NEWS & VIEWS

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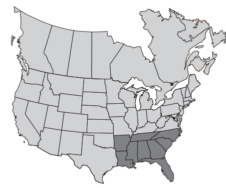

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Effects of Soil Flooding and Drying on Phosphorus Reactions

IN RECENT YEARS, there have been increased reports of phosphorus (P) deficiency in rice and crops rotated with rice on medium-textured soils (silt loams to silty clay loams). There have also been reports of response to P on recently leveled clay soils in the Mississippi River Delta. More fields are being flooded during the winter to enhance waterfowl habitat, manage rice straw, reduce red rice, and suppress winter weed growth.

Phosphorus behavior is not the same in soils that are continuously flooded compared to soils alternately dried and flooded. The duration and depth of flooding affects soil oxygen (O_2) levels, soil pH, P availability, and the levels and forms of some micronutrients. The purpose of this publication is to explain the P reactions under different soil conditions, to offer tips to avoid P deficiency, and to provide information for increased responses to fertilizer P applications.

What happens to soils under flooded conditions?

Oxygen levels—When a soil is flooded (anaerobic conditions), microorganisms use the available soil O_2 to survive. Free O_2 in the soil is usually depleted within a couple of days after flooding. The longer the soil is flooded, the lower the soil O_2 levels become (more reduced). Some O_2 movement does occur from the air, through the floodwater into about the upper ¼ to ½ in. of soil. The deeper the flood, the less O_2 can move from the air into the soil. Most upland crops cannot tolerate prolonged saturation or flooding. In contrast, rice has the ability to transport O_2 from the leaves and stems to the roots. The area immediately around rice roots is usually oxygenated compared to the rest of the soil.

The soil O_2 status can be measured using specialized electrodes and is termed the redox potential. The redox potential is measured in millivolts. The lower the redox potential (more negative), the more reduced (less O_2) the soil is. If the soil O_2 supply is deficient, soil bacteria are forced to get O_2 from other compounds in the soil in the following general order, from first to last: nitrate-nitrogen (NO_3-N), manganese oxide (MnO_2), iron hydroxyoxide (FeOOH), and sulfate-sulfur (SO_4-S). If the functionality of these compounds is exhausted, microorganisms can use some of the energy stored in soil organic compounds and by fermenting organic matter to carbon dioxide (CO_2) and methane (CH_4).

Soil pH—After a soil is flooded, regardless of its original pH before flooding, the pH will approach neutrality (pH 6.5 to 7.5). The pH of alkaline soils declines and the pH of acid soils increases. The change in pH upon flooding may take up to several weeks, depending on the soil type, organic matter levels, microbial population, temperature, and other soil chemical properties (**Figure 1**).

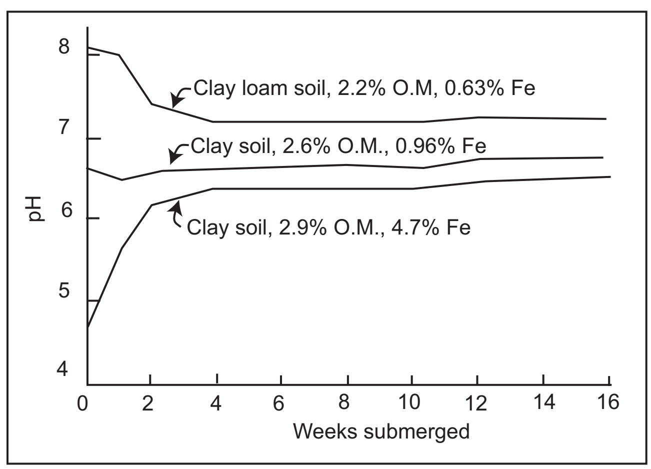

Figure 1. Effect of flooding on soil pH.
Adapted from The Chemistry of Submerged Soils Ponnamperuma, Advances in Agronomy, 1972.

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Soil P—There are two categories of P in soils: organic and inorganic. Soil organic P forms are not readily available to plants. Inorganic P can be grouped into five general categories: iron (Fe) phosphates, aluminum (Al) phosphates, calcium (Ca) phosphates, reductant soluble phosphates (soluble under reduced soil conditions), and occluded Fe and Al phosphates (phosphate covered with Fe_2O_3 or AlO_3 and not available until the covering is removed). Phosphorus must be in the soluble orthophosphate form (HPO_4^{2-}, $H_2PO_4^-$) to be taken up by rice and all other plants.

