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Nitrogen utilization efficiency and the productivity of wheat in crop rotation under different rates of nitrogen

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Abstract— This research was carried out under the temperate climate condition of Ilam province, Iran, during 2011-2013 growing seasons to determine the suitable crop rotation for enhancing nitrogen (N) uptake, utilization, and use efficiency of wheat. Treatments were arranged in a split plot based on RCBD with four replications. The main plots were 6 pre-sowing plant treatments (control, Perko PVH, Buko, Clover, Oilseed radish and combination of three plants Ramtil, Phasilia, clover), and sub-plots were allocated to four levels of nitrogen fertilizer (Zero, fertilizer recommendation, 50% lower and 50% higher than the recommended fertilizer). Results showed that nitrogen use efficiency (NUE), nitrogen uptake efficiency (NUpE), nitrogen utilization efficiency (NUtE) and Nitrogen efficiency ratio(NER) in wheat were significantly affected by crop rotation and nitrogen fertilizer and their interaction. The lowest and highest NUE were in oilseed radish- wheat and fallow- wheat rotation, respectively. The highest and lowest NUtE were observed in oilseed radish-wheat and fallow- wheat rotation, respectively. Perko-Wheat rotation with the consumption of nitrogen based on fertilizer recommendation for wheat due to economic performance and high nitrogen uptake and use efficiency, were evaluated better than any other rotation.

Keywords—rotation, nitrogen uptake efficiency, nitrogen utilization efficiency, wheat

I. INTRODUCTION

There are about 160 species in Brassica genus which are mostly annuals and Biennials. This genus of crop plants has a good forage potential. Plant breeding science with new progresses has produced new varieties with both forage and oil usages. Perko varieties were derived from the crosses between tetraploid plants of winter rapeseed (Brassica napus L.varnapus) and Chinese cabbage (Brassica campestris L.var. sensulato). New plants are superior to their parents in different aspects.Buko variety is a new amphiploid plant obtained by crossing tetraploid winter rapeseed, Chinese cabbage and turnips (Brassica campestris L.var. Rapa).Oilseed radish with scientific name (Raphanus sativus L.)is a genus belong tothe Brassica and for various uses, e.g. oil, green manure, feed and fodder[11, 17].This plant in many countries, including Canada, is cultivated in gardens in order to cover crop. Oilseed radish is growing quickly in the cool seasons. Ramtil (Guizotia abyssinica) belongs to Asteraceae family, Phasilia (Phacelia tanacetifolia) to Boraginaceae[18] and clover to Fabaceae family which allare grown for feeding.

Food and agriculture organization (FAO)through a 40-year study confirmed that 33 to 60 percent increase in crop yield has been due to fertilizer use in different countries and the organization is named fertilizers as the key element for food security. Nitrogen is one of the macro nutrients are effective in improving plant growth and productivity[12]. As, nitrogen (N) is often the most limiting nutrient for crop yield in many regions of the world [5], 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[7].Worldwide, nitrogen use efficiency (NUE) for cereal production including wheat is approximately 33%[27]. NUE may be affected by crop species, soil type, temperature, application rate of N fertilizer, soil moisture condition and crop rotation [8].

Lopez-Bellido and Lopez-Bellido [15] 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[32].

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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 [8]. The influence of preceding crop on the N uptake of the following crop has long been recognized. quantified winter wheat response top receding crop and crop management. Nitrogen efficiency indices decrease with increasing N level, especially under dry soil condition [8]. According to Sowers et al. (1994), the application of high N rates may result in poor N uptake and low NUE due toexcessive N losses[28].

According to Brussaard et al, (2007) the NUE of net production per unit is absorbed amount of nitrogen[1]. Tittonell et al, (2007) defined conversion efficiency or productivity as kilogram dry matter per kilogram absorbed elements[31]. Ortiz et al., (2002) stated that by increasing the N fertilizer NUpE and productivity decreased and leadedto a reduction in the NUE[23]. Huggins et al., (1997) also found that high levels of nitrogen slowly increased nitrogen uptake availability that was reduced on NUE[10]. Ortiz et al (2002) and Muurinen et al (2007) reported that increased the N fertilizer nitrogen utilization efficiency decreased, despite an increase in grain yield [23, 22].

