不同生态系统土壤氨基酸氮的组成及含量

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摘要：采集于内蒙古白音锡牧场、陕西澄城、杨凌、宜川和太白山等地不同生态系统的 12 个土样，用 6 mol/L HCl 水解，经 H 型酸性阴离子交换树脂柱纯化后，用 Beckman 121 MB 型氨基酸分析仪测定了 17 种常见氨基酸。测定结果表明，不同生态系统土壤酸解氨基酸含量有很大差异，表现为草甸土壤(氨基酸含量为 2283.9μg N/g)＞森林土壤(1733.6μg N/g)＞草原土壤(856.3μg N/g)＞农田土壤(平均为 248.5±37.8μg N/g)，并且氨基酸氮与土壤全氮有极显著的正相关关系($p<0.01$)；在氨基酸中以中性氨基酸所占比例最大，平均为 53.99%，其次为碱性和酸性氨基酸，分别为 24.94%和 20.59%，含硫氨基酸最少，仅为 0.48%。游离氨基酸以草甸土壤最高，为 14.58μg N/g，其它土壤在 1.14～8.67μg N/g 之间，大部分在 2～3μg N/g。游离氨基酸不仅数量低，而且种类也比酸解氨基酸少。不管是酸解氨基酸，还是游离氨基酸，在 0～20 cm 土层的含量均大于 20～40 cm 土层，从不同土壤样品的平均结果看，对酸解氨基酸，0～20 cm 土层为 960.9μg N/g，20～40 cm 土层为 528.9μg N/g；对游离氨基酸氮，0～20 cm 土层 6.28μg N/g，20～40 cm 土层 2.22μg N/g。施用氮肥能够增加土壤中酸解氨基酸和游离氨基酸的含量。酸解氨基酸氮与土壤微生物体氮和可矿化氮有密切正相关关系，相关系数分别为 0.888($p<0.01$)和 0.580($p<0.05$)，表明土壤酸解氨基酸在土壤氮素供应和稳定不同生态系统土壤生产力上起有重要作用。

关键词：生态系统；土壤；氨基酸

Constituent and Amount of Amino Acid in Different Ecological System Soils

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Abstract: The twelve soil samples used in the experiment were collected from Baiyin Xi, Inner Mongolia, Taibai Mountains, Chengcheng, Yichuan, and Yangling, Shaanxi, representing different ecological systems, such as pasture, forest, meadow and arable lands. The air-dried soils were hydrolyzed with 6 mol/L HCl for 20h. After the hydrolysates were purified with the column of H-type acidic anion exchangeable resin, seventeen amino acids were determined on Beckman 121 MB amino-acid analyzer. The results show that the amounts of acidic hydrolyzable amino acids varied significantly among the soils in different ecological systems with 2283.9μg N/g in meadow soil, 1 733.6μg N/g in forest soil, 856.3μg N/g in steppe soil and 248.5±37.8μg N/g in arable soil, respectively. There was a very significant positive correlation between hydrolyzable amino acid and total nitrogen (significant at $p=0.01$). The amount of lysine, glycine, aspartic acid and alanine was higher among seventeen amino acids. These four amino acid nitrogen accounted for 45.5% of total amino acid nitrogen. The content of cysteine, methionine, tyrosine, phenylalanine,

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isoleucine, proline and serine was lower, accounted for 16.13% of total amino acid nitrogen, other amino acids, such as glutamic acid, arginine, valine, threonine, leucine and histidine was medium, constituted 38.39% of total amino acid nitrogen. A little of cysteine was found in forest soil, pasture soil and meadow soil, while it was undetected in arable soils. In the four kinds of acidic hydrolyzable amino acids, neutral amino acid nitrogen, basic amino acid nitrogen, acidic amino acid nitrogen and sulfur - containing amino acid nitrogen accounted for 53.99%, 24.94%, 20.59% and 0.48% of total amino acid nitrogen, respectively. Free amino acid content was higher in meadow soil (14.58μg N/g), and it ranged from 1.14μg N/g to 8.67μg N/g in other soils. Most of soils had 2～3μg N/g. The results indicated that not only the amount of the free amino acid was lower, but also the kind of the free amino acid was fewer compared with acidic hydrolyzable amino acid. Only 4～6 kinds of free amino acid were detected in most of soils. The amount of glutamic acid was the highest among free amino acid with a average of 1.58 μg N/g, and aspartic acid followed with a average of 0.66μg N/g. The amount of free acidic amino acid, free neutral amino acid and free basic amino acid was 2.24μg N/g, 1.67 μg N/g and 0.42μg N/g, and their percentage to total amount free amino acid was 51.8%, 38.6% and 9.6%, respectively. The free sulfur-containing amino acid was not detected in any soil, and the successive order about four kinds of free amino acid was not similar with acidic hydrolyzable amino acid.

