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No·till On The Plains

Three ‘*R*’s of No-till

by Charles Long

Do reading, writing, and arithmetic lead to no-till success? Probably not in-and-of themselves; however, they are necessary to handle the business end of farming. Dan Schultz admits to not liking school too much as a youngster, although he did learn the basic three ‘*R*’s, and now he’s making a science of what he calls “the three ‘*R*’s of no-till.” His key components for no-till success are Rotations, Residue, and Resources.

Dan, his wife Joan, and their two daughters live north of Grainfield, KS, (halfway between Colby & Wakeeney) on a farming & cattle operation that’s headquartered in Sheridan County and extends into Gove and Thomas counties. Dan is also a Channel Bio seed dealer and an agent for Red River Commodities, while Joan is a licensed cosmetologist with her own salon in Grinnell, KS.

To be clear: ‘Schultz Farms’ owns most of the equipment and hires the labor, with this entity being owned by Dan, his older brothers—Darren & Doug—and their dad, Don. Whether owned or rented, all land is held outside of this ‘umbrella’ entity and managed separately under various arrangements—Dan considers himself merely the caretaker of a portion of it, which includes land owned by Dan’s parents, as well as Joan’s parents. Cropland under Dan’s care is about 79% dryland and 21% pivot irrigated, all of it 100% no-till.

Photo by Dan Schultz.

Dan seeding stacked wheat.

Contents

Dan expresses great gratitude to his parents for encouraging him and giving him the opportunity to come back and farm after completing two years at Dodge City Community College. He says, "There have been surveys about how long you've been farming. Truthfully, I haven't known anything different. I haven't had a desire to do anything else."

As he was growing up, Dan's family practiced full tillage. They had been watching some other pioneers of no-till, and Schultzes began working that direction in the late 1980s and early '90s. Dan says, "When we started this timeline from conventional-till, then we started looking at what we've got: Wheat stubble—we will spray it and plant milo in it. About the early '90s we started planting some dryland corn, but then we always thought we had to bring it out the third year to till." He explains, "Chem-fallow [of milo or corn stalks] was sun-baked and wind-blown by the following fall. So then we changed our thoughts—we took the fallow out of it . . . just tweaking the system, just keep trying to push the system." Accordingly, Dan planted some wheat directly into milo stalks, primarily using spring wheat for a few years. For awhile, he had a rotation of wheat >>corn >>sunflowers >>milo (directly to wheat), "but dry winters showed that [rotation's] weakness." Eventually, Dan added dryland soybeans to get from corn or milo to winter wheat, and now cover crops and forages for that same role.

"Every time we made a step closer to that commitment to 100% no-till, our results continued to improve."

Dan credits what he learned on his irrigated acres helped him decide to go all no-till on everything, including dryland: "The irrigation part of things kind of brought us along here because we went from all-till on the irrigation to ridge-till, and every time we made a step closer to that commitment to 100% no-till, our results continued to improve—our soils did, our holding capacities of water did—and so we saw that each step we made to less and less tillage was positive."

Dan continues, "Several pieces of the farm have been complete no-till since 1992. Through that period of time, there have been others that have—and we have—tried a little strip-till. At one time we felt we needed to go in and do a little tillage on certain pieces of ground for whatever reason, but have always come back to no-till commitment, and that is where I am now, personally. Tillage is not even a factor in my operation, in my mindset."

Photo by Charles Long.

Dan's 2009 cover-crop millet into dryland corn stalks, sprayed out and soon to be drilled to wheat. However, for the majority of Dan's dryland acres, soybeans are the transition from corn (or milo) to wheat. Summerfallow (chem-fallow) has been banned on his farm for many years now.

Leading Edge

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No-till on the Plains Inc's Mission: To assist agricultural producers in implementing economically, agronomically, and environmentally sound crop production systems.

Objective: To increase the adoption of cropping systems that will enhance economic potential, soil and water quality, and quality of life while reducing crop production risks.

