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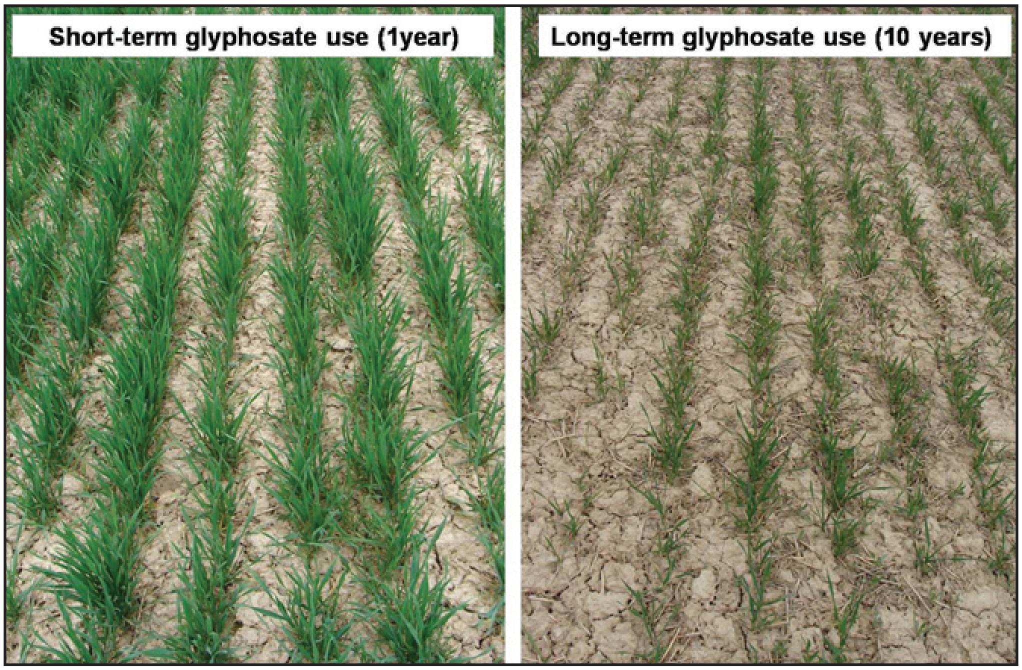
Dr. Don Huber

What's New in Ag Chemical and Crop Nutrient Interactions

The shift to less tillage, herbicide resistant crops, and extensive glyphosate application has significantly changed nutrient availability and plant efficiency for a number of plant nutrients.

Understanding glyphosate's mode of action and impact of the RR gene, indicates strategies to offset negative impacts of this monochemical system on plant nutrition and its predisposition to disease. A basic consideration in this regard should be a much more judicious use of glyphosate. This article provides an update of information on nutrient and disease interaction affected by glyphosate and the RR gene(s), and includes recently published research in the European Journal of Agronomy and other international scientific publications.



Dr. Bott, U. of Hohenheim, Stuttgart, Germany

Fields observations in winter wheat production systems made in Southwest-Germany in 2008 & 2009 point to potential negative side-effects of long-term glyphosate use.

About Glyphosate

Glyphosate is a strong metal chelate. Metal chelates are used extensively in agriculture to increase solubility or uptake of micronutrients that are essential for plant physiological processes. They are also used as herbicides and other biocides (nitrification inhibitors, fungicides, plant growth regulators, etc.) where they immobilize specific metal cofactors (copper [Cu], iron [Fe], manganese [Mn], nickel [Ni], and zinc [Zn]) essential for enzyme activity. In contrast to some compounds that chelate with single or few metal species, glyphosate is a broad-spectrum chelate with both macro- and micronutrients (calcium [Ca], magnesium [Mg], Cu, Fe, Mn, Ni, and Zn). It is this strong, broad-spectrum chelating ability that also makes glyphosate a broad-spectrum herbicide and a potent antimicrobial agent, since the function of numerous essential enzymes is affected.

Primary in understanding glyphosate's herbicidal activity concerns inhibition of the enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) at the start of the Shikimate physiological pathway for secondary metabolism. By inhibiting enzymes in the Shikimate pathway a plant becomes highly susceptible to various soilborne pathogens. It is this pathogenic activity that actually kills the plant. If glyphosate is not translocated to the roots because of stem boring insects or other disruption of the vascular system, aerial parts of the plant may be stunted, but not killed.

Degradation of glyphosate in most soils is slow or nonexistent since it is not 'biodegradable' and is primarily by microbial co-metabolism when it does occur. It is not readily degraded and can accumulate for years (in both soils and perennial plants). Very limited degradation may be a safety feature with glyphosate since most degradation products are toxic to normal as well as RR plants. However, phosphorus (P) fertilizers can desorb accumulated glyphosate that is immobilized in the soil to damage and reduce the physiological efficiency of subsequent crops.

