第 23 卷第 12 期
2003 年 12 月

生 态 学 报
ACTA ECOLOGICA SINICA

Vol. 23,No. 12
Dec.,2003

农田土壤磷素淋溶及其预测

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摘要:农田土壤磷的淋溶损失,不仅造成肥料利用率降低、农业生产成本上升,还能引起地下和地表水体富营养化。在综合大量中外文献的基础上,阐述了农田土壤磷素淋溶问题的提出、淋溶对水体富营养化的贡献、淋溶液中磷素的形态及其比例、影响土壤磷素淋溶的因子、淋溶机理、预测方法,并对农田土壤磷素淋溶及其预测作了展望。

关键词:农田土壤;磷;淋溶;预测方法

Phosphorus leaching from agricultural soils and its prediction

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Abstract: Phosphorus (P) is an essential element for plant growth. It also is a key element for eutrophication of water bodies. The loss of P from agricultural soils not only leads to a decrease in the utilization ratio of fertilizers and an increase in the cost of agricultural production, but also gives rise to the eutrophication of surface water and ground water. Eutrophication, caused by P enrichment, first came to the fore in the 1960s, most notably in the Great Lakes region of the USA and Canada. In the following decade, a host of other water bodies, suffering from varying degrees of phosphorus enrichment, were identified around the world. There are two ways for phosphorus to enter water bodies-point source and non-point source. Human beings did not pay enough attention to P loss from agricultural land to water bodies until the 1960s because of its limited movement in soils. P may be lost from agricultural land to water bodies by several processes. These include erosion, surface runoff and leaching. It is reported that about 35% of the P inputs to natural waters now come from agriculture in the UK, 70% in Denmark, and 38% in Germany. Since most soils have a very high absorption capacity for P, usually far exceeding the quantities of P added as manures or fertilizers, it has long been considered that leaching losses of P from soil to water are negligible in most cases. The concentration of P required to trigger eutrophication in fresh water is extremely small (as low as 0.02～0.035 mg P/L. The problem of P leaching from soil to water was generally not considered important until the 1980s. When researchers first measured P losses in drainage water in the UK and USA. It was reported that P in drainage water came from farmyard manure applied to sandy soil. More recently, reports about P leaching from loam and clay soils were published. Most researchers belive that the P in leach water is associated with the particulate fraction (PP). However, Heckrath and Brookes found that dissolved reactive phosphorus (DRP), ranging between 66%

基金项目:教育部留学回国人员科研启动基金资助项目;陕西省自然科学基金资助项目(2002D09)

收稿日期:2002-08-23;修订日期:2003-07-10

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Foundation item: The scientific research foundation for returned overseas Chinese scholars, State Education Ministry and Natural Science Foundation of Shaanxi Province (No. 2002D09)

Received date: 2002-08-23; **Accepted date**: 2003-07-10

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and 86% of total P (TP), was the largest fraction in drainage water from Broadbalk. One possible mechanism involved in this could be preferential flow. Many factors, including climate factors, soil factors and hydro-geologic factors, impact P leaching. Scientists now want to predict the trend of P leaching from soil to water bodies. Two kinds of methods are currently used to predict P leaching. In one method, predictions are based on certain soil properties. For example, Brookes *et al* suggested that the ratio between $CaCl_2$-extractable P and Olsen-P, termed "Change-point", might be a useful predictor of the soil-P concentrations at which there is significant risk of P movement from soil to water. Van der Zee *et al* used the phosphate saturation degree (PSD) to determine critical levels of P saturation in soil in terms of maintaining acceptable P concentrations in the groundwater. Another way to predict P leaching is to use mathematic models. Many models have been used. Meissner *et al* developed a model-MORPHO (MOdelling of Regional PHOsphorus Transport) to calculate flow and transport processes during re-wetting. Initial modeling results about the variation of subsurface P-leaching losses for a selected site will be presented and conclusions for the calculation of re-wetting scenarios, risk assessments and future work will be derived. In order to reduce P leaching from agricultural systems, the overall goal should be to balance off-farm P input in feed and fertilizer with outputs in harvested products, while managing soils in ways that maintain productivity. Practical and innovative measures will be employed for the control of agricultural P-leaching to water.

