氮素形态对专用小麦中后期根际土壤微生物和酶活性的影响

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摘要:采用盆栽方法研究了酰胺态氮、铵态氮和硝态氮对强筋小麦(*Triticum aestivum* L.)"豫麦 34"、中筋小麦"豫麦 49"和弱筋小麦"豫麦 50"生育中后期根际微生物和土壤酶活性的影响。结果表明,专用小麦根际真菌、细菌、放线菌数量和土壤脲酶、蛋白酶、硝酸还原酶活性以及根际 pH 值对氮素形态的反应不同。"豫麦 34"施用硝态氮,对根际土壤真菌、细菌(除成熟期外)和放线菌数量均具有明显的促进作用;"豫麦 49"施用铵态氮,根际土壤细菌和放线菌数量最大,根际真菌数量在孕穗期和开花期以酰胺态氮处理最大,而成熟期以硝态氮处理最大;"豫麦 50"施用硝态氮,对根际土壤真菌、细菌和放线菌数量均具有明显的促进作用。不同专用小麦品种均表现为在酰胺态氮处理下,根际土壤脲酶活性最高;在铵态氮处理下,根际土壤蛋白酶活性最高;在硝态氮处理下,根际土壤硝酸还原酶活性和 pH 值最高。

关键词:氮素形态;专用小麦;根际微生物;根际土壤酶 ;根际 pH 值
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Effects of nitrogen forms on rhizosphere microorganisms and soil enzyme activity under cultivation of contrasting wheat cultivars during booting and grain filling period

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Abstract: Soil microorganisms and enzymes are main components of soil biochemical properties. They play an important role in nutrient transformation and decomposition of crop residues. Application of different forms of nitrogen is an important measure to regulate nitrogen metabolism of wheat (*Triticum aestivum* L.). In order to understand the effects of nitrogen forms on rhizosphere microbial populations and soil enzyme activity under cultivation of contrasting wheat cultivars with specialized end-uses from booting stage to grain filling period, pot experiments were carried out on a sandy loam at the Experimental Farm of Henan Agricultural University during 2004 —2006. The soil contained 9.1 $g \cdot kg^{-1}$ organic matter, 0.90 $g \cdot kg^{-1}$ total N, 22.68 $mg \cdot kg^{-1}$ olsen-P and 0.23 $g \cdot kg^{-1}$ NH_4OAc-K. Each pot (30cm in diameter and 40 cm in height) was filled with 20 kg of sieved soil. Cultivars used in the study were: Yumai 34′ (a strong gluten cultivar), Yumai 49′ (medium gluten) and Yumai 50′ (weak gluten). Nitrogen forms were $CO(NH_2)_2$-N, NH_4^+-N as NH_4HCO_3 and NO_3^--

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N as $NaNO_3$. Nitrification inhibitors dicyandiamide (DCD) was applied to each pot. Prior to sowing, each pot received 3.06 g N, 2.9 g P_2O_5 and 3.3 gK_2O, and additional 2.04 g N was also applied to each pot during the elongation stage. Seven plants from each pot were selected when plants had five leaves. The experiment was arranged in a completely randomized design with ten replications, and all pots were managed in the same way. Rhizosphere soil samples in a depth of 5 —20 cm for each treatment were taken at booting, flowering and ripening stage of wheat, respectively. Samples were fully mixed, put into sterile bags and transported to the lab as quickly as possible. Part of soil sample was sieved through a 1 mm screen for analysis of microbial quantity, and part was air-dried for determination of soil enzyme activities, including urease, protease and nitrate reductase with sodium phenoxide colorimetry, ninhydrin colorimetry and 2,4-D restraining, respectively. This study showed that the quantity of microorganisms, activity of enzymes and pH in rhizosphere soils planted with contrasting wheat cultivars for specialized end-uses responded differently to nitrogen forms. The quantity of fungi, bacteria(with the exception of ripening stage of wheat) and actinomyces were the highest for wheat cultivar 'Yumai 34' received NO_3^--N. while for cultivar 'Yumai 49', bacteria and actinomyces in rhizosphere soil were promoted greatly by NH_4^+-N, fungi populations were stimulated by $CO(NH_2)_2$-N in booting and flowering stages and by NO_3^--N during grain filling. When NO_3^--N was applied to wheat cultivar Yumai 50', the quantity of fungi, bacteria and actinomyces in rhizosphere soil were increased greatly. The activity of urease, protease and nitrate reductase in rhizosphere soil of all three wheat cultivars were stimulated by $CO(NH_2)_2$-N, NH_4^+-N and NO_3^--N, respectively, and pH were the highest in NO_3^--N treatments.

