Adjusting Nutrient Recommendations for High Yielding Corn

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Take Home Points

1. The University of Kentucky bases its phosphorus (P) and potassium (K) recommendations on interpretations of soil test correlation and calibration data. University scientists verify these recommendations on an ongoing basis and have found them to be adequate to support modern, high yield corn grain production.
2. Differences between University of Kentucky fertilizer recommendations and recommendations from other sources arise from differences in recommendation philosophies, which fall on a spectrum of sufficiency (fertilizing to maximize yield) to build and maintain (fertilizing to maintain the amount of nutrient in the soil).
3. In high yield corn grain production paying attention to timing, placement, and source of nutrients is just as critical as the rate of nutrient applied.
4. Ultimately, the small increase in nutrient removal over the past 40 years as a result of increased yields is outweighed by modern corn hybrids' ability to access soil nutrients and the extra nutrition built into University of Kentucky fertilizer recommendations to compensate for field and climate variability.
5. University recommendations are a starting point. Tracking your soil test levels over time, along with your fertilizer inputs and yields (nutrient removals) provides valuable information to help guide site specific nutrient recommendations.

We get a lot of questions about adjusting nutrient recommendations for the higher yields Kentucky corn growers see today. Often consultants and farmers question whether "outdated university recommendations" can support today's high corn yields. Right now, in the fall, many farmers are making nutrient decisions for next year's crop, so let's take a minute and address these questions.

First, let's review some basics about nutrient management and crop nutrient requirement. For the most part, we're going to address the "primary macronutrients," phosphorus (P) and potassium (K) in this article, but nitrogen (N) is also an important primary macronutrient. Macronutrients are those required in the greatest amount by plants. In addition to N, P, & K, there are three "secondary macronutrients," calcium (Ca), magnesium (Mg), and sulfur (S). The secondary macronutrients are also required in large amounts, but we expect Kentucky soils to provide these secondary nutrients and so we don't typically need to add them with fertilizer. The micronutrients are required in far lower amounts than the macronutrients. For example, N concentrations in plant tissues will typically be 1,000,000x greater than molybdenum (Mo) concentrations. A plant sufficient in all the essential elements on average will have about 30x higher N concentrations than P or S, the macros required in the lowest amount, but still have 10x more P and S than chlorine (Cl), the micro that occurs at the highest concentration in plant tissue. As a side note, P and S present an interesting case. Phosphorus is required in lower amounts than two of the secondary macros, Mg and Ca, but is still considered a primary because typical soils do not provide enough P to support optimum growth and so we need to fertilize the soil with P. Historically, we did not need to apply S fertilizer because our soils were high in S from atmospheric deposition and because fertilizers used to have lots of impurities, including S. However, fertilizer manufacturers have reduced these impurities and air quality regulations have reduced S deposition, so S is a nutrient we want to keep an eye on. On sandy soils with low organic matter and high crop demand we now often see a need to add fertilizer S (for more information on S refer to AGR-198. (http://www2.ca.uky.edu/agcomm/pubs/agr/agr198/agr198.pdf).

Getting back to the original question, do current recommendations support high yielding corn? Let's think about how we determine the rate of fertilizer required for top yields. Back in the 1960's a USDA scientist, Dr. George Stanford, wrote a paper that described N fertilizer rate as an equation. This equation holds for other nutrients as well and is a useful way to think about fertilizer rate decisions. In its most basic form, Stanford's Equation says fertilizer rate (R_f) is equal to total plant uptake of that nutrient (P_n), minus nutrient supplied by the soil (S_n), and divided by fertilizer efficiency(E_f).

$$R_f = \frac{P_n - S_n}{E_f}$$

Plant nutrient uptake represents the total amount of nutrient taken up by the crop on an area basis. We can determine this number by multiplying the amount of plant biomass by the concentration of nutrient in that plant biomass. This number is sometimes confused with nutrient removal, which would be the mass of grain removed from the field at harvest multiplied by the nutrient concentration in that grain.

