The Science of Roundup Ready® Technology, Glyphosate, and Micronutrients

Part IV - Glyphosate and Diseases in Roundup Ready® Crops

A limited number of research studies have suggested that glyphosate, the active ingredient in Roundup agricultural herbicides, may increase the population of some fungal crop pathogens. While these preliminary studies demonstrate some changes in soil fungal populations, there is no evidence of an increased incidence of disease or of effects on yield. At recommended use rates, the overall body of scientific evidence indicates that Roundup® agricultural herbicides will have no unreasonable adverse effects on fungal pathogens in the soil or associated with plants. Glyphosate application and alleged increases of disease in glyphosate-tolerant versus conventional (non-tolerant) crops will be discussed here in Part IV of the series "The Science of Roundup Ready® Technology, Glyphosate, and Micronutrients."

Studies Assessing Specific Disease Organisms

A variety of studies have looked at the effects of glyphosate on fungal pathogens, but such studies are difficult to extrapolate to effects under actual field condition. For example, some studies have indicated an increased population of *Fusarium* spp. when grown on a synthetic medium amended with different concentrations of glyphosate herbicides[1,2]. However, other studies demonstrate reduced conidial germination, mycelial growth, and sporulation of *Fusarium solani f. sp. glycine*, *Fusarium graminearum schwabe*, and *Rhizoctonia solani* in pure culture[3,4]. Similarly, de Alvarez et al.[5] studied the effect of glyphosate on *Rhizoctonia solani* (a pathogen) and *Trichoderm sp.* (an antagonist species that suppresses growth of *R. solani*) under laboratory conditions and found no effect on pathogen growth or antagonism.

While these results may appear to be contradictory, the experiments take place under different artificial conditions, and these conditions are known to be important. It is known, for example, that growth and formation of *Fusarium* spp. is highly dependent upon the composition of synthetic media and environmental conditions[6]. Further, the effects of glyphosate on soil microorganisms in soil samples vs. pure cultures have been compared in several studies[7,8,9,10] suggesting that artificial media assays are of limited relevance in predicting effects under field conditions. Thus, while an increase in field levels of *Fusarium* spp. has been documented following glyphosate application[1,11], these increases were not associated with increased disease frequency or with yield loss.

Some field studies have indicated that stress imposed by herbicide application (in non-herbicide tolerant crops) or the presence of additional nutrients and moisture from residues of herbicide-treated weeds (increased in conservation tillage/herbicide tolerant systems), in conjunction with physical and environmental factors, can indirectly lead to increased disease in crops[12,13,14,15,16,17]. However, these effects reflect choice of weed control technology and cropping systems, not an adverse effect of glyphosate or of glyphosate tolerance genes.

Environmental conditions also play a significant role in the development of diseases in plants, including, for example, Fusarium head blight (FHB) in wheat, where recent research indicates that inoculum production is critically dependent on rainfall. Several field-based studies confirmed that warm and moist conditions during anthesis are the key factors for FHB development[18,19,20].

Comparing Glyphosate-Tolerant Soybeans to Conventional Soybeans

The use of glyphosate-tolerant (GT) soybeans with in-crop application of glyphosate is a proven, efficient production technology. Like conventional varieties, commercially available GT soybean varieties vary considerably in disease tolerance. For example, when comparing disease tolerance scores of Asgrow® Brand Roundup Ready® soybean varieties, the distribution of low, medium, and high disease-tolerant varieties is essentially the same as that observed for genetically similar conventional soybean varieties[21]. Similarly, wheat varieties have a wide range of tolerance to FHB[22]. Thus, differences in susceptibility to pathogens may be related to the innate susceptibility of the cultivars or varieties and not the presence of the Roundup Ready trait or application of glyphosate herbicides. Ideal studies would use side-by-side comparisons between the GT cultivars and the non-transgenic parental isoline (similar genetics but not genetically modified).

A significant body of research, including work with soybean isoline populations, demonstrates that the susceptibility of glyphosate-tolerant soybeans is no different than that of conventional varieties following application of selected herbicides[23,24,25,26,27]. The researchers also concluded that the susceptibility of soybean to SDS or white mold was not altered by the application of glyphosate[23,25,24]. Mueller, et al.[27] evaluated 2335 publicly and privately developed soybean cultivars and their ancestral lines over three years for response to *Fusarium solani f. sp glycine* (Fsg) under greenhouse conditions. Their results show no difference between the Roundup Ready and conventional cultivars. Njiti, et al.[24] evaluated five Roundup Ready cultivar pairs with varying Sudden death syndrome (SDS) susceptibility (maturity groups II – VI, six locations) with and without glyphosate application. The Fsg root infection severity, colony forming units per gram of root, SDS leaf scorch disease index, and grain yield were determined. Across environments within each maturity group, there were no significant effects of glyphosate on any metric. The authors concluded from this study that the development of SDS on Roundup Ready soybean is influenced by genotype. Further, the use of herbicide-tolerant crops such as GT soybeans could reduce damage from herbicide stress observed in conventional cultivars[3,24].

