

农田土壤剖面反硝化活性及其影响因素的研究^①

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摘 要

用培育法研究了我国3种农田土壤剖面各层土壤的反硝化活性及其影响因素。结果表明,潮土剖面各层土壤中以0~20cm土壤的反硝化活性为最高,培育20天时的反硝化活性达到49%,而下层土壤的反硝化活性,除52~65cm土层外,则都很低;加葡萄糖或肥土清液,明显地提高了各层土壤的反硝化活性,且以前者的作用更大些,但加磷则无此作用。

黄泥土(中等肥力)剖面中各层土壤的反硝化活性,也以0~20cm土壤为最高。培育20天时的反硝化活性达到74%,随剖面深度的加深,反硝化活性逐渐减小。加葡萄糖和肥土清液对表土的反硝化活性没有明显的影响,却明显地提高了40~100cm各层土壤的反硝化活性。但加磷对各层土壤的反硝化活性则都无明显的影响。

红壤(花生地)剖面中各层土壤的反硝化活性都极低。加葡萄糖或肥土清液能提高表土的反硝化活性,但对其下各层土壤的反硝化活性却没有影响。加磷未能提高各层土壤的反硝化活性。

相关分析表明,培育20天土壤反硝化活性与土壤有机质含量呈极显著的正相关($r = 0.827^{**}$),而与土壤速效磷含量和土壤pH无此相关性。

关键词 农田土壤 反硝化活性 影响因素

反硝化作用是土壤氮素循环中的重要一环,它直接关系到化肥氮的损失和污染环境,因而成为土壤氮素研究者关心的一个重要问题。以往,许多研究者对土壤反硝化与土壤基本性质、碳源、水分等因素之间的关系已作了很多研究^[1,2],但研究的供试土壤一般都是表层土壤,而在田间条件下,土壤剖面各层中都可能进行反硝化作用。因此,对整个剖面层次土壤的反硝化活性进行研究,将有助于明确土壤反硝化作用发生的主要层次。本试验选择了我国三个重要农作区的三个代表性剖面,对其各层土壤的反硝化活性及主要影响因素作了比较研究。

一、材料与方 法

(一)供试土壤 3种类型土壤(0~100cm)剖面样品分别采自河南封丘中国科学院封丘生态站的小麦地,江苏常熟小麦地和江西鹰潭中国科学院鹰潭生态试验站的花生地。土壤的基本性质见表1。

(二)土壤反硝化活性的测定方法(¹⁵N示踪—气体通量法) 称取供试土壤20g于250mL三角瓶中,加入5mLK¹⁵NO₃(N, 1mg/mL),其¹⁵N丰度为54.98%。设4个处理:(1)对照,加入蒸馏水25mL;(2)加磷处理,加入2mLKH₂PO₄

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表 1 潮土、黄泥土、红壤剖面各层土壤的基本性质
Table 1 Basic properties of selected soils

采样地点 Site	土壤类型 Soil	剖面深度 Layer (cm)	pH值	有机质 OM (g/kg)	全氮 Tot. N (g/kg)	速效磷 Avai. P (P, mg/kg)
河南封丘	潮土	0~20	8.8	6.4	0.45	8
		20~32	8.9	2.6	0.33	4
		32~52	8.9	5.3	0.56	3
		52~65	9.0	5.3	0.52	5
		65~85	9.1	3.3	0.53	6
		85~100	9.1	1.9	0.36	8
江苏常熟	黄泥土	0~20cm	6.52	31.9	1.74	4.8
		20~40cm	7.40	19.9	0.97	3.6
		40~60cm	7.51	11.7	0.71	2.2
		60~80cm	7.58	9.1	0.52	1.8
		80~100cm	7.62	8.8	0.50	1.8
江西鹰潭	红壤	0~20cm	4.9	10.6	0.64	3.3
		20~60cm	5.0	4.5	0.35	0.8
		60~100cm	5.2	3.6	0.29	0.6

