UF | IFAS Extension
UNIVERSITY of FLORIDA

AE507

Factors Affecting Phosphorus Leaching and Groundwater Concentrations for the Plasticulture Vegetable-Production System[1]

Sanjay Shukla, Gregory S. Hendricks, Thomas A. Obreza, and Willie Harris[2]

Phosphorous Fertilizer and Vegetable Production

Successful commercial production of vegetables and melons requires a continuous supply of available soil phosphorous (P) during the growing season, which often requires application of P fertilizer. However, applying fertilizer in excess of plant needs can cause a surplus of soil P that may leach into groundwater. Subsequently, this leached P may travel to surface water where it can adversely impact a freshwater body. Although considered less mobile than nitrogen, P leaching does occur in Florida due to its sandy soils and can affect the quality of water leaving farmlands. The degree of P loss from agricultural fields depends on rainfall and irrigation, distance to the water table, the ease with which water can move through the soil (i.e., the conductivity), and the type of crop produced.

Most vegetable crops grown in Florida (e.g., watermelon and tomato) are produced on raised crop beds infused with granular fertilizer (including P) and covered with plastic mulch. The majority of vegetable and melon crops are produced in south Florida where the groundwater is shallow and can reach the surface during the wet season (June–October). Highly conductive sandy soils with shallow water table depths mean that most plant-available P (labile P) not used by the crop during the growing season can quickly leach from the root zone into shallow groundwater, where subsequently a large part of it travels to the farm's drainage system.

Although Best Management Practices (BMPs) have been developed to reduce the loss of nutrients (like P) to the environment, limited information exists on the main factors that control P loss to Florida groundwater. For example, while it is generally accepted that both irrigation and fertilizer P impact groundwater P, growers often ask if controlling one is more advantageous than the other in their efforts to reduce P leaching. There exists no easy tool to link fertilizer P input and other factors to groundwater P concentration. The authors of this publication explored the development of simple relationships to predict the response of groundwater P to changes in fertilizer P and irrigation inputs in Immokalee, Florida. We also examined if such a relationship varies by growing season (spring and fall). Long-term data (six growing seasons) from a farm in Immokalee, Florida, were used to explain the effects of soil and agronomic factors, along with seasonal rainfall, on groundwater P. We then developed simple equations to predict groundwater P concentrations using these factors.

---

1. This document is AE507, one of a series of the Agricultural and Biological Engineering Department, UF/IFAS Extension. Original publication date August 2014. Visit the EDIS website at http://edis.ifas.ufl.edu.

2. Sanjay Shukla, associate professor, Agricultural and Biological Engineering, UF/IFAS Southwest Florida Research and Education Center, Immokalee, FL; Gregory S. Hendricks, senior engineer, Agricultural and Biological Engineering, UF/IFAS Southwest Florida Research and Education Center, Immokalee, FL; Thomas A. Obreza, professor, Soil and Water Science and Extension administration; and Willie Harris, professor, Soil and Water Science; UF/IFAS Extension, Gainesville, FL 32611.

Data from Tomato and Watermelon Fields

Tomato (*Solanum lycopersicum*) and watermelon (*Citrillus lanatus*) were grown during the spring and fall seasons for three years (six growing seasons) at the UF/IFAS Southwest Florida Research and Education Center, Immokalee, Florida. Immokalee fine sand is the main soil type for the study site with a soil profile consisting of A, E, and Bh horizons. The crops were grown with two different irrigation methods, seepage and subsurface drip irrigations, and with two different fertilizer P rates. The two fertilizer rates were (1) average rates used in southwest Florida in 2004 for the two crops and (2) recommended rates based on the manual *Water Quality/Quantity Best Management Practices for Florida Vegetable and Agronomic Crops* (http://www.freshfromflorida.com/content/download/32110/789059/Bmp_VeggieAgroCrops2005.pdf). The average rates (called "GI" here) varied from 162 to 172 lb/ac P_2O_5, while the recommended P input ("RI") varied from 0 to 120 lb/ac P_2O_5. The RI rates were based on a Mehlich-1 soil P (M1P) test. Traditional seepage irrigation, which involves artificially raising the shallow water table to provide sufficient soil moisture in the root zone, was used with both GI and RI fertilizer P rates. The RI treatments were also applied under subsurface drip irrigation, which involved installing drip lines 45 cm (18 in) below the soil surface to provide soil moisture to the root zone. The RI fertilizer rates were used with subsurface drip (RI-SD). For the GI fields, the water table was higher than the RI fields, which resulted in higher soil moisture (16%–20% by volume) for GI compared with RI (8%–12% vol). Soil samples were taken during each season and analyzed for M1P. Groundwater samples, taken from shallow groundwater (above the Bh horizon or spodic layer) on a weekly basis, were analyzed for total P (TP). Soil moisture and depth to groundwater were also measured.