The First *R*: Rotations

Concerning rotations, Dan expresses, "If you want to speak of rotations, ideas that we are trying, we see that I do not have a set rotation: It's a moving target. As I contemplate this, I think what no-till has brought to my operation is opportunities." Dan continues, "That is my mantra: No-till presents opportunities. Maybe I try to oversimplify things here a little bit, but it all comes back to the soil. No matter how you want to look at rotations, I think soil health and soil biology have got to be a big factor in that." Because of this thought process, Dan tries to plant what he thinks will be best-suited for a field based on residue levels, cropping history, weed / disease / insect pressures, and always with an eye on grain markets. Dan continues, "I really believe that with our rotational diversity, we don't know what we're doing sometimes. How can we have the insects or weeds know what we're doing?" —alluding to not being overly consistent with crop sequence, lest the pests adapt to ('learn') the system.

Strip-till—been there, done that. Now: "Tillage is not even a factor in my operation, in my mindset."

Dan's crops on both dryland and irrigated ground include corn, milo, soybeans, wheat, and both oilseed and confectionary sunflowers (usually confectionary on irrigated, and oilseed on dryland). Millet, oats, and other forages are planted on dryland only. Soybeans and sunflowers never are planted following one another, due to both low residue and disease concerns. Wheat, corn, and milo are stacked occasionally ('stacked' refers to planting the same crop two consecutive years, preceded by a lengthy break from that species).

Dryland soybeans replacing fallow in northwest Kansas? Dan admits it's risky, but it's been working: his farm-wide dryland average yields were 32 bu/a in '08, 37 bu/a in '09, and about 15 bu/a in '10—although there were some zeros previously. Still searching for better rotations, he's started putting spring forages in to replace some dryland soybean acres: specifically, a blend of oats, spring triticale, field peas, radish, and turnips. This mix is hayed, grazed, or sprayed out (purely a cover crop).

Photo by Charles Long.

Irrigating a mix of fertilizer, radish & turnips broadcast the day prior (early Sept. '09). Says Dan, "We've grown our soil biology, and it's hungry."

Dan comments, "Cover crops have been tried, and we are really in the conception stage—we don't know, we don't understand this. I believe that increasing organic matter in the soil is vital. I believe the ground must be covered." Dan adds, "We are trying to look at the next step that we see and fill in here maybe with covers and what they can bring. We've grown our soil biology, and it's hungry." Accordingly, millet was planted into corn stalks in June '09 and sprayed out in August, then planted to dryland wheat that made 65 bu/a.

Also in '09, Dan planted soybeans for a cover crop in some low-residue pivot corners. Although the yield potential was excellent in September '09, these beans were killed with dicamba: Dan thought they had more value as standing residue. Planted to hay oats the next spring: "I'm extremely pleased with the hay production from those fields."

In early Sept. '09, Dan experimented with a mixture of turnips, radishes, and fertilizer broadcast into wheat stubble on part of a pivot to observe the effects on the 2010 confectionary flowers. He notes "beautiful planting conditions" in the cover-cropped area, and no visible increase in disease (the crop wasn't yet harvested as of press time).

*R*esidue (Mulch Cover)

On the importance of leaving residue attached, Dan comments: "We fear—out west here—wind probably most of all. Anytime we detach residue we make it subject to take off, so in this early stage of cover crops we're trying to realize and study that too. We've all had that real good stubble, planted into it, and catch one of those freak windstorms. We come back the next day and it's swept clean." He cites the example of drilling a mix of beans, milo, etc. into standing sunflower stalks on some pivot corners in the spring of '09. Using 7.5-inch rows with the air drill, most of the stalks were broken off. That night a very strong wind moved the sunflower stalks to the grader ditch and left the field bare. To avoid this happening again, Dan realized he had to do something different, which was changing the rotation. So he's been trying sunflowers into stripper-harvested wheat stubble, then following the flowers with corn (irrigated) or milo (dryland), using a planter to keep more of the sunflower stalks intact. He doesn't yet know if the new rotation is a net economic benefit or not, but he likes having a lot of wheat stubble remaining after the sunflowers are harvested.

Dan gives another example of how low residue has hurt: "A couple of years ago as we pushed the envelope, we ran into one of those summers where we had dryland corn 'burn up' [drought: no grain yield]. It was chopped [for silage], and that year I fought it all winter—and that will never happen again. That corn, if it 'burns up,' it's going to stay right there and it's going to be next year's starting [point]. We continue to learn and that's what we build our biases off now is our experiences; so it's all about trying to build soil, and residue, and organic matter. That's my focus."