溶液(P, 1mg/mL)和23mL蒸馏水;(3)加葡萄糖处理,加入2mL葡萄糖溶液(C, 5mg/mL)和23mL蒸馏水;(4)加高肥土壤上清液处理,加入黄泥土(高肥)溶液的上清液(水:土=2:1)5mL和20mL蒸馏水。测定潮土剖面各层土壤反硝化活性时各处理均重复3次,黄泥土(中等肥力)和红壤(花生地)剖面各层土壤各处理均重复2次。三角瓶口用橡皮塞封口,瓶塞周围用704胶密封。橡皮塞中间打一小洞,内插玻璃管,管外再套一段细的硅橡胶管,其口用硅橡胶塞封口,供取气样用。从取样口将三角瓶抽成真空,通入氮气,再抽真空,如此反复3次,然后通入1个大气压的高纯氮,最后将取样口用704胶密封,放入培养箱中,32℃±1℃温度下培育。分别于培育2、5、9、14、20天时采气样,并将气样注入抽成真空的储气小瓶(容积为12mL)中,瓶口用704胶密封。每次取样后,三角瓶与试验初期一样,抽成真空,通入1个大气压的纯氮,反复3次,继续培养。采集的气样在本所Finnigan MAT 251质谱仪上测定反硝化产生的¹⁵N₂和¹⁵N₂O气体的¹⁵N丰度,并计得反硝化量^[3]。以产生的反硝化气体N量(¹⁵N₂O + ¹⁵N₂)占加入¹⁵N肥料量的百分数(反硝化率)作为土壤反硝化活性的量度。

二、结果与讨论

(一)潮土

表2的结果表明,对照处理在培育20天时,以表层土壤的反硝化活性为最高(反硝化率为49.3%),以下各层土壤都较低。表层土壤反硝化率与下层土壤的反硝化率的差异达1%水平,但是表层以下各层土壤的反硝化率之间的差异则未达到5%显著水准。表层土壤的反硝化活性之所以比较高,可能与其有机质含量较高有关。加葡萄糖后培育20天时各层土壤的反硝化率都显著高于对照,虽然仍以表层土壤的反硝化率为最高,但是,加葡萄糖对下层土壤反硝化率提高的程度则大于表层,各层土壤的反硝化率趋于接近。例如20~32cm和85~100cm这两层土壤的反硝化率分别达到69.1%和62.9%,为对照处理的8~11倍,而表层土壤只达到88.0%为对照的近一倍。加磷对各层土壤在培育20天时的反硝化率都无明显的影响。加入肥土清液后,各层土壤的反硝化率都有明显的提高,但其提高的程度不如加葡萄糖的大。各土层相比,仍然以表层土壤的反硝化率为最高。

表 2 潮土剖面中各层土壤不同处理的反硝化活性¹⁾(培养20天后测定)
Table 2 Denitrification potential (DP) in the soil profile of upland fluvo-aquic soil with different treatments (incubation 20 days)

土层深度 Layer (cm)	对照 CK	加葡萄糖 + glu.	加磷 + P	接种肥土清液 + clear solution of fertile soil
0~20	49.3aA	88.0aA	31.2aA	72.9aA
20~32	8.3bB	69.1bB	6.7cC	32.8bcB
32~52	11.3bB	66.4bB	15.6bB	41.4bB
52~65	20.7bB	68.6bB	12.3bB	27.6cB
65~85	6.2bB	45.9cC	6.1cC	39.2bB
85~100	5.7bB	62.9bBc	4.5cC	38.6bB

1)反硝化活性(DP)=(¹⁵N₂+¹⁵N₂O)-¹⁵N量/加入¹⁵N量×100%.

The ratio of denitrification product (¹⁵N₂+¹⁵N₂O)-¹⁵N to addition of N fertilizer -¹⁵N

