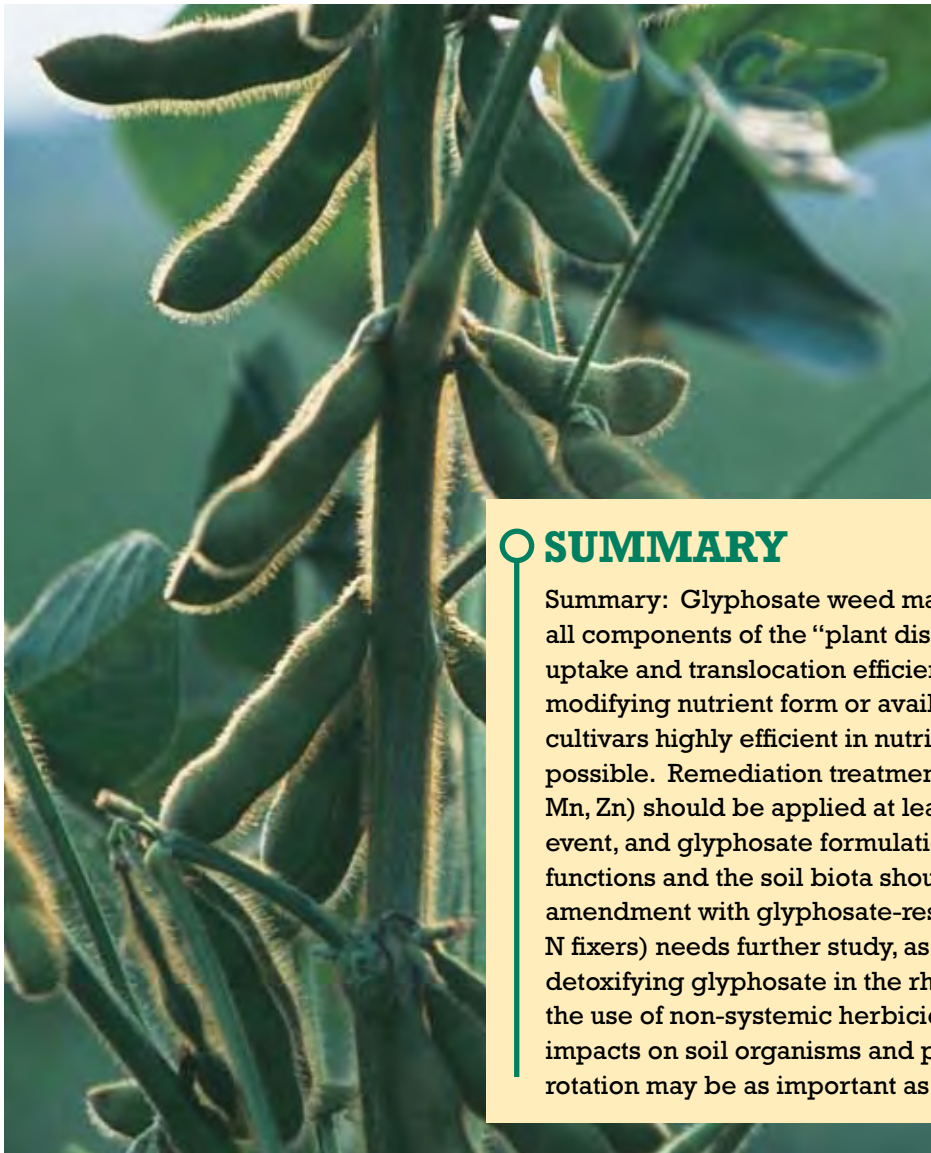


# What About Glyphosate-Induced Manganese Deficiency?

*Take heart. There are strategies to get around the far-reaching non-target effects that this most extensively used herbicide in the history of agriculture can have on susceptible plants.*

**G**lyphosate [N-(phosphonomethyl) glycine] is the most extensively used herbicide in the history of agriculture. Glyphosate weed management programs in field crops have provided highly effective weed control, reduced concern for residual chemicals in the environment, simplified management decisions, and resulted in cleaner harvested products. This relatively simple compound (modification of the essential amino acid glycine) is an economical and effective broad-spectrum systemic herbicide that can have extensive non-target effects on nutrient availability, soil environment, and agricultural sustainability. Through its active chelation of specific mineral elements, glyphosate