Key Words: nitrogen forms; specialty wheat cultivars; rhizosphere microorganism; rhizosphere enzyme activity; rhizosphere pH

土壤微生物和酶是土壤生物化学特性的重要组成部分,在营养物质转化、有机质分解等方面起重要作用[1],是评价土壤质量的重要指标,已成为近年来土壤学界研究的热点之一。研究表明,施肥对土壤微生物和酶活性有着重要的影响。施肥较不施肥的土壤酶活性提高[1]、微生物数量明显增多[2]。在适宜的施肥量下,土壤酶活性和微生物数量达到最大[3,4]。改进施肥方法如增施有机肥[5,6]、有机无机肥料配施[7,8]和施用包膜控释尿素[9],有利于提高土壤微生物和酶活性。另有试验报道,不同氮素形态可以有效调控小麦氮素营养,进而影响其生长发育[10~14],但氮素形态对专用小麦根际微生物和土壤酶活性的影响还鲜有报道。为此,本试验以强筋、中筋和弱筋小麦为材料,在盆栽条件下研究了酰胺态氮、铵态氮和硝态氮对小麦中后期根际微生物和土壤酶活性的影响,旨在进一步揭示氮素形态对小麦生长发育的生态效应,为合理的氮素运筹提供理论依据。

1　材料与方法

1.1　试验设计与处理

盆栽试验于 2004 ~2006 年连续两年在河南农业大学科教园区进行。用土取自园区耕作层,土壤为黄潮土,有机质含量 9.1 $g\cdot kg^{-1}$,pH 值为 7.94,全氮含量 0.90 $g\cdot kg^{-1}$,速效氮含量 67.54 $mg\cdot kg^{-1}$,速效磷含量 22.68 $mg\cdot kg^{-1}$,有效钾含量 0.23 $g\cdot kg^{-1}$。装土前过筛,每盆装土 20 kg (盆钵直径 30 cm,深 40 cm)。选用的专用小麦品种为:强筋小麦"豫麦 34"、中筋小麦"豫麦 49"和弱筋小麦"豫麦 50";3 种氮素形态分别为:$CO(NH_2)_2$-N (分析纯尿素)、NH_4^+-N(分析纯 NH_4HCO_3)、NO_3^--N (分析纯 $NaNO_3$)。计 9 个处理组合,完全随机区组排列,重复 10 次。每盆分别施纯氮 5.1 g,P_2O_5 2.9 g 和 K_2O 3.3 g,P、K 肥于播种期一次性施入,N 肥在播种期和拔节期每盆分别施入 3.06 g 和 2.04 g。混肥前每盆施入总氮量 10% 的硝化抑制剂双氰胺(DCD),以保证氮素形态的相对稳定。施用的肥料和土壤在装盆前充分混匀,每盆上层均覆 5cm 未混肥土壤,以尽量避免氮素的挥发损失。试验于 10 月 15 日统一播种,每盆播种 14 粒,5 叶期定苗,每盆定 7 株。定期灌水,各处理保持一致的土壤相对含水量。

1.2 测定项目与方法

1.2.1 土样采集

各处理分别在小麦孕穗期、开花期和成熟期,于晴天 10:00 左右,将 5 ~20 cm 根系带土样挖出,用根际土壤采集方法[15]取土。土样混匀后装入无菌纸袋,立即带回实验室。将新鲜土样研磨过 1 mm 筛,一部分测定土壤微生物数量,另一部分土样经自然风干,测定 pH 值和土壤酶活性。

