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Full Length Article

Effects of Precision Seeding and Laser Land Leveling on Winter Wheat Yield and Residual Soil Nitrogen

Cunjun Li[1], Yongsheng Wang[2*], Chuang Lu[1] and Heju Huai[1]
[1]*Beijing Research Center for Information Technology in Agriculture, Beijing 100097, China*
[2]*Key Laboratory of Regional Sustainable Development Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China*
[*]For correspondence: wyswqj@163.com

Abstract

Precision agriculture (PA) has been suggested as a management tool to increase crop performance and improve environmental quality. Few studies have simultaneously investigated the economic and environmental benefits of PA. This study aims to evaluate the effects of PA technology on winter wheat yield and residual soil nitrogen in central China. Three treatments, single precision seeding technology (PS), integrated precision seeding with laser land leveling technologies (PLS), conventional land leveling and conventional seeding technologies (CLS) were evaluated in winter wheat cropland of central China. Wheat yield components and residual soil nitrogen were measured in harvest time. The abundance of soil ammonia-oxidizer archaea (AOA) and soil ammonia-oxidizer bacteria (AOB) was determined using real-time PCR polymerase chain reaction to explore the microbial mechanisms of residual soil nitrogen under PA application. The result showed that PLS treatment rather than PS treatment significantly increased wheat yield, straw biomass and wheat nitrogen uptake after one season of application. PS and PLS treatments resulted in significant increase of C/N ratio, while only PLS treatment significantly increased soil pH value. Furthermore, PS treatment significantly reduced residual soil NO_3^--N and NH_4^+-N, whereas PLS treatment only significantly decreased residual soil NH_4^+-N. Both PS and PLS treatments did not affect the abundance of AOB *amoA* gene copy numbers, but significantly stimulate the abundance of AOA *amoA* gene copy numbers. These results indicate that PA application reduced residual soil nitrogen via changing the abundance of AOA resulting from the increased C/N ratio and soil pH value. Our study also suggested that integrated PLS treatment was the good application pattern than single PS treatment to improve wheat yield and reduce residual soil nitrogen.

Keyword: Precision seeding; Laser land leveling; Wheat yield; Residual soil nitrogen; Ammonia-oxidizers

Introduction

Enhanced food demand is needed to satisfy by improving crop yield from the decreased cultivated land areas induced by rising population growth and rapidly urbanization in China (Bai *et al*., 2014). Large inputs of nitrogen fertilizer and pesticide in intensive agriculture has led to eutrophication of surface water, nitrate pollution of groundwater, acid rain and soil acidification, and other forms of air pollution (Ju *et al*., 2009). Precision agriculture (PA) was beneficial to crop production and environment protection originated from more targeted use of fertilizer and pesticide (Cassman, 1999; Bongiovanni and Lowenberg-DeBoer, 2004; Gebbers and Adamchuk, 2010). Evaluation of PA technologies and facilities were separately carried out from the aspects of crop yield and nutrients use efficiency (Swinton and Lowenberg-DeBoer, 1998; Pampolino *et al*., 2007; Sapkota *et al*., 2014). Moreover, the economic and environmental benefits of PA application were still controversial. It is essential to explore the mechanisms underlying the associations between PA application and agricultural production and environment.

PA technologies and facilities were widely used in tillage, seeding, fertilization, irrigation, plant protection and harvest (Bracy *et al*., 1993; Jat *et al*., 2009; Sapkota *et al*., 2014). Precision seeding technology provided an approach to keep seed quantity and quality based on real-time monitoring system and global position system (Griepentrog *et al*., 2005). Previous studies indicate that precision seeding technology reduces the dosage of seed, decrease the operating cost of agricultural machinery and increase the crop yield and farmer's income (Bracy *et al*., 1993; Auernhammer, 2001; Dai *et al*., 2014). However, the seeding quality and crop growth were influenced by uneven fields with dikes and ditches in conventional leveled fields (Jat *et al*., 2006). It is necessary to integrate the precision seeding with advanced land leveling technology in order to obtain higher benefits in agricultural production (Kahlown *et al*., 2002). Laser land leveling is a process of smoothen