Both of acidic hydrolyzable amino acid and free amino acid content in 0～20cm layer were higher than that in 20～40cm layer. The average content of amount of acidic hydrolyzable amino acid of all soil samples in 0～20cm layer and 20～40cm layer was 960.9μg N/g and 528.9μg N/g, respectively, and free amino acid in corresponding layer was 6.28μg N/g and 2.22μg N/g, respectively. After continuous supplying of nitrogen fertilizer, acidic hydrolyzable amino acid increased 16.3μg N/g for red manual loessial soil and 56.6μg N/g for manual loessial soil, respectively, compared to no application of nitrogen fertilizer. The increased amino acid was mainly neutral amino acid in red loessial soil and mainly basic amino acid in manual loessial soil, indicating that the effect of nitrogen fertilizer on the acidic hydrolyzable amino acid of different soils was not same. Application of nitrogen fertilizer increased the percentage of acidic hydrolyzable amino acid to total nitrogen in soil compared with no application of nitrogen fertilizer, but the difference was small (average 1.85%). Free amino acid content in soils with nitrogen fertilizer applied was increased by 3.28μg N/g, compared to that of soils without application of nitrogen fertilizer. These facts indicated that the nitrogen fertilizer played an important role on increasing and stabilizing acidic hydrolyzable and free amino acids.

The content of amino acid is one important indicator of soil fertility. The results of investigation showed that acidic hydrolyzable amino acids had a good correlation not only soil microbial biomass nitrogen ($r=0.888$, significant at $p=0.01$), but also with mineralizable nitrogen in soil ($r=0.580$, significant at $p=0.05$). The facts suggested the amino acid play an important role in nitrogen supply capacity and stabilizing productivity of soil in different ecological system.

Key words: ecological system; soil; amino acid

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大多数表层土壤中 90% 以上的氮为有机化合物[1]。土壤有机氮的形态复杂,Bremner[2]用 6 mol/L 的盐酸,在加热回流(或密闭)条件下,酸解土壤 12～24h 后,把土壤有机氮分为酸解性氮和非酸解性氮,酸解性氮进一步鉴定为氨基酸氮、氨基糖氮、氨态氮和未知氮。氨基酸氮占土壤全氮的 30%～45%[1],是主要的水解产物。氨基酸氮主要存在于土壤有机质中的蛋白质和多肽[1,3],它的组成和含量直接影响着土壤氮素的供应状况[4]。国外学者在土壤氨基酸的研究方面已做了不少工作[1],而国内研究大多数着重于氨基酸氮

在土壤有机氮组成中的比例[4~7],并未进一步鉴定其种类及含量。本研究采取不同生态系统的土壤样品,以研究土壤氨基酸的组成及含量。

1　材料和方法

1.1　供试土样

供试土样分别采集于内蒙古白音锡牧场、陕西澄城、杨陵、宜川和太白山等地,共 12 个土样(表 1)。

表 1　不同生态系统土壤的基本化学性质

Table 1　Some chemical properties of soils in different ecological systems

土壤编号 Soil No	土类 Soil type	土层 Layer (cm)	植被或前作 Vegetation or pre-crops	有机碳 (g/kg) Organic C	全氮 (g/kg) Total N	C/N Ratio	pH (H_2O)
1	暗栗钙土①	0~20	草原(内蒙古中国科学院白	19.16	2.20	8.71	7.35
2	暗栗钙土	20~40	音锡牧场试验站)⑦	7.81	0.92	8.49	7.76
3	暗棕壤②	0~20	阔针叶混交林(太白山)⑧	45.00	4.37	10.30	5.42
4	暗棕壤	20~40	阔针叶混交林(太白山)	18.17	2.08	8.74	5.75
5	高山草甸土③	0~20	草甸(太白山)⑨	74.32	5.91	12.58	6.37
6	红垆土④	0~20	小麦(5a 不施 N)⑩	5.88	0.76	7.73	7.62
7	红垆土	0~20	小麦(5a 连续 N)⑪	5.96	0.80	7.45	7.80
8	黄绵土⑤	0~20	小麦(陕北宜川)(12)	5.34	0.71	7.52	7.74
9	红油土⑥	0~20	玉米(连续 6a 不施 N)⑬	6.81	0.95	7.16	7.76
10	红油土	0~20	玉米(连续 6a 施 N)⑭	7.04	1.00	7.06	7.67
11	红油土	20~40	玉米⑮	4.95	0.69	7.14	7.82
12	红油土	0~20	大豆⑯	9.24	1.37	6.74	7.51