Key words: agricultural soils; phosphorus; leaching; prediction method

文章编号:1000-0933(2003)12-2689-13 **中图分类号**:X53 **文献标识码**:A

自 20 世纪 60 年代首次在美国和加拿大的大湖地区发现由磷素引起的水体富营养化现象以来,人们惊讶地发现,世界上许多地上(江、河、湖、水库等)和地下水体都出现程度不同的磷素富营养化现象;尤其是欧美发达国家,这一现象更加普遍[1]。据报道,英格兰和威尔士的 96 条主要河流中,有 73%的河水中可溶性磷的含量达到和超过 0.1mg P/L,水体中磷浓度达到 0.02mg P/L 时就会导致富营养化[2,3]。我国水体富营养化问题,近一、二十年有所发展,比如,1978～1980 年对我国 34 个湖泊和水库进行的调查表明,当时富营养化的湖泊占调查数的 14.7%,而 1987～1989 年调查的 22 个湖泊中富营养化的已占 63.6%,呈现出明显的上升态势[4];一些地方也相继出现水体富营养化现象。水体富营养化是由于 N、P、C 等植物营养元素在水中富集,使水体中浮游生物(特别是蓝绿藻类)及水草过量繁殖,水体缺氧,透明度降低,恶臭,并产生某些有毒物质;这些问题导致水体不仅不能适于人类饮用、工业利用和鱼类生长,而且也破坏了环境的美化舒适,影响旅游业发展[1～111]。本文拟就农田土壤中磷素通过淋溶进入水体的数量(浓度)、形态、机理及其预测方法等方面做一综述。

1 问题的提出

磷素不但是植物必需的大量营养元素之一(施用磷肥对植物的增产作用早已被大量的农业生产实践所证实);而且也是动物体中不可或缺的重要元素[26];然而,磷也是引起水体富营养化的主要元素之一,而且是关键元素[1～4,38,44,48,52]。

1957 年,英国著名的土壤学家 J E Russell 在他的著作"The world of the soil"中曾描述土壤磷素处在"非水溶状态",从而导致土壤磷素"显然永远处在土壤表面"。很多农业科学家也传统的认为磷素在土壤中是不移动的,因而,为了获得作物高产,鼓励农民大量施用磷肥而不用担心磷素的淋溶损失。20 世纪 90 年代以前,国内也少有人相信农田土壤中的磷素能进入水体;尤其是通过淋溶进入水体;又由于土壤中高浓度的磷对植物的生长并没有不利的影响,因此,农民每年都向土壤中施入远超过植物所能带走的磷素,结果使土壤中累积了大量的磷,对地下和地上水体构成威胁[1]。我国有关磷素的研究,以前主要集中在磷的吸附、解吸和提高磷肥利用率方面,由于施用磷肥的历史远比欧美发达国家短,水体富营养化程度总体较低[1];但是,由于近十几年我国经济发展迅猛,对农业的投入也不断加大,施肥量有增无减,尤其是一些经

济发达地区和经济作物基地,过量施肥的现象很普遍;已经出现一些地方农田中的磷素进入水体而产生水体富营养化现象[1~3,5~8,10,11,13~20]。如:苏南太湖流域是我国农业最发达的地区之一,农业集约化程度较高,是高投入、高产出区,全区面积仅占全国的 0.4%,而化肥消费量占全国的 1.3%[6]。

2 农田土壤磷素淋溶

2.1 造成水体富营养化的磷素来源

磷素进入水体分"点源"和"非点源(面源)"两类来源;在最初发现水体富营养化时,人们认为引起水体富营养化的磷素主要来自城镇生活污水和含磷的工业废水(点源污染);但是,自从 20 世纪 60 年代后期,随着世界范围内无磷洗涤剂的广泛使用和越来越多的工业废水及城镇生活污水的排放得到控制和处理,由于磷素的进入而引起的水体富营养化问题,不但没有得到解决,而且有不断加剧的趋势[37,45,47~49]。Moss 等认为来源于农业的磷素是造成英国水体富营养化的主要部分[1];据 P C Brookes 等报道,英国自然水体中约 35%的磷来自农业,德国的比例为 38%,而丹麦达到 70%[2]。联合国粮农组织估计中国农田磷进入水体的量为 19.5kg/hm^2;太湖地区农田磷流失量中,渗漏占 31%,其中,旱地地表磷流失量比水田高出 4 倍[5]。因此,农业"面源"污染,逐步或者已经成为造成地下和地表水体富营养化的重要来源。

