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Nitrogen use efficiency of wheat as affected by preceding crop, application rate of nitrogen and crop residues

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Abstract

This study was carried out under temperate climate condition of Khorasan province, Iran, during 2006-2008 growing seasons to determine the suitable crop rotation for enhancing nitrogen use efficiency of wheat. A three-factor experiment was laid out as split-split plot arrangement (RCBD) with three replications. Main plots were five preceding crops for wheat practices viz. wheat, potato, silage corn, clover and sugar beet. Sub plots were N fertilizer rates in preceding crop including no N (control), 50% lower than recommended N rate, recommended N rate and 50% more than recommended rate. The sub-sub plots were preceding crop residue return including no residue return (control) and 50% return. Results showed that nitrogen use efficiency (NUE), nitrogen uptake efficiency (NUpE), nitrogen utilization efficiency (NUtE), nitrogen harvest index (NHI) and grain protein content (GPC) in wheat were significantly affected by preceding crop. Fertilizer N rate applied on preceding crops, significantly influenced NUE, NUpE and grain protein content of wheat. NUE, NUpE, NUtE and NHI of wheat grown after potato recorded the highest values. While, the lowest NUE indices and grain protein content of wheat were found for wheat-wheat rotation. The higher NUE of wheat in the potato-wheat rotation was due to the higher NUpE in this rotation. NUE and NUpE in all crop rotations reduced with increasing N fertilizer rate. Return of crop residue had no significant effect on NUE indices expect NHI.

Keywords: crop rotation; crop residues; fertilizer; N indicators; nitrogen uptake efficiency

Introduction

As, nitrogen (N) is often the most limiting nutrient for crop yield in many regions of the world (Giller, 2004), N fertilizer is one of the main inputs for cereals production systems. The increase of agricultural food production worldwide over the past four decades has been associated with a 7-fold increase in the use of N fertilizers. Therefore, the challenge for the next decades will be to accommodate the needs of the expanding world population by developing a highly productive agriculture, whilst at the same time preserving the quality of the environment (Hirel et al., 2007). Losses of fertilizer N have been attributed to the combined effects of denitrification, volatilization and leaching. Large amount of fertilizer N loss to the environment could cause a serious environmental problem such as groundwater contamination (Chen et al, 2004). Reduction of applied N fertilizer rate to an optimized level can reduce soil nitrate leaching (Power et al., 2000).

Worldwide, nitrogen use efficiency (NUE) for cereal production including wheat is approximately 33% (Raun and Johnson, 1999). NUE may be affected by crop species, soil type, temperature, application rate of N fertilizer, soil moisture condition and crop rotation (Halvorson et al, 2001). Mahler et al., (1994) indicated that research is required to increase crop NUE and profitability in semi- arid condition, and to develop sustainable farming systems in response to continually increasing economic and environmental pressures. Lopez-Bellido and Lopez-Bellido (2001) showed that nitrogen efficiency indices significantly affected by crop rotation and N fertilizer rate. Yamoah et al. (1998), studying particular N efficiency indices, concluded that efficiency is greater in crop rotation systems than in monoculture systems. Some of the general purposes of crop rotation are: to maintain soil structure, increase soil organic matter, increase water use efficiency, reduce soil erosion, reduce the pest infestation, reduce reliance on agricultural chemicals and improve crop nutrient use efficiency (Halvorson et al., 2001. Riedell et al., 2009). The influence of preceding crop on the N uptake of the following crop has long been recognized. Anderson (2008) quantified winter wheat response to preceding crop and crop management. Nitrogen efficiency indices decrease with increasing N level, especially under dry soil condition (Huggins and Pan, 1993). According to Sowers et al. (1994), the application of high N rates may result in poor N uptake and low NUE due to excessive N losses.

According to Bundy and Andraski (2005), nitrogen remaining in residues of potato after harvest represents a significant N addition to cropland and this N can contribute significantly to subsequent corn yield (11-20%). Although, Thuy et al. (2008) showed that the retention and incorporation of crop residues in rice based cropping systems often has little or no short-term benefits on rice yield. Winter wheat based rotations are main cropping system in Iran, but little information exists on better preceding crops for wheat under cold climate in Iran. Conventional crop rotations are not much diverse and all with short periods. An improved understanding of NUE of wheat is needed to increment sustainability of winter wheat base rotations. The objectives of this research were to evaluate the effects of preceding crop, N fertilizer rate and return of crop residue on N efficiency indices of wheat.