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the land surface from its average elevation using laser equipped drag buckets to achieve precision in land leveling (Jat *et al*., 2006). Laser-assisted precision land leveling has been reported to withstand stress and stabilize yields via enhancing survival of young seedlings and robustness of crop (Fangmeier *et al*., 1999; Jat *et al*., 2009). PA was adopted in three strategies in the developing countries as single PA technology, PA technology package and integrated PA technology (Mondal and Basu, 2009). However, the benefits of integrated precision seeding with laser land leveling technologies have been few studied so far.

Agricultural production caused extremely large amounts of the nitrogen accumulation in soil profiles after harvest, leading to the non-point pollution under rainfall or irrigation periods (Ju *et al*., 2009). Agricultural practices (tillage, fertilization, irrigation) and crop absorbing exert strong effects on transformation and residual of soil nitrogen. Ammonia oxidation to nitrite, the first and rate-limiting step of nitrification, is catalyzed by two groups of prokaryotes, including ammonia-oxidizing archaea (AOA) and ammonia-oxidizing bacteria (AOB) (Zhang *et al*., 2010). A number of studies have examined the effects of precision nutrients and water management on both residual and leaching of soil nitrogen in cropland (Pampolino *et al*., 2007; Hedley *et al*., 2010). Little is known about how soil nitrogen transformation and relevant microorganisms respond to precision tillage or precision seeding practice. Lacking of a comprehensive understanding the effects of PA on residual soil nitrogen impeded the PA popularization and application.

In this study, our objectives were (1) to examine the effects of precision seeding and laser land leveling application on winter wheat crop yield components and residual soil nitrogen, as well as the abundance of ammonia-oxidizer after harvest; and (2) to distinguish the differences between single PS and integrated PLS; and (3) to clarify the mechanisms between the abundance of ammonia-oxidizer and residual soil nitrogen.

Materials and Methods

Site Description

The experiment was conducted at the modern agriculture demonstration district, located in Changge city (113°58'26 E, 34°12'06″N), Henan province in central China. The monsoon climate dominates the region with a mean temperature of 17.9°C and a mean annual precipitation of 711.1 mm. The experimental soil (0–20 cm) was a typical medium loam soil with 93.77% sand, 2.66% silt and 356% clay. Top soil (0–20 cm) organic matter is 18.40 g kg^{-1}, alkali-hydrolyzale nitrogen is 101.22 mg kg^{-1}, available phosphorus is 9.83 mg kg^{-1}, available potassium is 98.44 mg kg^{-1}, and soil pH value is 7.65.

Experiment Design and Treatments

Three treatment combinations involving two types of land leveling (conventional and Laser-assisted) and two seeding practices (conventional and precision) were evaluated in the winter wheat during 2014~2015. The experiment design was a randomized completely block design. Conventional land leveling combined with conventional seeding was chosen as the conventional cultivation (CLS). In order to distinguish the benefits of single and integrated PA practices, two treatments were established as follow: (1) conventional land leveling and precision seeding (PS); (2) laser-assisted land leveling and precision seeding (PLS). The size of the main plots was 300 m×150 m, and divided into three equal replicates.

Land Leveling

Land was first ploughed and pulverized at the optimum moisture level with a cultivator, and then leveled and smoothen using a scraper attached to the tractor in the conventional land leveling. A laser-equipped drag scraper with an automatic hydraulic system (1PJ-2500, PAIDE, China) attach to the tractor was used to level the land after ploughing in the laser land leveling treatment. The field was survey at 10 m distance to record the average elevation for leveling before running the laser leveler. The elevation value was entered into the digital control box for controlling the scraper at the desired elevation point (Jat *et al*., 2006).