1.2.2 根际土壤微生物

采用梯度稀释法制备土壤悬液,采用涂抹平板计数法测定细菌、真菌、放线菌的数量。培养基分别为牛肉膏蛋白胨培养基、马丁氏培养基、高氏一号培养基[16]。计算结果以烘干土为单位。微生物种群计数时设 3 个稀释浓度,3 次重复。

1.2.3 根际土壤酶活性

取采集的土样 4g,用茚三酮比色法[17]测定蛋白酶活性。各取土样 5 g,分别用苯酚钠比色法[17]和 2,4-D 抑制法[15]测定脲酶和硝酸还原酶活性。计算结果以风干土为单位。3 次重复。

1.2.4 根际土壤 pH 值

取采集的土样 5 g,按水土比例 5:1 配制溶液,采用电位法测定。3 次重复。

试验数据用 SPSS version 10.0 统计软件进行分析。

2 结果与分析

2.1 氮素形态对不同专用小麦品种根际土壤微生物数量的影响

2.1.1 对根际土壤真菌数量的影响

由表 1 可见,专用小麦品种的根际真菌数量在开花期升至最高,成熟期有所降低。但不同专用小麦品种根际真菌数量对氮素形态的反应不同。强筋小麦"豫麦 34"在硝态氮处理下,根际真菌数量最大,孕穗期和开花期以铵态氮处理最小,成熟期以酰胺态氮处理最小。经方差分析,在孕穗期和成熟期,硝态氮比另外两个氮素处理根际真菌数量显著增加。中筋小麦"豫麦 49"根际真菌数量在孕穗期和开花期以酰胺态氮处理最大,硝态氮处理最小,铵态氮处理居中。成熟期以硝态氮处理最大,铵态氮和酰胺态氮处理较小。在孕穗期,酰胺态氮比另外两个氮素处理根际真菌数量显著增加,在开花期和成熟期 3 种氮素形态处理差异不显著。弱筋小麦"豫麦 50"在硝态氮处理下根际真菌数量最大,在孕穗期以铵态氮处理最小,在开花期和成熟期以酰胺态氮处理最小。在孕穗期和成熟期,硝态氮处理下的根际真菌数量较另外两个处理显著增加。

表 1 氮素形态对不同专用小麦品种根际土壤真菌数量的影响($\times 10^4$ cfu·g^{-1} dry soil)

Table 1 Effects of different forms of nitrogen on rhizospheric fungi of wheat cultivars with specialized end-uses

品种 Cultivars	氮素形态 Nitrogen forms	生育时期 Growth stage		
		孕穗期 Booting stage	开花期 Flowering stage	成熟期 Ripening stage
豫麦 34 Yumai 34	酰胺态氮 $CO(NH_2)_2$-N	0.56 ±0.12cd	3.26 ±0.29c	0.78 ±0.10d
	铵态氮 NH_4^+-N	0.37 ±0.11d	2.98 ±0.12c	1.73 ±0.40bc
	硝态氮 NO_3^--N	1.07 ±0.31b	3.28 ±0.63c	2.63 ±0.25a
豫麦 49 Yumai 49	酰胺态氮 $CO(NH_2)_2$-N	1.99 ±0.27a	3.49 ±0.06bc	1.75 ±0.51bc
	铵态氮 NH_4^+-N	1.07 ±0.43b	3.34 ±0.26c	1.74 ±0.18bc
	硝态氮 NO_3^--N	1.04 ±0.23b	3.29 ±0.61c	2.09 ±0.36abc
豫麦 50 Yumai 50	酰胺态氮 $CO(NH_2)_2$-N	0.82 ±0.09bc	3.94 ±0.14ab	0.81 ±0.13d
	铵态氮 NH_4^+-N	0.71 ±0.18bcd	3.96 ±0.18ab	1.66 ±0.19c
	硝态氮 NO_3^--N	1.94 ±0.26a	4.12 ±0.33a	2.44 ±0.49ab

表中同一栏内不同小写字母表示在 0.05 水平上差异显著,下同 Different small letters within the same column means significant difference at 0.05 level, the same below