2.2 农田土壤磷素进入水体的途径

农田土壤中磷进入地表和地下水体中的途径主要有 3 条,即地表径流、侵蚀和淋溶(渗漏或亚表层径流)[1,2,5~10,33,39,49,53,68,77];由于土壤和磷素之间能发生剧烈地反应,土壤吸持固定磷素的容量很大,磷素在土壤中很难移动[5,16];而且,由于磷肥主要施在耕层,磷素含量很低的下层土壤是一个吸持磷素的巨大容量库,所以,多数人认为土壤中的磷沿剖面垂直向下淋溶的可能性不大,地表径流和土壤侵蚀被广泛认为是主要途径[5~15,17~25],淋溶(包括亚表层径流)量极少,可以忽略;Sharpley 等、Miller 等、Isermann 等以及 Vighi 等认为,土壤磷流失的主要途径是地表径流和土壤侵蚀[1,41]。国内众多学者也持相同的观点[5~11,13,21,22,24];即使有个别土壤发生磷向下淋溶现象,也是由于土壤质地太轻(如砂土),而且施入了大量的新鲜有机肥料[2]。据 Vetter 等报道,长期大量施用新鲜猪粪(185~660 kg/ hm^2)于砂壤土中,用双乳酸提取的磷(可溶性)含量在土壤剖面下 90cm 深处有明显的增加;超过施用量 13%的磷在土壤剖面下 60~90cm 处累积[1]。

然而,上世纪 90 年代以后,在较粘重土壤和施用无机磷肥土壤中磷素淋溶至土体下部或淋溶进入地下或地表水体的报道逐年增多。Heckrath 和 Brookes 等在对英国洛桑试验站著名的长期土壤肥料试验地(1843 年开始)65cm 下排水管中排出水进行分析发现,水中所含磷浓度很高,有时可达近 2 mg P kg^{-1},而且以可溶的反应性无机磷(MRP)为主要成分,占排水中总磷含量的 66%~86%,即使在单施有机肥而不施化肥 150 多年的小区,排水中可溶的反应性无机磷含量可占总磷的 55%~90%[2];R O Maguire 等研究发现,在美国的 Delmarva(Peninsula)地区,农田土壤中的磷素以淋溶(深层淋溶和亚表层径流)形式迁移出土体的比例高于地表径流的比例[51]。E Barberis 等发现意大利 5 块施肥量高的土壤中通过淋溶排出土体的磷素(以有机磷为主)占多数[61]。K Börling 等在瑞典[62]、P J Bulter 等在英国[65]、F Godlinski 等在德国[69]、G F Koopmans 等在荷兰[87]、G H Rubæk 等在丹麦[89]、G S Toor 等在新西兰[93]、S M Vandsemb 等在挪威[95]、J W Cox 等在澳大利亚[96]、G Kilroy 等在爱尔兰[100]、A Sapek 等在波兰[103]以及 R W McDowell 等在美国[52,73,75]均得出农田土壤中磷素以淋溶形式损失的量与以地表径流和土壤侵蚀形式损失的量相当或淋溶量更大的报道。而我国却鲜有这方面的报道[5~24]。

2.3 农田土壤磷素淋溶的形态及其比例

Heckrath 和 Brookes 等认为,研究随土壤剖面 65cm 下的排水管的排出水淋溶的磷素可以从总磷(TP)、总颗粒附着磷(TPP)和总溶解态磷(TDP;又分为反应性无机磷-MRP 和溶解性有机磷-DOP)等形态进行研究;他们研究得出,长期(150 多年)不同施肥土壤排水中 TDP 和 TPP 占总磷含量(TP)比例的顺序为:TDP (66%~71%) > TPP (23%~35%);在 TDP 中,MRP 占绝大多数(约为总磷含量的 66%~86%)[2]。该结论与Challey 等的结果一致(MRP、TPP 和 DOP 分别为 62%~68%、17%~25%和 11%~17%)[1]。B L Turner 等对质地分布从砂壤到粉粘壤的 4 种原状土壤渗漏计(高 135cm,直径 80cm)按常规