Seeding and Crop Management

Winter wheat was seeded at 20 cm row spacing in 5^{th} October 2014, using a press drill with fertilizer attachment after land leveling in the conventional seeding. In the precision seeding treatment, monitoring system and global position system (Wheat seed monitor 100, PAIDE, China) was applied in the conventional seeder to ensure the quantity and linearity of the seeding (Mei *et al*., 2013). The seeding rate in the conventional and precision seeding treatments was 225 kg ha^{-1} and 195 kg ha^{-1} respectively. Wheat was irrigated at tillering by flooding the plots up to the point where about 6 cm water was standing in the field. Compound fertilizer (N:P:K=23:16:6) was applied in the amount of 725 kg ha^{-1} as basal fertilizer, and 225 kg ha^{-1} at tillering with the irrigation.

Sample Collection and Measurement

Eighteen sampling point (row×column=3×6) was arranged at 50 m × 50 m spacing using portable GPS (Trimble Juno 3B) in each treatment. Wheat from two randomly selected 1×1 m^2 was cut at 10 cm above ground level surrounding each sampling point at maturity. The crops were sun-dried and threshed with a plot to determine grain yield and straw biomass. Grain yield was measured at 13% moisture content and straw biomass was dried to constant weight at 70°C.

The total N content of grain and straw were determined using the Kjeldahl determination method (Bao, 2000). Soil samples (0–20 cm) were collected in three subsamples surrounding each sampling point and pooled to one composite sample. Soil DNA was extracted from a 0.5 g fresh soil using the Fast DNA SPIN Kit for soil (Q BIOgen Inc., Carlsbad, CA, USA) following the manufacturer's instructions. The *amoA* genes of ammonia-oxidizing archaea (AOA) were amplified using the primer pairs *amoA1F* (5′-GGGGTTTCTACTGGTGGT-3′) and *amoA2R* (5′-CCCCTCKGSAAAGCCTTCTTC-3′). The *amoA* genes of ammonia–oxidizing bacteria (AOB) were amplified using the primer pairs *Arch-amoAF* (5′-STAATGGTCTGGCTTAGACG-3′) *and Arch-amoAR* (5′-GCGGCCATCCATCTGTATGT-3′). The quantification of *amoA* genes was performed using real-time quantitative PCR method previously described by Chen *et al*. (2013). Concentrations of nitrate (NO_3^--N) and ammonium(NH_4^+-N) in the fresh soil were extracted with 2 mol L^{-1} KCl and determined by an continuous-flow auto analyzer (Seal AA3, Germany). Total soil carbon (TC) and nitrogen (TN) contents were determined by an element analyzer. Soil pH value was determined by a pH meter after the soil was mixed with distilled water and particles allowed to settle (ratio of soil to water, 1 to 2.5 *w*/*v*).

Statistical Analyses

Results of the wheat yield components, wheat nitrogen uptake, soil NO_3^--N, NH_4^+-N, TC, TN concentrations, soil pH values and the abundance of soil AOA and AOB were statistically analyzed by one-way ANOVA. Significant differences among mean values were assessed by least significant difference (LSD) test. Linear regression analyses were used to examine the relationships between the abundance of ammonia-oxidizers and the measured soil variables in all three treatments. All statistical analyses were conducted using the SPSS software package (version 16.0), and statistical significant differences were set with P values < 0.05 unless otherwise stated. All statistical plots were conducted using the SigmaPlot software package (version 10.0).

Results

Wheat Yield Components and Nitrogen Uptake

In the CLS treatment, wheat yield and straw biomass were 7342.94 kg ha^{-1} and 9462.34 kg ha^{-1}, respectively. PS treatment did not significantly increase wheat yield and straw biomass, while PLS treatment significantly increased wheat yield and straw biomass by 22.51% and 34.51%, respectively. For wheat spike number, the significant difference was only found between CLS and PLS treatments. However, PA treatment had no significant effects on the ratio of grain to straw (Fig. 1).

