilizer was applied. Winter wheat, a widely used local cultivar "Changwu521", was sown at a rate of 150 kg ha^{-1} for all the treatments. The planting row distance was 20 cm in BF, SM, GM and SGM, and it was alternatively 40 and 20 cm in PM. The crop was grown under natural precipitation without any supplemental irrigation during the six experimental years. Herbicide was applied early in the reviving stage of winter wheat every year to control weeds.

Sampling and measurements

Winter wheat

Four 1 m-long rows of winter wheat plants were selected randomly in the first four experimental years and ca 100 plants in the two subsequent experimental years, and pulled from each plot. Next, the roots were cut off at the connection between the root and the stem, and ears and stems (including leaves) were pooled from the same plots. After air-drying, ears were separated into grains and glumes by threshing, and then grains, glumes and stems (including leaves) were weighed. Subsamples comprising 100 g of grain, 50 g of glumes and 50 g of stems were oven-dried at 90 °C for 30 min initially, and then at 70 °C for 48 h to determine the dry weight and for chemical analyses. Grains, glumes and stems (0.25 g) were digested using the H_2SO_4–H_2O_2 method (Bao 2007), and the total N concentration was measured using a high-resolution digital colorimeter autoAnalyzer 3 (AA3, SEAL company, Germany). The total N uptake of crop was calculated by multiplying the dry matter weights for grain, glumes and stems by their corresponding N concentrations.

Winter wheat was harvested using a combined harvester. The fresh weight of grains from each plot was weighed in the field, and ca 1 kg of grain from each plot was sampled, cleaned and oven-dried to calculate the water content of the fresh clean grain. The grain yield was expressed as the dry weight, which was calculated from the fresh grain weight of each plot and the relevant impurity and water content.

Soybean

Just before it was mowed at flowering, five to ten soybean plants were sampled randomly from each plot, and separated into stems and roots. After being washed, air-dried and weighed, subsamples of 100 g stems and 10 g roots were oven-dried for the dry weight and biomass calculation, and determination of the plant N concentration and N uptake.

Soil

Five soil cores at depths of 0–40 cm with 10 cm increments and two soil cores at depths of 40–300 cm with 20 cm increments were collected with an auger (inner diameter = 4 cm) from each plot before winter wheat sowing and at harvest. Soil from the same layer in each plot was merged and 500 g of thoroughly mixed soil was collected as a sample for the soil analyses. The soil water content of each sample was determined gravimetrically after oven drying at 105 °C for 24 h. Soil nitrate–N was extracted from 5 g of fresh soil with 50 mL of 1 mol L^{-1} KCl and then measured with hydrazine sulfate colorimetric method using a high-resolution digital colorimeter (AA3, SEAL company, Germany).

Data calculation

Soil water storage

Soil water storage (WS, mm) was calculated as:

$$\begin{aligned}\mathrm{WS}\,(\mathrm{mm}) = {} & \text{soil bulk density}\left(\mathrm{g\,cm^{-3}}\right)\\ & \times \text{soil depth increment}\,(\mathrm{cm})\\ & \times \text{soil water content}\,(\%) \times 10/100\end{aligned}$$

Soil water recharge

Soil water recharge (mm) during the summer fallow was calculated as:

$$\text{Soil water recharge}\,(\mathrm{mm}) = \mathrm{WS}_2\,(\mathrm{mm}) - \mathrm{WS}_1\,(\mathrm{mm}),$$

where WS_1 is the soil water storage in the 0–300 cm soil layer at harvest of winter wheat, when is also the start of the summer fallow, and WS_2 is the soil water storage in the 0–300 cm soil layer at subsequent winter wheat sowing after summer fallow.

Nitrate–N residue in soil

Nitrate–N residue in soil (NR, kg N ha^{-1}) was calculated as follows:

$$\begin{aligned}\mathrm{NR}\left(\mathrm{kg\ N\,ha^{-1}}\right) = {} & \text{soil bulk density}\left(\mathrm{g\,cm^{-3}}\right)\\ & \times \text{soil depth increment}\,(\mathrm{cm})\\ & \times \text{nitrate-N}\left(\mathrm{mg\,N\,kg^{-1}}\right)/10\end{aligned}$$

Nitrate–N change in soil

Nitrate–N change in soil (NC, kg N ha^{-1}) during the summer fallow was calculated as:

$$\mathrm{NC}\left(\mathrm{kg\ N\,ha^{-1}}\right) = \mathrm{NR}_2\left(\mathrm{kg\ N\,ha^{-1}}\right) - \mathrm{NR}_1\left(\mathrm{kg\,N\,ha^{-1}}\right),$$

where NR_1 is the nitrate–N in a specific soil layer at harvest of winter wheat, the start of the summer fallow, and NR_2 is the nitrate–N content in the corresponding soil layer at subsequent winter wheat sowing after summer fallow.

Nitrate–N loss and accumulation in soil

Nitrate–N can be lost from the top soil due to denitrification, bio-immobilization and leaching, and then accumulated in the deep soil layers due to leaching during the summer fallow. The nitrate–N loss (kg N ha^{-1}) was determined as the sum of the negative NCs in consecutive topsoil layers, where the nitrate–N content was significantly lower at the end compared with that at the start of the summer fallow. Nitrate–N accumulation in deep soil (kg N ha^{-1}) was determined as the sum of the positive NCs in consecutive soil layers in deep soil layers, where the nitrate–N content was increased significantly at the end of the summer fallow (Dai et al. 2013).

Statistical analyses

Two-way analysis of variance (ANOVA) with the mixed procedure of Statistical Analysis System program was conducted to determine the significance of differences in grain yield (Table 3), total N uptake (Table 4), nitrate–N residue (Table 5), soil water recharge (Table 6), nitrate–N loss (Table 7) and nitrate–N accumulation (Table 8). The treatment and year and their interaction were considered as fixed effects and the block as a random effect. One-way ANOVA was conducted to determine the significance of differences in soil water recharge (Fig. 2), soil nitrate–N loss and accumulation (Fig. 3) in each soil layer from 0 to 300 cm. When the ANOVA results were significant, the Duncan's multiple range test were used to determine the significance of the difference between means with a significance level of $P < 0.05$. Regression analysis was conducted to determine the best-fit equation and corelation between grain yield and nitrate–N residue, total N uptake and nitrate–N residue in Fig. 4, as well as nitrate–N residue and nitrate–N loss, soil water recharge and nitrate–N loss, nitrate–N residue and nitrate–N accumulation, and soil water recharge and nitrate–N accumulation in Fig. 5.