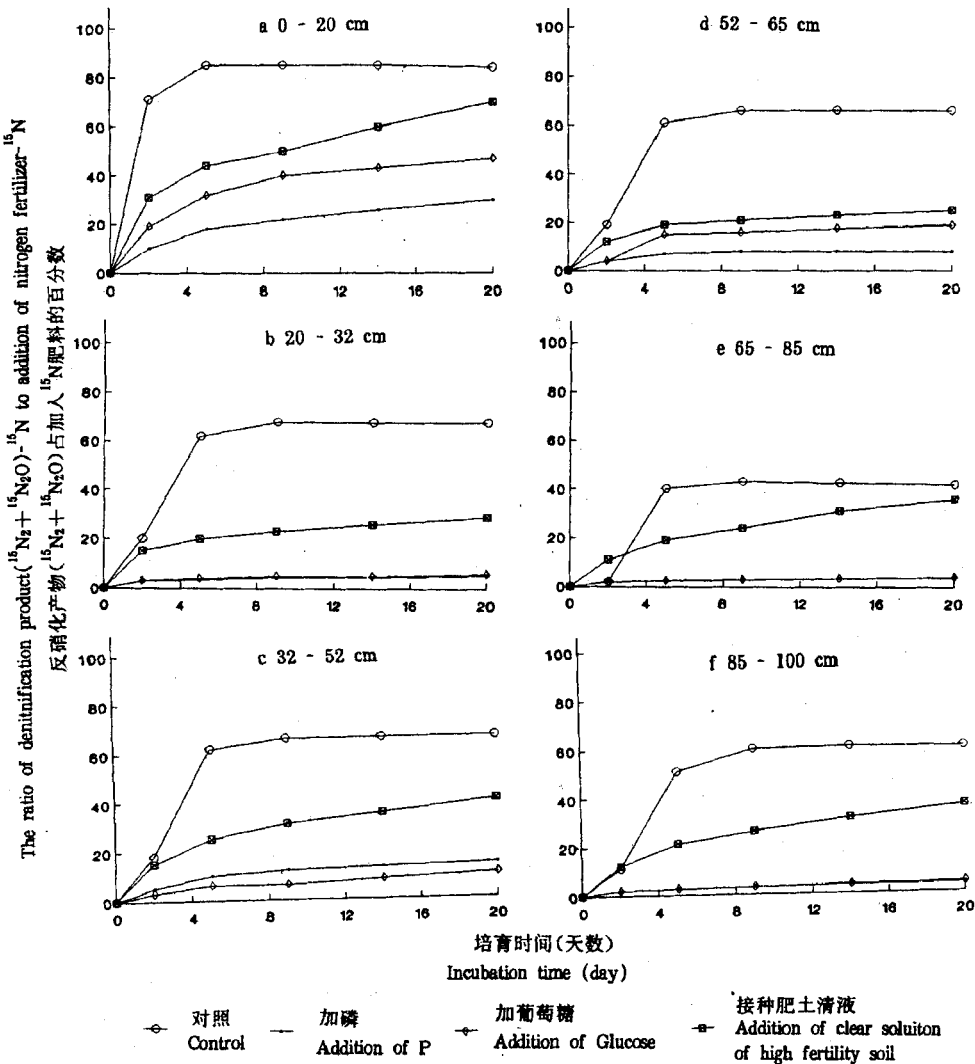


图1 潮土剖面各层土壤反硝化活性的动态变化

Fig.1 Dynamic of DP activity in soil profile of upland fluvo-aquic soil

从潮土剖面(0~100cm)各层土壤的反硝化率随时间的变化(图1)可以看出反硝化速率的变化趋势。对照处理0~20cm表层土壤的反硝化速率以0~2天中最高,此后逐渐降低,但仍远高于其他各层土壤的反硝化速率。52~65cm土层土壤的情况与表层土壤的相似,但速率较低。其余各层土壤的反硝化速率,在整个培育期间都很低。这一趋势与各层土壤有机质含量的差异相一致。

加葡萄糖后反硝化率随时间变化的趋势表明,葡萄糖主要是提高了表层土壤0~2天中的反硝化速率和下层土壤2~5天中的反硝化速率。与对照相比,加磷对各层土壤反硝化速率都无明显的影响;加肥土清液提高了试验初期的反硝化速率,特别是下层土壤。表层土壤0~2天中的反硝化率从对照的19%提高到33%,而下层土壤的反硝化速率约提高了3~5倍;接种肥土清液还提高了2~5天中的反硝化速率,但对5~20天期间反硝化速率的影响则不明显。