Nitrogen concentration of grain and straw from the PS and PLS treatments were not significantly different compared to the CLS treatment (Table 1). Compared with the CLS, PLS treatments significantly increased grain nitrogen uptake, while no significant higher grain nitrogen uptake was found in PS treatment. For the straw nitrogen uptake, no significant differences were found among all treatments. In the PLS treatment, the total nitrogen uptake was 224.97 kg ha^{-1}, which was significantly higher than that of CLS and PS treatments (Table 1).

Soil Chemical Properties

PS and PLS application tended to increase TC and reduce TN, resulting in the significantly increase of the C/N ratio (Fig. 2). There was no difference in soil pH value between CLS treatment and PS treatment, which was much lower than that of PLS treatment. PS rather than PLS treatment significantly reduced the residual soil NO_3^--N concentration. Compared with CLS treatment, lower soil NH_4^+-N concentration was simultaneously detected in PS and PLS treatments (Fig. 2).

Abundance of Soil and AOB

Both PS and PLS treatments significantly stimulated the abundance of AOA *amoA* gene copy numbers, but the difference between PS treatment and PLS treatment was not significant. The slightly higher of the abundance of AOB *amoA* gene copy numbers were found in the PS treatment, however, the differences of the abundance of AOB *amoA* gene copy numbers among the three treatments were not significant (Fig. 3).

Relationships between Soil Ammonia-oxidizers and Soil Chemical Properties

Both soil NO_3^--N and soil NH_4^+-N concentrations were negatively correlated with the abundance of AOA *amoA* gene. Furthermore, the abundance of AOA *amoA* gene was positively correlated with the C/N ratio and soil pH value. The C/N ratio and soil pH value could explain 37% and 25% of the abundance of AOA *amoA* gene, respectively (Table 2). However, there was no significantly relationship between the abundance of AOB *amoA* gene and the detected soil characteristics (Table 2).

Discussion

Published studies revealed different effects of precision agricultural technologies on wheat yield with increases (Fangmeier *et al*., 1999; Bai *et al*., 2013) or no effects (Jat *et al*., 2009). In our study, we found that single precision seeding application did not show clear effects on wheat yield, whereas integrated precision seeding with laser land leveling significantly increased wheat yield (Fig. 1a).

Table 1: Nitrogen concentration and uptake of winter wheat grain and straw under different experimental treatments (n=18)

Treatment	Content (%)		Uptake (kg ha^{-1})		Total uptake (kg ha^{-1})
	Grain	Straw	Grain	Straw	
CLS	1.64 ± 0.02a	0.63 ± 0.04a	117.95 ± 6.93b	67.78 ± 4.73a	177.22 ± 9.01b
PS	1.68 ± 0.03a	0.71 ± 0.03a	126.54 ± 5.51ab	68.18 ± 7.21a	198.97 ± 8.81b
PLS	1.65 ± 0.04a	0.68 ± 0.04a	149.08 ± 10.93a	75.89 ± 5.22a	224.97 ± 10.73a

Mean ± standard deviation. Values sharing same differ non-significantly ($P > 0.05$)

Table 2: Correlation coefficients (R^2) between the abundance of ammonia-oxidizers and soil characteristics (n=54).

Ammonia-oxidizers	NO_3^--N (mg kg^{-1})	NH_4^+-N (mg kg^{-1})	TC (%)	TN (%)	C/N	Soil pH
AOA	0.22(-)*	0.51(-)**	0.03	0.09	0.37(+)**	0.25(+)*
AOB	0.14	0.03	0.04	0.02	0.01	0.01

Note: Significance: *, $p < 0.05$; **, $p < 0.01$. For all correlations, n = 30 (+): positive relationship; (–): negative relationship