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Other Information on Soil Microflora, Including Fungi

Soil fungi exist as a part of robust, responsive soil microbial communities. Thus, effects of glyphosate on overall microbial flora are pertinent to discussions of glyphosate and fungal disease, and have been extensively investigated[28]. Results of standardized tests with glyphosate formulations for submission to regulatory agencies indicate no long-term effects on microorganisms in soil even at rates that exceed maximum use rates. In addition, independent researchers have reviewed numerous laboratory and field studies investigating the effects of glyphosate on soil bacteria and fungi[29,30]. Although some laboratory tests have shown effects on nitrogen-fixing bacteria[31,32] and soil fungi[33,10], effects are typically observed only under artificial laboratory conditions and at glyphosate concentrations well above normal field application rates. Several researchers have concluded that it is difficult to extrapolate results from the laboratory to the natural soil environment[33,34,10]. In studying microorganisms from soil in pine plantations, Busse et al.[10] state: "Our findings suggest that artificial media assays are of limited relevance in predicting glyphosate toxicity to soil organisms and that field rate applications of glyphosate should have little or no effect on soil microbial communities in ponderosa pine plantations."

Long-term studies following repeated applications of Roundup agricultural herbicides in the field for six[35] or over 10 years[36,37] have shown no detectable adverse effects on soil microbes. Investigations by Haney et al.[38,39] related to the increased use of glyphosate-tolerant crops indicate that glyphosate was degraded over time by soil microbes, even at high application rates, without adversely impacting the soil microbial community. In addition, results from field studies evaluating the fungal component of the soil microbial community indicate that glyphosate treatment has no deleterious effects on beneficial soil fungi[40,37,10,8,9]. The history of safe use and yield data obtained during more than a decade of Roundup Ready crop production reinforce the conclusion that soil microbes and microbially-mediated processes are not adversely impacted by field-rate applications of glyphosate.

Disease Protection from Glyphosate?

Preliminary research conducted by Washington State University suggests that glyphosate may suppress Asian soybean rust *(Phakopsora pachyrhizi)* in Roundup Ready soybeans[41,42]. Research by Monsanto scientists also indicates that glyphosate controls leaf rust in Roundup Ready wheat[41]. Control is proportional to the concentration of glyphosate inside the leaf tissue, but concentration on leaf surfaces did not contribute to rust control, suggesting a systemically mediated effect.

Other work at Washington State University suggests glyphosate may be active against some soil-borne plant pathogens[43]. Hansen et al.[44] observed a reduction in the severity of FHB in spring wheat and durum after the application of a Roundup agricultural herbicide to Roundup Ready soybeans and subsequent spray drift to the cereal crops. However, application of glyphosate herbicide had no significant effect on the level of *Fusarium* infection in harvested grain of oat[45]. Glyphosate exhibits herbicidal activity by inhibiting a single enzyme, EPSPS (5-enol-pyruvylshikimate-3-phosphate synthase)[46]. This protein is ubiquitous and essential in plants and microorganisms, including bacteria and fungi, and it is likely that inhibition of EPSPS contributes to the observed suppression of disease.

Laboratory and field studies in the early 2000's suggested that glyphosate was active against rusts (*P. triticina*, *P. striiformis*) in glyphosate resistant wheat[47]. Further investigations using a broader spectrum of plant pathogens demonstrated that application of glyphosate as technical material or as a Roundup® agricultural herbicide formulation can suppress the incidence and/or severity of a range of plant diseases using either pre- or post-infection applications[48]. Data from a recent study on Rhizoctonia Crown and Root Rot (RCRR) of sugarbeet showed highly significant differences between conventional and glyphosate-based weed management practices, with glyphosate increasing final stand and reducing RCRR[49].

In Summary

Collectively, the available scientific evidence do not suggest that glyphosate-tolerant crops have an increased susceptibility to disease. This observation is strongly reinforced by grower surveys demonstrating that the overall performance of glyphosate-tolerant soybeans, as measured by yield and constant increase in acreage, is equal to or greater than that of conventional varieties. While there is considerable variation in varietal susceptibility to disease, this is related to varietal characteristics independent of both the herbicide tolerance traits and of the application of Roundup agricultural herbicides. Long term studies of free-living microorganisms in the soil or associated with plants support the conclusion that adverse effects on these organisms are unlikely to result from glyphosate application at normal field rates. Preliminary data suggest that glyphosate applications may have the ability to suppress some important fungal diseases in some Roundup Ready systems.

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