2.1.2 对根际土壤细菌数量的影响

从表 2 可以看出,专用小麦品种的根际细菌数量在孕穗期后一直呈下降趋势,但氮素形态对不同专用小

麦品种根际细菌数量有一定的影响。除成熟期外,强筋小麦“豫麦 34” 根际细菌数量在硝态氮处理下最高,酰胺态氮处理最低,铵态氮处理居中。方差分析表明,在孕穗期和开花期,硝态氮比另外两个氮素处理的根际细菌数量显著增加。中筋小麦“豫麦 49”根际细菌数量以铵态氮处理最高,硝态氮处理最低,酰胺态氮处理居中。在孕穗期,铵态氮处理比另外两个氮素处理根际细菌数量显著增加。弱筋小麦“豫麦 50”根际细菌数量以硝态氮处理最高,铵态氮处理最低,酰胺态氮处理居中。在孕穗期和成熟期,硝态氮比另外两个氮素处理的根际细菌数量显著增多。

表 2　氮素形态对不同专用小麦品种根际土壤细菌数量的影响($\times 10^6$ cfu·g^{-1} dry soil)

Table 2　Effects of different forms of nitrogen on rhizospheric bacteria of wheat cultivars with specialized end-uses

品种 Cultivars	氮素形态 Nitrogen forms	生育时期 Growth stage		
		孕穗期 Booting stage	开花期 Flowering stage	成熟期 Ripening stage
豫麦 34 Yumai 34	酰胺态氮 $CO(NH_2)_2$-N	10.90 ± 1.46d	4.81 ± 1.13d	1.46 ± 0.43bc
	铵态氮 NH_4^+-N	20.78 ± 1.07b	6.01 ± 1.18d	3.67 ± 0.89ab
	硝态氮 NO_3^--N	26.69 ± 3.78a	10.78 ± 2.51a	1.56 ± 0.97bc
豫麦 49 Yumai 49	酰胺态氮 $CO(NH_2)_2$-N	16.52 ± 4.79c	7.97 ± 1.64bc	2.72 ± 1.04abc
	铵态氮 NH_4^+-N	26.95 ± 2.03a	8.65 ± 1.71b	3.36 ± 1.02abc
	硝态氮 NO_3^--N	14.78 ± 3.91cd	7.22 ± 1.34c	2.40 ± 1.03abc
豫麦 50 Yumai 50	酰胺态氮 $CO(NH_2)_2$-N	13.45 ± 2.01cd	9.36 ± 2.19ab	1.35 ± 0.28bc
	铵态氮 NH_4^+-N	11.17 ± 2.08d	6.31 ± 1.67cd	1.04 ± 0.63c
	硝态氮 NO_3^--N	23.06 ± 3.11ab	12.11 ± 2.43a	4.19 ± 1.24a

2.1.3　对根际土壤放线菌数量的影响

表 3 表明,专用小麦品种根际放线菌数量在孕穗期较高,随后呈下降趋势,但不同专用小麦品种对氮素形态的反应不同。强筋小麦“豫麦 34”的根际放线菌数量以硝态氮处理最高,另外两个氮素处理表现趋势不一。经方差分析,在孕穗期,硝态氮比另外两个氮素处理的根际放线菌数量显著增加。中筋小麦“豫麦 49” 的根际放线菌数量在铵态氮处理下最高,硝态氮处理最低,酰胺态氮处理居中。在孕穗期,铵态氮处理下根际放线菌数量较另外两个氮素处理显著增加。弱筋小麦“豫麦 50”在硝态氮处理下,根际放线菌数量最高,在孕穗期,酰胺态氮处理最低,在开花期和成熟期,铵态氮处理最低。在孕穗期,硝态氮比酰胺态氮处理根际放线菌数量显著增加;在开花期和成熟期,硝态氮比铵态氮处理根际放线菌数量显著增多。

表 3　氮素形态对不同专用小麦品种根际土壤放线菌数量的影响 ($\times 10^5$ cfu·g^{-1} dry soil)

Table 3　Effects of different forms of nitrogen on rhizospheric actinomyces of wheat cultivars with specialized end-uses