* 红垆土采集陕西澄城县;红油土采集陕西杨凌;0~20cm 土层与 20~40cm 在相同采样点采取 Red manual loessial soil was sampled from Chengcheng, Shaanxi, and manual loessial soil was sampled from Yangling, Shaanxi; Soil samples of 0~20cm layer and 20~40cm layer were collected from same sampling point. ① Dark chestnut; ② Dark brown earth; ③ high mountain meadow soil; ④ Red manual loessial soil; ⑤ Loessial soil ⑥ Manual loessial soil; ⑦ Pasture for grazing, soil sample was collected from Baiyin Xi, Inner Mongolia; ⑧ Forest, soil sample was collected from Taibai mountains; ⑨ Meadow, soil sample was collected from Taibai mountains; ⑩ Wheat, no applying nitrogen fertilizer continuously 5 years; ⑪ Wheat, applying nitrogen fertilizer continuously 5 years; ⑫ Wheat; ⑬ Maize, no applying nitrogen fertilizer continuously 6 years; ⑭ Maize, applying N nitrogen fertilizer continuously 6 years; ⑮ Maize; ⑯ Soybean.

1.2　土壤化学分析和氨基酸的测定

(1)土样采回后,立即检去植株根系,风干,过 1mm 筛孔;充分混匀后,部分土样进一步研细,过 0.25mm 筛孔,分别用作测定土壤基本性质、氨基酸、微生物体氮和可矿化氮。

(2)土壤酸解氨基酸氮　土壤用 6 mol/L HCl,在 110℃ 下封管水解 20h 后取出冷却[8],将水解液过滤到蒸发皿中,并用少量蒸馏水多次淋洗残渣,随后,在水浴锅(40~50℃)上干燥滤液,干燥后的残留物用 2~3 ml 去离子水溶解,蒸干。如此重复进行 2~3 次,使 HCl 完全挥发,最后一次蒸干后,用 pH2.2 的缓冲液溶解定容后,经 H 型酸性阴离子交换树脂柱纯化,用 Beckman 121 MB 型氨基酸分析仪测定各种氨基酸的含量[8]。

(3)土壤游离氨基酸　游离氨基酸用蒸馏水(土∶液=1∶5,振荡 0.5h)浸取,过滤后,将滤液按上法干燥(只进行 1 次),溶解,纯化后,检测各种氨基酸氨。

(4)土壤化学和生物性质　有机碳用 $K_2Cr_2O_7$ 外加热容量法[9],全氮用半微量开氏法[10],pH 值用玻璃电极法(土∶0.01 mol/L $CaCl_2$=1∶2)[11];土壤可矿化氮用 2 周淋洗通气培养法[12],土壤微生物体氮用改进的熏蒸-淹水培养法[13]。

2　试验结果

2.1　不同生态系统土壤酸解氨基酸的分布规律

土壤酸解产物中主要可简别的含氮化合物是氨基酸氮,一般占土壤全氮含量的30%～45%[1]。在进行测定的12个土样中(表2),酸解氨基酸氮含量变化在195.1～2283.9μg N/g,平均671.4±685.8 μg N/g,并与土壤全氮($X_{T.N}$)同步增高,二者之间的回归方程为$Y_{AA\text{-}N}=-68.59+0.408X_{T.N}$($r=0.992$,$p<0.01$),占土壤全氮含量的25.67%～48.18%,平均34.24%±4.2%,酸解氨基酸氮含量的变异程度($C.V=102.1\%$)远比与全氮比值的变异性($C.V=21.1\%$)大。总体上看,自然土壤中的酸解氨基酸含量远大于农田土壤,在自然土壤中,以草甸土壤最大,为2283.9μg N/g,森林土壤次之,为1733.6μg N/g,草原土壤最小,为856.3μg N/g;农田土壤平均仅为248.5±37.8μg N/g。在自然土壤中酸解氨基酸氮不仅含量高,而且与全氮的比例也较农用土壤大,前者平均为40.8%±4.2%($n=5$),后者仅为29.6%±4.8%($n=7$)。