Resources, the Third *'R'*

Dan depends on many resources to help him make informed decisions. One of these he calls his "Circle of Friends"—other producers in his area. "There's a handful of us that are very committed to this. Within that circle of friends we have earned or built a respect there. We confide in each other . . . . We are hungry for answers. We get together frequently, phone, down the road, whatever. We look at different ideas. You name it—it's being tried." Dan continues, "We compare notes, what we like, what we don't like, what we saw. That bunch of guys to me is so valuable because we really have built a good trust. We get together whether we are talking cash rent or returns per acre. We are pretty frequent to share that stuff."

Crop rotation: "It's a moving target. What no-till has brought to my operation is opportunities."

Dan also credits No-till on the Plains as helping immensely due to the experts it puts him in touch with, people who are very approachable and willing to help; he especially mentions Ray Ward, Dwayne Beck, Jill Clapperton, and Matt Hagny. Dan also thinks that being a seed dealer for Channel and an agent for Red River Commodities gives him access to excellent sources of information from experts in these companies. Dan further gathers insight via the test plots he conducts every year.

Photo by Charles Long.

Dan examines the soil characteristics in an irrigated field. All of his land is under continuous no-till management. This field had manure applied in the recent past, but nearly all the pieces have decomposed already, releasing the nutrients into the soil profile. Note the thatch of mulch.

Irrigation is another valuable resource to Dan's farm. All pivots can be checked by cell phone for shutdown, GPS direction, and speed. All pivots have been set up to fertigate. Dan describes how the pivots are equipped to conserve water: "We went all drop nozzles, low pressure. We've got a resource here we've got to watch. We've got to take care of that." An additional measure is the installation of gypsum ("gyp") blocks at 1, 2, 3, and 4-foot depths. The amount of moisture available at these depths (read by a handheld meter) helps to determine the need for irrigation. These gyp blocks will probably be replaced by electronic sensors that will transmit moisture information to a cell phone or computer.

Soil tests on Dan's fields going back to the 1980s have been kept, and he continues to soil test on a regular schedule. He also utilizes tissue tests to spot problems before they get out of hand. These tests reinforce his idea that no-till is working to build his soil. Dan says, "Dad always raised us that if you take care of the soil, it will take care of you." He comments further, "We've got soil tests that show that as we kept moving toward full commitment to no-till, every step over time, we kept seeing improvement in our nutrient levels, kept seeing improvement in our organic matter levels, our pHs were actually decreasing a little bit [a *good* thing in his soils], so there it gave us something we could say, 'Yeah, we've got things going in the right direction here,' and that's what helped me make the commitment that it's time to go [to permanent no-till]."

Dan applies manure to as many fields as possible, as another soil-building activity to enhance fertility and increase organic matter. He's trying to add about 15 tons per acre under the pivots about once every five years. He would like to also

Photo by Dan Schultz.

Dan planting dryland corn into sunflower stalks, being a self-proclaimed gambler. However, "I wouldn't recommend this rotation," and Dan himself only rolls the dice when he has: A) a really heavy thatch of wheat residue left over from the wheat grown the year prior to the flowers; *and*, B) a full profile of moisture in the spring.

do this on the dryland fields but availability and distances make this difficult. At first, he incorporated the manure with tillage. He met Jill Clapperton at a meeting and was telling her about it. She asked him why he incorporated it, and explained that incorporation was unnecessary. He listened. Now the manure remains visible on the soil surface until it has decayed. The pivots that last had manure applied show some manure pieces yet and have very impressive crops of corn on them. (*Editors' Note: Manure isn't a cure-all, and it certainly can make some nutrient deficiencies worse, e.g., zinc.*)

"Trying to build soil, and residue, and organic matter. That's my focus."

Putting It in Practice

Schultz Farms' planter is a 24-row, 30-inch (60-ft) JD planter with variable-rate planting capabilities, new in '09, and basically stock except for a liquid fertilizer setup, Keetons, and Yetter floating row cleaners with depth bands and 13-wave coulters. Depending on planting conditions, the row cleaners may be raised clear up or allowed to move a limited amount of residue. Even though his fields show very impressive amounts of residue, the stands are excellent. The coulters are removed if conditions are wet enough that they cause problems. Dan thinks that in dry conditions the coulters save much wear on the opener blades and bearings. For 2010, Dan added a 30-ft, *15-inch* JD 1790 planter (24 rows total), which doesn't have any liquid fertilizer capability: It was used primarily for soybeans as well as some milo this year. This planter does have Keetons and 13-wave coulters.