Results

Grain yield

In comparison with BF, the yearly average grain yield was increased by 6 % with PM, and decreased by 7, 5 and 5 % with SM, GM and SGM, respectively (Table 3). Moreover, the results varied among years. Compared with BF, the grain yield was increased by 44 and 13 % for PM in 2008–2009 and 2010–2011, respectively, whereas it was decreased by 16 % in 2012–2013, and there were no significant effects in other years. The grain yield was decreased by 8 and 24 % for SM in 2011–2012 and 2012–2013, respectively, and it was not significant affected in other years. GM and SGM decreased the grain yield by 37 and 31 % in 2012–2013, respectively, but they had no effects on the grain yield in other years.

Total N uptake of crop

Compared with BF, the yearly averages showed that total N uptake was decreased by 13 % with SM, whereas it was not affected by PM, GM and SGM (Table 4). The effects of soil surface managements on total N uptake varied among years. PM increased the total N uptake by 48 % in 2008–2009, but decreased it by 13 and 34 % in 2011–2012 and 2012–2013, respectively, and there were no significant effects in other years. Significant decreases in total N uptake of 11, 31 and 21 % occurred with SM in 2011–2012, 2012–2013 and 2013–2014, respectively, but SM had no effects on total N uptake in other years. GM and SGM decreased the total N uptake by 29 and 25 % in 2012–2013, but increased it by 23 and 14 % in 2011–2012, respectively, and they had no effects in other years.

Nitrate–N residue in soil at winter wheat harvest

Compared with BF, the yearly average nitrate–N residue in the 0–300 cm soil layer at winter wheat harvest was decreased by 35 % with PM, by 32 % with SM, and by 18 % with SGM, but there was no significant change with GM (Table 5). Moreover, the effects of soil surface managements on nitrate–N residue also varied among years. PM decreased the nitrate–N residue by 34, 39 and 50 % in 2009–2010, 2010–2011 and 2012–2013, respectively, but there were no significant changes in other years. SM respectively decreased the nitrate–N residue by 34 and 35 % in 2009–2010 and 2010–2011, but there were no significant changes in other years. Nitrate–N residue was increased by 64 % in 2013–2014 with GM, but GM had no significant effects in other years. SGM decreased the nitrate–N residue by 33 and 37 % in 2009–2010 and 2010–2011, respectively, but there were no significant changes in other years.

Soil water recharge during the summer fallow

The effect of summer rainfall on the soil water recharge was marked. In the summers of 2010 and 2011, the soil water recharge reached to a soil depth of 300 cm; in the summers of 2013 and 2014, it reached to a soil depth of ca 240 cm; whereas in the summers of 2009 and 2012, it only reached to a soil depth of 140 cm (Fig. 2). Compared with the average for BF over the years, the soil water recharge was increased by 12 % with PM, and decreased by 20 and 16 % with GM and SGM, respectively, and not affected by SM (Table 6). The results also varied with years. PM increased the soil water recharge by 22, 13 and 26 % in the summers of 2010, 2011 and 2014, respectively, but it had no significant effects in other summers. The soil water recharge was also increased by 21 and 8 % with SM in the summers of 2010 and 2011, respectively, whereas decreased by 34 % in the summer of 2012, but not affected in other summers. It was decreased by 13–58 % with GM in most summers, but it had no effects in the summers of 2010 and 2014.

Table 3 Grain yield of winter wheat (kg ha^{-1}) affected by different soil surface managements in six experimental years from 2008 to 2014

Treatments[#]	2008–2009	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014	Average
BF	3301 ± 325b[§]	3365 ± 405ab	5070 ± 135b	7639 ± 195ab	3877 ± 410a	7799 ± 486ab	5175 ± 171b
PM	4741 ± 402a	3646 ± 245a	5751 ± 324a	7278 ± 436bc	3243 ± 160b	8141 ± 328a	5467 ± 124a
SM	3342 ± 375b	3145 ± 172b	5021 ± 101b	7032 ± 478c	2931 ± 362bc	7535 ± 471b	4834 ± 181c
GM	3342 ± 375b	2973 ± 246b	4958 ± 99b	8086 ± 583a	2448 ± 200d	7667 ± 659ab	4912 ± 152c
SGM	3342 ± 375b	3067 ± 394b	5190 ± 141b	7712 ± 119ab	2673 ± 115 cd	7650 ± 378a	4939 ± 142c
Average	3614 ± 367C	3239 ± 213D	5198 ± 71B	7549 ± 218A	3035 ± 145D	7759 ± 187A	
		Sum of squares		F values			
Year		460,138,028		756**			
Treatment		6,381,378		13**			
Year × treatment		11,261,836		5**			

Data are expressed as averages based on four replicates. Different lowercase letters in the same column and different uppercase letters in the same row indicate significant differences at $P < 0.05$

** $P < 0.01$

[§] Average value ± SD

[#] Treatments: *BF* bare fallow, *PM* plastic film mulch, *SM* straw mulch, *GM* green manure, *SGM* straw mulch plus green manure

Table 4 Total N uptake (kg N ha^{-1}) affected by different soil surface managements in six experimental years from 2008 to 2014

Treatments[#]	2008–2009	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014	Average
BF	95 ± 15b[§]	104 ± 14a	151 ± 6ab	155 ± 17b	101 ± 11a	207 ± 30a	136 ± 8a
PM	140 ± 19a	99 ± 11a	156 ± 11a	135 ± 9c	66 ± 3b	202 ± 22a	133 ± 7a
SM	96 ± 9b	98 ± 3a	139 ± 9b	138 ± 19c	69 ± 8b	163 ± 21b	117 ± 9b
GM	96 ± 9b	96 ± 8a	148 ± 11ab	191 ± 15a	72 ± 10b	212 ± 15a	136 ± 6a
SGM	96 ± 9b	93 ± 8a	157 ± 3a	177 ± 12a	76 ± 3b	218 ± 8a	136 ± 2a
Average	105 ± 12C	98 ± 5C	150 ± 5B	159 ± 14B	77 ± 4D	200 ± 8A	
		Sum of squares		F values			
Year		213,801		245**			
Treatment		6250		9**			
Year × treatment		21,190		6**			