表2 不同生态系统土壤酸解氨基酸的含量(μN/g)

Table 2 Amounts of acidic hydrolyzable amino acids of soils in different ecological systems

氨基酸 Amino acids	土样 Soil samples													
	1	2	3	4	5	6	7	8	9	10	11	12	∑ Total	平均 Mean
酸性氨基酸①														
天冬氨酸②	110.2	48.7	175.2	62.3	263.5	24.9	25.9	25.8	33.8	35.8	27.7	57.9	891.7	74.3
谷氨酸③	74.6	30.3	122.9	40.1	204.0	19.0	20.0	32.8	24.6	27.0	22.1	33.7	651.1	54.3
总和④	184.8	79.0	298.1	102.4	467.5	43.9	45.9	58.6	58.4	62.8	49.8	91.6	542.8	128.6
碱性氨基酸⑤														
赖氨酸⑥	83.1	31.2	305.4	63.5	224.9	25.5	23.7	26.3	27.0	47.9	36.3	34.0	928.8	77.4
组氨酸⑦	36.0	13.8	51.2	26.1	91.8	10.6	9.4	10.6	8.6	14.3	11.0	12.5	395.5	33.0
精氨酸⑧	66.9	20.7	122.0	27.3	163.7	15.1	18.7	20.0	20.4	27.3	20.1	22.0	544.2	43.4
总和	186.0	65.7	578.6	116.9	480.4	51.2	51.8	56.9	56.0	89.5	67.4	68.5	1868.9	155.7
中性氨基酸⑨														
苏氨酸⑩	50.6	20.9	92.2	25.6	153.4	9.0	9.8	12.5	13.6	12.6	10.5	15.8	426.5	35.5
丝氨酸⑪	43.5	16.5	79.9	20.0	135.7	6.6	6.9	14.3	10.0	10.7	7.8	13.2	365.1	30.4
脯氨酸⑫	30.6	12.8	77.8	17.6	115.0	8.1	10.6	8.0	16.9	16.0	11.2	27.4	352.0	29.3
甘氨酸⑬	103.7	43.2	173.5	62.7	293.3	24.6	26.6	35.0	33.6	34.2	27.9	45.1	903.4	75.3
丙氨酸⑭	74.6	27.8	144.1	39.9	230.2	16.8	17.8	31.5	23.4	23.9	19.4	35.5	684.7	57.1
缬氨酸⑮	70.0	21.7	91.5	17.3	145.5	12.6	17.0	15.1	10.1	12.8	11.5	28.5	453.6	37.8
异亮氨酸⑯	29.5	11.3	47.0	8.87	1.3	9.0	5.8	11.8	7.1	7.6	10.3	12.1	231.6	15.3
亮氨酸⑰	50.1	40.4	83.5	18.1	114.3	12.8	11.9	18.0	14.1	14.9	12.8	22.1	413.0	34.4
酪氨酸⑱	6.2	3.82	4.2	2.42	2.2	1.1	1.2	2.9	0.4	0.3	0.3	0.5	65.5	5.5
苯丙氨酸⑲	19.9	6.73	5.6	7.8	47.7	3.8	4.6	6.1	5.5	5.6	5.0	8.0	156.3	13.0
总和	478.7	205.3	849.3	220.2	1328.6	104.4	112.2	155.2	134.7	138.6	112.2	205.0	4047.4	337.3
含硫氨基酸⑳														
胱氨酸㉑	4.6	0.2	4.1	0.3	3.0	tr	tr	tr	tr	tr	tr	tr	12.2	1.0
蛋氨酸㉒	2.7	3.0	3.5	1.7	4.4	2.7	1.2	0.9	1.7	1.5	1.9	1.8	27.0	2.3
总和	7.3	3.2	7.6	2.0	7.4	2.7	1.2	0.9	1.7	1.5	1.9	1.8	39.2	3.3
氨基酸氮总量㉓	856.8	353.2	1733.6	1022.2	2283.9	195.1	211.4	271.6	250.8	292.4	231.3	269.9		

