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Effect and economic benefit of precision seeding and laser land leveling for winter wheat in the middle of China

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ABSTRACT

Rapid socio-economic changes in China, such as land conversion and urbanization, are creating new scopes for the application of precision agriculture (PA).An experiment to assess the economic benefits of two precision agriculture methods was applied for one year – precision seeding and precision seeding with land leveling. Whilst the results for this were positive, of itself it did not provide evidence of longer terms gains. The costs of land leveling are accrued in a single year but the benefits could carry over into subsequent years. Thus, in this case if the PA method provides carry over benefits to future years, the economic assessment would incorrectly assign all the costs to a single year of benefits i.e.the benefit-cost ratio would be underestimated. To gauge whether there was carry over benefits in future years we looked at NDVI and GUI as proxies for future year benefits. For the single year experiment, our results showed that: (1) Winter wheat yield was increased 23.2% through the integration of precision seeding and laser leveling technologies.(2) Both the single technology and the integrated technologies significant reduced the concentration of soil ammonium nitrogen at the depths of 60 cm; (3) The benefit/cost ratio's of the treatments exceeded that of the baseline by approximately 10% which translated to an increase of several hundred US$ per hectare. The NDVI analysis showed that the effect of laser land leveling could last to the next two years. When considering the multi-year impact of land leveling, the benefit/cost ratio of PSLL will increase to 23.5% and 22.9% with and without laser land leveling subsidies. Making clear the economic benefits of using PA technologies will likely promote application of the technologies in the region.

1. Introduction

It has become increasingly challenging to produce more food with limited land, water and environmental resources to meet the needs of a rapidly growing population. The purpose of precision agriculture (PA) is to improve the economic and environmental benefits of agriculture and to reduce harm to the environment, under the premise of crop yield, quality and food safety (Cassman, 1999; Li, 2008; Gebbers and Adamchuk, 2010; Schieffer and Dillon, 2015). Current technologies of precision agriculture mainly involve the combined application of information technologies such as Remote Sensing (RS), Geographical information Systems (GIS), Global Navigation Satellite Systems (GNSS) and sensors placed on agricultural machines for laser land leveling, planting, variable rate fertilizer application, harvesting, and spraying, as well as water-saving irrigation facilities. However, there are few studies about the evaluation of PA in the field. In China, the potential impacts of PA application in terms of yield, quality and farm incomes have not yet been fully demonstrated which is likely an important factor constraining its promotion (e.g. Kuehne et al., 2017).

Seeding is the most important part of the crop production process since it directly impacts germination, crop growth and yield, thus affecting crop productivity and the ensuing economic benefits (Ansari et al., 2006; Li et al., 2010). Precision seeding is the key to promoting PA, as well as the prerequisite and basis for promoting other precision applications: irrigation, fertilization, and harvesting (Li et al., 2005). Precision seeding technology can not only improve the germination rate, save seeds (Yazgi and Degirmencioglu, 2007; Karayel, 2009), optimize population density, and increase crop yields (Giannini et al., 1967; Raoufat and Matbooei, 2007; Karayel, 2009), but also reduce labour inputs such as thinning which all lead to improved farm incomes (Zhao et al., 2010). A key determinant affecting seeding success is the quality of land preparation (Ahmed et al., 2014). Laser land leveling machines

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can ensure precise farmland leveling, effectively improving the micro-topographical conditions of farmland, thus laying the foundation for precision seeding (Xu et al., 2007). In general, it can increase crop yields (Rickman et al., 1998; Jat et al., 2006), improve the efficiency of fertilizer and water use (Jat et al., 2006; Choudhary et al., 2000; Ahmed et al., 2014; Ashraf et al., 2017), and thereby increase economic benefits (Jat et al., 2009; Ashraf et al., 2017). There are some concerns that laser land leveling affects the soil salinity and fertility of the soil since during laser land leveling some top soil is removed from the crest and moved to the trough (Walker et al., 2003). Ashraf et al. (2017) indicated that there was no significant difference for available nitrogen, phosphorous, potassium and organic matter in level and unlevel fields.

Most previous research focus on the application effects and economic benefits of applying one single technology with little research focusing on integrated technologies. No attempt has been made to study the effects on the integrated precision seeding and laser land leveling technologies in China. Therefore, this study aims to evaluate the impacts of precision seeding and its integrated technologies with laser land leveling on the winter wheat yield, residual soil nitrogen and the resulting economic benefits. Winter wheat is a common crop in the central plains of China. The experiments were conducted in Henan Province in which the total wheat production and per unit yield are both the highest in China. It further aims to study the carry over effect of the land leveling component. That is, the benefits of land leveling are still apparent 2–3 years after the initial cost of leveling.