Fertilizer P and plant P uptake data were used to develop a simple P budget and estimate surplus P (fertilizer P minus crop P uptake) in crop beds for each season. The surplus P is an indicator of P left in the field after the crop is harvested. The surplus represents the potentially leachable P that can move to the groundwater. The M1P, fertilizer P, surplus P, rainfall, and water table depth were examined to identify important factor(s) that influenced the groundwater P concentration. Once important factors were identified, simple equations (which will be discussed later) were developed to examine if groundwater P concentrations could be estimated from readily available data used by growers to manage their crops.

Phosphorous Surplus and Mehlich-1 P

Soil M1P was similar for GI, RI and RI-SD (Shukla, Hendricks, Obreza, and Harris, 2014) when all three systems received fertilizer P for the first three growing seasons (spring 2004, fall 2004, and spring 2005). Mehlich-1 levels stabilized around 55 mg/kg (ppm) for both RI systems and showed a gradual decrease after P application stopped. On the other hand, applying P fertilizer every season despite the sufficient plant-available P already present in the soil resulted in M1P value reaching a high of 145 ppm by the end of the last season (fall 2006; Fig. 1). The M1P for the GI fields was almost three times the value measured in RI and RI-SD fields (Fig. 1).

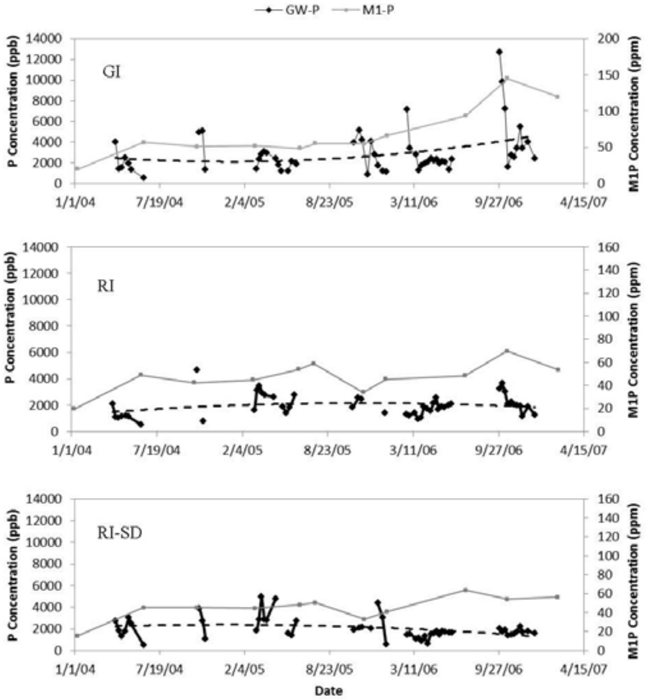

Figure 1. Groundwater total phosphorus (P) and soil Mehlich-1 P (M1P) concentrations for average grower (GI), recommended (RI), and recommended with sub-drip (RI-SD) water and fertilizer P inputs for the period of study (2004–2006). Groundwater samples were collected biweekly during crop season, and M1P samples (0–20 cm) were collected before and after crop season. Dotted lines show second order polynomial trend for P concentration over the period of study for each treatment.

Credits: Sanjay Shukla, Gregory S. Hendricks, Thomas A. Obreza, and Willie G. Harris

Phosphorus buildup (shown by M1P values for the GI fields in Figure 1) was also supported by the accumulated surplus P values (shown in Figure 2). The accumulated surplus includes the potential surplus carried forward from the previous season. Application of fertilizer P beyond plant needs resulted in the highest surplus for the GI fields by the end of the sixth season (Figure 2). This high surplus P for the GI was the main reason for buildup of P in the soil that resulted in a M1P value of 145 ppm by the end of the study (fall 2006). In contrast, the peak accumulated surplus P (Figure 2) for both RI and RI-SD systems occurred during the middle of the study (spring 2005) and was only a third (74–75 lb/ac) of the respective values for the GI fields. After spring 2005, accumulated P surplus values for both RI systems (RI and RI-SD) became negative (a result of no fertilizer P), showing that plant needs were satisfied by P surplus from the previous season. Hence, a steady decline in accumulated surplus P started in fall 2005 and reached a minimum (30–36 lb/ac) by the end of the study (Figure 2). The accumulated surplus P for GI (270 lb/ac) was almost seven times greater than the two recommended systems (RI = 30 lb/ac, RI-SD = 36 lb/ac). The gradually increasing trend in surplus P (Figure 2) is similar to the trends in groundwater P for the GI (Figure 1), indicating that surplus P was a good indicator of P concentrations in groundwater beneath the vegetable fields. Not all surplus P will reach the groundwater; a part of the surplus P can be transformed or adsorbed by the soil before reaching groundwater. Like in the GI fields, the surplus P trends for RI and RI-SD (Figure 2) were similar to the groundwater P trends in these fields (Figure 1).