On irrigated corn, using the 30-inch planter, about 80 lbs of N and some S are applied 3.5 inches from the row, supplied from a 1600-gallon tank towed behind the planter. The remaining N goes on via fertigation. On dryland corn, milo, and sunflowers, Dan typically applies all fertilizer at planting. While it takes a little longer to apply all the fertilizer with the planter, Dan says it saves time in the long run. (Occasionally he will resort to streaming N onto the crop after it's planted.) For all crops, whenever he applies N, he also includes S at a 10:1 ratio. For all his corn and flowers, Dan places pop-up via Keeton seed firmers, using a gallon of Nortrace Riser mixed with three gallons of water (the Riser provides tiny doses of N-P-K as well as highly available micronutrients). Dan previously applied this same pop-up on soybeans and milo, noting to himself that he needs to get his new 15-inch planter set up with pop-up capability.

Dan's wheat, forages, and cover crops are seeded with a 40-ft 1850 JD air drill, fully loaded with suitcase weights. The drill is a '96 model that has been rebuilt numerous times. It is entirely stock except the original 1-inch-wide firming wheels were replaced with 'narrow' Deere firming wheels (introduced in '06). With the air drill, Dan has always applied dry fertilizer pop-up at wheat planting, except for fall of 2010 when he chose to broadcast the MESZ instead, due to time constraints. He recognizes "a certain amount of risk" with this decision, but notes that his soil P levels are

Photo by Dan Schultz.

Dan bought this manure, and hired the spreading onto his field in January, while frozen. Dan prefers to stockpile and compost it for awhile.

decent, and he'll fertigate N onto the wheat under the pivots this fall. For dryland wheat into soybean stubble, he will spray paraquat, UAN, and thiosul on some of it preplant or pre-emerge. Additional fertilizer is streamed on in the spring.

Instead of owning a field sprayer, all of Dan's spray applications are done by commercial sprayers. Dan has divided his farming operation into four territories with each assigned to one of four commercial sprayers. So, four sprayers can be running at one time if needed. Dan explains why he doesn't have his own sprayer: "If I throw a sprayer into the mix, something else is going to suffer—either irrigation management is going to suffer, the cattle are going to suffer, or the dryland production is going to suffer, because someone is going to have to be pulled off something else to do that [spraying]."

Dan has divided his farm into four territories with each assigned to one of four commercial sprayers. So, four sprayers can be running at once, if needed.

Harvest is done with Schultz Farms' combine along with the help of a neighbor who does custom harvesting. Yield monitors and yield mapping are deployed on the combines. To enhance the stability of the residue, Dan's used stripper heads on wheat since '07, and he likes the fact that the residue is much more able to trap snow. Due to the scarcity of harvest help, and the difficulty getting the grain hauled from the field, Dan says, "We purchased a bagger [in '08] and are really glad that we have it for this fall ['09]. We can drop a bag in the field and save a lot of truck time and cost and labor and just put combines and grain carts in the field, and we're going." Labor for Dan's operation consists of himself, Schultz Farms' full-time hired hand (when available), and Dan's dad and his father-in-law as needed. If possible, additional help is hired for harvest.

Minding the Details

Dan hawks over the details of the seeding process. For the planters or the air drill, ground speeds are kept between 4 and 5.5 miles per hour. Dan further notes, "I don't plant any naked seed. We apply the seed treatment on wheat. Corn already comes with it. Milo has it. Beans have it."

Dan plants wheat at 275 – 300 seeds/yd^2 on dryland (1.3 to 1.4 million seeds/a), and 300 – 350 on irrigated, based on a chart from Phil Needham. Dan hasn't grown a lot of stacked wheat, although he thinks that with some of the strengths in new varieties and with more affordable fungicides, he may do more of this, especially if stubble levels become low in a field.

Milo is utilized on some acres, although Dan grows mostly corn instead: "Milo isn't my crop of choice, but I like the residue of a sorghum crop. It's consistent; it's easy to handle, easy to plant through, and stays longer." Milo goes in with one of the planters, with a seed drop of about 55,000. Corn populations range from 18,000 on dryland up to 34,000 on irrigated.