施肥量施入氮磷钾肥并种植多年生黑麦草、模拟降雨量为 1100mm 下，连续 2a 磷淋溶状况的研究表明，渗漏水中可溶性磷（抽滤过 0.45μm 筛）（TDP）占绝大多数（54%～79%），其中，反应性无机磷（RP）远比非反应性（有机）磷（UP）多，它们分别占量的 62%～71%和 29%～38%；颗粒磷（PP）只占总磷的 21%～46%[28]。而 Howse 等报道英国牛津地区一粘壤土的排水中磷以颗粒附着态为主[1]。J L Lu 对英国洛桑试验站 Broadbalk 试验地土壤剖面 65cm 下排水中磷形态及其含量研究表明，排水中总磷含量很高，多数在 1 mg/L 以上，最高达到 4.834 mg/L；其中，以颗粒附着态磷（PP）所占比例最大，其次是可溶态反应性磷（MRP），可溶态有机磷（DOP）比例最小；它们分别占总磷（TP）的 54%、36%和 10%①。G S Toor 等用原状土渗漏计（高 70cm，直径 50cm）方法研究土壤中不同施肥处理渗漏水中磷素含量得出，渗漏液中总磷（TP）浓度多数在 950～1385 μg/L 之间；颗粒附着态磷（TPP）和可溶性磷（TDP）的数量相当，分别占总磷的 51%和 49%[56]。

2.4 农田土壤磷素淋溶的影响因素

影响农田土壤磷素淋溶的因素很多，也很复杂，如：气候因子（包括降水量、降水强度、降水历程、蒸发量等）、土壤因子（包括土壤结构、质地、导水率、容重、有机质含量、$CaCO_3$ 及游离 Al，Fe_2O_3 含量、土壤磷含量、生物活性、pH 以及覆盖程度和表面粗糙度等）、水文地理因子（包括坡度、地下水位等）和农作管理因子（施肥数量、种类、方式及时间，灌溉、耕作及轮作制度等）[1～6,13,15,21,26,31,35,37,42,44～46,48,49,57,58,65]；本文不准备详述，仅举例说明。Cox 等对澳大利亚南部牧草地磷素淋溶研究表明，磷素淋溶损失量与降水量有极强的相关性，而且，淋溶高峰与降水强度关系密切[112]。Heckrath 等也得出磷素淋溶量与降水量的良好相关性[2]。Addiscott 等认为，耕作可以增加土壤表面粗糙度，使土壤饱和导水率增大，从而增加磷素的淋溶损失量；但是，耕作能减小土壤容重，减少淋溶量；当然，耕作时农机轮子可以使土壤形成裂缝，容易形成优先流而促进淋溶；耕作还可以压实亚表层土壤而促进土壤磷素的亚表层径流（淋溶）等[46,57,78]。Heckrath 等证明对土壤的扰动，会增加颗粒附着态磷（TPP）的比例而减小可溶态反应性无机磷（MRP）的比例；Broadbalk 试验地 65cm 下的排水管，在 1993 年更换前后排出水中 TPP 和 MRP 的浓度占总磷（TP）浓度的比例分别是 8%～15%、78%～86%和 23%～35%、66%～71%[2]。

3.5 农田土壤磷素淋溶的可能机理

农田土壤磷素淋溶是由水分运动作为动力完成的。通过降水或灌溉进入土壤的水分，除蒸发外，根据在土壤中的流向可分为地表径流（Overland flow or Runoff）、间层流（Interflow or Subsurface flow）、基质流（Matrix flow or Saturated/piston flow）和优先流（Preferential flow or Macro-pore/By-pass flow）四种方式；除地表径流外，其它水分流动方式都会造成磷素的淋溶损失。其中，优先流（或大孔流）的作用最大[27,49,71]。P M Haygrath 等引用 Brorman 等的描述各土壤类型水分流动示意图[49]（图 1）。

总体而言，在水分条件满足时，长期施用有机肥（尤其是新鲜畜禽粪肥）、质地较轻的土壤更容易发生磷素淋溶。E Barberis 等对意大利西部一个平原土壤质地为粗壤土和细壤土的五个监测点研究发现，由于大量施用牛粪和猪粪及其厩肥，使土壤表层的有机质含量达 1.6%～4.7%，又由于地下水位较高（0.7～3m），所以，从耕层 60cm 以下土壤中用 $CaCl_2$ 浸提出来的磷可达 0.38 mg/L 以上，其中，有机磷占总磷的 61%～92%，而且，深层的比例大于浅层的[61]。据 D M Nash 等报道，由于澳大利亚土壤风化程度较高，土壤普遍缺磷，因此，单独施用无机磷肥，土壤下层 3m 处磷含量不增加，而施用粪肥的土壤却有明显的增加[75]。Johnston 等在英国洛桑长期牧草试验地得出同样的结果[2]。而 Brookes 等对英国洛桑的另一长期肥料试验地（主要种植冬小麦和马铃薯）65cm 下排出水中磷素形态及其含量研究表明，不论施用化肥还是有机肥处理，排出水中都有一定量的磷含量，其中，可溶性无机磷占绝对多数，可溶性有机磷的比例很小，长期施用有机肥处理的总磷浓度和可溶性有机磷含量都很低；这块试验地土壤质地为砂质粘壤，为什么会有高浓度的磷（主要为无机磷）淋溶呢？他们认为一方面，土壤经过连续施用 100 多年的磷肥，土壤耕层累积