## SUMMARY

Summary: Glyphosate weed management programs can influence all components of the “plant disease triangle” by reducing plant uptake and translocation efficiency, changing soil biology, and modifying nutrient form or availability in the environment. Crop cultivars highly efficient in nutrient uptake should be selected where possible. Remediation treatments for micronutrient deficiency (Fe, Mn, Zn) should be applied at least eight days after the glyphosate event, and glyphosate formulations least inhibitory to plant essential functions and the soil biota should be used where possible. Biological amendment with glyphosate-resistant organisms (Mn reducers and N fixers) needs further study, as well as more effective means of detoxifying glyphosate in the rhizosphere. Alternate weed control or the use of non-systemic herbicides should be considered to minimize impacts on soil organisms and predisposition to disease. Herbicide rotation may be as important as crop rotation in the future.

inhibits vital physiological functions to cause death of susceptible plants and microorganisms. Many commercial crop plants have been genetically modified to partially compensate for the physiological disruption caused by glyphosate so that they tolerate the chemical. Although glyphosate resistance in genetically modified corn and soybeans reduces the efficiency of manganese (Mn) uptake and physiological efficiency 10 to 50 percent, depending on the genetic nutrient uptake efficiency of the particular transformed variety or hybrid, other physiological effects of glyphosate (reduced uptake and translocation of Fe, K, and Mn, physiological immobilization of Mn, reduced root nodulation and N-fixation, drought stress, early maturity, and disease increase) may go largely unnoticed in commercial practice without a near-isogenic comparison available. Glyphosate tolerant (Roundup Ready®) crops required the application of almost 50 percent more Mn to meet their physiological sufficiency than conventional soybean varieties. Glyphosate in root exudates of weeds and GM tolerant plants changes the rhizosphere biology to reduce the availability of Fe, Mn, and other essential mineral nutrients for crop uptake. Glyphosate-induced Mn deficiency can compromise plant resistance mechanisms mediated through the shikimate pathway so that diseases such as take-all, Fusarium head scab and root rot, Corynesporium root rot, and numerous other diseases increase after glyphosate is applied for weed control. Our research the past 15 years has been directed at developing strategies to ameliorate the deleterious effects of glyphosate

on nutrient efficiency and disease susceptibility that will optimize its benefit as a herbicide.

### Strategies

Strategies to ameliorate Mn immobilization by glyphosate include:

- Mn enrichment (fertilization and biological enhancement)
- Detoxification of glyphosate in root exudates or soil residual.
- Modification of cultural practices to enhance Mn availability.

Our initial hope was to use glyphosate as a carrier for several micronutrients that are deficient in various Indiana soils and thereby improve the economic viability of micronutrient fertilization by eliminating the need for a separate trip across the field. It became apparent early on that tank mixes of glyphosate and various mineral elements were incompatible and reduced the efficacy of the glyphosate as a herbicide (Table 1) while providing little available nutrient advantage or plant

response. Ammonium sulfate (“water softener”) and different glyphosate formulations can reduce the antagonism and immobilization of Mn to improve weed control. Normal uptake and translocation of foliar-applied Mn was not observed until at least eight days after glyphosate was applied. The greatest soybean yield response on high organic soils was with both Mn and Cu applied 8 to 12 days after the glyphosate.

The highest yields for corn were obtained by foliar-applying Zn 15 days after glyphosate was applied in northwestern Indiana, while tank mixes of various Zn products reduced yields as much as 35 bu/A under heavy weed pressure because of reduced herbicidal efficacy of the glyphosate-Zn complex that formed (Table 2). Zinc significantly increased Roundup Ready corn yield only when applied 15 days after the glyphosate in an irrigated field.