We report on a one year study of the inputs and outputs from trials of precision seeding (PS), precision seeding with land leveling (PSLL) and compare the results with conventional farming. To capture the carry over effect of land leveling, and to enhance the single year of economic data, we adopt remote sensing approach to capture its impact in subsequent years. Remote sensing technology can provides various yield-directly related crop parameters for crop condition and yield forecasting, such as Normalized Difference Vegetation Index (NDVI), which closely related to the vegetation vigor, has been recognized for its ability to monitor crops and as an estimator of crop yields since early 1980s (Bastiaanssen and Ali, 2003; Labus et al., 2002).

2. Materials and methods

The research method is composed of two parts: part one is to carry out a one-year field experiment to obtain the yield, nitrogen residue application effect, economic benefits of precision sowing, and laser flat + precision sowing; part two is to use the four-year remote sensing data to study the multi-year effect of laser leveling, and finally evaluate the economic benefit obtained from the multi-year cost sharing correction test. See Fig. 1 for specific method flow.

2.1. Site descriptions

The experimental work was undertaken at the 2011 National Collaborative Innovation Pilot for Modern Agriculture (113°58′26″E, 34°12′06″N), located in Chang'ge City, Henan Province, China. This area typically deploys a winter wheat-summer maize rotation. The north temperate continental monsoon climate dominates, with a mean annual temperature of 14.3 °C, a mean annual rainfall of 711.1 mm, and a mean annual frost-free period of 217 days. The soil is medium textured: topsoil (0–20 cm) organic matter is 18.40 g kg^{-1}, alkali-hydrolyzable nitrogen is 101.22 mg kg^{-1}, rapidly available phosphorus is 9.83 mg kg^{-1}, rapidly available kalium is 98.44 mg kg^{-1}, and soil pH value is 7.65.

2.2. Experiment design

Fig. 2 shows the field layout of the experiment, the treatments and the sampling points. The experiment comprised three land leveling and seeding treatments: precision seeding (PS), integrated precision seeding and laser land leveling (PSLL), and local large-scale conventional farming (C). The size of the main plot was 300 m × 150 m with sub-plots of 50 m × 50 m. There were 18 sampling points in each treatment. PS equips conventional planters with a wheat seeding monitoring system and a GPS navigation system developed by the National Engineering Research Center for Agricultural Information Technology (NERCITA) for accurate seeding (Fig. 3). This allows precision control of seeding evenness, and row straightness. The

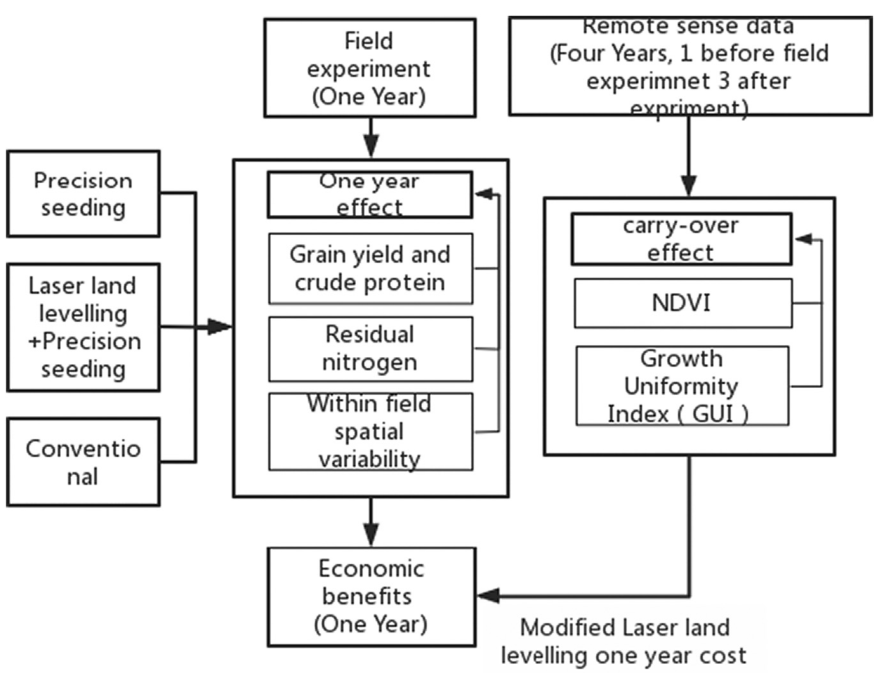

Fig. 1. Flow diagram of this study.