① J L Lu. Characteristics of phosphorous forms in drainage water discharged from Broadbalk experiment. 2002. *Pedosphere*.

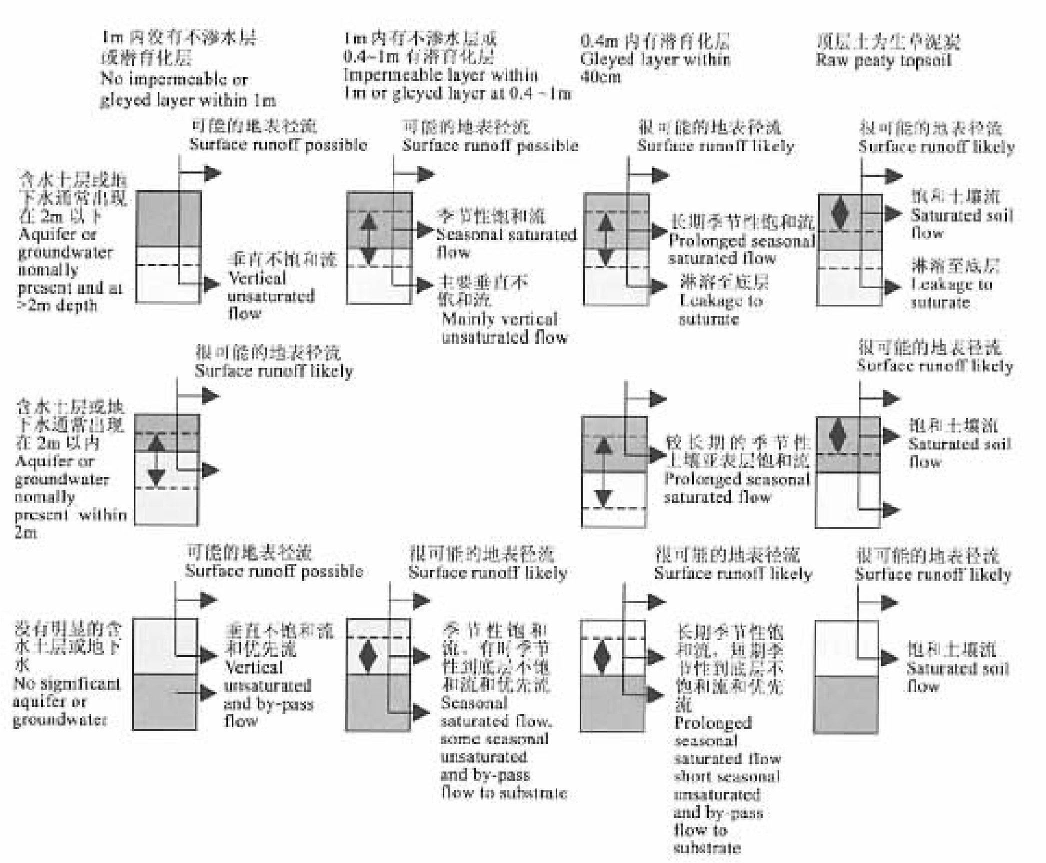

图 1　土壤水分流动分类(引自 Haygarth 等,2000,Fig. 3)[38]

Fig. 1　Classification of the hydrology of soil types (from Haygarth *et al*. 2000, Fig. 3)[38]

了大量的磷素,达到了饱和状态;加之土壤中有很多裂缝、动物洞穴以及腐烂根孔,有降雨时,大量的可溶态磷素随水流,沿着这些通道(优先流)迅速到达土壤下部[1,2,42]。G J Heckrath 曾对英国洛桑试验站同一块试验地,在降雨开始后的 12h 内,每隔 0.5h 对排水中总磷及可溶性无机磷等进行分析表明,降雨开始后约 0.5h 排水中总磷及可溶性无机磷等浓度达到最大值①。