Data are expressed as averages based on four replicates. Different lowercase letters in the same column and different uppercase letters in the same row indicate significant differences at $P < 0.05$

** $P < 0.01$

[§] Average value ± SD

[#] Treatments: *BF* bare fallow, *PM* plastic film mulch, *SM* straw mulch, *GM* green manure, *SGM* straw mulch plus green manure

Table 5 Nitrate–N residue (kg N ha^{-1}) in the 0–300 cm soil layer at winter wheat harvest affected by different soil surface managements in six experimental years from 2008 to 2014

Treatments[#]	2008–2009	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014	Average
BF	68 ± 33a[§]	190 ± 47a	160 ± 32a	61 ± 45a	101 ± 42ab	80 ± 34b	110 ± 28a
PM	44 ± 14a	126 ± 16b	99 ± 25b	48 ± 10a	50 ± 29c	65 ± 26b	72 ± 8c
SM	68 ± 24a	125 ± 74b	105 ± 30b	26 ± 18a	60 ± 20bc	63 ± 19b	74 ± 22c
GM	51 ± 15a	147 ± 32ab	142 ± 41ab	42 ± 12a	129 ± 24a	131 ± 23a	107 ± 12ab
SGM	60 ± 23a	128 ± 51b	102 ± 67b	34 ± 13a	122 ± 24a	97 ± 21ab	90 ± 24bc
Average	58 ± 30C	143 ± 27A	122 ± 26A	42 ± 11C	93 ± 11B	87 ± 12B	
		Sum of squares		F values			
Year		142,853		21**			
Treatment		30,220		6**			
Year × treatment		32,606		1*			

Data are expressed as averages based on four replicates. Different lowercase letters in the same column and different uppercase letters in the same row indicate significant differences at $P < 0.05$

** $P < 0.01$; * $0.01 < P < 0.05$

[§] Average value ± SD

[#] Treatments: *BF* bare fallow, *PM* plastic film mulch, *SM* straw mulch, *GM* green manure, *SGM* straw mulch plus green manure

SGM decreased the soil water recharge by 46 and 56 % in the summers of 2012 and 2013, respectively, but it had no effects in other summers.

Nitrate–N loss and accumulation during the summer fallow

Since the variation in summer rainfall, the effects of soil surface managements on nitrate–N loss also varied among summers. Nitrate–N loss was found mainly in the top 80 cm soil in the summers of 2010 and 2011, and in the top 40 cm soil in the summers of 2013 and 2014, but almost no nitrate–N loss in the summers of 2009 and 2012 (Fig. 3). Averaged over the years, the nitrate–N loss was decreased by 51, 53, 50 and 34 % with PM, SM, GM and SGM, respectively, although the decrease by SGM was not statistically significant (Table 7). Compared with BF, the PM, SM,

Table 6 Soil water recharge (mm) in the 0–300 cm soil layer during summer fallow affected by different soil surface managements in the field experiment from 2009 to 2014

Treatments[#]	2009	2010	2011	2012	2013	2014	Average
BF	132 ± 30ab[§]	227 ± 20b	259 ± 23b	117 ± 31a	178 ± 29a	195 ± 15b	185 ± 8b
PM	145 ± 14a	277 ± 20a	294 ± 10a	99 ± 12ab	178 ± 14a	246 ± 29a	206 ± 7a
SM	128 ± 11ab	274 ± 11a	281 ± 15a	77 ± 30bc	160 ± 41a	207 ± 35b	188 ± 10b
GM	101 ± 9c	256 ± 24ab	226 ± 11c	50 ± 22c	76 ± 17b	177 ± 21b	148 ± 7c
SGM	112 ± 5bc	249 ± 24ab	254 ± 9bc	63 ± 15bc	79 ± 10b	178 ± 7b	156 ± 4c
Average	124 ± 7C	257 ± 15A	263 ± 10A	81 ± 19D	134 ± 11C	200 ± 14B	
Summer rainfall	280	458	453	285	332	351	
		Sum of squares		F values			
Year		563,503		259**			
Treatment		56,148		33**			
Year × treatment		33,923		4**			

Data are expressed as averages based on four replicates. Different lowercase letters in the same column and different uppercase letters in the same row indicate significant differences at $P < 0.05$

** $P < 0.01$

[§] Average value ± SD

[#] Treatments: *BF* bare fallow, *PM* plastic film mulch, *SM* straw mulch, *GM* green manure, *SGM* straw mulch plus green manure

Table 7 Nitrate–N loss (kg N ha^{-1}) during summer fallow affected by different soil surface managements in six experimental years from 2009 to 2014

Treatments[#]	2009	2010	2011	2012	2013	2014	Average
BF	0 ± 0a[§]	66 ± 15a	58 ± 14a	5 ± 1a	14 ± 11ab	11 ± 2a	26 ± 4a
PM	0 ± 0a	17 ± 3b	24 ± 12b	15 ± 3a	0 ± 0b	19 ± 7a	13 ± 3b
SM	8 ± 15a	27 ± 11b	26 ± 7b	0 ± 0a	0 ± 0b	12 ± 5a	12 ± 4b
GM	0 ± 0a	24 ± 12b	12 ± 15b	0 ± 0a	19 ± 19ab	22 ± 3a	13 ± 2b
SGM	6 ± 19a	27 ± 15b	14 ± 23b	0 ± 0a	41 ± 8a	14 ± 7a	17 ± 8ab
Average	3 ± 7C	32 ± 9A	27 ± 8A	4 ± 4C	15 ± 3B	16 ± 3B	
		Sum of squares		F values			
Year		14,100		7**			
Treatment		3219		2*			
Year × treatment		14,093		2*			

Data are expressed as averages based on four replicates. Different lowercase letters in the same column and different uppercase letters in the same row indicate significant differences at $P < 0.05$

** $P < 0.01$; * $0.01 < P < 0.05$

[§] Average value ± SD

[#] Treatments: *BF* bare fallow, *PM* plastic film mulch, *SM* straw mulch, *GM* green manure, *SGM* straw mulch plus green manure

GM and SGM decreased the nitrate–N loss in the summers of 2010 and 2011 by 74 and 58 %, 59 and 55 %, 64 and 79 %, and 60 and 76 %, respectively, whereas there were no significant effects in other summers.