品种 Cultivars	氮素形态 Nitrogen forms	生育时期 Growth stage		
		孕穗期 Booting stage	开花期 Flowering stage	成熟期 Ripening stage
豫麦 34 Yumai 34	酰胺态氮 $CO(NH_2)_2$-N	8.68 ± 2.57cd	5.64 ± 0.91a	0.83 ± 0.28b
	铵态氮 NH_4^+-N	10.68 ± 1.99cd	2.10 ± 0.69d	2.05 ± 0.64ab
	硝态氮 NO_3^--N	16.25 ± 4.50ab	5.65 ± 2.00a	1.35 ± 0.91ab
豫麦 49 Yumai 49	酰胺态氮 $CO(NH_2)_2$-N	10.65 ± 3.10cd	3.81 ± 0.68abcd	1.89 ± 0.84ab
	铵态氮 NH_4^+-N	20.39 ± 3.43a	3.97 ± 0.65abc	2.30 ± 1.08ab
	硝态氮 NO_3^--N	7.84 ± 1.32d	3.67 ± 1.28bcd	0.62 ± 0.23b
豫麦 50 Yumai 50	酰胺态氮 $CO(NH_2)_2$-N	8.18 ± 1.58d	3.32 ± 0.68bcd	2.08 ± 0.86ab
	铵态氮 NH_4^+-N	9.29 ± 1.65cd	2.18 ± 1.18cd	1.04 ± 0.64b
	硝态氮 NO_3^--N	13.58 ± 3.04bc	5.03 ± 0.80ab	3.09 ± 0.46a

2.2　氮素形态对不同专用小麦品种根际土壤酶活性的影响

2.2.1　对根际土壤脲酶活性的影响

由表 4 可见,在小麦生育的中后期,根际土壤的脲酶活性均呈下降趋势。不同专用小麦品种均表现为酰

胺态氮处理下,根际土壤的脲酶活性最高,硝态氮和铵态氮处理的则较为相近(弱筋小麦“豫麦 50”在孕穗期除外)。方差分析表明,强筋小麦“豫麦 34”在孕穗期,酰胺态氮处理的根际脲酶活性显著高于另外两个氮素处理;中筋小麦“豫麦 49”在成熟期,酰胺态氮处理的根际脲酶活性显著高于硝态氮处理;弱筋小麦“豫麦 50”在孕穗期,酰胺态氮和铵态氮比硝态氮处理的脲酶活性显著增加。其余氮素处理间根际脲酶活性的差异均不显著。

表 4 氮素形态对不同专用小麦品种根际土壤脲酶活性的影响(NH_3-N μg·g^{-1} dry soil,37 ℃,24 h)

Table 4 Effects of different forms of nitrogen on rhizospheric urease activity of wheat cultivars with specialized end-uses

品种 Cultivars	氮素形态 Nitrogen forms	生育时期 Growth stage		
		孕穗期 Booting stage	开花期 Flowering stage	成熟期 Ripening stage
豫麦 34 Yumai 34	酰胺态氮 $CO(NH_2)_2$-N	4.94 ± 0.17a	3.74 ± 0.42bcd	3.12 ± 0.16abcd
	铵态氮 NH_4^+-N	4.57 ± 0.13b	3.38 ± 0.10d	2.82 ± 0.25cd
	硝态氮 NO_3^--N	4.51 ± 0.26b	3.42 ± 0.10d	2.80 ± 0.27cd
豫麦 49 Yumai 49	酰胺态氮 $CO(NH_2)_2$-N	4.64 ± 0.16ab	4.36 ± 0.21a	3.24 ± 0.16abc
	铵态氮 NH_4^+-N	4.49 ± 0.25bc	4.13 ± 0.13abc	2.99 ± 0.27bcd
	硝态氮 NO_3^--N	4.39 ± 0.29bc	4.17 ± 0.22ab	2.69 ± 0.16d
豫麦 50 Yumai 50	酰胺态氮 $CO(NH_2)_2$-N	4.32 ± 0.12bc	3.88 ± 0.11abcd	3.51 ± 0.12a
	铵态氮 NH_4^+-N	4.12 ± 0.19c	3.85 ± 0.37abcd	3.21 ± 0.13abc
	硝态氮 NO_3^--N	3.73 ± 0.40d	3.55 ± 0.38cd	3.35 ± 0.22ab