Flooding (saturation) generally increases the availability of P to rice crops. The increase in P availability to rice under flooded conditions involves the reduction of ferric (Fe^{3+}) phosphate to ferrous (Fe^{2+}) phosphate and the release of P from insoluble Fe and Al compounds and some dissolution of Ca phosphates at higher CO_2 levels in the soil solution. It may take several weeks after flooding until P is released by these processes (**Figure 2**). This initial flush of released P can be adsorbed onto clay particles and Al hydroxides (AlOOH), and may actually result in a temporary decrease in P availability in some soils with large amounts of active Fe and Al.

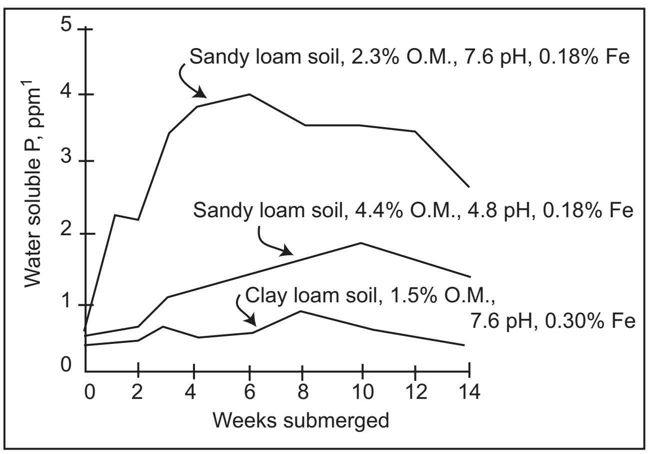

Figure 2. Effect of flooding on available P.
Adapted from The Chemistry of Submerged Soils Ponnamperuma, Advances in Agronomy, 1972.
[1]ppm = parts per million

Maintaining medium to high levels of soil test P helps to hedge against the potential "tie-up" of P and to ensure that soil solution P can be rapidly replenished as plant roots deplete it. Phosphate ions diffuse, or move from areas of high concentration in the soil to areas of low concentration, more readily in moist to flooded soils compared to dry soils. This diffusion distance is less than 0.02 in.

Do current soil test extractants accurately predict the need for P by rice?

There is concern that the current conventional soil test extractants (for example: Bray 1, Mehlich 3, Bray 2, Olsen, etc.) commonly used for upland crops (aerobic conditions) at public and private soil testing laboratories may be poor tools to assess the need for P fertilization for rice. Most soil test P extractants measure only a portion of the inorganic P pool. Studies by University of Arkansas and Texas A&M scientists indicate that extractable P levels tend to increase with increased time after flooding. This same research showed that correlation of extractable P under reduced soil conditions, compared to oxidized conditions, did not generally help to improve the ability to predict plant uptake of P.

Long-term irrigation using well water with high concentrations of Ca^{2+}, magnesium (Mg^{2+}) and bicarbonate (HCO_3^-) has led to increased soil pH in some rice fields. In fields with alkaline soils, most of the soil P may be found in Ca compounds which do not release plant-available P upon flooding. The high concentration of Ca in the soil and irrigation water may result in the precipitation of insoluble Ca^{2+} phosphate compounds for a short time and reduce P availability. Recent research with rice in Arkansas has shown there is a greater potential for a P response by rice on higher pH (equal to or greater than 6.5) silt loam soils compared to more acid soils (less than 6.5). As a consequence, the University of Arkansas considers soil pH and Mehlich 3-extractable P in making soil test interpretations and fertilizer P recommendations for rice (*Better Crops*, 1999, Volume 83, No. 4).

Seasonal variability in soil test P levels is related to the soil O_2 status and changes in temperature and microbial activity, as well as the soil mineralogy. Generally, extractable soil P levels decrease after a flooded field is drained. This makes it particularly difficult to develop a valid soil test P interpretation for rice and rotational crops. Recent research in Arkansas has demonstrated that Mehlich 3-extractable P in spring-sampled fields can be much lower following rice as compared to samples collected after a soybean crop on the same soils receiving different P fertilizer rates (**Table 1**).

Table 1. Effect of fertilizer P applied to previous crop (soybean or rice) in 1998 on spring 1999 Mehlich 3 soil test P level.