Averaged over the years, nitrate–N accumulation was decreased by soil surface managements, i.e., decreases of 56, 45, 31 and 39 % with PM, SM, GM and SGM, respectively, compared with BF (Table 8). Nitrate–N accumulation occurred mainly in the

Table 8 Nitrate–N accumulation (kg N ha^{-1}) during summer fallow affected by different soil surface managements in six experimental years from 2009 to 2014

Treatments[#]	2009	2010	2011	2012	2013	2014	Average
BF	70 ± 21a[§]	36 ± 13a	73 ± 31a	22 ± 7a	58 ± 12a	55 ± 11a	52 ± 11a
PM	19 ± 4b	18 ± 12a	37 ± 10b	0 ± 0a	44 ± 12ab	21 ± 14bc	23 ± 3b
SM	48 ± 20ab	29 ± 14a	79 ± 14a	0 ± 0a	18 ± 2b	0 ± 0c	29 ± 7b
GM	48 ± 12ab	28 ± 12a	78 ± 17a	8 ± 3a	33 ± 6ab	23 ± 6abc	36 ± 8b
SGM	11 ± 4b	37 ± 8a	65 ± 7ab	12 ± 5a	31 ± 9ab	37 ± 20ab	32 ± 5b
Average	39 ± 7B	30 ± 9B	66 ± 12A	9 ± 2C	37 ± 2B	27 ± 8B	
		Sum of squares		F values			
Year		44,816		22**			
Treatment		14,634		9**			
Year × treatment		18,445		2*			

Data are expressed as averages based on four replicates. Different lowercase letters in the same column and different uppercase letters in the same row indicate significant differences at $P < 0.05$

** $P < 0.01$; * $0.01 < P < 0.05$

[§] Average value ± SD

[#] Treatments: *BF* bare fallow, *PM* plastic film mulch, *SM* straw mulch, *GM* green manure, *SGM* straw mulch plus green manure

60–200 cm soil layer in the summers of 2010 and 2011, the 60–140 cm soil layer in the summers of 2013 and 2014, and the 20–100 cm soil layer in the summers of 2009 and 2012. PM decreased the nitrate–N accumulation by 73, 49 and 62 % in the summers of 2009, 2011 and 2014, respectively, and the decreases in other years were not significant. SM decreased the nitrate–N accumulation by 68 and 100 % in the summers of 2013 and 2014, respectively, and it had no effects in other summers. SGM decreased the nitrate–N accumulation by 84 % in the summer of 2009, but there were no significant effects in other years.

Discussion

Nitrate–N residue in soil affected by grain yield and total N uptake under different soil surface managements

Usually, the grain yield and total N uptake increase may decrease the nitrate–N residue in soil, as reported by Liu et al. (2015). In the present study, the decreased nitrate–N residue was also associated with the increased grain yield (Fig. 4A). For instance, PM decreased the nitrate–N residue in 2010–2011 when the grain yield was increased, owing to the decreased soil water evaporation and increased soil water storage (Gao et al. 2009). However, the results also varied with soil surface managements and years. For example, in 2012–2013 with the lowest precipitation and the highest potential evapotranspiration over all the experimental years, the serious water stress resulted in the grain yield decease in all soil surface managements. However, the decreased grain yield did not result in nitrate–N residue increase, and even decrease in PM. Also, the decreased nitrate–N residue was not accompanied by the increased total N uptake (Fig. 4B). For example, the SM decreased the total N uptake, but did not increase the nitrate–N residue in the late three experimental years. This means that apart from the grain yield and total N uptake, other factors could also affect the soil nitrate–N residue, such as the soil N bio-immobilization and soil N mineralization (Limon-Ortega et al. 2008; Zhang et al. 2012a). For PM, SM and SGM, returning wheat straw (high C/N ratio) to the soil enhanced N bio-immobilization, and thus resulted in the nitrate–N residue decrease (Shindo and Nishio 2005). Soil water is a main environmental factor influencing soil N mineralization (Borken and Matzner 2009). In the years of 2011–2012 and 2013–2014 with more precipitation and less potential evapotranspiration