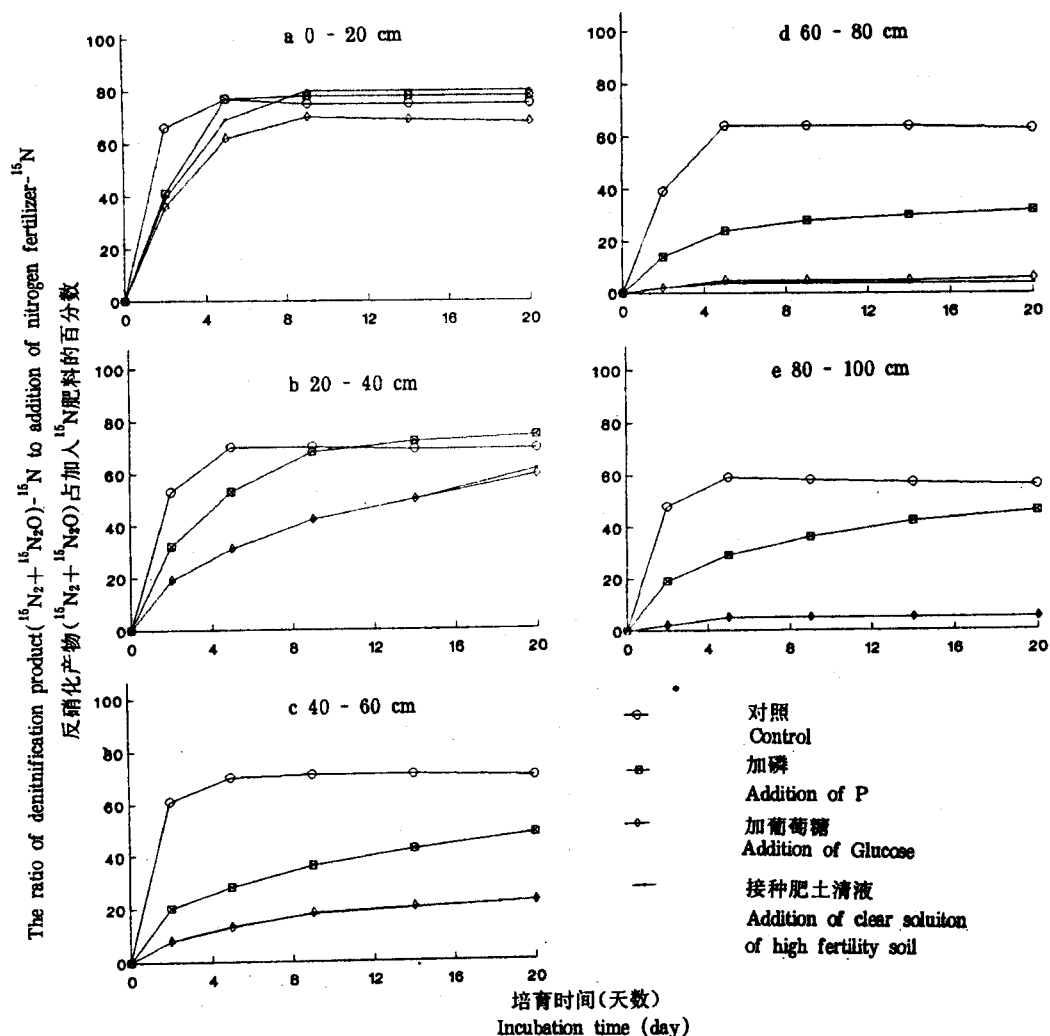


图2 黄泥土剖面各层土壤反硝化活性的动态变化

Fig.2 Dynamic of DP activity in soil profile of paddy soil

从这些结果来看,潮土各层土壤的反硝化活性都比较低或很低,这与该土壤的易分解性有机物质的含量较低和微生物活性较弱有关。

(二)黄泥土(中等肥力)

表3看出,黄泥土剖面各层土壤不同处理培育20天时,对照处理各层土壤中也以表层土壤的反硝化活性为最高,其反硝化率达到73.9%,远高于潮土表层土壤的反硝化率;20~40cm土层的反硝化活性与表层土壤的相近,但是,其下各层土壤的反硝化活性则随深度的加深而明显降低。与对照相比,加葡萄糖对0~20cm土层土壤培育20天时的反硝化活性没有明显的影响,但却提高了下层土壤,特别是40cm以下各层土壤的反硝化活性,这与这几层土壤有机质含量较低有关。加磷对黄泥土剖面各层土壤反硝化活性影响不大。加肥土清液对0~20cm土层土壤的反硝化活性没有明显的影响,但显著地提高了其下各层土壤的反硝化率。