With attentiveness to rotations, residue, and resources, plus the skills to make solid business decisions, Dan and his farm are in no-till for the long haul.

Photo by Dan Schultz.

Dan's operation takes on another load of fertilizer in Dec. '09, which gets stored in the tubular bulk bags until spring planting of forages, etc. Dan comments that it's risky by early summer when hailstorms are more prevalent. Note that a special bag material is needed when storing MESZ due to the sulfur component.

Softer Footprints

We've previously discussed reducing soil compaction with tracks or large radial tires with proper inflation (see 'Pressure Relief' [Sept. '05] & 'Tread Lightly' [Jan. '08]). Producers are putting this in action, with favorable results.

Photo by Kent Stones.

Wheat harvest 2009 on the Kent Stones operation in north-central KS. Apparently Kent got quite serious about reducing soil compaction after a day spent digging and observing with one of his consultants in '08. Kent now runs the *big* tires on both of his *big* combines: "We went with the 650/85 R38 duals on the drives and 28L*26 on the steering. This is the lowest psi option that JD makes available."

Photo by Kevin Wiltse.

A couple years ago, Kevin Wiltse outfitted his new CIH 3320 sprayer (100-ft booms) with 650/65 R38 radial tires. He's pleased with the reduction in soil compaction in the wheel track, as well as the softer ride. Wiltse runs the recommended 18 – 20 psi in them, which is a fairly 'soft shoe' for a high-capacity sprayer (see table in 'Tread Lightly,' Jan. '08 issue).

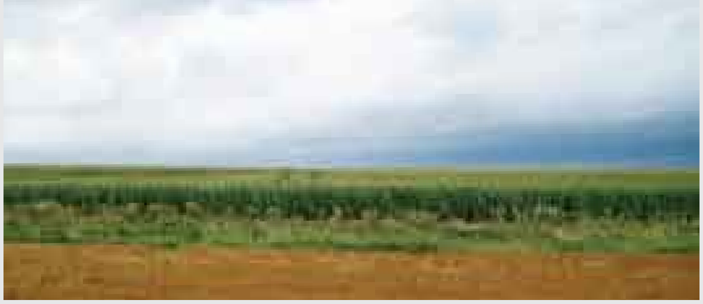


Photo by Matt Hagny.

Most producers with wide tires on their sprayers have begun spraying cross-ways (perpendicular) to their 30-inch rows.

Stalks: Keep 'Em Standing

On several occasions, we've commented on the need to keep stalks standing, as tall and intact as possible, not only for durability of the mulch cover (a good thing) but also for ease of planting the next crop. Another hazard with pulverizing the stalk, etc., is the residue (and potentially the soil) blowing away—into fence-rows, hedgerows, road ditches, and elsewhere. These are lost resources.

One aspect of this is to do as *little* processing of corn stalks as possible when harvesting. Choose *fluted* snap rolls instead of knife rolls. And avoid heads that have separate cutting knives to shave the stalks off closer to the ground (Drago, Geringhoff); the stalk chopping is really a disaster for no-till with disc-opener seeders since you then have a mat of shredded residue to cut through. Choose heads and snap rolls that do the least amount of stalk breakage, and run the head just barely below the ears. (If you have trouble with the stalks pulling loose the tubes, wires, or hoses from your tractor, drill, or planter, consider adding a heavy knock-down bar or pipe across the front.)

Photo by Kent Stones.

During corn harvest in '09, Kent Stones was running different corn head models on his two combines in alternating swaths: A new JD 608, and an older JD 893—both with knife rolls. "The new head has a geometry forcing a lower cut on the stalks. I remember thinking at the time, 'I'm not so sure I like this.' " After planting 2d-year corn into those stalks and catching a 60-mph wind, he was *sure* he didn't like it—most of the residue tumbled away. In the photo, the shorter, paler corn plants are rows harvested with the 893, where the residue piled up 3 – 4 inches deep after blowing off the shorter, more pulverized stalks from the 608 head (note the bare soil). To alleviate the problem, Stones went to fluted snap rolls (instead of knife rolls) and will tilt the feeder house frame to allow a flatter operating angle.

Photo by Tony Downs.