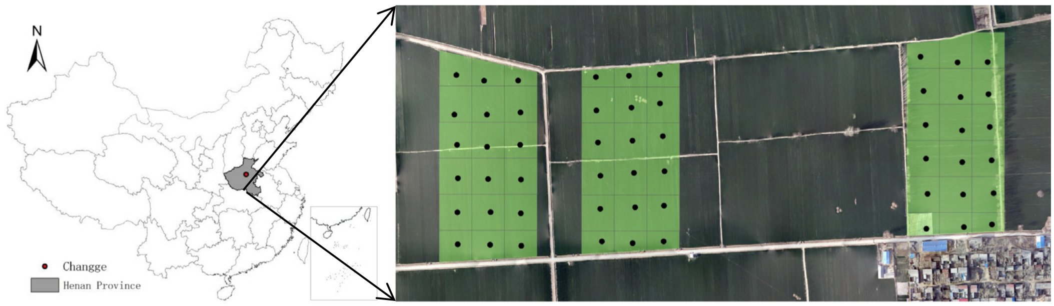

Fig. 2. Experiment design and sampling point distribution.

1PJ-2500 laser land leveling machinery developed by NERCITA was used for non-longitudinal cross slope leveling (Fig. 4), with a width of 2.5 m and a leveling accuracy of 2 cm. Other treatments used conventional machines for land leveling.

The winter wheat variety for testing was Xi Nong 979. It was planted on October 5th, 2014. The seeding density of PS and PSLL were 195 kg ha^{-1}, and C was 225 kg ha^{-1} all with row spacing at 16.5 cm. Base fertilizer was applied at 750 kg ha^{-1} (N: P: K = 23:16: 6) and another 225 kg ha^{-1} compound fertilizer was applied in early March 2015 following rainfall in the jointing stage. The wheat was irrigated once only during its growth period by local farmers using conventional hose sprinklers (commonly known as the “little white dragon”) (Sui et al., 2005). The amount and timing of irrigation, fertilization, topdressing, spraying and other management measures of the winter wheat during its growing period were identical for all the three treatments. During October 2014 to July 2017, laser land leveling and precision seeding was applied once in PSLL in October 2014.

2.3. Sample collection and measurement method

For each treatment there were 18 sampling points with a spacing of 50 m × 50 m by a handheld GPS (Trimble Juno 3B). At maturity, the wheat was harvested manually at 1m^2 around the sampling points. The grains were threshed using a plot thresher, dried in a batch grain dryer and weighed. Grain yields of wheat was reported at 12% moisture content. Some of the grain was then crushed, mixed, sifted and measured for the Kjeldahl nitrogen content by using the Kjeldahl method (Helrich, 1990), and further converted to crude grain protein content with a conversion factor of 6.25. Concurrently, soil samples were taken from three spots randomly chosen around the sampling points, using an auger with a diameter of 5 cm to collect soil samples at 0–60 cm soil depth (20 cm per layer), placed in a ziplock bag and brought back to the lab. Soil moisture was measured in an oven at 105 °C. Nitrate and ammonium nitrogen were extracted from fresh soil by using 1 mol L^{-1} KCL solution. Soil nitrate and ammonium concentration were measured using a flow analyzer (Seal AA3).

2.4. Economics analysis

The economic analysis considered all inputs, including the service charge for cultivation, the cost of seed, fertilizer, pesticide (irrigation water in the experimental area was free of charge) and farm management costs. Land preparation, planting, fertilizer and pesticide application, irrigation, and harvesting were all undertaken by agricultural machinery cooperatives and farmers' cooperatives. Thus, labour inputs were already included in these paid services. The farm belongs to

Fig. 3. The accurate seeding machinery.

Fig. 4. The laser land leveling machinery.

Henan Food and Oil Group, so management costs refers to wages paid to those management personnel of the Group responsible for land management. The total cost for each treatment was estimated using the following equation:

$$TCC = C_1 + C_2 + C_3, C_i = \sum_{i=0}^{n} \binom{n}{i} I = I_i * P_i \quad (1)$$

Where TCC = total cost of cultivation, C_1 = agricultural material cost, C_2 = agro-mechanization service cost, C_3 = managerial pay; i = agricultural inputs e.g. seed, fertilizer, pesticide, I_i = amount of the i^{th} agricultural input, P_i = price of the i^{th} agricultural input.

Gross returns (GR) were calculated by multiplying grain yield by minimum support price of wheat (0.4 US$ kg^{-1}) offered by the government of China. Net returns (NR) were calculated as the difference between gross returns and the total cost of cultivation (NR = GR - TCC). The benefit/cost ratio computed by dividing the GR TCC.

2.5. Remote sense data

NDVI parameters during March to May can provide good estimates of winter wheat condition and yield in the North China Plain (Zhao et al., 2012). Given the aim of PSLL to produce a uniform seeding and growth we consider that PSLL will reduces spatial variability and accelerates the crops growth than under conventional farming approaches. This study used a new remote sensing monitoring index-Growth Uniformity Index (GUI) (Song Xiaoyu, 2009) developed from NDVI to judge the growth condition levels of the wheat and to assess the carry over effects.

2.5.1. Data collection

GF-1 satellite images from 2014 to 2017 covering the study area were downloaded from the United States Geological Survey website and Land Observation Satellite Data Service Platform (Table 1).