Plant nutrient uptake and nutrient removal are similar for silage and hay and represent a situation where closer attention to soil testing is needed. For example, a corn crop yielding 230 bu/a might have a whole crop dry weight of 21,000 lb/acre and an average tissue N concentration of 1.2%, resulting in a total N uptake of 252 lb/acre. However, that same corn crop might have a grain N concentration of 1.1%, resulting in a total N removal of 120 lb/acre. Since we need a healthy plant to produce the grain, we need to make sure we are providing an adequate amount of nutrient to the whole plant at the right time during the growing season. Plants need to have a "sufficient" amount of nutrient in the tissue to support optimum performance. When the tissue concentration is below this optimum level or "critical level" we say the plant is deficient (Figure 1). The trick in nutrient management is keeping the plant in the sufficient range with the minimum fertilizer investment. Looking at Stanford's equation we can clearly see that if yields are increasing over time, then plant nutrient uptake (P_n) has also increased over time, and so, it follows that the fertilizer requirement (R_f) has also increased over time with yields. Well, this isn't necessarily the case. We need to understand where soil test recommendations for P and K come from to understand why.

The S_N, or the amount of nutrient provided by the soil, can be a little more confusing and tough to nail down, particularly for a nutrient like N that can rapidly change between forms and is often mobile, meaning it can be lost from the soil system. Except in very limited situations where there is a lot of organic N in the soil, like after a manure application or leguminous cover crop, we don't have a functional soil test for N in rainfed regions like Kentucky. As a side note, Mehlich 3 has not been correlated or calibrated for S, because back when the correlation and calibration work was done we were getting S for free and therefore didn't need a S soil test – so don't believe anyone who tells you they can make a S recommendation based on your soil test. However, even nutrients like P that are immobile in the soil can be confusing, partly because of how we talk about soil testing. Soil testing provides us with an index of the amount of nutrient that might become available during the growing season, not the total amount of a nutrient in the soil and not even the amount of plant available nutrient in the soil. The University of Kentucky Soil Testing Lab (UKSTL) reports nutrients using units of pounds per acre. However, the number reported is not the amount of plant available nutrient per acre, it's simply the amount nutrient extractable by the Mehlich 3 solution per unit of soil. This begs the question, if the number reported from a soil testing lab is just the amount of Mehlich 3 extractable nutrient, which isn't the total or even the plant available amount of nutrient, how do we use that number to guide fertilizer rate? The processes of correlation and calibration allow us to make fertilizer recommendations from soil test data.

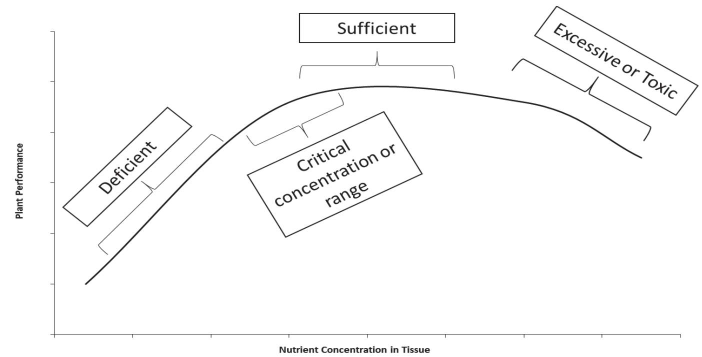


Figure 1. Plant nutrient status can be defined as deficient, sufficient, or excessive (which might result in toxicity). The critical range or concentration is the plant tissue nutrient concentration above which increases in tissue concentration do not result in increased plant performance. Below the critical range adding that nutrient results in increased plant tissue concentration and increased plant performance (yield).