**Bio-enrichment.** We have been unable to obtain consistent responses to preplant or at-plant

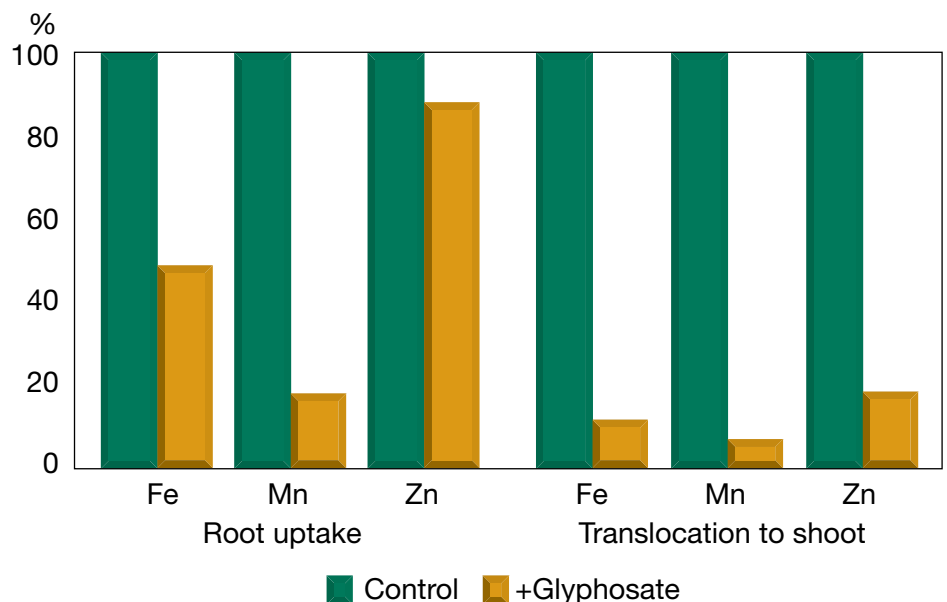


Figure 1. Effect of glyphosate\* on nutrient uptake and translocation by “non-target” plants, Eker, et al. 2006. (\* 2.5% of recommended herbicidal rate of glyphosate.)

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**Table 1. Effect of Mn and Zn sources on herbicidal efficacy of glyphosate on RR soybeans.**

Treatment/nutrient source	Rate	Yield bu/A	Weed control %
No herbicide*	None	46	0
Glyphosate **	24 oz/A	57	100
Glyphosate + MnCO <sub>3</sub>	0.5 #Mn/A	75	91
Glyphosate + MnSO <sub>4</sub>	0.5 #Mn/A	70	93
Glyphosate + Mn EDTA chelate	0.25 #Mn/A	72	100
Glyphosate + Mn AA chelate	0.15 #Mn/A	67	85
Glyphosate + Zn0	0.5 #Zn/A	49	33
Glyphosate + Zn chelate	0.25 #/A	40	40
Glyphosate + ZnO +P	0.5 #/A	41	20

\* Heavy weed pressure

\*\* Applied as WeatherMax<sup>®</sup> formulation at 24 oz/A + ammonium sulfate

**Table 2. Effect of zinc application on corn yields and herbicide efficacy.**

Treatment	Irrigated*		Rain-fed*	
	Yield (bu/A)	% weed kill	Yield (bu/A)	% weed kill
None	132	0	172	0
Glyphosate only	178	100	205	100
Glyphosate + Zn (Tank mix)	143	30	189	30
Zn 15 days after glyphosate	195	100	210	100

\* Very heavy weed pressure (grass and broad-leaved weeds), very light weed pressure on the rain-fed plot.

applications of biologicals evaluated on Roundup Ready crops, possibly because of toxicity of the glyphosate to them. We did, however, obtain a significant 9 bu/A yield response to one mixture of biologicals on late-planted RR corn under rain-fed but not irrigated conditions in northwestern Indiana to indicate a potential benefit to this approach. Biologicals should be selected that are not only effective Mn reducers, but also must be tolerant to glyphosate and its toxic metabolites in root exudates.

**Detoxifying glyphosate.** As little as 2.5 percent of the recommended rate of glyphosate can greatly inhibit uptake and translocation of Fe and Mn by non-target plants (Figure 1). Calcium can help detoxify glyphosate in root exudates; however, Mn in soybean tissue was 6-8 ppm higher with in-furrow

gypsum than with liming. Corn yields were 10 bu/A higher with in-furrow gypsum under irrigation and also under rain-fed conditions if additional Zn was applied as a seed treatment.

**Modifying cultural practices.**

The greatest impact of glyphosate is on low-nutrient-available soils or under conditions that limit nutrient availability. Selection of nutrient efficient varieties or hybrids is especially important since there is a large difference in efficiency within a plant species and this can compensate for some of the reduced efficiency imposed by the glyphosate tolerant gene. Crop sequence, tillage, mulches, soil pH, nitrogen form, and moisture management affect Mn availability.

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