2.5.2. Data processing

With the support of ENVI (The Environment for Visualizing Images), preprocessing of the GF-1 data included radiance calibration, atmospheric correction, RPC orthgraph correction and geometric correction. For the geometric corrections, high-definition digital images were selected as the base map, image to image method was used for correction. The NDVI value for the study area was calculated by the BandMath function of ENVI. The NDVI was calculated from these individual measurements as follows:

$$NDVI = \frac{\rho_{NIR} - \rho_R}{\rho_{NIR} + \rho_R} \quad (2)$$

Where, NIR is the band 4 of GF-1 image and Red denotes band 3 of GF-1image.

2.6. Growth uniformity index

The Growth Uniformity Index (GUI) was calculated as follows. The value of GUI is between 0 and 1, higher values indicate a better and more uniform growth.

$$GUI = 1 - \frac{NDVI_{CV}}{NDVI_{CV\,\min} + NDVI_{CV\,\max}} \quad (3)$$

Table 1
The information of GF-1 satellite images of experimental site.

Satellite	Spatial resolution	Quality Level	Date			
GF-1	16 M	1A	2014.03.14	2015.03.13	2016.03.11	2017.03.16

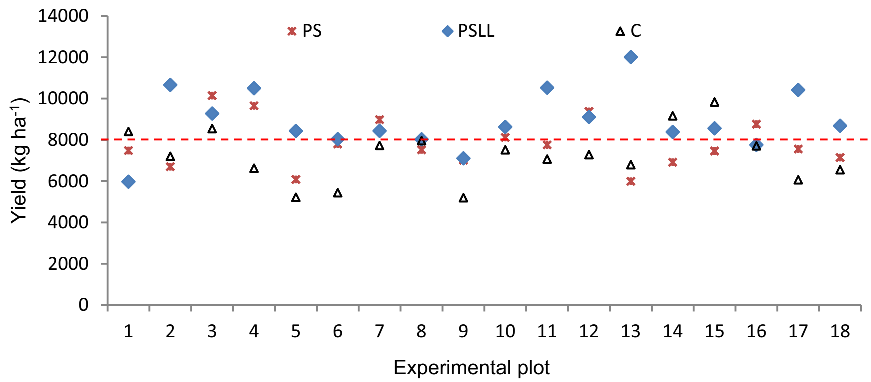

Fig. 5. Wheat yield at the 18 sampling points in each of the three treatments.

Where, $NDVI_{CV}$ is the Coefficient of Variance of NDVI; $NDVI_{CV\ \min}$ is the minimum value of the coefficient of variation of NDVI at the same time phase; $NDVI_{CV\ \max}$ is the maximum value of the coefficient of variation of NDVI at the same time phase.

2.7. Data analysis

The result of grain yield, crude protein and residual nitrogen were shown to obey normal distributions. Data were subjected to analysis of variance (ANOVA) and analyzed using the general linear model procedure of the Statistical Product and Service Solutions (SPSS16.0). Treatment mean values were separated by Fischer's protected least significant difference (LSD) test at $P \le 0.05$.

3. Results

3.1. Grain yield and crude protein

A visualization of the experimental plot yields is shown in Fig. 5. Of all the 18 sampling points in each of the three treatments, 33% of PS had a grain yield higher than 8000 kg ha^{-1} compared to 83% of PSLL and only 22% of C. In terms of average yield, PS increased winter wheat grain yield by 7.8%, but the effect was not remarkably, while PSLL significantly increased by 23.2% (Fig. 6a). Average crude protein content of PS, PSLL and C were 13.6%, 13.6% and 13.7% respectively, the difference was not significant (Fig. 6b).

3.2. Residual nitrogen

After the winter wheat harvest, soil residual nitrate nitrogen concentration decreased as soil depth increases, under all treatments (Fig. 7a). However, compared with conventional farming, precision agricultural practices tend to have lower soil residual nitrate but this difference was not significant. Compared with C, the soil residual nitrate nitrogen concentration at the depth of 0-60 cm in PS and PSLL was 7.9% and 4.9% lower respectively.

Soil residual ammonium nitrogen concentration at different soil depths was similar in all treatments (Fig. 7b). It was slightly higher in soil at the 20-40 cm depth than other layers. Precision agricultural practices significantly reduced the soil ammonium nitrogen concentration ($P \le 0.05$). PSLL was more effective than PS in reducing the soil ammonium nitrogen concentration. Soil ammonium nitrogen concentration at the depth of 0-60 cm in PS and PSLL was reduced by 26.3% and 38.2%, respectively, and there were no significant differences under the two treatments.