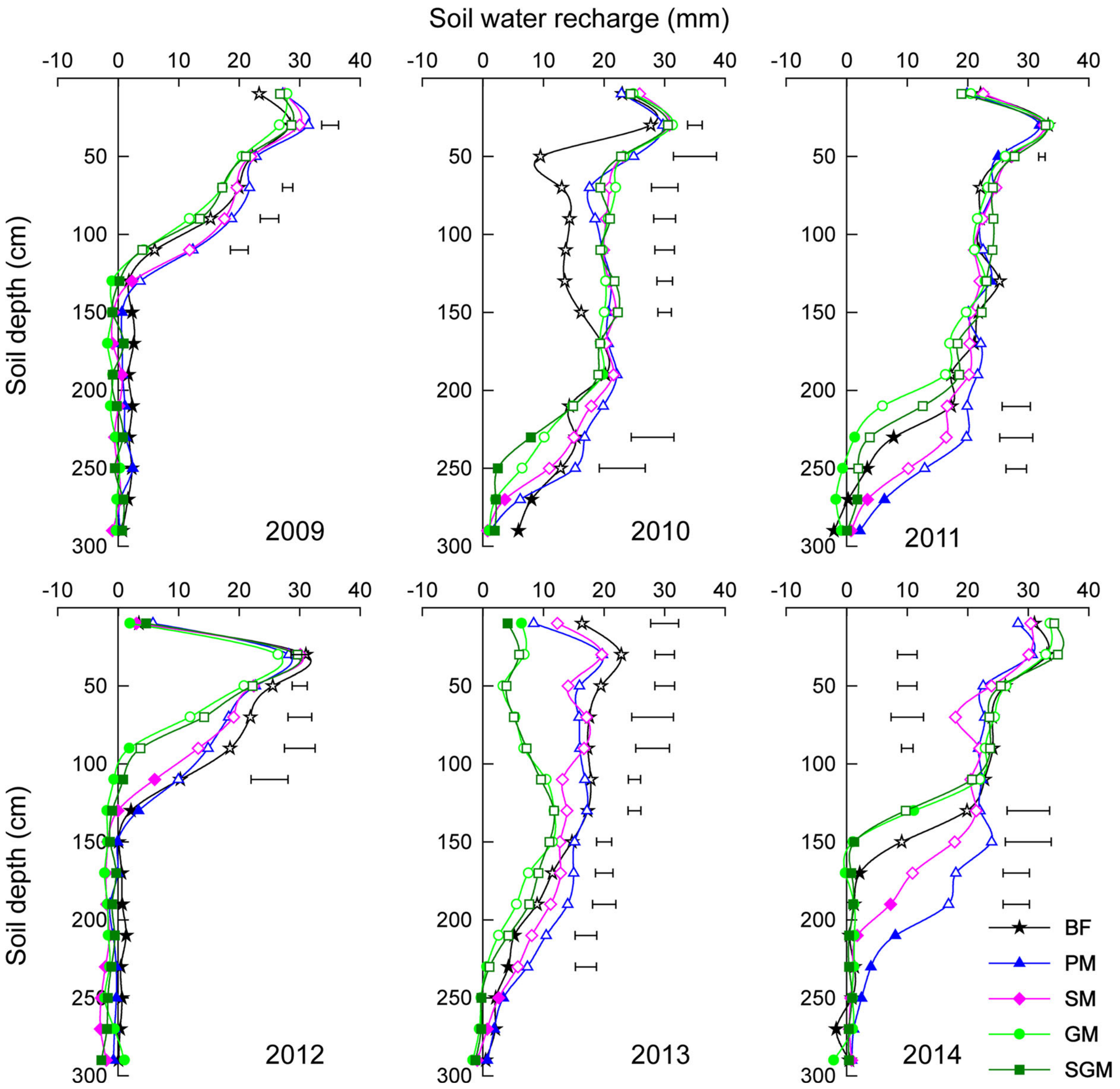

Fig. 2 Distribution of soil water recharge in the 0–300 cm soil layer with different soil surface managements during the summer fallow. *Hollow spots* indicate that the difference of soil water storage at the end compared to that at the start of the summer fallow is significant. *Error bars* denote the LSD at $P \leq 0.05$. Treatments: *BF* bare fallow, *PM* plastic film mulch, *SM* straw mulch, *GM* green manure, *SGM* straw mulch plus green manure

than the long-term average, the PM, SM and SGM did not decrease nitrate–N residue due to higher soil N mineralization as a result of higher soil water content. Furthermore, GM was not able to decrease the nitrate–N residue, even increase it in the sixth experimental year. In southwest Sweden, continuous planting ryegrass during the winter fallow increased the nitrate–N residue due to the increased N mineralization capacity (Blombäck et al. 2003). The much greater increase of nitrate–N residue with GM should be attributed to increasing soil N fertility by extra N input from the biological N fixation of legumes (Basamba et al. 2007; Sharma et al. 2010). However, this process was very slow, and thus the soil nitrate–N residue was only increased till the sixth year, the last experimental year.