Nutrients reside in different soil pools, which provide long-term to short-term nutrient supply as well as immediately available or labile nutrients (Figure 2). For example, many soils have very large pools of P stored in minerals that don't dissolve easily, in fact much of this P might never become available to crops. However, when the soil is warm and moist, organic matter has some P that easily transforms, or mineralizes, to inorganic phosphate that plants can use. This is one reason we often see plants grow out of a nutrient deficiency after a couple warm days. Soil test extractants, like Mehlich 3 used here in Kentucky, extract portions from each of these pools. These extractants were designed to provide a reproducible relationship between extracted nutrient and plant nutrient sufficiency. In other words, we look for a soil test critical level that indicates plants grown on that soil will have a nutrient tissue concentration above the tissue critical level seen in Figure 1. We call this process of determining soil test critical level soil test correlation. One way to go about this is to conduct studies at multiple sites where the yield with adequate fertilizer is compared to a check where no fertilizer was applied. The relative yield for that nutrient would be calculated as the yield without fertilizer divided by the yield with sufficient fertilizer. This sort of correlation study would be conducted at multiple sites that span a range of soil test concentrations. Plotting these relative yields, which should mostly fall below one (assuming the yields of fertilized plots exceed the unfertilized plots), against soil test provides a curve that can be evaluated to determine the critical soil test level, often defined as soil test above which relative yield > 0.95. Figure 3 provides an idealized relationship established through soil test correlation. Often in the real world the relationship between soil test and yield is a lot fuzzier than what is shown here. As a result, we make bets based on probability of a response to fertilizer at a specific soil test. Research has found that the lower the Mehlich 3 extractable P or K the higher the probability that fertilizer will pay off with higher yields.

The next step in building soil test recommendations, calibration, divides soil test results into interpretive categories and assigns fertilizer rates to these categories. For example, UKY's AGR1 (http://www2.ca.uky.edu/agcomm/pubs/agr/agr1/agr1.pdf) divides soil test P into very low, low, medium and high categories, corresponding to high, medium, low, and no fertilizer recommendations. Calibration determines how much fertilizer should be applied for each of these categories. A calibration study should measure yield response to multiple fertilizer rates and be conducted at multiple sites. Typically, we look for sites with soil test concentrations below the critical level identified during the correlation phase, but sometimes correlation and calibration are conducted simultaneously. Figure 4 shows an idealized yield response curve for three different field sites, each with a different soil test nutrient value. Notice that we can get to virtually the same yield with different soil test levels in some instances, it just takes more fertilizer to get there at the lower soil test values. Sometimes fields with low soil test levels yield much better or much worse than fields with high soil test levels, this is because a field's productivity and fertility are separate issues. A field can be very fertile, but not productive. What's more, the plant doesn't care much whether it gets its nutrients from the soil or the fertilizer you add.

Now we're finally getting to the heart of the question, are university recommendations too low to support modern yields? This question implies that other sources provide higher fertilizer recommendations than the university, even for the same soil test levels. However, most private sector nutrient advisers or soil testing labs rely on university soil test correlation and calibration (if your lab or consultant has performed correlation or calibration you should ask to see their data, it might be very informative). As a side note, correlation and calibration studies must be conducted locally to represent your soil and climate conditions. Similarly, you cannot use recommendations based on one chemical extractant, like Mehlich 3 used by UKSTL, for results from another extractant, like Bray or Olsen. The difference between recommendations usually comes from different soil test philosophies. Most fertilizer recommendation systems use either a sufficiency approach, a build and maintain approach, or a hybrid of these two approaches. The sufficiency philosophy relies on applying the amount of fertilizer required to maximize yield each year. The build and maintain approach tries to build soil test levels rapidly to an optimum level and to replace nutrients removed by crop harvest or soil sorption. A pure build and maintain approach never has zero application. Most systems use some hybrid that does provide a zero fertilizer recommendation when soil test hits some level above which there is a very low probability of yield return. At the low end of the soil test scale build and maintain approaches recommend much more fertilizer than would be expected to maximize yield. The sufficiency approach requires more frequent soil testing and fertilizer applications and requires confidence in good soil test calibration and correlation data. The build and maintain approach is less profitable, but might be considered more risk averse since recommended rates are much higher than what crops require for maximum yield.