① Acidic amino acid; ② Aspartic acid; ③ Glutamic acid; ④ Total; ⑤ Basic amino acid; ⑥ Lysine; ⑦ Histidine; ⑧ Arginine; ⑨ Neutral amino acid; ⑩ Threonine; ⑪ Serine; ⑫ Proline; ⑬ Glycine; ⑭ Alanine; ⑮ Valine; ⑯ Isoleucine; ⑰ Leucine; ⑱ Tyrosine; ⑲ Phenylalanine; ⑳ Sulfur-containing amino acid; ㉑ Cysterine; ㉒ Methionine; ㉓ Total amounts of amino acids

不管什么土壤,在17种酸解氨基酸中,以赖氨酸、甘氨酸、天冬氨酸和丙氨酸所占比例较大(表2),4者共占酸解氨基酸总氮的45.5%;而胱氨酸、蛋氨酸、酪氨酸、苯丙氨酸、异亮氨酸、脯氨酸、丝氨酸所占比

例较低,7 种共占酸解氨基酸总氮的 16.13%,其余 6 种酸解氨基酸,如谷氨酸、精氨酸、缬氨酸、苏氨酸、亮氨酸和组氨酸居中,共占酸解氨基酸总氮的 38.39%。在森林、草原和草甸土壤中,含有少量的胱氨酸,但在农田土壤中未检测出。不同酸解氨基酸含量的顺序与 Khan & Sowden[14]在寒温带的研究结果一致,优势的酸解氨基酸似乎是微生物细胞中的主要氨基酸。

如果按照 Campbell 等[15]把氨基酸分为酸性、碱性、中性和含硫氨基酸 4 类的话(表 3),在这四类酸解氨基酸中,中性氨基酸所占比例最大,平均为 53.99%,其次为碱性和酸性氨基酸,分别为 24.94%和 20.59%,含硫氨基酸最小,仅为 0.48%.

表 3　四类酸解氨基酸氮的含量(12 个土样平均)

Table 3　Amounts of four kinds of acidic hydrolyzable amino acids (Average amounts of 14 soil samples)

项目 Terms	酸性氨基酸 Acidic amino acid	碱性氨基酸 Basic amino acid	中性氨基酸 Neutral amino acid	含硫氨基酸 Sulfur-containing amino acid
平均含量(μg N/g)①	128.6	155.7	337.3	3.3
标准差(μg N/g)②	129.9	179.9	379.2	2.6
变异系数(%)③	101.1	115.5	112.4	76.7
占氨基酸总量的%④	20.58	24.92	53.98	0.52
占土壤全氮的%⑤	7.09	8.59	18.60	0.19

① Average amounts of four kinds of amino acids; ② Standard deviations; ③ Variation coefficients; ④ The percentage of average amount of every kinds of amino acids to total amount of amino acids; ⑤The percentage of average amount of every kinds of amino acids to total soil nitrogen

2.2　土壤中酸解氨基酸的层次分布规律

不同土层,酸解氨基酸氮的含量也有差别(表 2)。从含量上看,不管草原土壤(土壤 1 和 2)、森林土壤(3 和 4),还是农田土壤(10 和 11),0~20cm 土层酸解氨基酸氮的总量均显著高于 20~40 cm 土层,从 3 种土壤平均看,0~20 cm 土层酸解氨基酸氮为 960.9 μg N/g,20~40 cm 土层为 528.9 μg N/g,这种差异与全氮的分布规律一致;从与土壤全氮比例看,草原土壤 0~20 cm 和 20~40 cm 土层基本一致,分别为 38.95% 和 38.39%,而对森林土壤和农田土壤,0~20 cm 土层远低于 20~40 cm 土层,森林土壤相差 8.51%,农田土壤相差 4.7%,造成这一差异的原因似与草原土壤有深厚的土壤腐殖层有关,这仍需今后进一步研究。

2.3　不同生态系统土壤游离氨基酸的分布规律

游离氨基酸主要在于土壤溶液和孔隙中[3],来源于根系、土壤微生物分泌物和土壤中各种有机物质的降解产物。不同土壤类型,其含量不同(表 4),以高山草甸土最高,为 14.58μg N/g,以连续 5a 不施氮肥红垆土、20~40cm 的暗棕壤和黄绵土最低,分别为 1.14,1.42 和 1.71μg N/g,其它土壤均在 2μg/g 以上。高山草甸土最高,可能与有较多的有机质含量及根系和土壤微生物分泌的氨基酸在土壤中累积,气温低而未分解有关。