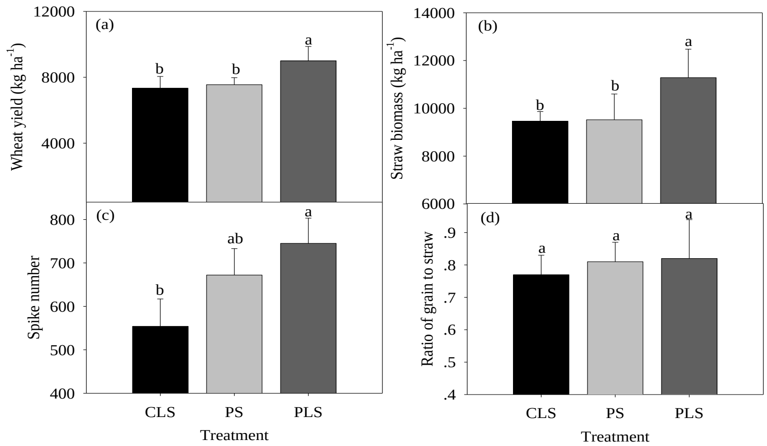

Fig. 1: Winter wheat yield components under different experimental treatments (n=18)

The different responses were attributed to the following two aspects. First, laser land leveling increased water and nutrient-use efficiency (Pal *et al*., 2003; Jat *et al*., 2006) and reduced the detriment of soil salinization to wheat booting and grouting (Jat *et al*., 2009; Bai *et al*., 2013). This can be proved by higher nitrogen uptake amounts in PLS treatment (Table 1). Second, laser-assisted precision land leveling enhanced wheat population density through providing the suitable growing environment (Zhu, 2009) and improving the survival of young seedlings (Rickman *et al*., 1998; Jat *et al*., 2006). In our study, the straw biomass and spike numbers were significantly higher in the PLS treatment than the others (Fig. 1b and c). Therefore, the higher biomass and spike number integrate with the larger nitrogen uptake led to the higher wheat yield in PLS treatment.

Residual soil nitrogen depended on the nitrogen fertilizer input, amount of available nitrogen released from soil mineralization process and crop nitrogen uptake (Fang *et al*., 2006; Ju *et al*., 2009). Many studies carried out to demonstrate that PA reduced leaching and residual of soil nitrogen through increased nitrogen use efficiency (Diacono *et al*., 2013), despite no positive results have also been documented (Ferguson *et al*., 2002; Link *et al*., 2006). In PS treatment, reduced residual soil NO_3^--N and NH_4^+-N concentrations may be attributed to the nitrogen immobilization due to the increased soil C/N ratio (Bengtsson *et al*., 2003). This also can be demonstrated by the unchanged soil TN concentration in our study (Fig. 2b). Besides, the increasing abundance of soil AOA accelerated nitrification leading to higher N loss via gaseous emission (Jung *et al*., 2014). However, reduced residual soil NH_4^+-N concentration was only found in PS and PLS treatments (Fig. 2f) though more nitrogen was absorbed by wheat (Table 1). The potential reasons include the soil compaction and higher soil pH value (Fig. 2d). Bai *et al*. (2013) reported that wheel crush of laser-assisted precision land leveling reduced the water infiltration rate by soil compaction, resulting in the soil NO_3^--N accumulation. Moreover, the promotion of soil mineralization and nitrification by increased soil pH (Fig. 2d) can also contributed to higher soil NO_3^--N contents (Gao *et al*., 2015).

Archaeal *amoA* genes are ubiquitous in soils, frequently outnumbering bacterial *amoA* genes. In our neutral soil, the abundances of the *amoA* genes in archaeal populations were higher than those of bacterial populations (Fig. 3). Nicol *et al.* (2008) demonstrated that bacterial *amoA* gene made up only 0.8–3.1% of archaeal *amoA* gene across all soils of varied pH ranging from 4.9 to 7.5.