Glyphosate: Not So Benign?

by Matt Hagny

SCIENCE

Hagny is a consulting agronomist for no-till systems, based in Wichita, Kansas.

Part I: The Science

For the past few decades, everyone *knew* that glyphosate was inert once it hit the soil, and that it had no residual activity. The science of that era taught us that glyphosate was so strongly bound to clay particles that none could be taken up by a newly planted crop, much less a crop planted a year later. However, some studies reported over the years, especially recently, do show that glyphosate applications can cause some serious problems for subsequent crops, whether or not they're glyphosate-resistant as Roundup Ready ('RR') (from the *Aroa* gene insertion event). But it's a hugely complicated issue, and not so easily studied as to what is occurring in the soil, and under which conditions. Let's explore:

First, we find that glyphosate does indeed persist in the soil *in available forms* for many weeks, months, or years, *and can be taken up by roots of newly planted crops*.[1] Much of this derives from the slow decomposition of mulch from plants which took up glyphosate while alive,[2] with glyphosate in plant material persisting 2 to 6 times longer than in bulk field soil.[3]

Photo by Volker Römheld.

Field trial at Hirrlingen, Germany, with winter wheat. All plots were sown on the same day, but glyphosate was applied at two different times ahead of sowing, and at two rates. 2 L/ha = 0.85 quarts/acre of 4-lb/gallon (ai) Roundup Ultra. (Source: Bott et al., 2009b.)

Glyphosate's damage to later vegetation may include poor uptake and impaired translocation of nutrients (especially iron, manganese, zinc, copper, nickel, magnesium, and calcium),[4] reduced drought tolerance, slowing

[1] S. Bott, T. Tesfamariam, A. Kania, B. Eman, N. Aslan, V. Römheld & G. Neumann, 2010a draft, Phytotoxicity of glyphosate soil residues re-mobilised by phosphate fertilisation, unpublished manuscript accepted by *Plant & Soil* in late 2010; S. Bott, B. Eman, N. Aslan, A. Kania, V. Römheld & G. Neumann, 2010b draft, Important factors for rhizosphere transfer of glyphosate: (I.) Role of weed density and soil type for phytotoxic effects in crop plants, unpublished manuscript submitted to *J. Agric. Food Chem*. in late 2010; A. Piccolo, G. Celano, M. Arienzo & A. Mirabella, 1994, Adsorption and desorption of glyphosate in some European soils, *J. Environ. Sci. Health* B29(6): 1105-1115; C.A. Lévesque & J.E. Rahe, 1992a, Review: Herbicide interactions with fungal root pathogens, with special reference to glyphosate, *Annual Rev. Phytopath*. 30: 579-602; M.M. de Andréa, T.B. Peres, L.C. Luchini, S. Bazarin, S. Papini, M.B. Matallo & V.L.T. Savoy, 2003, Influence of repeated applications of glyphosate on its persistence and soil bioactivity, *Pesq. agropec. bras. Brasilia* 38: 1329-1335; S.M. Carlisle & J.T. Trevors, 1988, Review: Glyphosate in the Environment, *Water, Air, Soil Pollution* 39: 409-420 (half-life from a few days to *years*); T. Tesfamariam, S. Bott, I. Cakmak, V. Römheld & G. Neumann, 2009a, Glyphosate in the rhizosphere—Role of waiting times and different glyphosate binding forms in soils for phytotoxicity to non-target plants, *Europ. J. Agron*. 31: 126-132; T. Tesfamariam, 2009b, Glyphosate Use in Agro-ecosystems: Identification of key factors for a better risk assessment, Ph.D dissertation (presented 2 Sept. 2009 at Univ. Hohenheim, Germany); O.K. Borggaard & A.L. Gimsing, 2008, Review: Fate of glyphosate in soil and the possibility of leaching to ground and surface waters, *Pest Mgmt. Sci*. 64: 441-456 (glyphosate half-life from 100 to 1,000 days depending on soil type; other studies have found half-life times ranging from a few days to 8 months).

[2] Tesfamariam et al., 2009a; P. Laitinen, S. Rämö & K. Siimes, 2007, Glyphosate translocation from plants to soil—does this constitute a significant proportion of residues in soil?, *Plant & Soil* 300: 51-60.