Interactions

Plant nutrition. Glyphosate can affect nutrient efficiency in the plant by chelating essential nutrient cofactors after application, since there is 100 to 1,000 times more 'free' glyphosate in the plant than all of the unbound cations. Chelation of Mn and other micronutrients after application of glyphosate is frequently observed as a "flashing" or yellowing that persists until the plant can resupply the immobilized nutrients. The duration of flashing is correlated with the availability of micronutrients in the soil. As a strong nutrient chelate, glyphosate can reduce physiological efficiency by immobilizing elements required as components, cofactors or regulators of physiological functions at very low rates. Thus, plant uptake or translocation of

Fe, Mn, and Zn is drastically reduced by commonly observed drift rates of glyphosate. This is reflected in reduced physiological efficiency, lower mineral nutrient levels in vegetative and reproductive tissues, and increased susceptibility to disease. Microbial activity is inhibited by glyphosate in root exudates to exacerbate plant nutrient stress common in low-available micronutrient soils.

Degradation. Glyphosate is not readily degraded in the soil and can probably accumulate for many years chelated with soil cations. Degradation products of glyphosate are as damaging to RR crops as to non-RR crops. Persistence and accumulation of glyphosate in perennial plants, soil, and root meristems can significantly reduce root growth and the development of nutrient absorptive tissue of RR as well as non-RR plants to further impair nutrient uptake and efficiency. Impaired root uptake not only reduces the availability of specific nutrients, but also affects the natural ability of plants to compensate for low levels of many other nutrients. Glyphosate also reduces nutrient uptake from the soil indirectly through its toxicity to many soil microorganisms responsible for increasing the availability and access to nutrients through mineralization, reduction, symbiosis, etc.

Sloughing of plant tissues through growth, necrosis, or mineralization of residues can release accumulated glyphosate from meristematic tissues in toxic concentrations to plants. The most damaging time to plant wheat in ryegrass 'burned down' by glyphosate is two weeks after glyphosate application to correspond with the release of accumulated glyphosate from decomposing meristematic tissues. This is contrasted with the need to delay seeding of winter wheat for two to three weeks after a regular weed burn-down in no-till to permit time for immobilization of glyphosate from root exudates and direct application through chelation with soil cations.

Crop rotation. One of the benefits of crop rotation is an increased availability of nutrients for a subsequent crop in the rotation. The high level of available Mn (130 ppm) after a normal corn crop, important in suppressing some soilborne pathogens, is not observed after glyphosate-treated RR corn. Thus, the lower nutrient availability after specific RR crop sequences may need to be compensated for through micronutrient application in order to optimize yield and reduce disease in a subsequent crop.

Herbicidal mode. As a strong metal micronutrient chelate, glyphosate inhibits activity of EPSPS and other enzymes in the Shikimate metabolic pathway responsible for plant resistance to various pathogens. Plant death is through greatly increased plant susceptibility of non-RR plants to common soilborne fungi such as Fusarium, Rhizoctonia, Pythium, Phytophthora, etc. that are also stimulated by glyphosate. It is very difficult to kill a plant in sterile soil by merely shutting down the Shikimate pathway unless soil borne pathogens are also present. It is the increased susceptibility to soilborne pathogens and increased virulence of the pathogens that actually kills the plants after applying glyphosate rather than the direct action of the chemical. Disease resistance in plants is manifest through various active and passive physiological mechanisms requiring micronutrients. Metabolic pathways producing secondary antimicrobial compounds, pathogen-inhibiting amino acids and peptides, hormones involved in cicatrisation (walling off of pathogens), callusing, and disease escape mechanisms can be compromised by glyphosate chelation of micronutrient cofactors critical for enzyme function.

Plant disease Interaction

Micronutrients are regulators, activators, and inhibitors of plant defense mechanisms that provide resistance to stress and disease. Chelation of these nutrients by glyphosate compromises plant defense and increases pathogenesis to increase the severity of many abiotic as well as infectious diseases of both RR and non-RR plants in the crop production system. Many of these diseases are referred to as 'emerging' or 'reemerging' diseases because they rarely caused economic losses in the past or were effectively controlled through management practices.

Non-infectious. Research at Ohio State University has shown that bark cracking, sunscald, or winterkill of trees and perennial ornamentals is caused by glyphosate used for under-story weed control, and that glyphosate can accumulate for 8 to 10 years in perennial plants. This accumulation of glyphosate can be from the inadvertent uptake of glyphosate from contact with bark (drift) or by root uptake from glyphosate in weed root exudates in the soil. Severe glyphosate damage to trees adjacent to stumps of cut trees treated with glyphosate can occur through root translocation and exudation several years after tree removal.

Infectious. Increased severity of the take-all root and crown rot of cereals after glyphosate usage has been observed for over 20 years, and take-all is now a 'reemerging' disease in many wheat producing areas of the world where glyphosate is used. A related disease of cereals, and the cause of rice blast, is becoming severe in Brazil and especially severe when wheat follows an RR crop in the rotation. Like take-all and Fusarium root rot, this soilborne pathogen also infects wheat and barley roots.