1998 P rate	1999 Soil test P		Difference in STP[1]	
lb P_2O_5/A	Rice	Soybean	Rice	Soybean
	- - - - - -	- - - - - - lb/A	- - - - - -	- - - - - -
0	11	22	-12	7
20	11	28	-16	13
40	11	30	-14	14
80	13	42	-15	28
120	13	45	-13	30

[1]Subtracted original soil test P in 1998 from spring 1999 soil test P.
Source: Slaton, RREC in Stuttgart, AR

These observations raise significant concerns about the time (environmental conditions) of sampling and its effect on the measured soil test P level and the ability to predict the need for P fertilizer for rice and rotational

crops (for example: corn, soybeans, grain sorghum, wheat).

As soils dry after field draining, the Fe and Al compounds that became soluble after flooding will react with native and applied fertilizer P to form insoluble P compounds. As fields dry, amorphous FeOOH compounds form which have a high chemical reactivity. They rapidly adsorb soluble phosphates, decreasing P availability. This "tie-up" or fixation of P is more extensive, and less reversible, under alternating flooding and draining than under either continuous flooding or continuously moist conditions. As a consequence of these reactions, P deficiencies may occur in crops that follow rice. Corn and wheat are crops that appear especially sensitive and should receive special P fertilization considerations following rice.

How can P deficiency be avoided in crops following rice, or in crops planted in fields flooded over the winter?

Many farmers are applying common P fertilizers at rates to deliver 46 to 92 lb of P_2O_5/A, at or just ahead of spring planting, to avoid potential P deficiencies. Some farmers have made fall P applications and then flooded the fields over the winter. There is a high risk that the fall-applied P may become "tied-up" as the soils dry and P is bound in insoluble Fe and Al compounds. This is especially a concern for spring-planted crops on soils that test medium or lower in extractable P.

Research on poorly drained soils in Arkansas which are subjected to periodic waterlogged conditions showed that P applications as late as early tillering increased wheat yields on low P soils. Wheat responded to topdressed P applications made anytime between planting and early March on these low P soils. In recent years, more and more farmers have been applying P with the first N application in the spring to stimulate tillering, to overcome P "tie-up", and to prevent P shortage as wheat begins rapid growth and nutrient uptake.

If corn or sorghum follows rice, there is probably a greater need to increase the broadcast P rate to overcome the potential for P "tie-up." Early season P deficiency can take a severe toll on corn and sorghum growth, dramatically reduce yields, and delay maturity. Starter fertilizers containing P can help minimize the risk of P deficiency in corn and sorghum. Although starter P is not a substitute for sufficient broadcast P, it is likely required if corn or sorghum follows rice or winter flooding to supplement good broadcast P fertilizer programs.

In soils that are alternately flooded and dried, it may be important to make annual applications of P at or near planting of spring planted crops to prevent the development of P deficiency on soils testing medium or lower in extractable P.

What is the best timing of P for rice?

Recent research with drill-seeded rice on alkaline silt loam soils indicates the best response by rice is likely when the P is applied pre-flood, and <u>not</u> preplant. In water-seeded (clear water or "mudded-in") rice systems, the optimum P application timing has not been evaluated.

Conclusion

Following rice with upland crops like cotton, corn, wheat, grain sorghum, or soybeans can result in reduced yields of these upland crops if soil test P levels are not maintained in the medium to high range, if adequate P fertilizer rates are not applied at appropriate times, or both. This "rice" effect may last two or more years in upland crops and may also be related to poor soil physical conditions, limited rooting, and mycorrhizal colonization of upland crops.

Farmers, crop advisers, consultants, and fertilizer dealers should understand the seasonal changes in soil test P levels that can occur with soil wetting and drying cycles. These cycles are real, will affect soil test results, and can influence fertilizer recommendations. Fertilizer P recommendations for rice, and for crops on fields rotated with rice, which are based strictly on a soil test P interpretation may need to be refined using information like soil pH, soil temperature at planting time, tillage system (no-till, conventional till), rice cultural system (drill seeded, clear water seeded, mudded-in/water seeded), and whether the field has been recently leveled or not.

One way to reduce the risk of P deficiency of crops following rice…or following winter flooding for wildlife habitat…is to build soil test P levels to the medium to high range and to apply at least 40 to 60 lb P_2O_5/A just ahead of the spring planted crops. For drill-seeded rice, on high pH soils (above 6.5), the best management practice would be to apply fertilizer P preflood.

When considering the need for P fertilization, farmers should think of ways to protect the fertilizer investment, maximize plant uptake, and reduce the risk for undesirable impacts on water quality. Runoff losses of P should be managed to minimize the potential for eutrophication of surface waters and harmful algae blooms. ■

For more information on crop nutrient management, visit the website at www.ppi-ppic.org

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