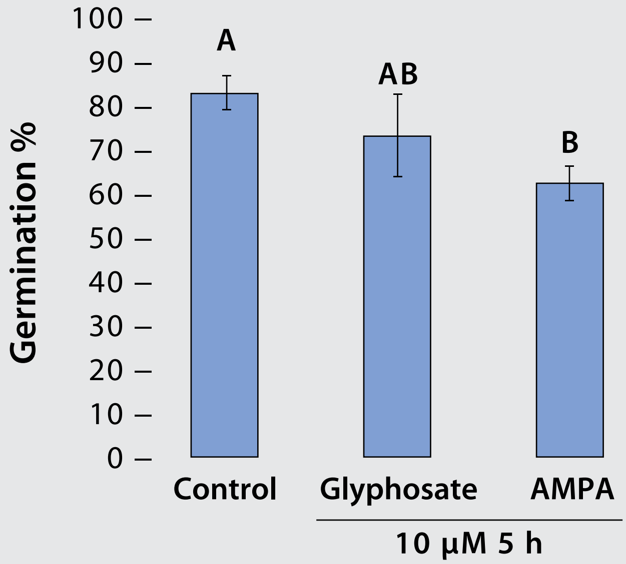
[3] J. Doublet, L. Mamy & E. Barriuso, 2009, Delayed degradation in soil of foliar herbicides glyphosate and sulcotrione previously absorbed by plants: Consequences on herbicide fate and risk assessment, *Chemosphere* 77: 582-589, and references therein.

[4] Tesfamariam et al., 2009a; Bott et al., 2010a draft (on different soils, different nutrients were affected by soil-applied glyphosate, some of them dramatically reduced and well into deficiency ranges); G. Neumann, S. Kohls, E. Landsberg, K. Stock-Oliveira Souza, T. Yamada, V. Römheld, 2006, Relevance of glyphosate transfer to non-target plants via the rhizosphere, *J. Plant Diseases & Protection* 963-969; S.O. Duke, K.C. Vaughn & R.D. Wauchope, 1985, Effects of glyphosate on uptake, translocation, and intracellular localization of metal cations in soybean (*Glycine max*) seedlings, *Pest. Biochem. Physiol.* 24: 384-394. Glyphosate-induced manganese (Mn) deficiency is often attributed to: the chelating properties of glyphosate itself in either the soil solution, or inside the plant; reduced root growth or other toxic effects of glyphosate & AMPA at the cellular level; and/or the competitive interaction between glyphosate and certain cationic nutrients near or on the root surface. (Tesfamariam et al., 2009a; Bott et al., 2010a & 2010b drafts.) No evidence of immobilization of nutrients within *leaves* has been found for foliar application of glyphosate on RR soybean. (S. Bott, T. Tesfamariam, H. Candan, I. Cakmak, V. Römheld & G. Neumann, 2008, Glyphosate-induced impairment of plant growth and micronutrient status in glyphosate-resistant soybean [*Glycine max* L.], *Plant & Soil* 312: 185-194.) However, research has shown that a complexing of micronutrients within *roots* may explain the depression of root-to-shoot transfer of essential micronutrients. (S. Eker, L. Ozturk, A. Yazici, B. Erenoglu, V. Römheld & I. Cakmak, 2006, Foliar-Applied Glyphosate Substantially Reduced Uptake and Transport of Iron and Manganese in Sunflower [*Helianthus annuus* L.] Plants, *J. Agric. Food Chem.* 54: 10019-10025, and references therein.) Some re-

of growth, reduction of vigor, etc.[5] Note, however, that the 'flashing' (paleness) of newly developing leaves from glyphosate injury—whether from root uptake or foliar—is now thought to be due to the plant-toxic AMPA (one of glyphosate's primary metabolites: i.e., what exists after the glyphosate breaks down), rather than solely from micronutrient deficiency symptoms.[6]

AMPA results from glyphosate-degradation processes in plant tissue *and in the soil* (both from microbial activity as well as non-biological breakdown). Most plants (including Roundup Ready crops) metabolize only minimal amounts of glyphosate, although the amount of foliar-applied glyphosate that gets converted to AMPA varies tremendously amongst plant species.[7] While AMPA is also translocated to root tips, and is even more persistent in the soil than glyphosate,[8] no evidence of root uptake of AMPA by subsequent vegetation has yet been found.[9] However, soil residual AMPA *does* reduce germination and vigor of seeds.[10]