2.2.2 对根际土壤蛋白酶活性的影响

表 5 表明,专用小麦品种根际土壤蛋白酶的活性在孕穗期后呈下降趋势,不同专用小麦品种对氮素形态的反应一致。根际土壤中蛋白酶活性在铵态氮处理下最高,硝态氮处理最低,酰胺态氮处理居中。方差分析表明,强筋小麦“豫麦 34”在开花期,铵态氮处理的根际土壤蛋白酶活性显著高于硝态氮处理;中筋小麦“豫麦 49”在孕穗期和开花期,铵态氮处理的根际土壤蛋白酶活性显著高于硝态氮处理;弱筋小麦“豫麦 50”在 3 个测定时期,不同氮素形态处理的根际土壤蛋白酶活性差异均不显著。

表 5 氮素形态对不同专用小麦品种根际土壤蛋白酶活性的影响(NH_2-N μg·g^{-1} dry soil,30 ℃,24 h)

Table 5 Effects of different forms of nitrogen on rhizospheric protease activity of wheat cultivars with specialized end-uses

品种 Cultivars	氮素形态 Nitrogen forms	生育时期 Growth stage		
		孕穗期 Booting stage	开花期 Flowering stage	成熟期 Ripening stage
豫麦 34 Yumai 34	酰胺态氮 $CO(NH_2)_2$-N	8.53 ± 1.16ab	6.13 ± 1.62bc	5.84 ± 1.18ab
	铵态氮 NH_4^+-N	8.66 ± 0.48ab	7.11 ± 0.42ab	6.77 ± 0.78ab
	硝态氮 NO_3^--N	7.07 ± 1.23bc	4.90 ± 1.05c	4.54 ± 0.35b
豫麦 49 Yumai 49	酰胺态氮 $CO(NH_2)_2$-N	9.32 ± 1.46ab	6.39 ± 1.16abc	6.25 ± 0.46ab
	铵态氮 NH_4^+-N	9.64 ± 0.23a	8.49 ± 1.20a	7.82 ± 2.00a
	硝态氮 NO_3^--N	6.01 ± 1.26c	6.20 ± 0.95bc	5.79 ± 0.32ab
豫麦 50 Yumai 50	酰胺态氮 $CO(NH_2)_2$-N	8.30 ± 0.85abc	7.79 ± 0.53ab	6.92 ± 0.23ab
	铵态氮 NH_4^+-N	8.40 ± 1.18ab	8.11 ± 0.90ab	6.92 ± 0.49ab
	硝态氮 NO_3^--N	7.63 ± 1.88abc	6.06 ± 1.24bc	4.94 ± 1.01b

2.2.3 对根际土壤硝酸还原酶活性的影响

由表 6 可见,不同氮素形态处理下,专用小麦品种的根际硝酸还原酶活性在孕穗期后表现出不同趋势。在硝态氮处理下,根际硝酸还原酶活性逐渐下降。而施用酰胺态氮和铵态氮,根际硝酸还原酶活性在孕穗期和成熟期较高,开花期较低。不同专用小麦品种均表现出在硝态氮处理下根际硝酸还原酶活性最高,在酰胺态氮和铵态氮处理下较低。经方差分析,不同专用小麦品种在硝态氮处理下,根际硝酸还原酶活性显著高于酰胺态氮和铵态氮处理,酰胺态氮和铵态氮处理间差异不显著。

表 6　氮素形态对不同专用小麦品种根际土壤硝酸还原酶活性的影响(NO_2^- N μg·g^{-1} dry soil,25 ℃,h)

Table 6　Effects of different forms of nitrogen on rhizospheric nitrate reductase activity of wheat cultivars with specialized end-uses