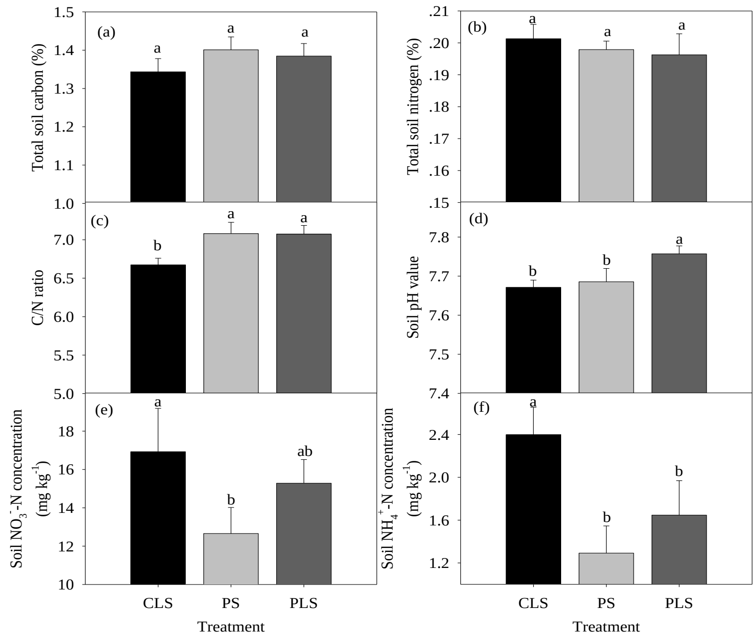

Fig. 2: Soil physical and chemical properties under different experimental treatments (n=18)

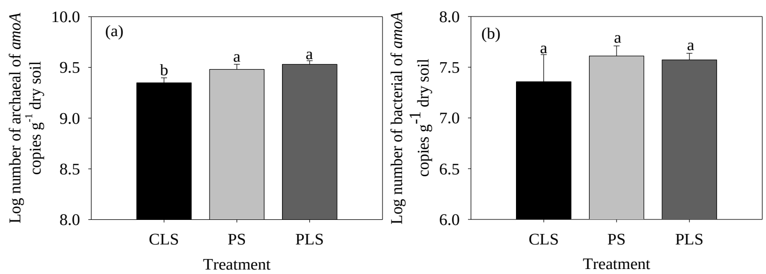

Fig. 3: Soil AOA and AOB *amoA* gene copy numbers under different experimental treatments (n=18)

Leininger *et al*. (2006) also detected the higher ratios of archaeal to bacterial *amoA* gene copy numbers in top soils with a pH range of 5.5–7.3. In addition, previous study revealed the different resource utilization patterns due to the distinguished evolution and specialized niche (Erguder *et al*., 2009). PS and PLS treatments significantly changed the abiotic and biotic characteristics of the studied area (Fig. 1 and 2). Soil AOA rather than AOB was significantly affected by PS and PLS treatments (Fig. 3). It was found that increased soil C/N ratio and soil pH was responsible to the intensified soil AOA (Table 2). Furthermore, significant negatively relationships between residual soil NO_3^--N and NH_4^+-N concentrations and the abundance of soil AOA were only observed (Table 2). This suggests that soil AOA and AOB communities play different roles in studied soil N transformation and respond differently to precision seeding and laser land leveling application. In the future, more times of plant and soil sampling is necessary to confirm the above results. Further studies are needed to assess the influence of the main soil nitrogen losses such as leaching or gases emission on the residual soil nitrogen.

Conclusion

PS treatment tended to increase wheat yield and significantly reduced residual soil NO_3^--N and NH_4^+-N concentrations, but PLS treatment significantly increase wheat yield and only reduced residual soil NH_4^+-N concentration. The increased abundance of AOA resulting from the increased C/N ratio and soil pH value, can well explain the reduced residual soil nitrogen. These results indicated that integrated PLS application was good application pattern than single PS application to improve wheat yield and reduced residual soil nitrogen.

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