Average recovery N efficiency (REN), agronomy N efficiency (AEN) and N partial factor productivity (PFPN) in Optimum N treatment was 44%, 11 and 56 kg kg-1, respectively, which were an increase of 139%, 214%, and 179% over Conventional. N treatment(REN 18%, AEN 3 kg kg-1, PFPN20 kg kg-1), respectively. Sites with high NUE (REN > 60%, AEN > 15 kg/kg, PFP > 50 kg/kg) in Optimum. N treatment was 21%, 10% and 46% of all sites, respectively, while no such sites was observed in Conventional. N treatment[2].

Hossaini et al,(2013) with increasing nitrogen application, NUE significantly between all levels of the nitrogen fertilizer is reduced. NUE index difference between the two conditions do not apply N fertilizer (control) and maximum nitrogen (270 kg N ha) is 44%. Also by increasing nitrogen fertilizer, NUpE decreased[9].

Rahimizadeh et al,(2010) reported that significant differences between preceding crops were observed for NUE, NUpE, NUtE, and NHI. 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.and NUE decreased with increasing N rate [25].

Winter wheat based rotations are main cropping system in Iran, but little information exists on better rotation for wheat under temperate 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 rotation, N fertilizer rate on N efficiency indices of wheat.

II. Materials and Methods

The field experiment was conducted from 2011 to 2013 at the Karezan region of Ilam, Iran (42º33′N, 33º46′ E) on a Silty- Clay with low organic carbon (1.26%and slightly alkaline soil (pH= 7.9). Other soil test parameters is presented in Table 1.This site characterized by temperate climates with 370 mm annual precipitation.

Table 1 - Results of soil tests implementation of experimental site

Soil depth (cm)	Soil texture	P (ppm)	K(ppm)	N%	OC%	pH	EC(ds/m)
0-30	**Silty- Clay**	**10.5**	**760**	**0.11**	**1.26**	**7.9**	**0.58**
31-60	**Silty- Clay**	**4.4**	**420**	**0.07**	**0.76**	**7.8**	**0.58**

The experiment was arranged in a split plot based on randomized complete block design with four replications. The main plots consisted of 6 pre-sowing plant treatments (control, Perko PVH, Buko, Clover, Oilseed radish and combination of three plants Ramtil, Phasilia, clover), and Sub plots were four N fertilizer rates including no fertilizer N(Control), 50% lower than recommended N rate, recommended N rate and 50% more than recommended N rate.

Winter wheat (Cv. Pishtaz) was planted on mid-November with arrow spacing of 15 cm and a seeding rate 200 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 (2m2) within each plot. Plant samples collected at harvest were separated into grain and straw and oven-driedat 60˚C for 72hr. Biomass and grain sub samples analyzed for total N content using a micro-Kjeldahl digestion with Sulfuric acid. The terminology of N efficiency parameters is in accordance with Delogu et al., (1998) and Lopez-Bellido andLopez-Bellido (2001),Rahimizadeh et al., (2010)Limon-Ortega et al., (2000),Moll et al., (1982), and Heffer (2008).

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

Where Ntis total plant N uptake. Nt was determined by multiplying dry weight of plant parts by N concentration and summing over parts for total plant uptake. N supply is Sum

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ofsoil 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}) =Gy / Nt [2]

Where Gyis grain yield

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

Nitrogen harvest index (NHI, %) =(Ng / Nt) × 100 [4]

Nitrogen efficiency ratio(NER, kg kg^{-1})= Yeco /Ng [5]

FNG (kg kg^{-1}) = Ng / Nt [6]

Where Ng is total grain N uptake. Ng 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 Duncan's multiple range test procedures by the SAS software.

III. RESULTS AND DISCUSSION

A. *Total Economic yield*

Results showed that the effect of rotation were significant ($P\leq0.05$)on the economic performance of the entire rotation (Table 2). The highest (15273 kg/ha) and lowest (4491 kg/ha) TEY of wheat observed for the perko-wheat and fallow-wheat rotations, respectively (Table 3). Effect of nitrogen fertilizer were significant ($P\leq0.05$)on the economic performance of alternative treatments (Table 2).