Table 1. Different levels of N fertilizer rate (kg N ha^{-1}) applied to preceding crops at the first year in the form of Urea (46%N)

Preceding crops	Control	50% lower than recommended rate	Recommended rate	50% more than recommended rate
Wheat	0	80	160	240
Potato	0	80	160	240
Silage corn	0	100	200	300
Berseem clover	0	15	30	45
Sugerbeet	0	90	180	270

Materials and methods

The field experiment was conducted from 2006 to 2008 at the Rokh Agriculture Research Station in Khorasan, Iran (35º35′ N, 59º23′ E) on a sandy-loam with low organic carbon (0.6%) and slightly alkaline soil (pH= 8.1). Other soil test parameters were total N= 0.06%, available P= 10.8 mg kg^{-1}, exchangeable K= 174 mg kg^{-1} and EC= 2.3 ds/m. This site characterized by cold climate and a forest period of about 132 days with 223 mm annual precipitation.

The experiment was laid out as a randomized complete block with a split-split plot arrangement and three replications. Five preceding crops (wheat, potato, silage corn, berseem clover and sugar beet) were allocated to the main plots. Sub plots were four N fertilizer rates in preceding crop including no fertilizer N (Control), 50% lower than recommended N rate, recommended N rate and 50% more than recommended N rate. Sub-subplots were preceding crop residue return with two levels of no residue return (control) and return of 50% of crop residues. At the first year, different levels of N fertilizer for each preceding crop were based on soil test recommendations (Table 1). At the second year, all plots received the same rate of N fertilizer for wheat (100 kg N ha^{-1}). The preceding crop residues on plots were shredded on late August (2007), followed by tillage that consisted of disking twice 10-15 cm deep before planting wheat.

Winter wheat (Cv. C 81-4) was planted on mid October with arrow spacing of 15 cm and a seeding rate 250 kg ha^{-1}. Weeds were controlled by 2,4-D and Clodinafop-propargyl herbicides. Soil samples were taken after harvest of each crop from the 0 to 30 cm and 30 to 60 cm soil depths using a soil Auger. Wheat grain yield (14% moisture) obtained by harvesting the center 3 m by 10 m with a plot combine, but yield components were determined from two randomly selected areas ($2m^2$) within each plot. Plant samples collected at harvest were separated into grain and straw and oven-dried at 60˚C for 72h. Biomass and grain sub samples analyzed for total N content using a micro-Kjeldahl digestion with Sulfuric acid. Wheat grain protein content was obtained by multiplying grain N content (%) by 5.7 (Halvorson et al., 2004). The terminology of N efficiency parameters is in accordance with Delogu et al., (1998) and Lopez-Bellido and Lopez-Bellido (2001).

Nitrogen uptake efficiency (NUpE, kg kg^{-1}) = N_t / N_{supply} [1]

Where N_t is total plant N uptake. N_t was determined by multiplying dry weight of plant parts by N concentration and summing over parts for total plant uptake. N_{supply} is Sum of soil N content at sowing, mineralized N and N fertilizer. According to Limon-Ortega et al., (2000), N supply was defined as the sum of (i) N applied as fertilizer and (ii) total N uptake in control (0 N applied).

Nitrogen utilization efficiency (NUtE, kg kg^{-1}) = G_y / N_t [2]

Where G_y is grain yield.

Nitrogen use efficiency (NUE, kg kg^{-1}) = G_y / N_{supply} [3]

Nitrogen harvest index (NHI, %) = (N_g / N_t) ×100 [4]

Where N_g is total grain N uptake. N_g was determined by multiplying dry weight of grain by N concentration.
The differences between the treatments were determined using analysis of variance (ANOVA). Statistical analyses were performed using LSD procedures by the SAS software.

Results and discussion

Nitrogen uptake efficiency

Nitrogen uptake efficiency reflects the efficiency of the crop in obtaining N from the soil. Increased NUpE has been proposed as a strategy to increase NUE by Raun and Johnson (1999). Results showed that wheat NUpE was affected by preceding crop and N fertilizer rates. Moreover, there was a significant interaction between preceding crop and N rate for NUpE (Table 2). The highest (0.75 kg kg^{-1}) and lowest (0.59 kg kg^{-1}) NUpE of wheat observed for the potato-wheat and wheat-wheat rotations, respectively (Table 3). NUpE of wheat grown after potato was 27% more than continuous wheat system, while there was no significant difference in wheat NUpE for the potato-wheat and corn silage-wheat rotations (Table 3).