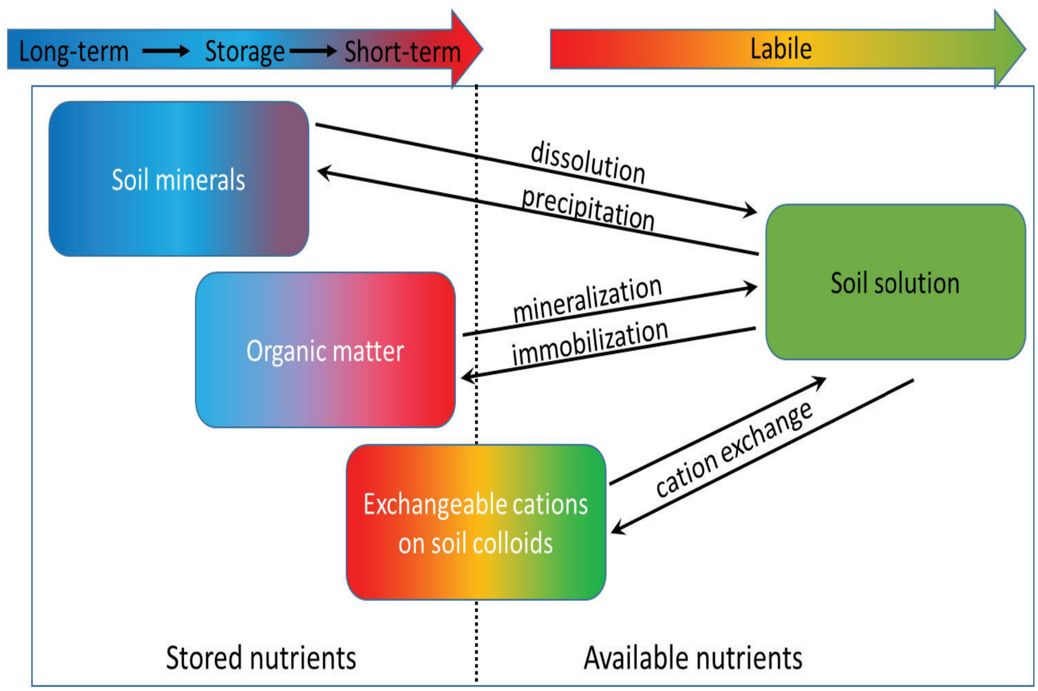
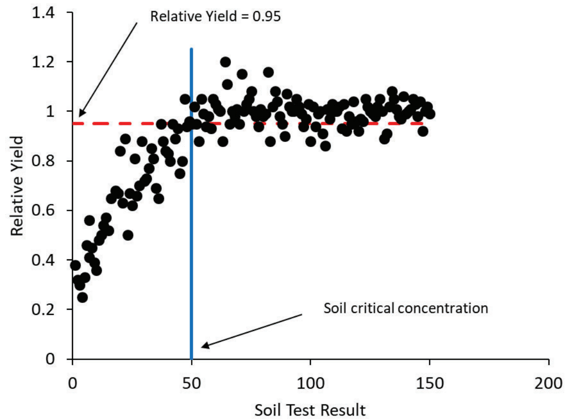
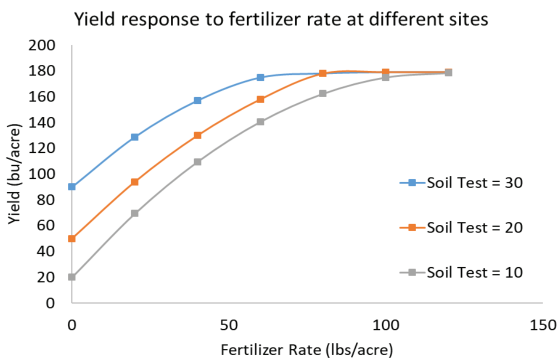


Figure 2. Soil testing extracts nutrients from different pools, which range from immediately available, or labile, to somewhat unavailable. These different soil nutrient pools provide short to long term nutrient storage (referred to as nutrient quantity) and immediate plant nutrient supply (referred to as nutrient intensity).