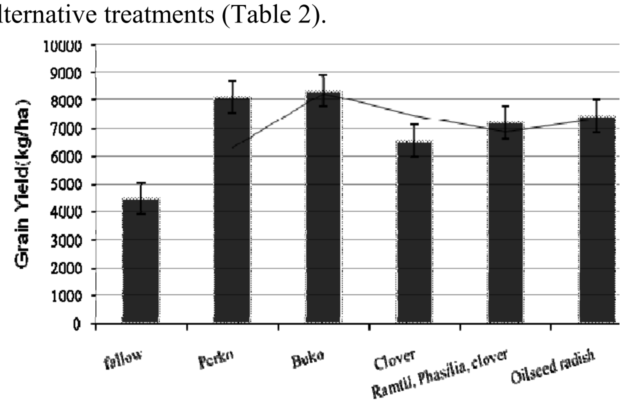

Fig 1.wheat grain yield affected by preceding crop

The highest (13309 kg/ha) and lowest (9908 kg/ha) TEY of wheat observed for the N Recommended rate and Control (no fertilizer), respectively (Table 3). The highest and lowest grain yield, with 8345, and 4491 kg/ha were obtained for Buko-wheat rotation and fallow- wheat rotation, respectively(Fig 1).

B. *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 (0.999kg kg-1) and lowest (0.761kg kg-1) NUpE of wheat observed for the Oilseed radish-wheat and fallow-wheat rotations, respectively (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[15]. Lee et al., (2004) indicated that NUpE was positively correlated with plant dry matter, leaf area index and leaf nitrogen content[13]. So, this result could explain by wheat yield variation in crop rotations. Oilseed radish-wheat and Perko-wheat rotation in terms of nitrogen recommendations,the highest NUpE(1.065 and 1.037 kg kg^{-1}) respectively, and fallow- wheat rotation in terms of nitrogen fertilizer Consumption recommended rate were the lowest NUpE (0.502 kg kg^{-1}).

Wheat yield in boku-wheat rotation was 185% more than fallow- wheat system and low yielding continuous wheat system had the lowest NUpE values (Fig 2). Therefore, higher mean NUpE in wheat for oilseed radish -wheat and perko-wheat rotation was due to higher grain yield compared with other rotations.The results showed that the total yield of rotation Perko- wheat and oilseed radish-wheat compared to fallow- wheat, were more 341 and 315%, respectively. 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 oilseed radish-wheat rotation applying N maximum rate, decreased wheat NUpE13.2% compared with control (no N). While, NUpE of wheat decreased 30% in continuous wheat system with applying 50% lower than recommended N rate(Fig 2). Our results agree with those of Lopez-Bellido and Lopez-Bellido (2001), Rahimizadeh et al., (2010), Husaini et al., (2013), Ortiz et al., (2002), Huggins and Pan., (1993)and Zhaoet al., (2006), who found that on NUpE decreased with increase N use rate.

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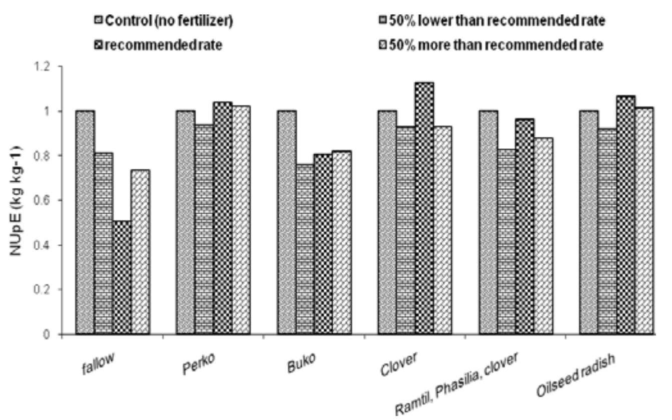
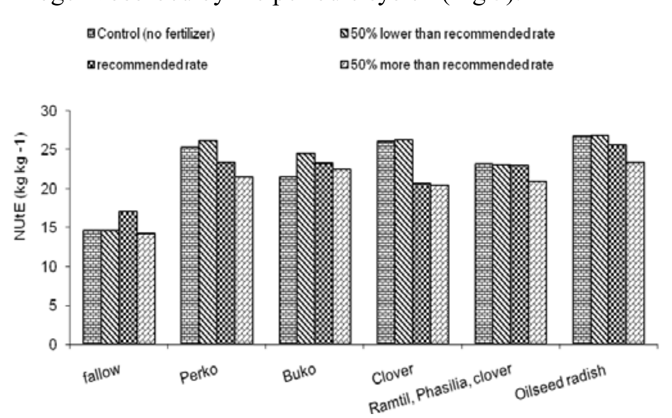