3.3. Within field spatial variability

Table 2 describes the differences between the plot treatments. The coefficient of variation suggests that the within field spatial variability of soil residual nitrate nitrogen and ammonium nitrogen (inorganic nitrogen) concentration of 0–20 cm layer was much higher than that for protein content or yield. Spatially the inorganic nitrogen concentration

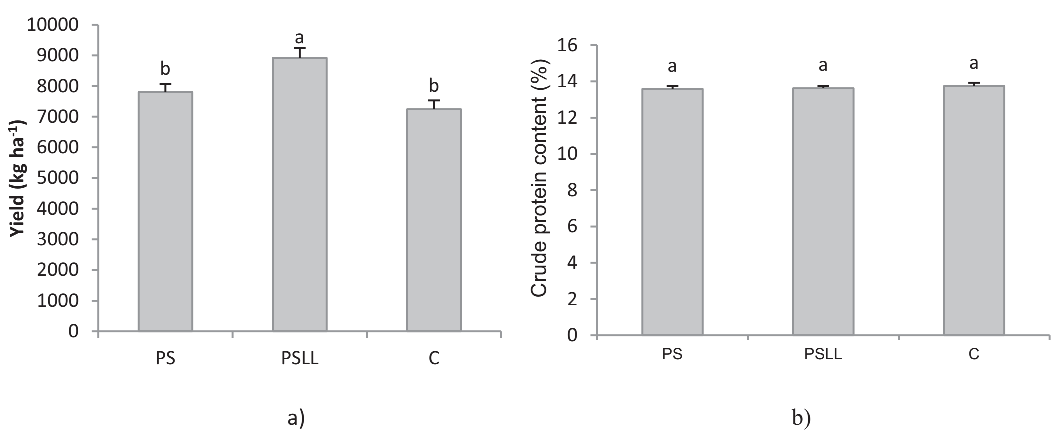

Fig. 6. a) Grain yield and b) crude protein content (lowercase letters indicate significant differences).

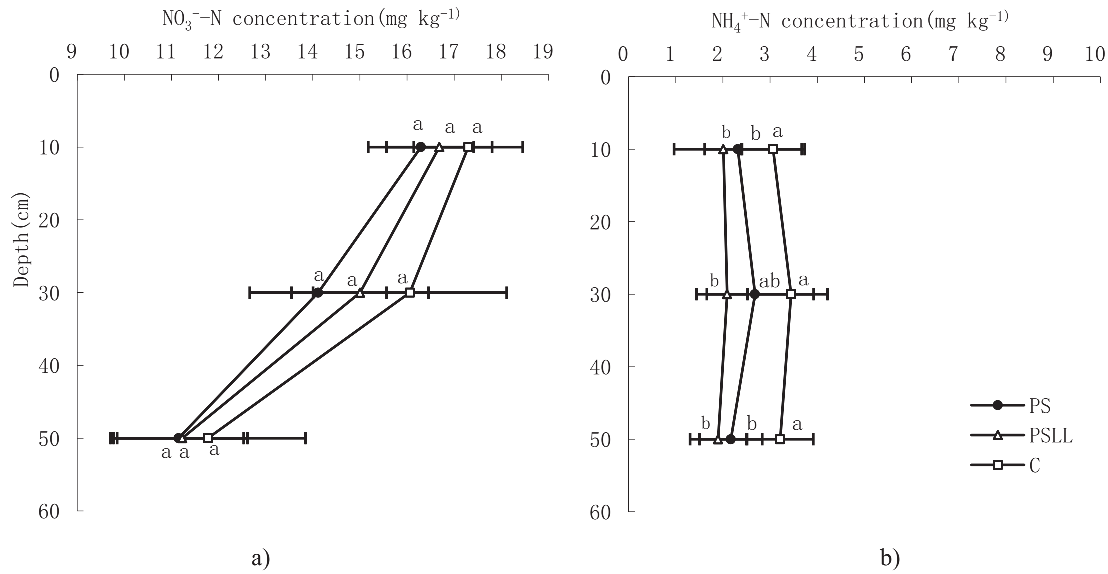

Fig. 7. a) Soil nitrate and b) ammonium nitrogen concentration at the depth of 0–20, 20–40, and 40–60 cm during wheat harvest (a and b in the figure indicate significant differences $P < 0.05$).

has no significant correlation with crop yield and protein content ($R^2 < 0.3$). Spatial variability of winter wheat yield is lower under PS and PSLL, compared with that under C, with the spatial variability of yield being the lowest under PS. PS and PSLL did not reduce the spatial variability of grain protein content and inorganic nitrogen concentration in the surface soil (0–20 cm).

