CROP ProtectionUpdate

Technology Development by MONSANTO

The Science of Roundup Ready® Technology, Glyphosate and Micronutrients

Part 1 - Glyphosate Chemistry, Efficacy and Interaction with Micronutrient Foliar Applications

Recently, some researchers have suggested a relationship between the use of glyphosate, Roundup Ready® crops, micronutrient deficiencies, and yield reductions. A variety of claims and multiple theories to explain their reported results have been presented. These theories range from reduced micronutrient uptake by Roundup Ready® soybean plants, to the binding of micronutrients by glyphosate inside the plant, as well as many additional themes. With this in mind, a series of questions and science-based answers are presented below to address these claims and also present a basic understanding of how glyphosate interacts with materials in the spray solution.

How Does Hard Water Affect Glyphosate Efficacy?

A chelator is a polydentate compound that can form more or less reversible complexes with polycationic metal ions. Sometimes metal cations, such as Calcium (Ca^{2+}), Magnesium (Mg^{2+}) and Iron (Fe^{2+}/Fe^{3}), are found in what is commonly known as "hard water." Glyphosate in formulated products is negatively (-) charged when dissolved in water at pH 4.6 and its mild chelating properties allow it to form reversible complexes with the Ca^{2+} and Mg^{2+} in hard water. This can result in a mild <10% reduction in the performance of the herbicidal effects of glyphosate[10] when used at recommended use rates. Water hardness is usually expressed as parts per million (ppm) of $CaCO_3$ or as grains per U.S. gallon (one grain per gallon = 17.1 ppm). Water with a hardness of 200 ppm or more is considered "hard" and can slightly reduce glyphosate performance. In areas where hard water is used in mixing glyphosate, ammonium sulfate (AMS) is recommended to be used with Roundup® agricultural herbicides. AMS conditions hard water because the sulfate anion can effectively compete with glyphosate for free Ca^{2+} and allow the free glyphosate to enter plant cells for normal herbicide activity.

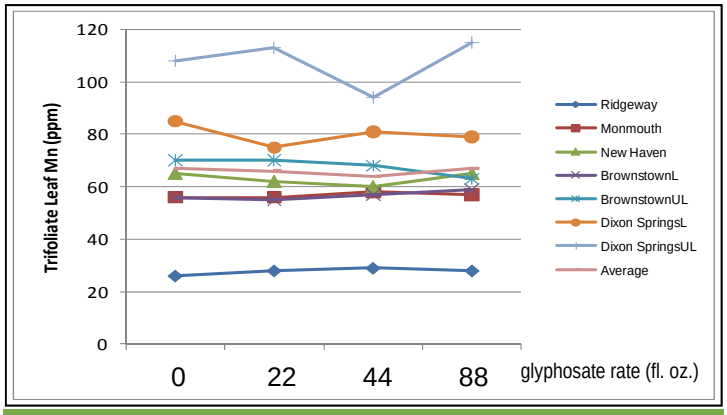

Figure 1. Trifoliate leaf Manganese concentration across three rates of glyphosate in 7 experiments in Illinois in 2004. L= field limed; UL= field un-limed. Ebelhar [6].

Are Tank Mixes of Glyphosate with Micronutrient Foliar Sprays a Good Idea?

Foliar sprays of micronutrients are used in crops, such as foliar manganese (Mn^{2+}) fertilizer in soybeans. Other micronutrients that may be applied in foliar sprays include boron (B), copper (Cu^{2+}), iron (Fe^{3+}), molybdenum (Mo^{2+}) and zinc (Zn^{2+}), which are positively (+) charged when dissolved in water. Since many foliar sprays are applied around the time of glyphosate treatments in Roundup Ready® crops, there is interest in tank-mixing glyphosate and micronutrients. As with the cations in hard water, glyphosate may reversibly complex the positively charged micronutrients in the spray solution. When this happens, glyphosate herbicidal performance may be slightly affected because the glyphosate-micronutrient complex may decrease the amount of free glyphosate[2]. Monsanto does not recommend tank-mixing glyphosate herbicides with micronutrients containing polycationic metal ions or foliar fertilizers; instead, if a micronutrient application is needed, Monsanto recommends making two separate applications: one for micronutrient application and another for weed control.

Does Glyphosate Affect the Availability of Micronutrients When Applied Separately?