According to Moll et al. (1982), variation in NUpE could be separated from grain yield variation. In addition, Lopez-Bellido and Lopez-Bellido (2001) indicated that differences between rotations with respect to grain yield, which is directly related to crop N uptake, account for the variation in the NUpE index. Lee et al., (2004) indicated that NUpE was positively correlated with plant dry matter, leaf area index and leaf nitrogen content. So, this result could explain by wheat yield variation in crop rotations. Results showed that there was a positive correlation between NUpE and grain yield of wheat (Table 4).

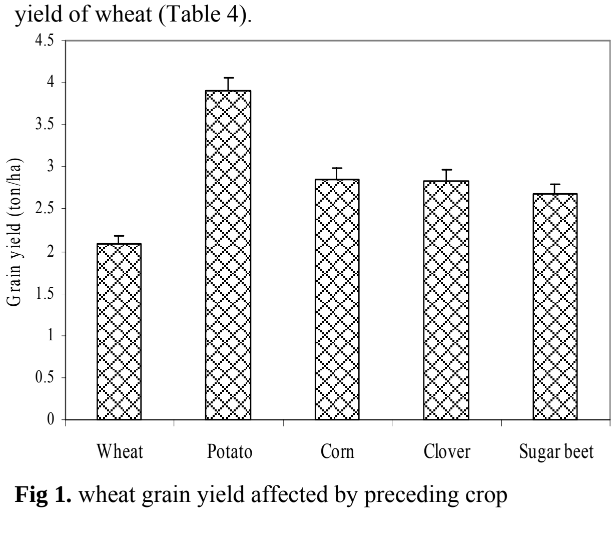

Fig 1. wheat grain yield affected by preceding crop

Table 2. The mean of squares of N use efficiency (NUE), N uptake efficiency (NUpE), N utilization efficiency (NUtE), N harvest index (NHI), and grain protein content (GPC) of wheat at different preceding crop, N rates and crop residue return.

		Ms				
	df	NUpE	NUtE	NUE	NHI	GPC
Preceding crop (A)	4	0.08 **	65.46 **	121.20 **	209.09 **	7.98 **
Error A	8	0.01	8.40	10.16	18.94	0.39
Fertilizer N rate (B)	3	1.41 **	9.15 ^{ns}	1270.80 **	32.52 ^{ns}	3.56 *
AB	12	0.02 **	8.57 ^{ns}	27.38 **	36.07 ^{ns}	2.05 ^{ns}
Error B	30	0.01	4.89	7.28	18.49	1.76
Crop residue return (C)	1	0.01 ^{ns}	34.30 ^{ns}	1.37 ^{ns}	137.09 *	2.25 ^{ns}
AC	4	0.01 ^{ns}	2.93 ^{ns}	3.15 ^{ns}	3.56 ^{ns}	3.22 **
BC	3	0.03 ^{ns}	3.41 ^{ns}	1.50 ^{ns}	16.12 ^{ns}	4.57 **
ABC	12	0.02 ^{ns}	1.34 ^{ns}	3.96 ^{ns}	13.89 ^{ns}	1.45 ^{ns}
Error C	40	0.01	1.94	3.59	12.42	0.61
%CV		8.23	4.79	9.44	5.01	10.57

* Significant at 0.05 probability level. ** Significant at 0.01 probability level. ^{ns} non significant.

Wheat yield in potato-wheat rotation was 89% more than continuous wheat system and low yielding continuous wheat system had the lowest NUpE values (Fig 1). Whereas, the effect of preceding crops on soil N content was not significant, this result may be due to improved soil structure, increased water availability or increased N mineralization rate for wheat by potato. Therefore, higher mean NUpE in wheat for potato-wheat rotation was due to higher grain yield compared with other rotations. Results indicated that, NUpE of wheat decreased with each incremental addition of N fertilizer and the lowest NUpE in each rotation was for maximum N rates (Table 3). In potato-wheat rotation applying N maximum rate, decreased wheat NUpE 17% compared with control (no N). While, NUpE of wheat decreased 30% in continuous wheat system with applying 50% lower than recommended N rate. Our results agree with those of Lopez-Bellido and Lopez-Bellido (2001) and Zhao et al., (2006), who found that on NUpE decreased with increase N use rate.