3　农田土壤磷素淋溶的预测

随着研究的进一步广泛和深入,欧美发达国家有关磷素由土壤淋溶进入水体的研究,已经主要集中在如何进行预报(测)和防治方面,但至今没有统一的认识;预测方法很多,但是,大体上可分为两类,即利用土壤理化性质预测和利用数学模型预测[1,2,26,32~34,42,52,59,77,87,88,90~92,94,95,98,99,104,105,107,108,110]。

3.1　利用土壤理化性质预测

有人用 $CaCl_2$ 浸提的磷含量作为土壤磷素淋溶的指标,认为凡是被 $CaCl_2$ 浸提出来的磷,均可以随水淋溶至土体下部[2,61,77,90,95]。N Hesketh 等提出了发生土壤磷素淋溶的"突变点"(Change-Point),即用土壤 Olsen-P 含量与 $CaCl_2$-P 含量分别为横轴和纵轴作相关曲线,曲线上的转折点相对应的 Olsen-P 含量即为该土壤的磷素淋溶的"突变点"(Change-Point);他们认为,当土壤 Olsen-P 含量小于"突变点"值时,不会发生磷素淋溶;反之,当土壤 Olsen-P 含量大于"突变点"值时,就会发生磷素淋溶[42]。据此,他们对采自英国

① G J Heckrath. Phosphorus accumulation and leaching in clay loam soils of the Broadbolk experiment. Ph. D. thesis, 1998.

不同地区性质相差较大的 8 种土壤进行预测，得出的“突变点”(Change-Point)土壤 Olsen-P 含量从 13 μg/L 到 119μg/L 不等。R W McDowell 等也应用“突变点”理论对英国丹佛(Devon)和美国宾西法尼亚(Pennsylvania)的各一个流域内磷的流失(包括地表径流和淋溶)进行预测，他们用 Water-P 或 $CaCl_2$-P 做纵坐标，Olsen-P 或 Mehlich-3P 为横坐标，得出丹佛(一个流域)和宾西法尼亚(一个流域)土壤发生磷素淋溶的“突变点”分别为 33～36 mg/L Olsen-P 和 185～190mg/L Mehlich-3P[75]。

荷兰人 van Der Zee 等提出了用由土壤剖面中反应性的无定型微结晶铁铝(草酸盐浸提)为非石灰性土壤中磷吸附容量(PSC)来预测磷素淋溶趋势(式(1))[1]：

$$PSC = (Fe_{ox} + Al_{ox})/2 \quad (\text{mmol P kg}^{-1}) \tag{1}$$

然后，根据 PSC 确定土壤磷饱和度(PSD)。

$$PSD = 100 \times P_{ox}/PSC(\%) \tag{2}$$

式中，P_{ox}为草酸盐浸提测定的土壤磷含量。

土壤磷饱和度(PSD)还可以通过 Langmuir 方程确定(式(3))。

$$PSD = \gamma KC/(1 + \gamma KC) \tag{3}$$

式中，K 为磷吸附常数；γ 是土壤总吸附磷与溶液中磷的比值(分配系数)；C 表示地下水中可溶态的反应性无机磷(MRP)含量(mg P/L)。

该预测方法提出后被很多学者成功地用来预测土壤中磷的淋溶趋势[27,75,87]。

此外，还有人应用平衡磷浓度(EPC_0)[29,90,113]或磷指数(P_{index})[59]或磷素位点指数(PSI)[87,89,90,92,94]作为指标较好的预测了土壤磷素的淋溶趋势。