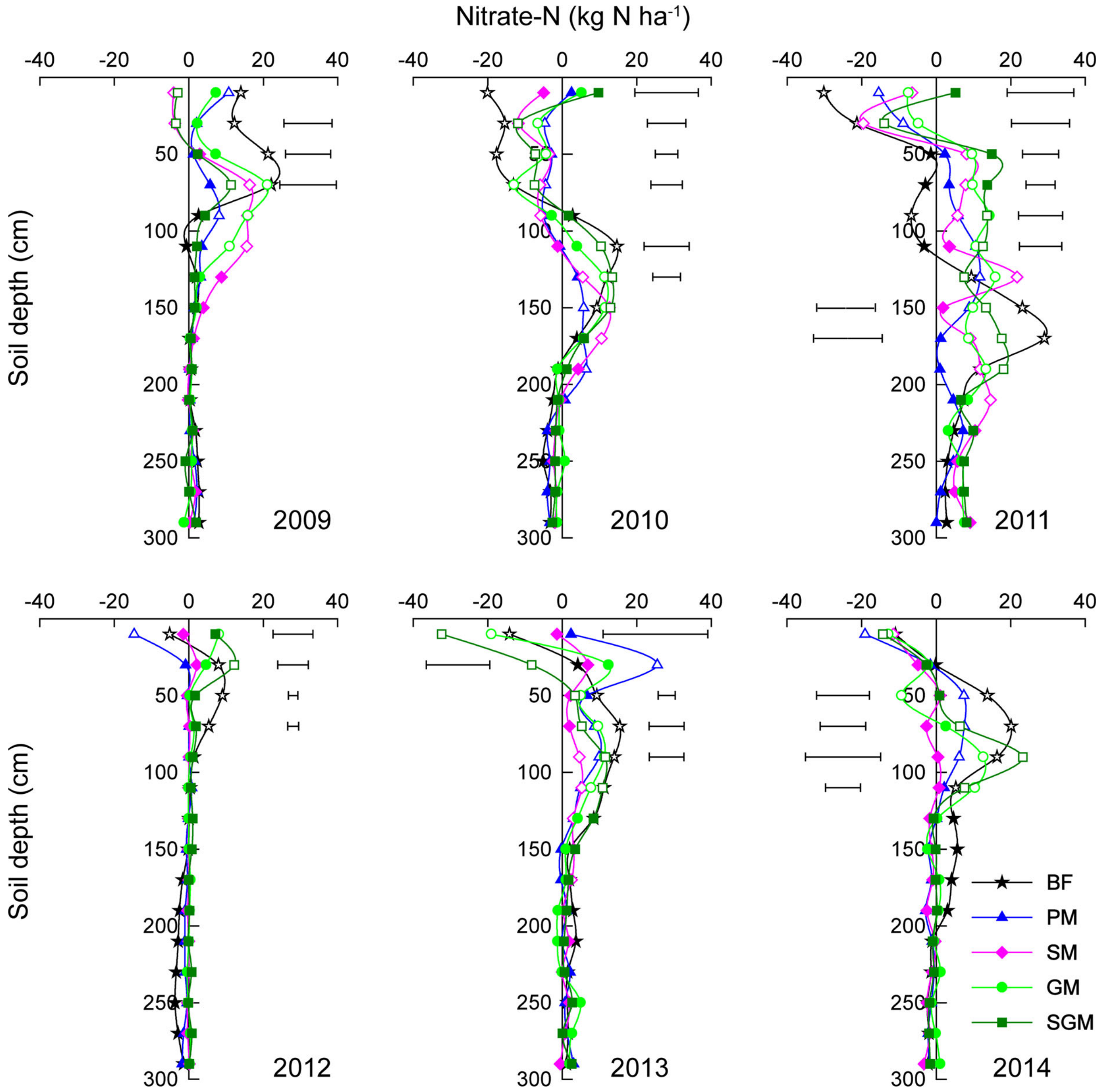

Fig. 3 Distribution of the nitrate–N loss and accumulation in the 0–300 cm soil layer with different soil surface managements during the summer fallow. *Hollow spots* indicate that the nitrate residues at the end of the summer fallow compared with those at the start are significantly lower or higher. *Error bars* denote the LSD at $P \leq 0.05$. Treatments: *BF* bare fallow, *PM* plastic film mulch, *SM* straw mulch, *GM* green manure, *SGM* straw mulch plus green manure

Soil nitrate–N loss and accumulation affected by nitrate–N residue and soil water under different soil surface managements

Apart from the nitrate–N residue at harvest, nitrate–N loss was obviously affected by soil water condition during the summer fallow (Fig. 5A, B). In the summers of 2010 and 2011 with more rainfall and less potential evapotranspiration than the long-term average, the amount of nitrate–N loss was larger because of higher nitrate–N residue and soil water recharge compared with other summers, a similar result was reported by Liu et al. (2015). However, the increased soil water recharge under PM and SM owing

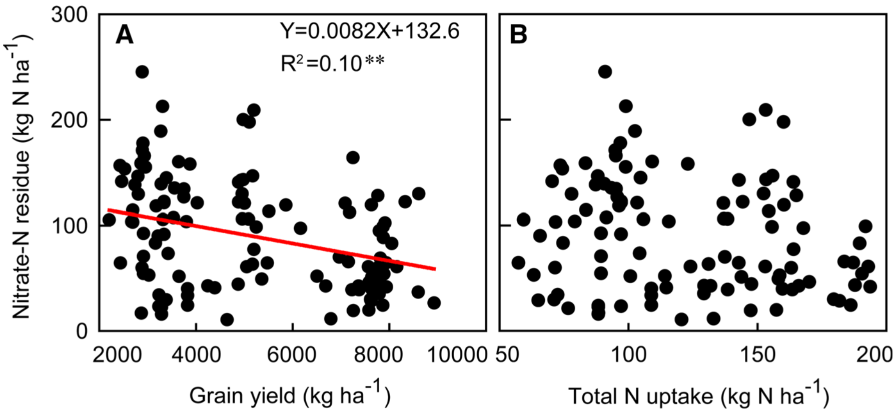

Fig. 4 Relationships between grain yield and nitrate–N residue (**A**), and total N uptake and nitrate–N residue (**B**) in six experimental years from 2008 to 2014

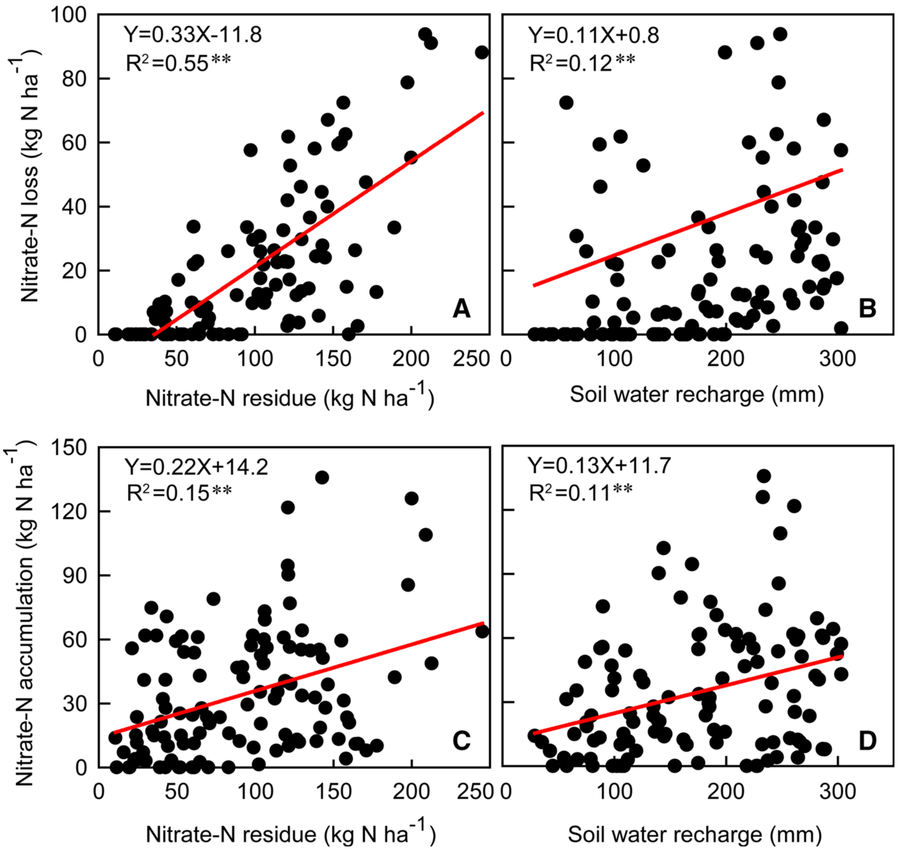

Fig. 5 Relationships between nitrate–N residue and nitrate–N loss (**A**), soil water recharge and nitrate–N loss (**B**), nitrate–N residue and nitrate–N accumulation (**C**), and soil water recharge and nitrate–N accumulation (**D**) in six experimental years from 2008 to 2014