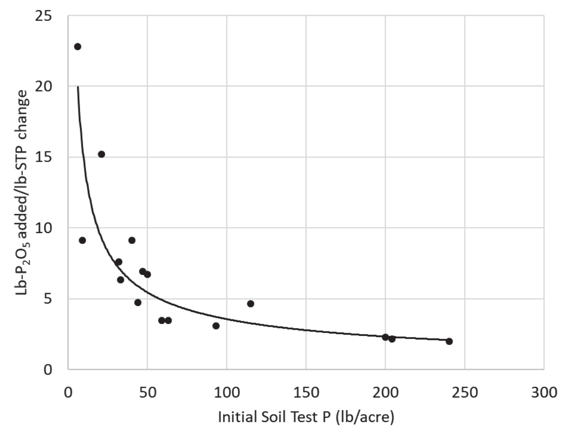
<u>Figure</u> 3. During soil test correlation, we calculate relative yield as the yield from an unfertilized plot divided by a plot with adequate fertilizer. This is repeated at multiple sites spanning a range of soil test concentrations. Often the soil test critical level or concentration is defined as the point above which relative yield exceeds 0.95.



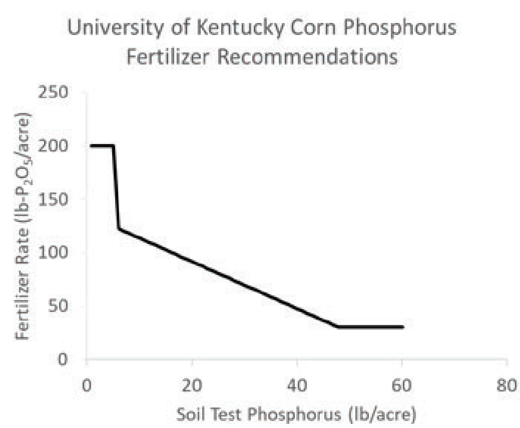
<u>Figure</u> 4. We conduct soil test calibration to determine what right fertilizer rate maximizes yield at different soil nutrient levels. In this example a calibration study with six fertilizer rates and a check was conducted at three different sites with soil test values of 30, 20, and 10 lb/a.

Finally, let's talk about soil nutrient buffer capacity and how it plays into all of this. Basically, buffer capacity refers to how much labile nutrient pools increase for each unit increase of total nutrient content in a soil. When we add fertilizer, particularly P fertilizer but to some extent for K as well, not all the fertilizer goes into the labile pools. A lot of the applied nutrient gets tied up by soil sorption or fixation. In fact, soils adsorb most of the fertilizer P that a farmer applies, with less than 15% of it making it into the plant in that first year. Soil P, which includes fertilizer applied in previous years, supplies up to 85% of the crop's need. University of Kentucky scientists conducted an experiment that demonstrated the buffer capacity concept clearly. They added different rates of P fertilizer to several Kentucky soils and measured the soil test change over time. Figure 5 shows that soils with soil test P below 50 lb/acre needed between 5 and 25 lb P_2O_5/acre to change soil test just one unit. By comparison soils that started above 50 lb/acre needed only 2 – 3 lb P_2O_5 to move soil test one unit (for more information see UK Agronomy Notes Vol. 34, No. 2 (http://uknowledge.uky.edu/cgi/viewcontent.cgi?article=1003&context=pss_notes).

Because of the variability in crop response seen across fields and between fields and because of the variability in buffer capacity between different soils, the University of Kentucky erred on the side of caution when establishing its soil test recommendations and used a conservative soil test critical level. Figure 6 shows the fertilizer P rate recommended by UK across a range of soil test values. At low soil test levels (STP: 0-5) UK recommends applying rates well above what would be required to maximize yield in order to help build soil test, through the mid-range soil test levels (5 – 50) our recommendations decrease rapidly and move towards sufficiency rates, but still include a slight insurance factor, and finally, at higher soil tests (50 – 60), where we do not expect to see a response to P, but might in a few situations, we reduce P recommendations to a low maintenance level of only 30 lb-P_2O_5/acre.



<u>Figure</u> 5. This data from Kentucky shows that the lower the initial soil test phosphorus (STP), the larger the rate of fertilizer required to change soil test phosphorus one unit. Soil buffer capacity causes this effect (Thom and Dollarhide, 2002).