Fig 2. NUpE of wheat affected by preceding crop and nitrogen rate

C. Nitrogen Utilization Efficiency

Nitrogen utilization efficiency reflects the ability of the plant to transplant the N uptakes into grain (Delogu et al., 1998).Crop rotation, nitrogen fertilizer and their interaction had a significant effect on the NUtE (Table 2).The highest and lowest NUtE of wheat observed for the oilseed radish -wheat and fallow-wheat rotations, respectively, and the highest and lowest value for wheat NUtE again obtained with to Oilseed radish-wheat and fallow-wheat rotations (25.56 and 15.09 kg kg^{-1}), respectively(Table 3).

In terms of nitrogen fertilizer, in the treatment 50% lower than recommended rate oilseed radish-wheat rotation produce 26.8 kg economic output per kg of nitrogen absorbed by the periodic system, while fallow-wheat in maximum nitrogen was produced(14.23 kg), economic output per kilogram of nitrogen absorbed by the periodic system(Fig 3).



3. NUtE of wheat affected by preceding crop and nitrogen rate

Delogu et al. (1998), Lopez-Bellido and Lopez-Bellido., (2001), Hirel et al.,(2007), Husaini et al., (2013) and Ortiz et al., (2002), showed that NUtE decreased with increasing N fertilizerrates

D. Nitrogen Use Eefficiency

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 oilseed radish-wheat (25.56 kg kg^{-1}) and Fallow-wheat (15.09 kg kg^{-1}) rotations, respectively (Table 3). The NUE of wheat grown after oilseed radish was 69% more than wheat NUE in Fallow -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 Fallow-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 oilseed radish -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.

Based on the comparison of means, with the increase N fertilizer is reduced efficiency, so that the highest and lowest NUE of wheat observed in no application control (no N) (22.85 kg kg^{-1}) and 50% more than the recommended (20.44 kg kg^{-1}), respectively (Table 3). Similar results Lopez-Bellido and Lopez-Bellido., (2001) Raunand Johnson.,(1999) and Montemuro et al., (2006) based on crop rotation and nitrogen fertilizer effects on NUE was reported. Power et al.,(2000), Hossaini et al., (2013) and Rahimi- Zadeh et al., (2010) 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, Moll et al (1982) reported That the highest NUE usually attracts is obtained by first fertilizer unit and its efficiency decreases with increasing fertilizer.

E. Nitrogen efficiency ratio(NER)

The results showed that NER 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 NER of wheat observed in Fallow-wheat(49.8 kg kg-1) and Boku-wheat (35.94 kg kg-1) rotations, respectively (Table 3).

F. Nitrogen ratio of the economic output of total nitrogen adsorbed(FNG)

The results showed that FNG 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 FNG of wheat observed in Boku-wheat (0.638 kg kg-1) and Fallow-

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wheat(0.303 kg kg-1) rotations, respectively (Table 3). The highest and lowest FNG of wheat observed in no application control (no N) (0.589 kg kg-1) and 50% more than the recommended (0.517 kg kg-1), respectively (Table 3).Rahimi-Zadeh, et al (2010), Hossaini et al (2013) also reported that increasing nitrogen fertilizer ratio of nitrogen uptake decreased to total economic output.