to the decreased soil water evaporation and increased soil water infiltration, did not increase the nitrate–N loss and even decreased it. Ruidisch et al. (2013) reported that PM during the radish growing season decreased the nitrate–N loss, since PM enhanced the nitrate–N retention for soil underneath the plastic film. Hansen et al. (2010) showed that SM during the wheat growing season also decreased the nitrate–N loss because of increasing net N immobilization. These may also be applicative in the present study. In addition, the lower infiltration rate for soil water from rainfall due to the straw retention in the furrow for the PM and over the entire soil surface for the SM, and the less soil nitrate–N residue at wheat harvest were the crucial factors for decreasing nitrate–N loss. GM and SGM also decreased the nitrate–N loss in these summers. There are two possible explanations for this. Firstly, the decreased amount and depth of downward movement of soil water recharge mitigated the downward movement of nitrate–N. Secondly, planting legume as a cover crop was effective in capturing soil nitrate–N because of its rapid growth (Plaza-Bonilla et al. 2015).

Nitrate–N accumulated in the deep soil was mainly derived from the loss of the top soil nitrate–N residue and that mineralized from the soil organic N, and the nitrate–N accumulation was obviously increased with the increase of nitrate–N residue and soil water recharge during the summer fallow (Fig. 5C, D). However, the results also varied with soil surface managements and years. For example, in the summers of 2010 and 2011, PM and SM increased soil water recharge and decreased nitrate–N residue, and SGM also decreased nitrate–N residue, but they did not affect nitrate–N accumulation in most cases. This indicated that apart from soil water recharge and nitrate–N residue, other factors could also affect the nitrate–N accumulation. As Heumann et al. (2013) showed that soil organic N mineralization was another factor influencing nitrate–N accumulation. Zhang et al. (2012a) also reported that nitrate–N accumulation decreased with decreasing soil N mineralization in eastern China. Therefore, constrained soil N mineralization due to the lowered soil surface temperature caused by the mulching the soil surface with wheat straw or planting green manure during the summer fallow (Zhang et al. 2009; Yin et al. 2016), was also the reason for the reduced nitrate–N accumulation in deep soil under different soil surface managements in the present study.

Conclusion

Soil nitrate–N residue, loss and accumulation were obviously affected by soil surface managements. PM was a beneficial measure for increasing the grain yield and decreasing the soil nitrate–N residue, loss and accumulation in most cases, but it was not an effective measure for increasing the total N uptake in a winter wheat-summer fallow system on dryland. Although SM did not show any benefit for the grain yield and total N uptake, it decreased the soil nitrate–N residue, loss and accumulation in most cases. The GM and SGM only decreased the grain yield and total N uptake in the year of 2012–2013. The GM decreased the nitrate–N loss and accumulation, and SGM decreased the nitrate–N residue, loss and accumulation in most summers. Above results revealed that increasing grain yield resulted in soil nitrate–N residue decrease, and nitrate–N loss and accumulation was restricted by the decreased nitrate–N residue and soil water recharge. In conclusion, PM is a preferable measure for lowering the risk of nitrate–N residue, loss and accumulation while improving grain yield.

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References

Bao SD (2007) Soil and agricultural chemistry analysis. China Agricultural Press, Beijing **(in Chinese)**

Basamba TA, Barrios E, Singh BR, Rao IM (2007) Impact of planted fallows and a crop rotation on nitrogen mineralization and phosphorus and organic matter fractions on a Colombian volcanic-ash soil. Nutr Cycl Agroecosyst 77:127–141

Blombäck K, Eckersten H, Lewan E, Aronsson H (2003) Simulations of soil carbon and nitrogen dynamics during seven years in a catch crop experiment. Agric Syst 76:95–114

Borken W, Matzner E (2009) Reappraisal of drying and wetting effects on C and N mineralization and fluxes in soils. Glob Change Biol 15:808–824

Chakraborty D, Garg RN, Tomar RK, Singh R, Sharma SK, Singh RK, Trivedi SM, Mittal RB, Sharma PK, Kamble KH (2010) Synthetic and organic mulching and nitrogen effect on winter wheat (*Triticum aestivum* L.) in a semi-arid environment. Agric Water Manag 97:738–748

Constantin J, Mary B, Laurent F, Aubrion G, Fontaine A, Kerveillant P, Beaudoin N (2010) Effects of catch crops, no till and reduced nitrogen fertilization on nitrogen leaching and balance in three long-term experiments. Agric Ecosyst Environ 135:268–278

Cui ZL, Zhang FS, Miao YX, Sun QP, Li F, Chen XP, Li JL, Ye YL, Yang ZP, Zhang Q, Liu CS (2008) Soil nitrate–N levels required for high yield maize production in the North China Plain. Nutr Cycl Agroecosyst 82:187–196

Dai J, Wang ZH, Li Q, Li MH, Li FC (2013) Effects of nitrogen application rate on winter wheat yield and soil nitrate nitrogen during summer fallow season on dryland. Acta Pedol Sin 50:956–965 **(in Chinese)**

Dai J, Wang ZH, Li FC, He G, Wang S, Li Q, Cao HB, Luo LC, Zan YL, Meng XY, Zhang WW, Wang RH, Malhi SS

(2015) Optimizing nitrogen input by balancing winter wheat yield and residual nitrate–N in soil in a long-term dryland field experiment in the Loess Plateau of China. Field Crop Res 181:32–41

Deng XP, Shan L, Zhang H, Turner NC (2006) Improving agricultural water use efficiency in arid and semiarid areas of China. Agric Water Manag 80:23–40