一般认为,土壤中游离氨酸氮在耕层很少超过 2μg N/g[1],可检测到的种类也较少[16]。测定表明,游离氨基酸不仅数量少,而且在种类上也低于酸解氨基酸(表 2 和表 4),种类最多的土壤是 5 号和 10 号,共检测到 9 种,大多数土壤只检测到 4~6 种,少者,如 6 号和 7 号土样,只有 2 种,所有土壤均检测到了酸性的谷氨酸,有 11 个土壤检测到了中性的甘氨酸,有 9 个土壤检测到了酸性的天冬氨酸,12 个土样中只有 1 个土样检测到脯氨酸,缬氨酸、胱氨酸、蛋氨酸、异亮氨酸、苯丙氨酸和精氨酸没有一个土样能够检测出,其余氨基酸,如苏氨酸、丝氨酸、亮氨酸、组氨酸和赖氨酸,在 12 个土样中有 2~8 个土样能够检测出,如果列成顺序则为谷氨酸(12/12,检出土样/全部土样)、甘氨酸(11/12)、天冬氨酸(9/12)、苏氨酸(7/12)、丝氨酸(7/12)、丙氨酸(3/12)、赖氨酸(3/12)、亮氨酸(2/12)、缬氨酸(11/12)、组氨酸(11/12)、脯氨酸(1/12)、胱氨酸(0/12)、蛋氨酸(0/12)、异亮氨酸(0/12)、酪氨酸(0/12)、苯丙氨酸(0/12)和精氨酸(0/12)。土壤层次和施肥对游离氨基酸种类似无影响。

表4 不同生态系统土壤中游离氨酸氮的含量(μg N/g)

Table 4 Some chemical properties of soils in different ecological systems

氨基酸 Amino acids	土样 Soil samples													
	1	2	3	4	5	6	7	8	9	10	11	12	∑ Total	平均 Mean
酸性氨基酸①														
天冬氨酸②	1.05	0.28	0.88	0.34	3.30	tr	tr	0.27	0.68	0.60	tr	0.51	7.91	0.66
谷氨酸③	3.19	1.46	1.09	0.44	3.95	0.99	1.75	1.01	1.27	2.04	0.61	1.20	19.0	1.58
总和④	4.24	1.74	1.97	0.78	7.25	0.99	1.75	1.28	1.95	2.64	0.61	1.71	26.91	2.24
碱性氨基酸⑤														
赖氨酸⑥	tr	tr	tr	tr	0.66	tr	tr	tr	tr	0.67	1.07	tr	2.40	0.20
组氨酸⑦	tr	tr	tr	tr	tr	tr	tr	tr	tr	1.94	0.64	tr	2.58	0.22
精氨酸⑧	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr
总和	—	—	—	—	0.66	—	—	—	—	2.61	1.71	—	4.98	0.42
中性氨基酸⑨														
苏氨酸⑩	1.87	0.30	0.23	tr	0.45	tr	tr	tr	0.20	1.04	tr	0.65	5.16	0.43
丝氨酸⑪	0.31	0.21	0.28	tr	2.39	tr	0.97	tr	0.63	0.62	tr	tr	5.41	0.45
脯氨酸⑫	tr	tr	tr	tr	1.96	tr	tr	tr	tr	tr	tr	tr	1.96	0.16
甘氨酸⑬	0.43	0.43	0.41	0.32	0.86	0.15	tr	0.27	0.50	0.65	0.24	0.27	4.53	0.38
丙氨酸⑭	tr	tr	0.24	0.32	0.79	tr	tr	tr	tr	0.40	tr	tr	1.93	0.16
缬氨酸⑮	tr	tr	tr	tr	tr	tr	tr	tr	tr	0.71	tr	tr	0.71	0.06
异亮氨酸⑯	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	—	—
亮氨酸⑰	tr	tr	tr	tr	0.22	tr	tr	0.16	tr	tr	tr	tr	0.38	0.03
酪氨酸⑱	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	—	—
苯丙氨酸⑲	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	—	—
总和	2.61	0.94	1.34	0.64	6.67	0.15	0.97	0.43	1.75	3.24	0.24	0.92	20.08	1.67
含硫氨基酸⑳														
胱氨酸㉑	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	—	—
蛋氨酸㉒	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	—	—
氨基酸氮总量㉓	6.28	2.68	3.31	1.42	14.58	1.14	2.72	1.71	3.70	8.67	2.53	2.63	51.97	4.33

