Nutrient Mass Budget—The Case of Florida Watermelon Phosphorus Export[1]

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Watermelon is one of the top five vegetable crops in Florida, contributing significantly to the state's vegetable industry crop value. Watermelons are grown widely in the state with raised beds, plastic mulch, and drip irrigation (Figure 1). Over the last 20 years, the Florida watermelon industry has shifted from seeded watermelon varieties to seedless watermelon varieties (Figure 2) (Maynard, 2003). Watermelon crops require phosphorus (P) for optimum growth and profitable crop production. The P needed by the crop can be derived from native, or legacy, P already in the soil or from fertilizers that are applied when the native P is not sufficient. The contribution of the native or legacy P pool to the crop nutrient requirement can be predicted from the Mehlich-1 soil test extractant (Hochmuth and Cordasco 2009; Olson et al. 2010*)*. In many watermelon-growing areas of the state there are concerns over nutrient loads of P in the environment, and best management practices (BMPs) are being recommended so that watermelon P fertilization does not unnecessarily add to the nutrient load.

An important part of understanding the potential benefit of BMPs is to know the pools of P available to the crop so that proper management strategies can be put in place to prevent loss of P from these pools to the environment. Calculating the *mass balance* for P for the environment is the first step. According to the US Forest Service, the mass balance for any "quantity of interest"—water, a given nutrient, etc.—in a system is determined by comparing inputs to outputs. (US Forest Serv. 2008). Sources of P to the watermelon crop can include synthetic or organic-material fertilizers, native soil organic matter, crop residue, legacy or native soil-P, atmospheric deposition, and P from irrigation waters. Outputs of P can include the P in the harvested watermelon fruits sold off-farm, and P lost through leach-ing and runoff. The nutrient mass balance approach, as used in this EDIS document, determines the nutrient status of a production system by comparing the nutrient sources and inputs to the system with the outputs or exports, and losses from the system.

Figure 1. Watermelon production in Florida on raised beds and plastic mulch.

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Figure 2. Seeded and seedless watermelon fruits (from D. N. Maynard 2003).

The nutrient mass balance of P of these pools (sources, recycled P, and outputs) can provide an indication of the potential for P to be lost from the site in runoff or leachate and determine if there is a net balance of P, or if P is being built up in the crop production system, or if there are potential losses of P to the environment. This mass balance information can help the farmer determine production practices for management attention to prevent environmental degradation and to maximize profits from fertilization practices.

Watermelon provides an interesting example of how the P nutrient balance on the farm has changed over time with changes to production practices and acreage, which changes seem to have little to do with responding to environmental protection. In this paper the calculations are described for the export of P from Florida in the state's watermelon fruits. This analysis uses data from the 2008 and 1985 Florida watermelon crops (USDA-ERS 2009).

Data for Mass Balance Calculations

Units and Terms

Pound (lb)

Kilogram (kg)

Gram (g)

Milligram (mg)

1 kg = 2.205 lb

The calculations of the export of P from Florida in the state's watermelon fruits are based on the following data from the 2008 harvest year (USDA 2009; USDA-ERS 2009):

26,700 acres planted

26,100 acres harvested

33,000 lbs per acre average yield

26,100 acres times 33,000 lbs per acre = 861,300,000 lbs harvested

There were 521,900,000 lbs (61% of the total of 861,300,000 lbs) shipped to out-of-state markets from Florida in 2008.

*Note: we are assuming that nearly 100% of the watermelons shipped out of the state were seedless fruits and that there were negligible seeded fruits. This is a fair assumption since the market is mainly for seedless fruits, only a small percentage of the crop is seeded pollenizers, and growers are now using special pollenizer plants that do not take up significant space in the fruiting field instead of seeded varieties to provide pollen for seedless watermelon production (Freeman and Olson 2007). The change to the seedless watermelon was driven by demand from the consumer for seedless fruits.

There are 11 mg P per 100 g edible fresh watermelon pulp, or "flesh" (USDA-ARS 2009).

*Note: we assume the edible pulp and rind make up about equal proportions by weight of the total fruit. This assumption was tested on 5 July 2010. A seedless watermelon (optimum ripeness) weighing 20.5 lb (9.30 kg) was separated into red pulp and rind. The rind portion weighed 10.5 lb (4.76 kg) and the red pulp portion weighed 10.0 lb(4.54 kg). There may be some variation for this proportion due to the variety (some might have thicker rinds than others), for degree of ripeness (overly ripe fruits may have the red color extending further into the rind layer), and personal preference for what is considered "rind." For calculation purposes, it appears reasonable to assume a 50:50 fresh weight ratio of rind and pulp.