Moreover, this study showed that return of crop residue had no significant effect on wheat NUpE. Long-term experiments have often shown a delayed effect of crop residues with little benefit on Yield increase until after 3 to 4 years of continuous residue application (Wang et al., 2007). So, more experimental data is needed to asses possible long-term effects of crop residue return.

Nitrogen utilization efficiency

Nitrogen utilization efficiency reflects the ability of the plant to transplant the N uptakes into grain (Delogu et al., 1998). The NUtE response to preceding crop was similar to the corresponding response of NUpE. The highest value for wheat NUtE again obtained with to potato-wheat rotation (31.8 kg kg^{-1}), while differences were not significant among any of the other rotation (Table 3). NUtE of wheat grown after potato was 16% more than continuous wheat system.

The difference in wheat NUtE between crop rotations may be due to several factors includes variation on wheat yield and harvest index among rotations. This result support the conclusion that potato increased wheat NUtE according to improve harvest index (HI) in wheat. In this study, preceding crops influenced on wheat HI and highest HI value observed in potato-wheat rotation. Muurinen et al. (2007), who concluded that increasing grain yield and HI increased NUtE, reported a strong relationship between NUtE and HI. Furthermore, according to Lopez-Bellido and Lopez-Bellido (2001) crop rotation has marked influence on the utilization of resources. Results showed that there was a positive correlation between NUtE and NHI (Table 4).

In this study, we did not find significant differences in wheat NUtE between N fertilizer rates. This result suggested that remobilization efficiency and partitioning of N from vegetative plant parts to the grain not respond to N fertilizer rate applied in preceding crop. However, Delogu et al. (1998) showed that NUtE decreased with increasing N fertilizer rates.

Nitrogen use efficiency

The results showed that NUE of wheat affected by preceding crop and nitrogen fertilizer rate in preceding crop and interaction between N rate and crop rotation was significant (Table 2). The highest and lowest NUE of wheat observed in potato-wheat (23.68 kg kg^{-1}) and wheat-wheat (18.05 kg kg^{-1}) rotations, respectively (Table 3). The NUE of wheat grown after potato was 24% more than wheat NUE in continuous wheat system (Table 3). In addition, the lowest NUE of wheat were always associated with the control treatment (no N) regardless of preceding crops. Reducing wheat NUE in continuous wheat system was due to lower grain yield and a greater supply of residual N in the soil profile and highly wheat NUE in the potato-wheat rotation may be ascribed to the higher wheat yield. Whereas, According to Moll et al. (1982), NUE multiplying N uptake efficiency by the N utilization efficiency, these finding support the conclusion that low NUE of continuous wheat is related to its low grain yield and NUpE compared with the other rotations.

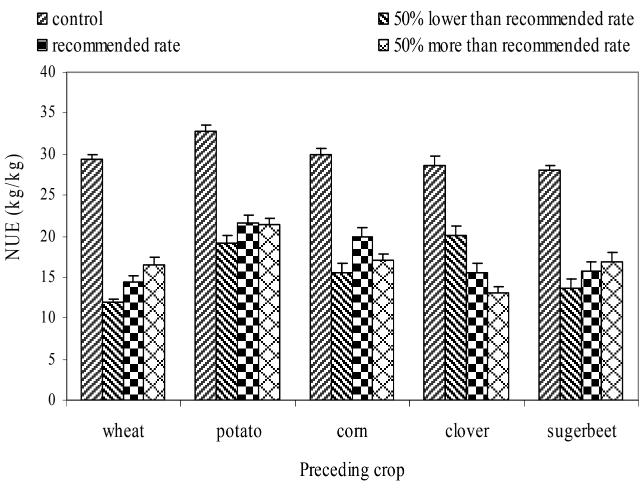

Fig 2. NUE of wheat affected by preceding crop and nitrogen rate

Table 3. N use efficiency (NUE), N uptake efficiency (NUpE), N utilization efficiency (NUtE), N harvest index (NHI), and grain protein content (GPC) of wheat at rotations, N rates and crop residue return