3.4. Economic benefits

Estimates of the inputs and their costs are shown in Table 3 and the total costs and benefits of the treatments are shown in Table 4. The total cost of cultivation for C were 1380.3 US$ ha^{-1} which were lower than those for PS and PSLL. Compared with C, PS and PSLL had additional costs of laser land leveling, seeding monitoring and GPS navigation. For this study, these costs were calculated as service charges, among which the laser land leveling charge was 185.6US$ ha^{-1}, and seeding monitoring and GPS navigation charge was US$23.2 per hectare. The Chinese government currently subsidies laser land leveling. Taking Tianjin for example, the rate of the government subsidy is US$116.0 per hectare (Agricultural Bureau of Tianjin, 2015). Therefore, the fees of precision agriculture for PS and PSLL were 92.8US$ ha^{-1} with laser land leveling subsidies and 208.8US$ ha^{-1} without laser land leveling subsidies.

As shown in Table 4, the benefit/cost ratio of C is 1.95 (Gross Benifit/Total Cost of Cultivation). PS increased this by 7.3% to 2.09, while the combined strategy of PSLL increased by 16.7% to 2.27 with laser land leveling subsidies or 8.1% to 2.11without the subsidies. Compared to C, the net return under PS increased by 15.5% (202.4 US$ ha^{-1}). The increase under PSLL was over 40% with subsidies (546.4US$ ha^{-1}) or over 30% (430.4 US$ ha^{-1}) without laser land leveling subsidies.

3.5. Carry-over effect

The NDVI results using the GF-1 data are shown in Table 5. The coefficient of variation (CV%) value of PSLL is lower than C in 2015 and 2017, are lower than PS in 2015–2017 suggesting a more consistent of the experiment results of crop yield, The CV value of PS is lower than C only in 2015. These results are consistent with the GUI value. However, the PS treatment suffered serious pest attack in 2016, with the PSLL treatment also slightly affected, especially on the east side nearest to the PS treatment (PSLL is in the west of PS as shown in Fig. 2). Removing the east margin of PSLL affected by pests in 2016 from the analysis, the value of C.V. and GUI of PSLL improved to 4.68% and 0.62 respectively which superior to those for C. Therefore, it can be concluded from the above analysis that applying laser land leveling in year one has positive carry-over effects to at least the third year but that the effect of precision seeding alone is unstable.

Thus, in the case of considering the carry-over effect of laser land leveling, the cost of laser land leveling could shared equally of three years, then the benefit/cost ratio of PSLL will increase by 20.9% to 23.5% and by 21.1% to 22.9% with and without laser land leveling subsidies.

Table 2
Spatial variability of grain yield, protein content and soil inorganic nitrogen concentration at the depth of 0-20 cm under different treatments.

Variables	Treatments	Number of sampling points	Minimum	Mean	Maximum	S.D.	C·V.%
Yield (kgha^{-1})	PS	18	5997.3	7805.5	10,149.8	1173.7	15
	PSLL	18	5969.8	8919.6	12,015.3	1456.2	16.3
	C	18	5196.8	7242.8	9836.2	1293.8	17.9
Crude protein content (%)	PS	18	12.8	13.6	14.6	0.6	4.8
	PSLL	18	12.6	13.6	14.8	0.7	5
	C	18	12	13.8	14.9	0.8	5.7
Soil inorganic nitrogen concentration of 0–20 cm layer (mg kg^{-1})	PS	18	10.4	18.5	33.9	5.8	31.1
	PSLL	18	12	18.7	29.9	5.9	31.8
	C	18	11.8	20.4	36.4	6.4	31.3

Table 3
Inputs and management measures.

Management	Input	Unit	PS	PSLL	C
Basal dressing (compound fertilizer, N:P:K = 23:16:6)	Amount of fertilizer	Kg ha^{-1}	750.0	750.0	750.0
Land preparation	Service fees for mechanical plowing and returning straw	US$ ha^{-1}	185.6	185.6	185.6
	Laser land leveling fees (with/without subsidies)	US$ ha^{-1}	0.0	69.6/185.6	0.0
Seeding	Seeds	Kg ha^{-1}	195.0	195.0	225.0
	Seeder fees	US$ ha^{-1}	23.2	23.2	23.2
	Seeding monitoring and GPS navigation fees	US$ ha^{-1}	23.2	23.2	0.0
Topdressing (compound fertilizer N:P:K = 23:16:6)	Amount of fertilizers	Kg ha^{-1}	225.0	225.0	225.0
	Fertilizer distributor fees	US$ ha^{-1}	23.2	23.2	23.2
Irrigation (once during 2014–2015)	Electricity + labor costs	US$ ha^{-1} Time^{-1}	92.8	92.8	92.8
	Pipe costs	US$ ha^{-1} Season^{-1}	309.3	309.3	309.3
Spraying	Herbicide (chemicals+ machinery fees)	US$ ha^{-1}	16.2	16.2	16.2
	Pesticide (chemicals+ machinery fees)	US$ ha^{-1}	18.6	18.6	18.6
	Prevention of pests, dry hot wind and lodging (chemicals+air spray)	US$ ha^{-1}	34.8	34.8	34.8
Harvesting	Harvester fees	US$ ha^{-1}	69.6	69.6	69.6
Wages of management personnel		US$ ha^{-1}	13.9	13.9	13.9

Note: Rate of laser land leveling subsidies is 115.8US$ha^{-1}.