<u>Figure</u> 6. University of Kentucky bases phosphorus fertilizer recommendations on soil test calibrations that are continually verified under Kentucky conditions. They are based on the probability of profitable yield response to fertilizer at a given soil test level.

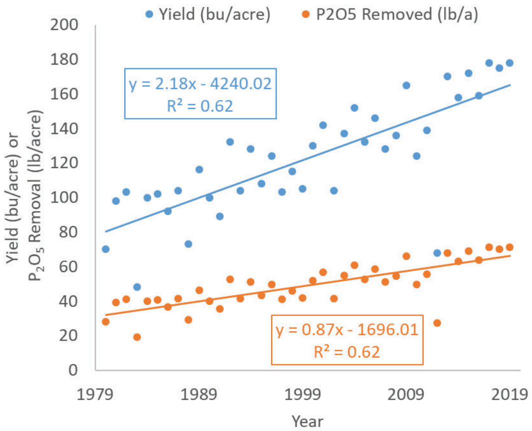


Figure 7. USDA-NASS data indicates that average corn yields in Kentucky doubled between 1980 and 2019. Assuming corn grain removes 0.4 lb/bu of P2O5 we can see that on average over that time frame P removal increased from about 30 to 60 lbs-P_2O_5/acre.

Data provided by USDA-NASS indicates the Kentucky corn yields have approximately doubled in the past 40 years (Figure 7). In that time crop P removal has stayed relatively constant at 0.4 lb P_2O_5 per bushel of corn and so average P_2O_5 removal with the harvested grain has increased from 30 to 60 lb P_2O_5/acre. However, UK research indicates that soil test does not drop 60 lb/acre in response to crop removal. Instead we would expect that if you followed University recommendations and applied 30 lb P_2O_5/acre to a field testing 50 lb P/acre and yielding 180 bu/acre your soil test might drop about 5 lb P/acre. However, remember that is still above the critical level and so in reality you have a very low probability of yields decreasing due to P deficiency at that soil test even if you didn't fertilize at all. What's more, the higher yields seen today compared to 40 years ago directly correlate to larger, more effective root systems. Plants acquire most of their P and K through diffusion that occurs over short distances near the roots. Modern hybrids are more efficient at accessing soil K and P. It is likely that today's high yielding systems require a downward adjustment in fertilizer recommendations relative to crop yield when compared to their predecessors.

In conclusion, soil testing involves collecting soil samples, analyzing them in a lab, interpreting those results, and finally making a fertilizer recommendation. Although not covered in this article, fertilizer placement, the type of fertiizer used, and timing of application influence determining the right rate to maximize profitability and support high yields. Soil test correlation and calibration field research conducted by the University of Kentucky underpin our P and K recommendations and are verified on an ongoing basis. Crop removal of these nutrients certainly increases with increasing yields, but higher yielding crops have root systems that are more efficient at accessing soil and fertilizer nutrients. Ongoing research at the University of Kentucky indicates that our soil test recommendations are adequate to support modern high yield corn production. Differences in fertilizer recommendations between the University and other sources result from differences between our interpretative philosophies. Finally, it is important to note that a single soil test report is only a snapshot in time. Much more can be learned by looking at soil test history for a field. If you consistently follow UK guidelines and see a dramatic drop in soil test to the low or very low categories, you might consider adjusting your fertilizer rate upwards. Likewise, if your soil test results fall in the upper range of our recommendations and you see your soil test continue to increase following UK recommendations, reducing your fertilizer rate might be a wise economic decision.

KENTUCKY YIELD CONTESTS

The Kentucky Extension Yield Contests are administered by the University of Kentucky Cooperative Extension Service. Funding for the contest comes from the Cooperative Extension Service, the Kentucky Corn Growers Association, Kentucky Soybean Board, Kentucky Small Grain Growers' Association and numerous Agribusinesses.

ENTRY INFORMATION

Kentucky Soybean Production Contest - December 1 Deadline

Kentucky Corn Yield Contest Entry - November 16 Deadline