Gao YJ, Li Y, Zhang JC, Liu WG, Dang ZP, Cao WX, Qiang Q (2009) Effects of mulch, N fertilizer, and plant density on wheat yield, wheat nitrogen uptake, and residual soil nitrate in a dryland area of China. Nutr Cycl Agroecosyst 85:109–121

Giletto CM, Echeverria HE (2013) Nitrogen balance for potato crops in the southeast pampas region, Argentina. Nutr Cycl Agroecosyst 95:73–86

Guo ZY (1992) Shaanxi soil. Science Press Publishing, Beijing **(in Chinese)**

Hansen EM, Munkholm LJ, Melander B, Olesen JE (2010) Can non-inversion tillage and straw retainment reduce N leaching in cereal-based crop rotations? Soil Till Res 109:1–8

Heumann S, Fier A, Haßdenteufel M, Höper H, Schäfer W, Eiler T, Böttcher J (2013) Minimizing nitrate leaching while maintaining crop yields: insights by simulating net N mineralization. Nutr Cycl Agroecosyst 95:395–408

Kettering J, Ruidisch M, Gaviria C, Ok YS, Kuzyakov Y (2013) Fate of fertilizer N-15 in intensive ridge cultivation with plastic mulching under a monsoon climate. Nutr Cycl Agroecosyst 95:57–72

Li Q, Wang ZH, Li FC, Dai J, Li MH, He G, Cao QH, Duan CL, Yu CW (2014) Effects of nitrogen fertilizer management on yield and nitrogen use efficiency in winter wheat growing on dryland with plastic film mulching. Acta Agron Sin 40:93–100 **(in Chinese)**

Limon-Ortega A, Govaerts B, Sayre KD (2008) Straw management, crop rotation, and nitrogen source effect on wheat grain yield and nitrogen use efficiency. Eur J Agron 29:21–28

Liu JL, Zhu L, Luo SS, Bu LD, Chen XP, Yue SC, Li SQ (2014) Response of nitrous oxide emission to soil mulching and nitrogen fertilization in semi-arid farmland. Agric Ecosyst Environ 188:20–28

Liu JL, Zhan A, Chen H, Luo SS, Bu LD, Chen XP, Li SQ (2015) Response of nitrogen use efficiency and soil nitrate dynamics to soil mulching in dryland maize (*Zea mays* L.) fields. Nutr Cycl Agroecosyst 101:271–283

Plaza-Bonilla D, Nolot J-M, Raffaillac D, Justes E (2015) Cover crops mitigate nitrate leaching in cropping systems including grain legumes: field evidence and model simulations. Agric Ecosyst Environ 212:1–12

Ruidisch M, Bartsch S, Kettering J, Huwe B, Frei S (2013) The effect of fertilizer best management practices on nitrate leaching in a plastic mulched ridge cultivation system. Agric Ecosyst Environ 169:21–32

Sharma AR, Singh R, Dhyani SK, Dube RK (2010) Moisture conservation and nitrogen recycling through legume mulching in rainfed maize (Zea mays)-wheat (*Triticum aestivum*) cropping system. Nutr Cycl Agroecosyst 87:187–197

Shindo H, Nishio T (2005) Immobilization and remineralization of N following addition of wheat straw into soil: determination of gross N transformation rates by ^{15}N-ammonium isotope dilution technique. Soil Biol Biochem 37:425–432

Stewart BA, Liang WL (2015) Strategies for increasing the capture, storage, and utilization of precipitation in semiarid regions. J Integr Agric 14:1500–1510

Thomsen IK, Christensen BT (1998) Cropping system and residue management effects on nitrate leaching and crop yields. Agric Ecosyst Environ 68:73–84

Vos J, van der Putten PEL (2004) Nutrient cycling in a cropping system with potato, spring wheat, sugar beet, oats and nitrogen catch crops. II. Effect of catch crops on nitrate leaching in autumn and winter. Nutr Cycl Agroecosyst 70:23–31

Wang J, Wang DJ, Zhang G, Wang Y, Wang C, Teng Y, Christie P (2014) Nitrogen and phosphorus leaching losses from intensively managed paddy fields with straw retention. Agric Water Manag 141:66–73

Xue C, Wang ZH, Li FC, Zhao HB, Zhou L, Li XH (2011) Effects of different fertilization and mulching cultivation methods on yield and soil water use of winter wheat on Weibei dryland. Sci Agric Sin 44:4395–4405 **(in Chinese)**

Yang N, Wang ZH, Gao YJ, Zhao HB, Li KY, Li FC, Malhi SS (2014) Effects of planting soybean in summer fallow on wheat grain yield, total N and Zn in grain and available N and Zn in soil on the Loess Plateau of China. Eur J Agron 58:63–72

Yang XL, Lu YL, Tong YA, Yin XF (2015) A 5-year lysimeter monitoring of nitrate leaching from wheat–maize rotation system: comparison between optimum N fertilization and conventional farmer N fertilization. Agric Ecosyst Environ 199:34–42

Yin W, Feng FX, Zhao C, Yu AZ, Hu FL, Chai Q, Gan YT, Guo Y (2016) Integrated double mulching practices optimizes soil temperature and improves soil water utilization in arid environments. Int J Biometeorol 60:1–15

Zhang FS (2009) Apply fertilizer guide for major crop in China. China agricultural University Press, Beijing **(in Chinese)**

Zhang SL, Lövdahl L, Grip H, Tong YN, Yang XY, Wang QJ (2009) Effects of mulching and catch cropping on soil temperature, soil moisture and wheat yield on the Loess Plateau of China. Soil Till Res 102:78–86

Zhang HY, Liu QJ, Yu XX, Lü GA, Wu YZ (2012a) Effects of plastic mulch duration on nitrogen mineralization and leaching in peanut (*Arachis hypogaea*) cultivated land in the Yimeng Mountainous Area, China. Agric Ecosyst Environ 158:164–171

Zhang ZL, Liu JS, Wang ZH, Zhao HB, Yang N, Yang R, Cao HB (2012b) Nitrogen recommendation for dryland winter wheat by monitoring nitrate in 1 m soil and based on nitrogen balance. Plant Nutr Fertil Sci 18:1387–1396 **(in Chinese)**