4. Discussion

4.1. Grain yield and crude protein

Our results indicate that precision seeding and integration of precision seeding and laser land leveling technologies could increase grain yield of winter wheat by 7.8% and 23.2%, respectively. These results are in agreement with previous studies that suggest crop yield increases of 5% -40% through the application of precision seeding or laser land leveling technologies, as well as improving the efficiency of water and fertilizer usage (Li et al., 1999; Yao, 2004; Li et al., 2005; Jat et al., 2006, 2009; Hashimi et al., 2017). PSLL was more effective than PS in increasing the yield and is attributed to the following aspects. Firstly, laser land leveling improves farmland flatness (Aquino et al., 2015) which makes planting depth even, improves crop germination and its growth environment (Burce et al., 2013; Marlowe et al., 2013), and enhances the effect of precision seeding. Secondly, precision seeding ensures the uniformity of seeding amount and row space (Yazgi and Degirmencioglu, 2007), thus reducing re - seeding rate and lapsus seeding rate, improves germination, optimizes the crop population density, and the better effect of laser land leveling could be achieve. In summary, laser land leveling and precision seeding complement each other are win-win for the crop yield. Crop grain quality depends not only on its genotype, but also on the environment and crop cultivation practices (Souza et al., 2004; Otteson et al., 2008). The results of this study show that PS and PSLL had wheat protein content comparable to that from conventional farming.

4.2. Residual nitrogen

Soil nitrate and ammonium nitrogen residues after harvest increase the risk of nitrogen leaching losses (Fang et al., 2006). Previous research has found that PA technologies, by increasing nitrogen utilization efficiency, can reduce soil nitrogen residues (Chen, 2003; Diacono et al., 2013). But there are also studies suggesting that PA technologies cannot reduce soil nitrate nitrogen residues (Ferguson et al., 2002; Link et al., 2006). In this study, PS and PSLL tend to reduce the level of soil nitrate and ammonium nitrogen residues after the winter wheat harvest (Fig. 5). In particular, the two treatments significantly affected the ammonium nitrogen concentration. The main reason is that the two PA treatments significantly increase wheat yields, which absorb more nitrogen, thereby reducing the nitrogen residues (Hatfield, 2000; Thrikawala et al., 1999). PSLL was less effective than PS in reducing nitrate nitrogen, mainly because the laser land leveling process compacts the farmland with multiple passes of the machinery, increasing the soil density, slowing down the moisture downward infiltration (Ahmed et al., 2014), and resulting in retention of the nitrate nitrogen that moves easily with water in the surface soil. However, PSLL was more effective than PS in reducing the ammonium nitrogen concentration, mainly because winter wheat grows better under PSLL, more nitrogen is absorbed and unlike nitrate nitrogen, ammonium nitrogen does not move easily with water.

4.3. Within field spatial variability

NDVI perceive the temporal and spatial variability of wheat yield (Labus et al., 2002; Zhao et al., 2012; Lopresti and Bella, 2015), the value of the physiological indexes (C·V) of yield (experiments data and NDVI perceive) shows that compared with conventional farming, PS and PSLL could reduce the spatial variability of winter wheat yield in 2015. Precision seeding can improve the uniformity of the seeding (Arzu et al., 2007; Karayel, 2009; Zhao et al., 2014), and laser land leveling can facilitate more uniform land for seeds, fertilizers, chemicals and other agricultural inputs (Brye et al., 2004; Ashraf et al., 2017). Both technologies contribute to reduce the spatial variability of winter wheat yield. But under laser land leveling, previous sub-surface soil layers may be exposed to the surface, and increase near-surface spatial variability among soil chemical, physical, and biological properties (Brye et al., 2004; Aquino et al., 2015) which may be the reason of

Table 4
Economic benefits of different wheat treatments during 2014–2015.

Economic indicators	PS	PSLL		C
		With subsidies	Without subsidies	
Conventional agriculture cost (US$ha^{-1})	1363.6	1363.6	1363.6	1380.3
Precision agriculture cost (US$ha^{-1})	23.2	92.8	208.8	0.0
Total cost of cultivation (US$ha^{-1})	1386.8	1456.4	1572.4	1380.3
Gross benefit (US$ha^{-1})	2898.0	3311.7	3311.7	2689.1
Net return (US$ha^{-1})	1511.2	1855.2	1739.2	1308.8
Benefit/cost ratio	2.09	2.27	2.11	1.95

Note: According to the e-commerce platform Jingdong, compound fertilizer is 0.5US$ kg-1 and seed is 0.6US$ kg-1.