Canadian research has shown that the application of glyphosate one or more times in the three years previous to planting wheat was the most important agronomic factor associated with high Fusarium head blight or scab (FHB) in wheat. There was a 75 percent increase in FHB for all crops and a 122 percent increase for crops under minimum-till where glyphosate was used. The most severe FHB occurs where an RR crop precedes wheat in the rotation. Glyphosate altered the plant's physiology to increase susceptibility of wheat and barley to FHB and increase the toxins these pathogens produce. The glyphosate changes in plant physiology are also associated with a transient tolerance of wheat and soybeans to rust.

Quite often overlooked is the increase in root and crown rot by FHB Fusaria with glyphosate and the production of mycotoxins in root and crown tissues with subsequent translocation to stems, chaff, and grain. Caution has been expressed in using straw and chaff as bedding for pigs or roughage for cattle because of mycotoxin levels that far exceed clinically significant levels for infertility and toxicity. This also poses a health concern for grain entering the food chain of humans.

Special considerations

Nutrient sufficiency. Extensive research has shown that increased levels and availability of micronutrients such as Mn, Zn, Cu, Fe, Ni, etc. can compensate for reduced nutrient efficiency and the inefficiency of RR crops. This may not be manifest in high fertility or nutrient toxic soils for quite a few years after moving to a monochemical strategy. The timing for correcting micronutrient deficiencies is generally more critical for cereal plants than for legumes in order to prevent irreversible yield and/or quality loss. Nutrient sufficiency levels from soil and tissue analysis adequate for non-GM crops may need to be increased for RR corps to be at full physiological sufficiency. Since residual 'free' glyphosate in RR plant tissues can immobilize most regular sources of foliar-applied micronutrients for 8 to 15 days, and thereby reduce the future availability of these materials, it may be best to apply some micronutrients 1 to 2 weeks after glyphosate is applied to RR crops.

The expense of an additional trip across the field for foliar application frequently deters micronutrient fertilization for optimum crop yield and quality. There are newly available micronutrient formulations (nutrient phosphites) that maintain plant availability without impacting herbicidal activity of the glyphosate in a tank mix, and plants have responded well from these micronutrient-glyphosate mixes. Simultaneous application of some micronutrients with glyphosate might provide an efficient means to overcome deficiencies in low fertility soils as well as mitigate the reduced physiological efficiency inherent with the glyphosate-tolerant gene and glyphosate immobilization of essential nutrients in the plant. Micronutrients such as Mn are not efficiently broadcast because of microbial immobilization to the non-available oxidized Mn form, but could be applied in a band or to the seed or foliage more efficiently.

Detoxifying. Some nutrients are relatively immobile in plant tissues (Ca, Mn) so that a combination of micronutrients may be more beneficial than any individual one. For example, foliar application of Mn could remediate for glyphosate immobilization. However, it is more effective when applied in combination with the more mobile Zn to detoxify sequestered glyphosate in meristematic tissues even when Zn levels in leaves may appear sufficient. Gypsum applied in the seed row has shown some promise for detoxifying glyphosate from root exudates since Ca is a good chelate with glyphosate (one reason ammonium sulfate is recommended in spray solutions with hard water is to prevent chelation with Ca and Mg, which would inhibit herbicidal activity).

Figure 1. *Schematic of glyphosate interactions in soil.*

Bio remediation. Biological remediation to compensate for glyphosate's impact on soil organisms important in nutrient cycles may be possible if the remediating organism is also glyphosate-tolerant and capable of overcoming the soil's natural biological buffering capacity. This would be especially important for nitrogen-fixing, mycorrhizae, and nutrient reducing organisms, but will be of limited benefit unless the introduced organisms are also tolerant of glyphosate. Modification of the soil biological environment through tillage, crop sequence, or other cultural management practices might also be a viable way to stimulate the desired soil biological activity.

Stress resistance. Maintaining plant health is a basic requirement for crop yield and quality. Plant tolerance to stress and many pathogens is dependent on a full sufficiency of micronutrients to maintain physiological processes mediated through the Shikimate or other pathways that are compromised in a glyphosate environment. Sequential application(s) of specific micronutrients (especially Mn and Zn) may be required to compensate for those nutrients physiologically lost through glyphosate chelation. Breeding for increased nutrient efficiency and disease resistance will be an important contributor to this objective.

Summary

Glyphosate is a strong, broad-spectrum nutrient chelate that inhibits plant enzymes responsible for disease resistance so that plants succumb to pathogenic attack. Widespread glyphosate-induced nutrient deficiency is reducing crop production efficiency and increasing plant disease. The various interactions of glyphosate with nutrition are shown in Figure 1.

Dr. Huber is emeritus professor at Purdue University.