Research studies in replicated plots evaluating combinations of manganese fertilization and glyphosate herbicide programs have been performed by numerous universities over a period of thirteen years. Several of these trials involve many combinations of glyphosate rates, timings and formulations, as well as different application variables for Mn^{2+}. Pennsylvania State University[5], The Ohio State University[4], Purdue University[13], University of Illinois[6], Virginia Tech[1] and University of Minnesota[11], all demonstrated no significant differences in yield responses between the various combinations of treatments when labeled rates of glyphosate were used. In addition to these studies that compared yields, trials done by University of Illinois[7] and Purdue University[13] showed no effect on in-plant Mn^{2+} levels across the various glyphosate treatments (Figure 1). To complement the university research, Monsanto has conducted similar field trials and investigations during 2008 and 2009. Three different varieties of Roundup Ready® soybeans were planted and two different herbicide regimes were applied either at V3 alone or at V3 and R1/R2, and two levels of Mn^{2+} were applied at V8 and R4. When compared to the initial levels of Mn^{2+} in the plants, foliar applied Mn^{2+} increased leaf concentrations of Mn^{2+} across all soybean varieties irrespective of glyphosate rates (Figure 2). Glyphosate did not reduce Mn^{2+} in the plants and there were no significant differences in leaf Mn^{2+} concentration resulting from glyphosate treatment regimes for any variety at both Mn^{2+} rate regimes evaluated. When looking at the yield results from the field studies in 2008 and 2009, there were no significant differences in soybean yields due to germplasm, Mn^{2+} rates or glyphosate applications (Figure 3). Within a Mn^{2+} rate regime, there were no significant differences in seed Mn^{2+} concentration when the unsprayed check treatment was compared to the two glyphosate treatments (data not shown). *This two-year study conducted by Monsanto reached the same conclusions as the studies conducted by multiple universities – glyphosate applications in Roundup Ready® soybeans do not reduce Mn^{2+} uptake, availability or utilization in the plant.* In addition, these studies corroborate previous research findings that suggest soybean germplasm often responds differently to the availability of mineral elements. It is also important to note that micronutrient levels vary naturally across different soybean varieties as seen in numerous Monsanto and university studies. Consequently, the data demonstrate that soybean varieties respond differently to micronutrient fertilization. Nutrient deficient soils can negatively affect soybean yield potential. Where Roundup Ready® soybeans are grown on nutrient deficient or nutrient limiting soil, Monsanto recommends appropriate fertilization.

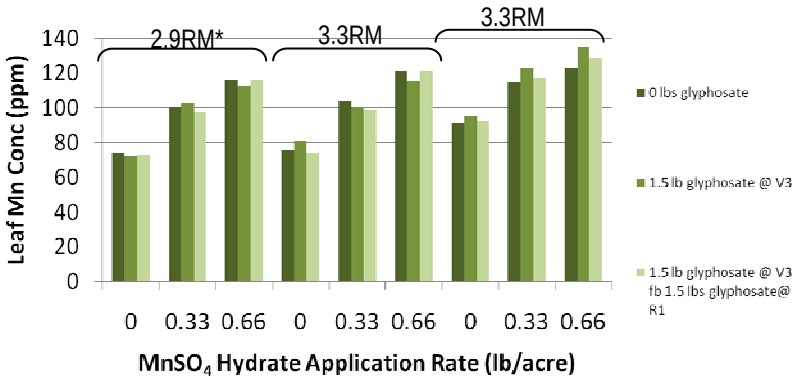

Figure 2. Leaf Mn concentration 14 days after the 2nd Mn application for 2.9, 3.3, and 3.3RM Roundup Ready ® Soybeans. *RM=Relative Maturity

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Are there micronutrient differences in Roundup Ready® crops compared to their non-GMO isogenic lines?

Monsanto is required by U.S. and International regulatory agencies to conduct numerous crop compositional analysis studies on Roundup Ready® crops. In these studies a glyphosate-treated Roundup Ready® crop is compared with an untreated isogenic control that does not contain the transgene but is otherwise genetically similar (Figure 4). There are often multiple commercial varieties in these trials for comparison. Micronutrient analysis is typically included in these studies and no trends in micronutrient differences across these studies have been established when comparing the transgenic variety to the non-transgenic control for any Monsanto biotechnology-derived traits. Figure 5 also demonstrates that the levels of zinc, iron and manganese have stayed within their expected ranges as the acreage of GMO soybeans have increased in the U.S. from 2000-2009.

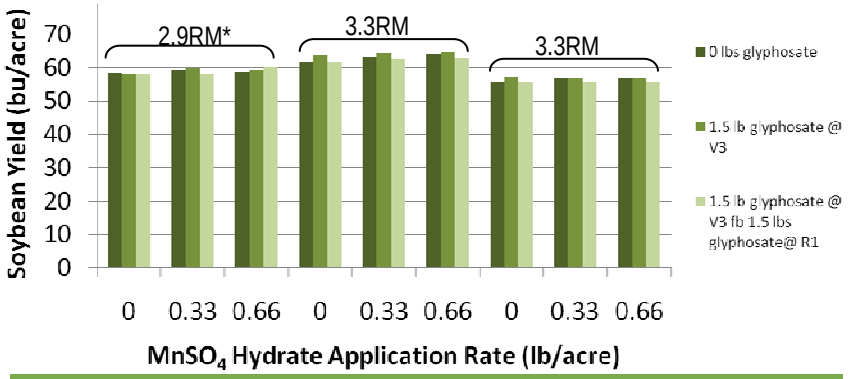

Figure 3. Soybean Yield (bu/acre) for 2.9, 3.3, and 3.3RM Roundup Ready® Soybeans. *RM=Relative Maturity

So, what does all this mean?