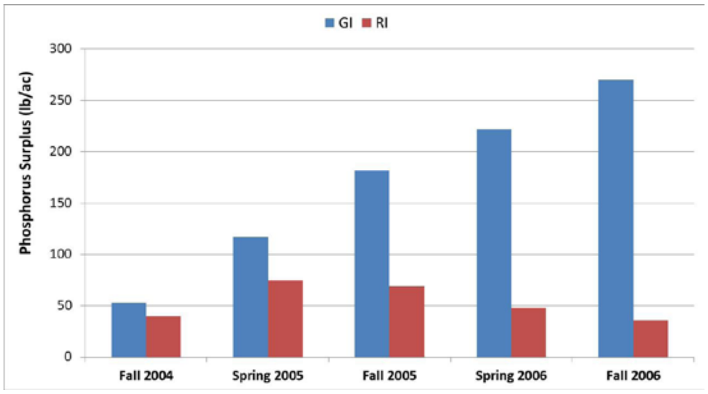

Figure 2. Seasonal accumulated surplus P (fertilizer P minus plant P uptake) for seepage-irrigated tomato-watermelon fields with average (GI) and recommended (RI) water and fertilizer P inputs.
Credits: Sanjay Shukla, Gregory S. Hendricks, Thomas A. Obreza, and Willie G. Harris

Factors Affecting Groundwater P Losses

Fertilizer P and plant uptake P had a stronger influence on groundwater P than water-related factors (rainfall, irrigation, soil moisture, and groundwater depth). Relationships with groundwater P were examined using the correlation coefficient (*r*), a statistical measure to represent the degree of correlation between two variables. The closer the *r* is to 1, stronger the relationship between the two factors. Positive *r* values indicate that when one variable increases the other also increases, while negative *r* shows the reverse, meaning that when one variable increases the other decreases. Groundwater P was related to M1P ($r = 0.64$), plant uptake P ($r = 0.54$), fertilizer P ($r = 0.49$), and surplus P ($r = 0.41$); these relations were confirmed to be statistically significant. Among the water-related factors, groundwater depth was the only one that had a relationship with the groundwater P ($r = -0.27$), although it was weak. Negative *r* here means that the deeper the groundwater depth, the lower the P concentration. A deeper water table increases the capacity of the soil to store rainfall without flooding the row-middles. After a significant rainfall, the water table can reach the soil surface, saturating the bottom of the bed and dissolving the fertilizer P in the bed. As the water table recedes, it can flush out the P from the bed. Furthermore, a deep water table also increases the time required for the P to reach the groundwater, which increases its potential to be retained in the soil. Fall and spring seasons differ in rainfall received, with spring being drier. Average regional rainfall in south Florida for the fall season (32 in) is 88% higher than the spring season (17 in). Water-related factors became important in explaining groundwater P when season-specific correlations were examined. For the spring season, two water-related factors—rainfall ($r = 0.52$) and soil moisture ($r = 0.46$)—became important in affecting the groundwater P concentrations. Mehlich-1 soil test P values were found to be a good predictor of groundwater P for the fall growing season, as well as on an annual basis. Fertilizer P was also found to be important, because it directly influenced M1P values in the soil.

Using a statistical technique called *multi-variate regression*, easy-to-use equations were developed for estimating groundwater P using more than one variable (multivariable). These equations are presented below.

Equation 1 $\mathrm{GWP}_{\mathrm{fall}} = 871 + 21.9\ \text{Mehlich-1P} + 15.6\ \text{Fertilizer-P}\ (r^2 = 0.93)$

Equation 2 $\mathrm{GWP}_{\mathrm{spring}} = -2476 + 12.8\ \text{Fertilizer-P} + 55.5\ \text{WaterTable} + 13.6\ \text{Rainfall}\ (r^2 = 0.76)$

Equation 3 $\mathrm{GWP}_{\mathrm{annual}} = 595 + 25.2\ \text{Mehlich-1P} + 10.2\ \text{Fertilizer-P}\ (r^2 = 0.67)$

1 ppm = 1000 µg/L; 1 ppm = 1 mg/kg; 1 in = 2.5400 cm; 1 lb/ac = 1.1209 kg/ha

GWP_{fall}, GWP_{spring} and GWP_{annual} are groundwater P concentrations (µg/L, parts per billion or ppb) above the Bh horizon for spring, fall, and annual periods, respectively; Fertilizer-P is the amount of P applied (kg/ha); Mehlich-1P is the average soil test P (mg/kg) for each season; Rainfall is the total rainfall (cm) for the spring season; and WaterTable is the average water table depth (cm) for the spring season.