Preceding crop	NUpE (kg kg $^{-1}$)	NUtE (kg kg $^{-1}$)	NUE (kg kg $^{-1}$)	NHI (%)	GPC (%)
Wheat	0.59	27.43	18.05	65.51	13.01
Potato	0.75	31.80	23.68	72.76	13.93
Corn	0.71	29.27	20.67	69.63	13.76
Clover	0.67	28.77	19.36	72.38	14.12
Sugerbeet	0.65	28.27	18.58	71.36	13.64
LSD (*P* <0.05)	0.05	1.93	2.12	2.90	0.51
N rate					
Control (no fertilizer)	0.89	29.80	29.79	69.08	13.51
50% lower than recommended rate	0.58	29.16	16.99	71.31	14.07
Recommended rate	0.58	29.02	17.44	71.05	13.97
50% more than recommended rate	0.53	28.45	16.05	69.88	14.34
LSD (*P* <0.05)	0.04	2.02	1.42	2.30	0.70
crop residue					
Control	0.67	29.64	20.18	71.40	14.11
%50 crop residue return	0.68	28.57	19.96	69.06	13.84
LSD (*P* <0.05)	0.02	1.33	2.15	1.05	0.63

This study showed that was a clear positive relationship between NUpE and NUE in all rotations (r = 0.83) and variation in NUtE contributed lower to variation in NUE among the rotations (Table 4). In conclusion, the effect of preceding crop and fertilizer rate on NUE was mainly through its effect on NUpE. Muurinen et al. (2007) indicated that NUpE has a stronger relationship with NUE than NUtE in cereals. In addition, May et al. (1991) reported that of the main traits contributing to differences in NUE, N uptake contributed to NUE in wheat when grown at different N application rates. These results agree with the finding of Raun and Johnson (1999) and Pierce and Rice (1988), who reported that suboptimal yields decrease NUE in continuous wheat system.

Our results indicated that wheat NUE decreased with increasing N rate, while no significant differences were observed between minimum and maximum rates of N applied (Table 3). NUE of wheat at maximum rate of N (50% more than recommended rate) was 46% lower than the control plot. Lack of significant differences in wheat NUE at lowest and highest N rates are attributable to the gradual increase in grain yield. The highest response of wheat NUE to increasing N rate was determined for the wheat-wheat rotation (Fig 2). This result suggests that the wheat response to N fertilizer in continuous wheat system lower than crop rotation system. Lopez-Bellido and Lopez-Bellido (2001) indicated that a decrease in NUE with increasing fertilizer rates is because grain yield rises less than the N supply in soil and fertilizer. Therefore, these results demonstrated that the best N rate, able to ensure good NUE. Sowers et al. (1994), Limon-Ortega et al. (2000) and Zhao et al. (2006) reported similar results and indicated that NUE decreased with increases N rate. Kanampiu et al. (1997) indicated that generally decreases NUE, NUpE and NUtE with increasing N fertilizer rate, but increases grain protein content and N loss. Moreover, results showed that return of crop residue had no significant effect on NUE.

Nitrogen harvest index

The N harvest index, defined as N in grain to total N uptake, is an important consideration in cereals. NHI reflects the grain protein content and thus the grain nutritional quality (Hirel et al., 2007).

Results indicated that NHI of wheat varied significantly with preceding crops (Table 2). The lowest and highest value for NHI observed in continuous wheat (65.5%) and potato-wheat rotation (72.8%), respectively. In wheat-wheat rotation NHI of wheat was significantly lower than other rotations, while there were no significant differences in wheat NHI between potato-wheat, clover-wheat and sugar beet-wheat rotations. This may contribute to a decrease in leaf area duration and grain filling period. Results indicated that leaf area duration of wheat grown after potato greater than other crop rotations (data not shown). These results agreeing with the finding of Delogu et al. (1998) who reported that NHI in continuous wheat was significantly different with crop rotations.

NHI was unaffected by N rate and none of the rotation × N rate interactions were significant. Montemurro et al. (2006) suggested that grain N uptake was positively correlated with yield, protein content and total N uptake and a significant positive correlation found in NHI, yield and total N uptake. Lopez-Bellido and Lopez-Bellido., (2001) showed that the increase in crop N uptake with rising N fertilizer rates was grater than the increase in grain yield, so there is less transfer of N to grain when N rates was increased.

NHI slightly decreased with return of preceding crop residue. Results obtained in this experiment showed that wheat grain yield was not affected by crop residue return, while return of crop residue slightly increased wheat biological yield (data not shown). Therefore, decrease of wheat NHI under return of crop residue contributed to the decline in wheat harvest index.