We assume there are likewise 11 mg P per 100 g of rind; no data were available in the literature to refute this assumption. Therefore, in each 200 g total fresh melon (100 g pulp plus 100 g rind) there are 22 mg P. It follows that there are **110 mg P per kg of fresh seedless watermelon fruit.**

There are 755 mg P in the seeds associated with100 g of pulp from seeded watermelons (USDA-ARS 2009). There are also 11 mg P in the 100 g pulp (see above). There are 11 mg P in 100 g rind, as above. In sum, there are 777 mg P in every 200 g of melon (seeds, plus pulp, plus rind). It follows that there are **3,885 mg P per kg of fresh seeded watermelon fruit.**

Calculations

There were 521,900,000 lb seedless watermelons shipped from the state in 2008 times 0.454 (kg/lb)= 236,942,600 kg shipped times 110 mg P per kg of fruit= 2.6063 X 10^{10} mg P. Therefore, 2.6063 X 10^{10} mg P =26,063 kg P times 2.205 lb/kg = 57,470 lb of P (elemental P) or 133,650 lb of P_2O_5 shipped from the state in 2008 in the seedless watermelons.

If we look back in time about 25 years, when all the watermelons were seeded, then we have an additional pool of P in the fruit from the seeds. The same 200 g sample of watermelon fruit has 755 mg P (USDA-ARS 2009) in the seeds. Seeds are rich in P. We also have the same 22 mg P in the pulp plus rind in the 200 g sample. Therefore, we have 3,885 mg P in a kg of fruit.

Using the same approach as above:

521,900,000 lb shipped times 0.454 kg/lb= 236,942,600 kg shipped times 3,885 mg P per kg of fruit= 9.2052 X 10^{11} mg P. Then 9.2052 X 10^{11} mg P =920,520 kg P = 2,029,751 lb of P (elemental P) or 4.72 million lb of P_2O_5 shipped if today's crop were all seeded fruits.

There is another aspect to this story:

In addition to shipping all seeded fruits 25 years ago, we were shipping about 50% more watermelons than today.

Using data from 1985, we shipped 839,700,000 lb. of watermelons from Florida. The calculations are: 839,700,000 lb shipped = 381,223,800 kg shipped times 3,885 mg P per kg of fruit= 1.48 X 10^{12} mg P. 1.48 X 10^{12} mg P =1,481,054 kg P = 3,272,340 lb of P (elemental P) or 7.61 million lb of P_2O_5 exported in 1985.

Twenty-five years ago we were exporting 57 times the amount of P through out-of-state sales than we are exporting today. Two reasons account for this difference. First, Florida ships fewer watermelons today than 25 years ago. Increases in Texas and Georgia shipments have made up for the decline in Florida production. The second reason is the switch to the seedless watermelon varieties over the last two decades. The switch was made for reasons of enhanced fruit quality for the consumer and enhanced economic stability for the grower.

Twenty-five years ago, the average P fertilizer application was 52 lb elemental P (120 lb P_2O_5) per acre, and today's rate is essentially the same (50 lb P) (Fla. Agr. Stats. Serv.1995; USDA 2007). This value is equivalent to the P fertilizer recommendation application rate that would be made if all soils were classified as having medium levels of Mehlich-1 P. In 1985 there were 59,000 acres of watermelons in Florida, each receiving the average of 52 lb P (total of 3,068,000 lb P), and in 2008 there were 26,700 acres planted, each receiving 50 lb P (1,335,000 lb P). Using the above calculations for fruits, we have the following P mass balances for what was applied (imported to the farms) and what was exported:

- 1985: 3,068,000 lb P applied and 3,272,340 lb of P exported (7% more exported than applied)
- 2008: 1,335,000 lb P applied and 57,470 lb of P exported (we exported only 4% of what was applied)

Watermelon is an interesting case in P mass balance. Getting rid of the seeds has had interesting consequences. We applied 2.3 times the total crop amount of P for watermelons in 1985 than we do for today's crop due to the reduced acreage today. However, we exported 57 times more P in 1985 than we did in 2008 because the crop was larger in 1985 and we grew seeded watermelon varieties (which contained more P) in 1985. Today, research has documented the usefulness of the Mehlich-1 soil test to predict P fertilizer needs.

The test has shown that many watermelon fields may not need P fertilizer or need considerably less than the maximum recommendation. Noteworthy is the fact that in 1985 we exported 204,000 lbs P more than were applied. Some of the extra probably came from legacy P in the soil prior to the application of fertilizer-P. However, in 2008 we applied 1,277,530 more than we exported. Historically we were exporting large amounts of P with seeded watermelon, but now with seedless types of watermelon we are exporting considerably less. In 1985 there was a net removal of P from the state, whereas now there is net accumulation of P. The P accumulation could increase the likelihood of environmental losses. This finding means that following phosphorus BMPs today (for example, not applying P when the nutrient is already in ample supply in the soil) is even more important than ever for controlling P on watermelon farms, especially on those farms in watersheds with P-impaired water bodies.

This paper is the result of a class project on nutrient mass balance for SWS/AGR 6932 in the Summer A session of 2010, taught by the authors, with students Caroline Rolman, Jerry Dewberry, Jonathan Jasinski, Steven Clemons, Daniel Tompkins, and Todd Leeson. The original question was posed by Mr. Pete Deal of USDA NRCS. It turns out to be a very interesting example of the intersection of environmental sciences and agricultural crop production dynamics.

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