3.2 利用数学模型预测

利用土壤理化性质预测具有方法简单易行，成本低廉的优点；但是，由于土壤磷素淋溶受到许多因素(气候、土壤、水文地理及农作管理等)的影响而非常复杂，用简单的土壤性质预测，一方面，应用范围小，另一方面，由于受到气候等因素的影响而导致偏估。因此，许多学者以数学模型进行预测[83,87,88,98,99,,101,102,104,107,108,110]。R A Hodgkinson 等应用 HOST 模型(考虑作物、土壤、排水及气候等因子)较好的预测了英国不同利用状况的 3 个小流域(分别为 150、260 和 90 hm^2)土壤磷素向水体淋溶的趋势[88]。G van der Salm 等(ANIMO)[91]、F Djodji 等(GLEAMS)[98]、E G Hope 等(TOPMODEL)[99]、J Magid 等(DAISY)[101]、R Meissner 等(MORPHO)[102]、M Russell 等(DYNAMIC)[104]、B Ulén 等(MODEL)[105]、T Burt 等(VSA)[107]、M B McGechan 等(MACRO)[108]以及 L Andersson 等(PARTLE)[110]在不同的国家建立了预测土壤磷淋溶(流失)的数学模型。如：Meissner 等[102]建立了 MORPHO 模型来预测一块地下水位较高的自然草地中磷素在亚表层淋溶取得较好的结果。

Morel 等[40]应用两种动力学模型，对土壤中的磷从土壤组成分上向溶液中的迁移进行了模拟。用同位素稀释法预测从土壤组分向溶液中淋溶的磷的数量(Qt)分别是：

氧化土(Oxisol) $Q_{(t)} = 0.013/[0.011(t+0.0001)^{-0.49}+0.001]$

淋溶土(Alfisol) $Q_{(t)} = 8.0/[0.40(t+0.01)^{-0.21}+0.016]$

如果同时考虑到溶液中磷浓度(Cp)的影响，将溶液中磷浓度(Cp)和随时间不断变化的从土壤组分向溶液中淋溶的磷的数量[$Q_{(Cp,t)}$] 用 Freundlich 动力学方程描述为：

氧化土(Oxisol) $Q_{(Cp,t)} = 34.4{C_p}^{0.75}t^{[0.248-0.020\log(Cp)]}$

淋溶土(Alfisol) $Q_{(Cp,t)} = 27.9{C_p}^{0.45}t^{[0.154-0.037\log(Cp)]}$

由于数学模型应用的参数太庞杂，不同地区由于自然条件及土壤的差异，给推广应用带来一定难度。

4 展望

围绕农田土壤磷素淋溶问题，人们各种各样研究的目的只有一个，即在保证农业生产持续发展的基础上，减少农业系统中磷素的流失；防止和减少水体富营养化[1]。

我国对农业土壤中磷淋溶进入水体导致富营养化方面的研究，至今仍未开展。如果尽早进行研究预

报，并加以控制，就可以避免重走发达国家的老路，即："发展-污染-发现-治理"。因此，应从以下方面开展工作：

（1）查明农田土壤磷素淋溶现状　通过研究，查明我国各地（尤其是南方地区）土壤磷素淋溶的可能性、主要过程（机理）以及淋溶对水体富营养化的贡献率。

据 Brookes 等对英国 8 个土壤性质差异较大的试验点的研究发现（资料），发生磷素淋溶的土壤 Olsen-P"阈值"各不相同，最高的达 119mg/kg，最低的只有 10mg/kg。我国幅员辽阔，土壤种类繁多，土壤性质及其磷素含量也差别很大，因此，有必要在各地都进行调查研究、监测（包括应用先进的 3S 技术监测土壤中磷素淋溶动向），查明磷素淋溶状况、趋势、机理，并提出相应的对策。

（2）合理利用土壤资源　科学区划，合理利用土壤，宜林则林，宜牧则牧，宜农则农，保持尽可能多的植被覆盖；少耕或免耕。

在离湖、河、江及水库等水源近的地方，应在农田与水源之间种植一些常年生植被；在地下水位较高和质地较轻的地方，种植耐瘠薄的作物（可以减少肥料的投入量）；尽量实行少耕或免耕，因为疏松的表层土壤，不但容易水土流失，而且极易发生磷素淋溶。

（3）经济合理施肥　根据作物、土壤及自然环境，选择适宜的磷肥种类、施用数量、施用时间、施用方式等。

磷素在土壤中的累积是发生淋溶的先决条件，据报道[5]，我国自施用磷肥以来，至 1992 年，累积在土壤中的磷可能有 1500×10^4t，这是埋在土壤中的巨大的"化学炸弹"；因此，要积极推行平衡施肥和计划施肥，以减少磷素在土壤中的累积。

（4）加强水分管理　合理灌溉，避免大水漫灌，减少农田排水量。

水分是磷素淋溶的介质，减少多余的水分向土壤下部及土体外的渗透，是减少磷素淋溶的根本举措（也可以节约水分）；因此，要大力推行节水灌溉。

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