图2结果表明,在培育20天时各层土壤的反硝化率的差异,主要是由初期反硝化速率的不同所致。在9天时各层土壤的反硝化率都已接近或达到最大值。与对照相比,加葡萄糖主要是显著地提高了各层土壤在0~2天和2~5天中的反硝化速率,特别是下层土壤,这与下层土壤有机质含量较低有关。0~2天中表层土壤的反硝化率从对照的37%提高到67%,而其下各层土壤的反硝化率却提高了约5~10倍。至培育5天时各层土壤反硝化率即都接近最高值。与对照相比,加磷对黄泥土剖面各层土壤反硝化活性的影响不大(图2)。而加肥土清液则明显地提高了0~20cm以下各层土壤的反硝化活性,主要是提高了培育初期的反硝化速率。这可能与下层土壤的微生物活性较低有关。

表 3 黄泥土(中等肥力)剖面中各层土壤不同处理的反硝化活性(培养20天后测定)

Table 3 Denitrification potential(DP) in the soil profile of paddy soil
with different treatments (incubation 20 days)

土层深度 Layer (cm)	对照 CK	加葡萄糖 + glu.	加磷 + P	接种肥土清液 + Clear solution of fertile soil
0~20	73.9	78.6	82.0	80.3
20~40	60.0	70.7	62.2	78.0
40~60	25.6	71.7	25.8	51.1
60~80	10.5	66.2	8.0	35.7
80~100	8.1	61.3	8.0	49.1

1) 反硝化活性(DP) = $(^{15}\text{N}_2 + ^{15}\text{N}_2\text{O}) - ^{15}\text{N}$ 量 / 加入 ^{15}N 量 $\times 100\%$ 。

(三)红壤(花生地)

红壤剖面各层土壤对照处理的反硝化率测定结果(表4)表明,红壤的反硝化活性很低,远低于黄泥土和潮土。0~20cm土层土壤的反硝化率在培育20天时仅为17.6%,20~60cm土层土壤更低至2.8%,60~100cm土层土壤的反硝化活性甚至已不能检出。加葡萄糖能显著提高红壤表土的反硝化活性,培育20天时反硝化率从对照处理的17.6%提高到51.2%,约提高了2倍,但对表层以下各层土壤的反硝化活性则无影响。从反硝化速率的动态变化(图3)来看,至培育9天时,表土加葡萄糖处理的反硝化速率才接近最高值,这与潮土和黄泥土的情况不同。加磷对剖面各层土壤的反硝化活性都无明显的影响;加入肥土上清液提高了表层土壤的反硝化活性,但不如加葡萄糖的作用明显,培育20天时的反硝化率从对照的17.6%提高到28.8%,而未能提高

表层以下各层土壤的反硝化活性。

表 4 红壤剖面中各层土壤不同处理的反硝化活性(培养20天后测定)
Table 4 Denitrification potential(DP) in the soil profile of upland red soil with different treatments (incubation 20 days)

土层深度 Layer (cm)	对照 CK	加葡萄糖 + glu.	加磷 + P	接种肥土清液 + Clear solution of fertile soil
0~20	17.6	51.2	19.8	28.8
20~60	2.8	0.5	1.7	1.3
60~100	0	1.0	0.2	3.0

1) 反硝化活性(DP)=(¹⁵N₂+¹⁵N₂O)-¹⁵N量/加入¹⁵N量×100%.