Grain protein content

Preceding crops significantly influenced grain protein content of wheat (Table 2). The lowest and highest grain protein content obtained for continuous wheat (13.01%) and wheat grown after clover (14.12%), respectively. While, there were not significant differences between other preceding crops (Table 3). Grain protein content of wheat increased with higher N rates. The highest protein value was obtained with the highest N rate, while there was not significant difference between maximum and minimum N rates (Table 3). Halvorson et al., (2004) indicated that grain protein content generally increased with increasing N rate.

Table 4. Correlation coefficient among grain yield, N uptake efficiency (NUpE), N utilization efficiency (NUtE), N use efficiency (NUE), N harvest index (NHI) and grain protein content (GPC) of wheat

	Grain yield	NUpE	NUtE	NUE	NHI
NUpE	0.47 **				
NUtE	0.38 **	0.44 **			
NUE	0.08 ns	0.83 **	0.47 **		
NHI	0.48 **	0.22 *	0.55 **	0.11 ns	
GPC	0.06 ns	-0.09 ns	-0.19*	-0.23 *	0.25 **

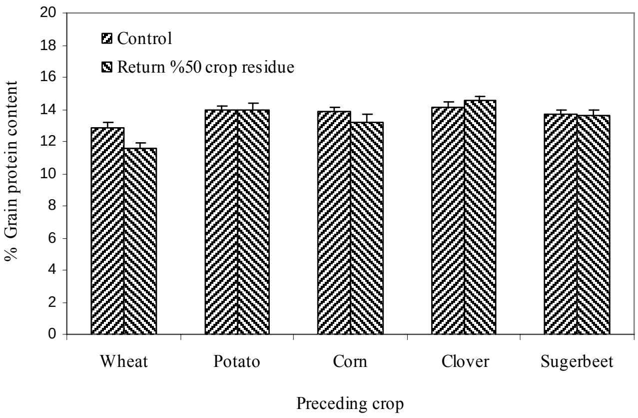

Fig 3. Interaction effect of preceding crop and return of crop residues on grain protein content of wheat

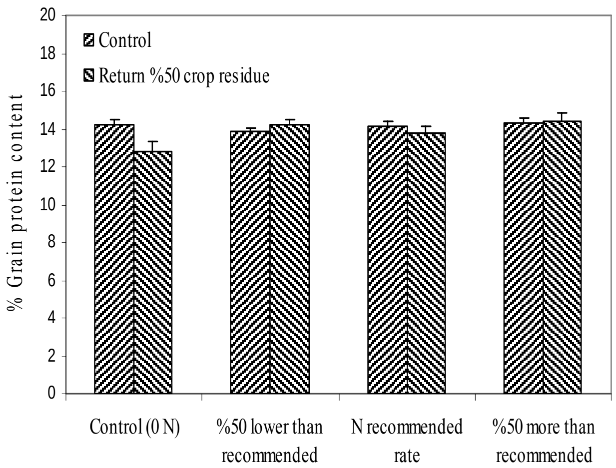

Fig 4. Interaction effect of N rates and return of crop residues on grain protein content of wheat

In addition, results showed that the effect of crop residue return on grain protein content of wheat influenced by preceding crop and N fertilizer rate (Table 2). Wheat and corn residues return decreased grain protein content of wheat, whiles wheat grain protein content did not responded to crop residue return after potato, clover and sugar beet (Fig 3). The lowest level of grain protein content (12%) was occurred in continuous wheat system after application wheat residues (Fig 3).

This result was because of higher C:N ratio of wheat residue compared with other preceding crops. Previous studies have reported that with applications of organic materials with a C/N ratio less than 15, net N mineralisation occurs almost immediately (Marstorp & Kirchman, 1991).

There was a crop residues return × N rate interaction for grain protein content of wheat. Return of crop residues decreased grain protein content of wheat by 10% under control treatment of N fertilizer (Fig 4). While, return of crop residue had not effects on grain protein content in other N rates. This result due to decreasing C:N ratio under no N application.

Conclusion

Significant differences between preceding crops were observed for NUE, NUpE, NUtE, NHI and grain protein content of wheat. The highest NUE, NUpE and NUtE were obtained for potato-wheat, while continuous wheat recorded the lowest NUE indices. Nitrogen fertilizer rates had a significant effect on NUE, NUpE and grain protein content in each rotation, but NUtE and NHI were not significantly affected by N fertilizer rate. This study showed that NUE decreased with increasing N rate. Thus, a potato-wheat cropping system planted on beds with low N supply is better than other double cropping systems wheat based. Return of crop residue had no significant effect on NUE indices expect NHI.

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