① Acidic amino acid; ② Aspartic acid; ③ Glutamic acid; ④ Total; ⑤ Basic amino acid; ⑥ Lysine; ⑦ Histidine; ⑧ Arginine; ⑨ Neutral amino acid; ⑩ Threonine; ⑪ Serine; ⑫ Proline; ⑬ Glycine; ⑭ Alanine; ⑮ Valine; ⑯ Isoleucine; ⑰ Leucine; ⑱ Tyrosine; ⑲ Phenylalanine; ⑳ Sulfur-containing amino acid; ㉑ Cysterine; ㉒ Methionine; ㉓ Total amounts of amino acids

土壤中游离氨基酸氮含量最高的谷氨酸,平均1.58μg N/g,次为天冬氨酸,平均0.66μg N/g。酸性游离氨基酸含量最高,平均2.24μg N/g,占游离总氨基酸氮的51.8%,次为中性游离氨基酸和碱性游离氨基酸,分别为1.67μg N/g和0.42μg N/g,占游离总氨基酸氮的38.6%和9.6%,含硫游离氨基酸最少,供试土样均未检测出,这一次序与酸解氨基酸不同。

不同土层,游离氨基酸含量不同,0~20 cm土层均大于20~40 cm土层,0~20 cm平均6.28μg N /g,20~40 cm平均2.22μg N /g,施用氮肥后,也会显著增加游离氨基酸含量(施用氮肥比不施用氮肥土壤平均增加3.28μg N /g),这种差异可能与0~20 cm土层根系和微生物活动强烈,含有氨基酸的分泌物较多有关,施氮后,增加了根系活性和生物量,从而分泌的氨基酸也相应增加。

3 讨论

过去进行的研究表明,气候条件和耕作制度是影响土壤酸解氨基酸组成和含量的主要因子,如在分解强烈的热带地区土壤中,由于碱性氨基酸容易与土壤中其它成分相结合,而生物分解性降低,因此相对含

量较高[17]。在测定的 17 种酸解氨基酸中，以碱性氨基酸中的赖氨酸含量最高，平均含量 77.4μg N /g，而其余几种碱性氨基酸的含量居于中间位置；另一方面，由于中性氨基酸种类多，其总量也最高。产生这一现象的原因可能与我们所用的供试土样采取于温带地区，氨基酸含量最高的暗棕壤和草甸土壤分别采集于寒冷的太白山中部和山顶，碱性氨基酸的生物分解性相对较高，其含量相对比热带地区土壤低，这一研究结果与 Sowden 等[18]的研究结果基本一致。

施用肥料是影响酸解氨基酸的又一因子。Allen 等[19]用 ^{15}N 示踪法研究表明，施氮后，土壤腐殖质中氨基酸氮所占全氮比例增加，王岩等[20]的研究表明，残留化学氮肥有一部分转化为氨基酸氮，张旭东等[21]的研究表明，有机肥料也能明显增加土壤中氨基酸氮的含量，而许春霞[4]的研究表明，施用尿素，会使氨基酸降低。研究表明，施用氮肥对氨基酸也有一定影响（表 2）。多年施用氮肥土壤比不施用氮肥土壤酸解氨基酸氮有所增加，红垆土（6 号和 7 号土壤）增加 16.3 μg N/g，红油土（9 号和 10 号土壤）增加 56.6 μg N/g。对红垆土主要增加的是中性氨基酸，而对红油土，主要增加的是碱性氨基酸，看来对不同土壤，施用氮肥对酸解氨基酸种类的影响也不同。施用氮肥后 2 种土壤氨基酸氮所占全氮的比例也有增加，但幅度不大，施用氮肥与不施用氮肥的对照平均相差 1.85%，表明施用氮肥对提高或稳定酸解氨基酸氮库具有重要作用。

氨基酸含量的高低是土壤肥力水平的重要标志之一[4,15]。研究表明，酸解氨基酸氮不仅与土壤微生物体氮[22]间有密切的正相关关系，相关系数为 0.888($p<0.01$)，对土壤微生物体氮的贡献可给出 78.9%的解释，而且也与土壤可矿化氮（未发表资料）间存在着正相性，相关系数为 0.580($p<0.05$)，对可矿化氮的贡献可给出 33.6%的解释。土壤微生物体氮与微生物量密切相关[23]，转化快，对土壤供氮有重要意义[24]；土壤可矿化氮反映着土壤中易矿化有机氮的多少。这些事实说明土壤酸解氨基酸氮在土壤氮素供应和稳定不同生态系统生产力上起有重要作用。

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