Table 5
NDVI mean and other parameters of winter wheat at reviving stage under different treatments for four years.

Date	Treatments	Number of points	Minimum	Mean	Maximum	S.D.	C.V.%	GUI	C.V.% pest adjusted	GUI pest adjusted
14/03/2014	C	432	0.71	0.75	0.79	0.03	4.11	0.50		
14/03/2014	C	432	0.61	0.75	0.78	0.03	3.49	–	–	–
13/03/2015	PS	144	0.56	0.58	0.60	0.01	1.29	0.65	–	–
	PSLL	144	0.54	0.58	0.60	0.01	1.87	0.49	–	–
	C	144	0.51	0.58	0.60	0.01	2.39	0.35	–	–
11/03/2016	PS	144	0.38	0.54	0.60	0.04	7.80	0.41	–	0.38
	PSLL	144	0.45	0.58	0.62	0.04	6.61	0.50	4.68	0.62
	C	144	0.39	0.57	0.61	0.03	5.41	0.59	–	0.57
16/03/2017	PS	144	0.60	0.70	0.73	0.02	2.80	0.42	–	–
	PSLL	144	0.62	0.70	0.72	0.01	2.03	0.58	–	–
	C	144	0.62	0.70	0.72	0.02	2.43	0.50	–	–

wheat yield spatial variability under PSLL is higher than under PS. And in 2016 and 2017, the NDVI C.V of PSLL were lower than C, but that of PS were not. Because a one-time application of laser land leveling lasts 3–4 years (Ashraf et al., 2017; Aryal et al., 2015).

4.4. Economic benefits

The economic impact of PA technologies on commodity crops with low prices (such an wheat and maize) is generally positive. The net annual income, obtained from laser land level fields (two in rice-wheat rotation and three in the maize-wheat rotation), was 32% higher, as compared to that from unlevel fields (Ashraf et al., 2017). Experimental results in the rice-wheat rotation field show that the application of laser land leveling technology increases farmers' annual income by \$145 ha^{-1} (Jat et al., 2009). Application of multiple PA technologies can achieve higher earnings than single technology applications (Finck, 1998; Lowenberg-De-Boer, 2000). Walker et al. (2003) and Abdullaev et al. (2007), however, reported that the net income was negative during the first year mainly because of cost incurred on laser land leveling was recovered in one wheat season only. This study estimates positive benefit/cost ratios and net return of different PA treatments compared to conventional farming.

Actually, it is not imperative to level the fields every year thereby adding to the cost of production. Ashraf et al. (2017) study shows that there is no need to level the fields at least upto 3 years. Aryal et al. (2015) supposed that a one-time application of laser land leveling lasts at least 4 years. This study use the remote sense image found that the laser land leveling lasts at least 3 years, and than the benefit/cost ratio of PSLL will increase about 5% percent.

The agricultural policies play a role in farmer's decision (Touza et al., 2008; Barnes et al., 2016), developing policies by the governments that encourage social services such as subsidies for PA technologies can help further promote the popularization and application of PA technologies in China.

5. Conclusions

(1) Compared with the local conventional large-scale farming, both precision seeding and integration of precision seeding and laser leveling increased the yield of winter wheat, with the latter being significantly and more effective. They could also reduce spatial variability of yield at the same time. With respect to crop quality, the PA methods had no deleterious impact on the grain protein content of the in-season wheat crops.

(2) Precision seeding and integration of precision seeding and laser leveling reduced the soil nitrate and ammonium nitrogen concentration at 0-60 cm layer after the wheat harvest compared with conventional farming to reduce ammonia volatilization and nitrate nitrogen leaching loss risk.

(3) In terms of economic benefits, precision seeding increased the benefit/cost ratio by 7.3%, while integration of precision seeding and laser leveling increased the benefit/cost ratio by 16.7% with laser land leveling subsidies in place or 8.1% without the subsidies. Net return under precision seeding increased by 15.5% (202.4 US\$ ha^{-1}). The increase under precision seeding and laser land leveling was over 30% (430.4 US\$ ha^{-1}) without laser land leveling subsidies or over 40% (546.4 US\$ ha^{-1}) with subsidies. As a one-time application of laser land leveling lasts for 3 years, after spilt the cost of laser land leveling between 3 years, The benifit increase under PSLL was raised 554.2 US\$ ha^{-1} without subsidies or 592.8 US\$ ha^{-1}with subsidies compared to C, both over 40%.

With respect to future research, further studies to evaluate the effectiveness and efficiency of different integrated precision agriculture technologies should be undertaken. These should include variable fertilization, variable spraying, variable irrigation and other measures, as well as methods of awareness raising of the higher economic and environmental benefits for dryland farming in the central plains of China.

Declaration of Competing Interest

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the position presented in the manuscript entitled.

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