G. Nitrogen Harvest Index(NHI)

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 (79.28%) and boku-wheat rotation (86.5%), respectively. In other words,the rotation Boku-wheat nitrogen uptake by more than 86% of the harvested crop is concentrated economic, while in other rotation flower proportions of nitrogen uptake by plants grown in economic output is accumulated, In fallow-wheat rotation NHI of wheat was significantly lower than other rotations, while there were no significant differences in wheat NHI between perko-wheat, clover-wheat, Oilseed radish-wheat, and Ramtil, Phacilia, Clover-wheat rotations. 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., (2005) showed that the increase in crop N uptake with rising N fertilizer rates was greater than the increase in grain yield, so there is less transfer of N to grain when N rates was increased. Table 2. The mean of squares of N use efficiency (NUE), N uptake efficiency (NUpE), N utilization efficiency (NUtE), N harvest index (NHI), Nitrogen efficiency ratio(NER),Total economic yield(TEY)of wheat at different rotation and N rates.

Table 2. The mean of squares of N use efficiency (NUE), N uptake efficiency

S.O.V	df	Mean-square(M.S)						
		NUE	NHI	TEY	NUpE	NUtE	NER	FNG
Replication	3	11.75	9.63	20017017	0.0171	32.46	69.76	0.0089
Rotation(A)	5	388.14**	93.15**	241583451 **	0.17**	209.61**	388.88**	0.257**
Fertilizer N rate(B)	3	20.88**	15.29 ns	62707254*	0.078**	46.26**	18.18**	0.0319**
AB	15	7.22*	8.48 ns	2929759ns	0.046**	10.91**	14.76**	0.0021ns

probability level. ** Significant at 0.01 probability level.nsnon significant.

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Table 3. N use efficiency (NUE), N uptake efficiency (NUpE), N utilization efficiency (NUtE), N harvest index (NHI), Nitrogen efficiency ratio(NER),Total economic yield(TEY) of wheat at rotations

	Fallow	perko	Buko	Clover	Ramtil ,Phacilia,Clover	Oilseed radish	LSD (P <0.05)
TEY(kg)	44719	15273	14003	11212	12065	14102	2875
NUpE(kg kg^{-1})	0.761	0.998	0.844	0.967	0.915	0.999	0.148
NUtE (kg kg^{-1})	15.09	24.03	22.89	22.30	22.47	25.56	2.502
NUE (kg kg^{-1})	10.92	23.25	18.75	22.18	19.90	24.63	4.235
NER (kg kg^{-1})	49.80	38.23	35.94	41.08	37.75	41.99	4.795
NHI (%)	79.38	85	86.5	83.4	83.6	84.48	4.15
FNG (kg kg^{-1})	0.303	0.631	0.638	0.562	0.590	0.611	0.0433

H. Conclusion

Significant differences between preceding crops were observed for NUE, NUpE, NUtE, NHI, NER and FNG content of wheat. The highest NUE, NUpE and NUtE were obtained for Oilseed radish-wheat, while fallow- wheat recorded the lowest NUE indices. Nitrogen fertilizer rates had a significant effect on NUE, NUpE, NUtE, FNG and NER content in each rotation, but NHI were not significantly affected by N fertilizer rate. This study showed that NUE decreased with increasing N rate. Thus, the total performance Perko-wheat rotation as fertilizer recommendation nitrogen and more than the recommended were greater than the other rotation, Thus Perko- Wheat rotation with the consumption nitrogen as fertilizer recommendations for wheat due to economic performance and high nitrogen uptake and use efficiency, Were evaluated better than any other rotation.

Table 4. N use efficiency (NUE), N uptake efficiency (NUpE), N utilization efficiency (NUtE), N harvest index (NHI), Nitrogen efficiency ratio(NER),Total economic yield(TEY) of wheat at N rates.

	Control (no fertilizer)	50% lower than recommended rate	Recommended rate	50% more than recommended rate	LSD (P <0.05)
TEY(kg)	9872	11212	13273	13071	852.3
NUpE (kg kg^{-1})	1.00	0.892	0.886	0.868	0.068
NUtE (kg kg^{-1})	22.852	23.524	22.085	20.445	1.247
NUE (kg kg^{-1})	20.201	20.353	20.644	18.564	1.365
NER (kg kg^{-1})	41.104	41.104	41.889	40.102	1.176
NHI (%)	83.74	84.57	83.93	82.65	1.27
FNG (kg kg^{-1})	0.589	0.581	0/540	0/517	0.025

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