Roundup® brand agricultural herbicides have been widely used for weed control in crops for over 30 years and growers' experiences have been extremely positive, including excellent weed control and increased profits. Speculation that glyphosate could affect micronutrient availability has received attention but no causal relationship with glyphosate has ever been established based on scientific studies. Recent chelation modeling studies showed that glyphosate does not effectively compete with natural plant chelators for the various micronutrients in plants[8]. Consequently, the micronutrient bioavailability within plants treated with glyphosate is within the expected natural range of these metals in plants without glyphosate treatment. Where Roundup Ready® crops are grown on nutrient deficient or limiting soil that can negatively affect yield potential, Monsanto recommends the appropriate fertilization. A thorough review of university research, confirmed by Monsanto trials, demonstrates that the Roundup Ready® soybean system with glyphosate does not negatively impact manganese uptake or accumulation or soybean yield potential. This conclusion is further reinforced by a recent Purdue University publication that concludes, "To date, there is limited scientific research data that suggest that plant diseases have increased in GM crops due to the use of glyphosate. Most importantly, the impact of these interactions on yield has not been demonstrated."[16] In summary, Monsanto's recommendations are in accord with the Purdue University report and a recent Iowa State University publication by Dr. Bob Hartzler in which he states, "The best recommendation remains to manage Roundup Ready® soybean similar to conventional varieties in terms of fertility management[9]."

	1998		1999		
Component	NK603 mean (range)	non-GMO mean (range)	NK603 mean (range)	non-GMO mean (range)	commercial hybrids tolerance interval (range)
calcium *(% dry wt.)*	0.0047 (0.0037-0.0056)	0.0046 (0.0033-0.0058)	0.0053 (0.0050-0.0058)	0.0053 (0.0050-0.0058)	0.0028, 0.0082 (0.0039-0.0076)
copper *(ppm)*	1.79 (1.19-2.37)	1.90 (1.50-2.33)	1.89 (1.77-1.99)	1.83 (1.69-1.97)	0.45, 3.16 (1.16-2.78)
iron *(ppm)*	22.71 (19.08-25.94)	22.95 (18.77-26.62)	22.73 (17.43-26.91)	21.81 (18.52-25.87)	10.60, 33.63 (15.42-29.34)
magnesium *(% dry wt.)*	0.12 (0.11-0.13)	0.12 (0.11-0.13)	0.12 (0.096-0.13)	0.11 (0.10-0.12)	0.079, 0.16 (0.089-0.15)
manganese *(ppm)*	6.47 (4.64-9.63)	6.55 (4.96-8.83)	6.73 (5.18-7.90)	6.42 (5.63-7.32)	2.50, 12.03 (3.86-10.47)
phosphorus *(% dry wt.)*	0.36 (0.32-0.39)	0.36 (0.32-0.39)	0.36 (0.31-0.39)	0.35 (0.32-0.37)	0.27, 0.42 (0.27-0.39)
potassium *(% dry wt.)*	0.36 (0.35-0.39)	0.36 (0.34-0.41)	0.36 (0.34-0.38)	0.38 (0.36-0.39)	0.31, 0.45 (0.32-0.45)
zinc *(ppm)*	28.35 (20.23-33.17)	28.72 (23.47-33.26)	23.78 (15.95-31.45)	23.21 (17.87-29.88)	9.89, 31.52 (13.51-27.98)

Figure 4. Compostional analysis of Roundup Ready® Corn 2 (NK603) compared with a non-GMO isogenic line.[12]

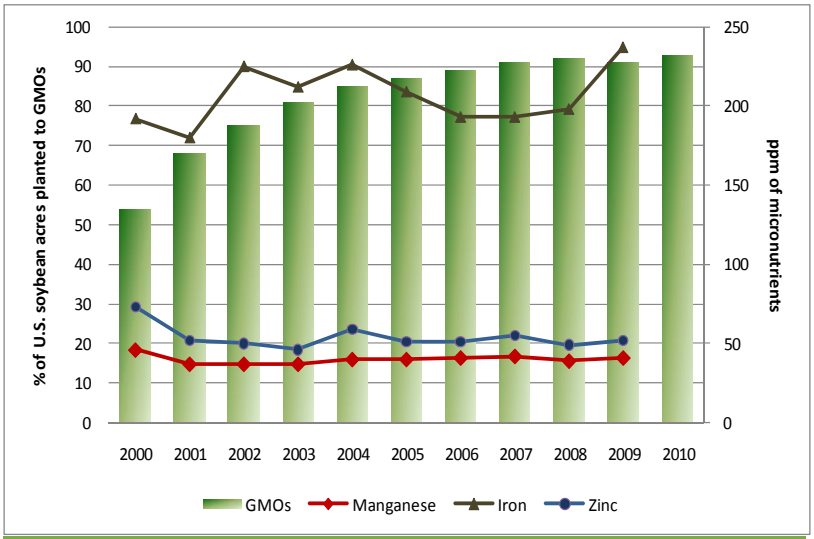

Figure 5. Percentage of GMO soybeans planted in the U.S. and concentrations of manganese, iron and zinc in soybean meal evaluated from 2000-2009.[14, 15]

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