品种 Cultivars	氮素形态 Nitrogen forms	生育时期 Growth stage		
		孕穗期 Booting stage	开花期 Flowering stage	成熟期 Ripening stage
豫麦 34 Yumai 34	酰胺态氮 $CO(NH_2)_2$-N	0.0069 ± 0.0006c	0.0017 ± 0.0007c	0.0037 ± 0.0008c
	铵态氮 NH_4^+-N	0.0093 ± 0.0015c	0.0019 ± 0.0003c	0.0046 ± 0.0009b
	硝态氮 NO_3^--N	0.0319 ± 0.0009b	0.0158 ± 0.0003b	0.0071 ± 0.0009a
豫麦 49 Yumai 49	酰胺态氮 $CO(NH_2)_2$-N	0.0069 ± 0.0001c	0.0018 ± 0.0005c	0.0022 ± 0.0006d
	铵态氮 NH_4^+-N	0.0063 ± 0.0015c	0.0028 ± 0.0003c	0.0013 ± 0.0006d
	硝态氮 NO_3^--N	0.0362 ± 0.0015ab	0.0182 ± 0.0073a	0.0069 ± 0.0016a
豫麦 50 Yumai 50	酰胺态氮 $CO(NH_2)_2$-N	0.0046 ± 0.0009c	0.0035 ± 0.0006c	0.0030 ± 0.0006c
	铵态氮 NH_4^+-N	0.0052 ± 0.0012c	0.0020 ± 0.0008c	0.0030 ± 0.0007c
	硝态氮 NO_3^--N	0.0416 ± 0.0012a	0.0200 ± 0.0056a	0.0050 ± 0.0018b

2.3　氮素形态对不同专用小麦品种根际土壤 pH 值的影响

从表 7 可以看出,除弱筋小麦“豫麦 50”在硝态氮处理下外,不同专用小麦品种的根际土壤 pH 值在孕穗期后均呈上升趋势,对氮素形态的反应也较一致。在硝态氮处理下根际 pH 值较高,在酰胺态氮和铵态氮处理下较低。经方差分析,在硝态氮处理下,小麦土壤根际 pH 值比酰胺态氮和铵态氮处理的显著升高,而酰胺态氮和铵态氮处理间差异不显著(弱筋小麦“豫麦 50”在孕穗期除外)。

表 7　氮素形态对不同专用小麦品种根际土壤 pH 值的影响

Table 7　Effects of different forms of nitrogen on rhizospheric pH of wheat cultivars with specialized end-uses

品种 Cultivars	氮素形态 Nitrogen forms	生育时期 Growth stage		
		孕穗期 Booting stage	开花期 Flowering stage	成熟期 Ripening stage
豫麦 34 Yumai 34	酰胺态氮 $CO(NH_2)_2$-N	7.63 ± 0.17d	7.96 ± 0.17c	8.18 ± 0.18cd
	铵态氮 NH_4^+-N	7.62 ± 0.11d	7.82 ± 0.12c	8.15 ± 0.12cd
	硝态氮 NO_3^--N	8.38 ± 0.16b	8.64 ± 0.16a	8.43 ± 0.16ab
豫麦 49 Yumai 49	酰胺态氮 $CO(NH_2)_2$-N	7.69 ± 0.32d	8.21 ± 0.34b	8.32 ± 0.34bc
	铵态氮 NH_4^+-N	7.72 ± 0.15d	8.10 ± 0.16bc	8.23 ± 0.16cd
	硝态氮 NO_3^--N	8.60 ± 0.11a	8.66 ± 0.11a	8.60 ± 0.15a
豫麦 50 Yumai 50	酰胺态氮 $CO(NH_2)_2$-N	7.67 ± 0.15d	8.00 ± 0.16c	8.11 ± 0.16d
	铵态氮 NH_4^+-N	8.02 ± 0.15c	8.03 ± 0.14c	8.19 ± 0.16cd
	硝态氮 NO_3^--N	8.59 ± 0.11a	8.52 ± 0.13a	8.56 ± 0.11a