Equations 1, 2, and 3 can be used to estimate the groundwater P concentrations (µg/L) in the shallow groundwater for the spring, fall, and annual periods. The main intent of these equations is to show the important factors that affect groundwater P concentration. These equations can be used to approximate the aggregated response of agronomic and water-related factors on groundwater P. These are applicable to similar production systems and environments, and illustrate that M1P and fertilizer P are the two most important factors that govern subsurface P losses for vegetable production in shallow water-table regions of Florida. The fall equation (Equation 1) does not include water-related factors due to large amounts of rainfall received during the first two months (September and October) of the fall season that occurs within Florida's wet period (June–October). Equation 1 shows that the amount of fertilizer P applied is a more important factor than water management for the fall season. For the dry spring season, irrigation (water table depth) also became an important factor that affected the leaching of P from the crop beds to the groundwater.

Example Application

Below is an example application of the above equations to estimate the potential groundwater P concentrations for two cases of fertilizer P applied during the fall crop season. We compare the impact that 84 kg/ha (75 lb/ac) of fertilizer P would have on groundwater compared with no P application for a soil with M1P of 30 mg/kg (ppm) at a vegetable farm in south Florida with shallow water-table environment. Equation 1 is applied for this scenario since it is applicable to the fall growing season.

With P input:

Equation 1 shows $GWP_{fall} = 871 + 21.9$ Mehlich-1P + 15.6 Fertilizer-P.

For this case, Fertilizer-P = 75 lb/ac and Mehlich-1P = 30 ppm or mg/kg (1 ppm = 1 mg/kg).

Equation 1 requires SI units.

Therefore, Fertilizer-P = 75 lb/ac = 84 kg/ha (1 lb/ac = 1.12 kg/ha).

From Equation 1, $GWP_{fall} = 871 + (21.9 \times 30) + (15.6 \times 84)$

$= 871 + 657 + 1310$

$= 2,838$ ppb (or mg/L).

With no P input:

For this case, Fertilizer-P = 0 lb/ac = 0 kg/ha, and Mehlich-1P = 30 ppm = 30 mg/kg.

Therefore, in Equation 1, $GWP_{fall} = 871 + (21.9 \times 30) + (15.6 \times 0)$

$= 871 + 657 + 0$

$= 1,528$ ppb.

By subtracting 1,528 ppb (no fertilizer P) from 2,838 ppb (with 75 lb/ac), we get 1,310 ug/L, which is the approximate reduction of P in groundwater achieved when fertilizer P is applied based on P soil test, which is the recommended BMP for vegetable production system in Florida.

Summary

Results showed that a greater focus on fertilizer management (vs. water management) is required during the wet fall season. However, for dry spring seasons, the focus should also be to carefully manage the irrigation for seepage-irrigated vegetable farms, because both water table and rainfall were found to be important factors in influencing P concentrations in groundwater beneath south Florida vegetable farms. The equations presented here require readily available data already used by vegetable growers to manage their crops. Growers use rainfall and water table depths to manage irrigation and drainage, and soil test P (M1P) is used to determine the amount of fertilizer P application for a specific crop. These equations are simple and can be used as screening tool by growers. Although the equations represent comprehensive long-term data, they may not work for all farms. The relationships are representative of dual cropping systems with plastic-mulched beds and shallow water-table conditions. The equations presented here should be used as a management tools by growers and not for any other purpose.

References

Hendricks, G.S., S. Shukla, T.A. Obreza, and W.G. Harris. 2014. Measurement and modeling of phosphorous transport in shallow groundwater environments. *Journal of Contaminant Hydrology* 164: 125–137. Available at http://dx.doi.org/10.1016/j.jconhyd.2014.05.003

Shukla, S., G.S. Hendricks, T.A. Obreza, and W.G. Harris. 2014. *BMP-Recommended Water and Phosphorus Inputs for Tomato and Watermelon Can Reduce Environmental Losses of Phosphorus and Save Water*. Gainesville: University of Florida Institute of Food and Agricultural Sciences. https://edis.ifas.ufl.edu/ae504.