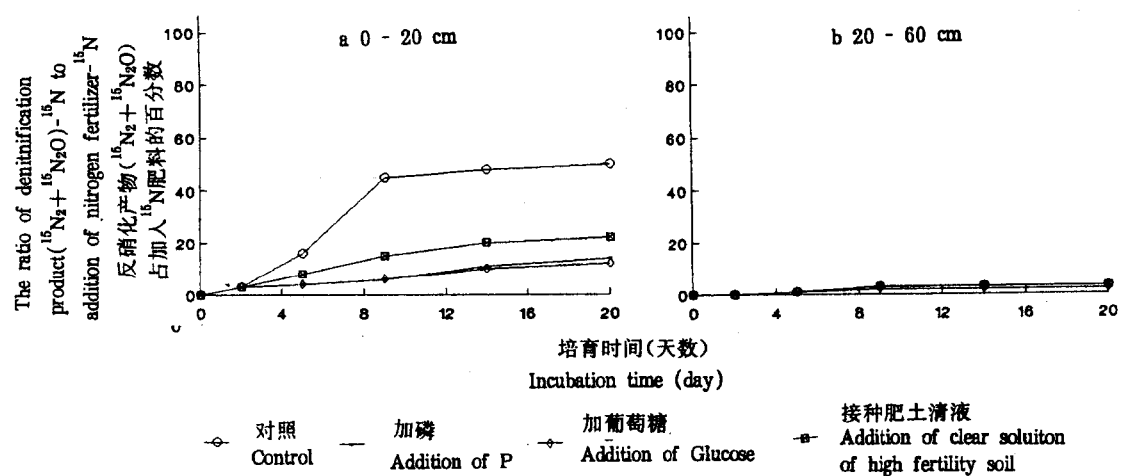


图3 红壤剖面 各层土壤反硝化活性的动态变化
Fig.3 Dynamic of DP activity in soil profile of upland red soil

三、讨 论

试验结果看出,在供试三种土壤中,以黄泥土的反硝化活性为最高,其次是潮土,而以红壤为最低;剖面中各层土壤的反硝化活性,3种土壤都表现出随深度的加深而降低的趋势。许多研究都报道了类似的结果^[4~7]。但是,黄泥土20~40cm土壤的反硝化活性明显高于潮土和红壤的相应土层,潮土下层土壤的反硝化活性又高于红壤,后者下层土壤的反硝化活性极低。相关分析表明,3种土壤各层在培育20天时的反硝化率与土壤pH、有机质和速效磷含量的相关系数分别为-0.138、0.827 * *和0.229,即反硝化率仅与土壤有机质含量呈极显著的正相关;加入葡萄糖大多能显著提高各层土壤的反硝化活性,与许多研究结果类似^[8~12]。但是,在试验中加葡萄糖未能明显提高黄泥土0~20cm和20~40cm土层土壤,以及红壤表层以下各层土壤的反硝化活

性。看来,前者可能与黄泥土0~40cm土层土壤的有机质含量较高有关;而加葡萄糖未能提高红壤表土以下各层土壤的反硝化活性的原因则可能是多方面的。加磷对3种土壤各层的反硝化活性都无影响;加入肥土清液提高了潮土各层土壤的反硝化活性,也提高了黄泥土40cm以下各层土壤的反硝化活性,但仅提高了红壤表土的反硝化活性,其提高的程度则都低于加葡萄糖的处理。

总的来看,可以认为,在大多数情况下,土壤的有机质含量是制约反硝化活性的主要因素,其次是微生物活性。

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INVESTIGATIONS ON DENITRIFICATION POTENTIAL IN AGRICULTURAL SOILS AS RELATED WITH AFFECTED FACTORS

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Summary

Denitrification potential (DP) of agricultural soils as related with affected factors was studied in incubation. Results indicated, in soil profile of upland fluvo-aquic soil DP was the highest(49%) in top soil (0~20cm) in incubation day 20 and was very low below the layer to 100cm, except for the horizon of 52~65cm. Addition of glucose promoted DP in all soil horizons, especially during the early period of the incubation. The increase in DP in all other horizons were higher than that in top soil, although the value of DP in top soil was still the highest. Addition of clear solution of fertile soil also increased the denitrification of all soil layers, but with less extent than that with addition of glucose. Addition of phosphorus had no effect on DP of all soil layers.

The highest of DP was also observed in the top soil of the paddy soil with moderate fertility and the value was 74% in 20-d incubation. DP decreased gradually as the depth of the soil profile. Addition of glucose or clear solution of fertile soil had no effect on DP in both 0~20cm and 20~40cm layers, but enhanced DP obviously in the layers from 40~100cm. No effect of addition of phosphorus on DP was not observed in all soil layers.

The values of DP in all soil layers of upland red soil profile collected from peanut field were very low, only 18% in top soil and near zero in the layers below surface soil in 20-d incubation. Addition of glucose or clear solution of fertile soil increased DP in top layer of 0~20cm in 20-d incubation, but had no effect on the layers below the top. No effect of addition phosphorus on DP of the red soil profile were observed.

It was found that there is a significant correlation of DP with the content of soil organic matter for all the soils studied, the correlation coefficient was 0.827**. However, no such correlation was found for DP with the content of soil available phosphorus and soil pH.

Key words Agricultural soils Denitrification potential Affected factors