3　结语与讨论

Miah [18]报道,小麦施用缓释氮肥乙二酰二胺,根际 pH、细菌数量比硫酸铵处理上升;而在硫酸铵处理下,真菌数量较高。这说明施用速效或缓效氮肥可影响土壤微生物的数量。本研究分析了酰胺态氮、铵态氮和硝态氮对专用小麦品种根际土壤微生物数量的影响,结果表明,小麦根际土壤微生物的数量对氮素形态的反应也不同。强筋小麦“豫麦 34”在硝态氮处理下,根际真菌、细菌(除成熟期外)和放线菌数量最高;中筋小麦“豫麦 49”在铵态氮处理下,根际细菌和放线菌数量最高,而根际真菌数量在孕穗期和开花期以酰胺态氮处理最大,成熟期时以硝态氮处理最大;弱筋小麦“豫麦 50”在硝态氮处理下,根际真菌、细菌和放线菌数量最高(表 1 ~ 表 3)。真菌能分解土壤中含氮的蛋白质类化合物而释放出氨,细菌在氨化作用过程中起重要作用,放线菌能同化无机氮[16]。因此,专用小麦在适宜的氮素形态处理下,根际微生物数量较大,有利于促进土壤中的氮素转化。根据前人和本试验结果,氮素形态对小麦根际微生物数量影响的原因可能在于:①氮素形态对作物根际的 pH 值有显著的影响,在硝态氮处理下,土壤 pH 值升高,在铵态氮处理下则降低[19, 20]。本研究采用 3 个专用小麦品种为试验材料,也得到同样结论(表 7)。小麦根际 pH 值变化进一步影响了土壤微生物

生长发育[21,22]。②氮素形态本身对微生物生长发育也有一定影响。朱红惠等[23]在室内分别采用含有铵态氮和硝态氮的培养基培养 AM 真菌,发现铵态氮处理虽然没有降低孢子的萌发率,但是能够抑制萌发的 AM 真菌菌丝的生长。刘晓芳等[24]也报道,当以铵态氮为唯一氮源时, 两株黑曲霉 ML2、ML4 均表现出较高的溶磷活性,但当铵态氮和硝态氮同时存在时,其溶磷能力却大幅度下降。③氮素形态对小麦的生长发育有着重要影响[10~14],尤其是影响小麦的根系[25,26]。而土壤微生物的生长活动与根系分泌物、脱落物等有密切关系,根系分泌物提供了根际微生物生长的主要碳源和能源[27]。但某一专用小麦品种在某一氮素形态下根际微生物数量较大的确切原因尚待明确。

Lomas[28]研究表明,在含有铵态氮或尿素的溶液中培养微氏海链藻(*Thalassiosira weissflogii*),其硝酸还原酶活性不足在硝态氮培养液中的 10%;而在含有硝态氮的溶液中培养,其脲酶活性仅有在铵态氮或尿素培养液中的 35%左右。本试验采用不同形态氮素处理专用小麦品种,结果表明,在酰胺态氮处理下,专用小麦的根际脲酶活性最高(表 4);在铵态氮处理下,根际蛋白酶活性最高(表 5);在硝态氮处理下,根际硝酸还原酶活性最高(表 6)。脲酶促进了土壤中含氮有机化合物的转化和尿素的水解,蛋白酶能够分解蛋白质、肽类为氨基酸,硝酸还原酶能酶促硝态氮还原成氨[17],因此,这 3 种土壤酶的活性对土壤中的氮素转化具有重要调节作用。而据王光华等[19]报道,在酰胺态氮处理下,大豆根际硝酸还原酶活性最高,铵态氮处理最低,硝态氮处理居中;在硫酸铵处理下,大豆根际脲酶活性较高。这与本试验的结果不一致,可能与氮素是否配施硝化抑制剂等有关。

土壤微生物的数量和酶活性影响作物的生长发育[2,29],小麦生长发育的壮弱又反过来影响土壤微生物的繁殖和活动以及土壤酶活性的高低[3]。在生产上,如何通过施用不同形态的氮素及其它栽培管理措施,使土壤微生物及酶活性有利于小麦的生长发育以及产量和品质的提高将是进一步研究的问题。

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