Not all the glyphosate in the soil is from spray droplets actually contacting the soil: The primary mechanism for movement into the soil is often the translocation



Seed exposure to the metabolite AMPA, but not glyphosate itself, caused reduction in germination. Conversely, hydroponic studies show reduced shoot & root growth from root exposure to glyphosate, but not AMPA. The two distinct toxicity factors may explain some of the variability of observed symptoms. Different letters indicate statistical significance at $P \leq 0.05$. (Sources: Bott et al., 2009b; Bott et al., 2010d draft.)

searchers conclude that reduced nutrient uptake associated with soil carryover of glyphosate is almost entirely due to impaired root growth because *anionic* nutrient uptake is also reduced. (Bott et al., 2010b draft.) Although little evidence exists, decreased uptake of Mn may also be due to glyphosate in the soil and/or in root exudates favoring *Agrobacterium* spp, which are Mn-oxidizers, i.e., capable of snatching electrons from the Mn ion to make it more positively charged and thereby *un*available to the plant. (R.J. Kremer & N.E. Means, 2009, Glyphosate and glyphosate-resistant crop interactions with rhizosphere microorganisms, *Europ. J. Agron*. 31: 153-161.) Glyphosate is also hypothesized to inhibit microbes making Mn available to plants: the Mn-'reducers,' which, in chemistry terms, means adding an electron (making the ion more negatively charged).

5 The primary mechanism of glyphosate's damage to plants (and some microbes) is the inhibition of 5-enolpyruvylshikimic acid-3-phosphate synthase (EPSPS), the critical enzyme in the shikimate pathway required for synthesis of chorismate, the precursor of several essential amino acids including phenylalanine, which is crucial to plant growth; production of tannins, flavonoids, lignin precursors, and other aminos is also impaired from lack of chorismate. (H. Holländer & N. Amrhein, 1980, The Site of the Inhibition of the Shikimate Pathway by Glyphosate, *Plant Physiol.* 66: 823-829; N. Amrhein, J. Schab & H.C. Steinrücken, 1980, The Mode of Action of the Herbicide Glyphosate, *Naturwissenschaften* 67: 356-357; Carlisle & Trevors, 1988.) Glyphosate's inhibition of root growth can also occur in Roundup Ready crops, including under Mn-*abundant* conditions. (Bott et al., 2008; Bott et al., 2010b draft; L.H.S. Zobiole, R.S. de Oliveira, D.M. Huber, J. Constantin, C. de Castro, F.A. de Oliveira & A. de Oliveira, 2010a, Glyphosate reduces shoot concentrations of mineral nutrients in glyphosate-resistant soybeans, *Plant & Soil* 328: 57-69.) However, some studies have found *no* reduction in root growth for glyphosate applied to RR corn, RR soybeans, or RR cotton. (M.C. Savin, L.C. Purcell, A. Daigh & A. Manfredini, ca. 2007, *AAES [Arkansas] Research Series #548*, pp 49-51 ["no effect of glyphosate on shoot dry weight or root weight for any of the species" during the 2 years of study].) (*Cf.* Bott et al., 2010b draft.) (Also *cf.* S. Bott, B. Sentürk, Y. Ceylan, T. Tesfamariam, V. Römheld & G. Neumann, 2010c draft, Important factors for rhizosphere transfer of glyphosate: (II.) Role of differences in sensitivity of crops to glyphosate, unpublished manuscript submitted to *J. Agric. Food Chem.* in late 2010.) Another mechanism of glyphosate damage in plants is the toxic intracellular metabolite AMPA, aminomethylphosphonic acid, which has effects distinct from glyphosate. (K.N. Reddy, A.M. Rimando, S.O. Duke & V.K. Nandula, 2008 , Aminomethylphosphonic Acid Accumulation in Plant Species Treated with Glyphosate, *J. Agric. Food Chem.* 56: 2125-2130; Bott et al., 2008.)

6 Kassim al-Khatib (weed scientist, U.C.-Davis), personal communication Sept. 2010; Bott et al., 2008. Roundup Ready corn & soybean varieties might themselves be less efficient at uptake and internal usage of Mn (as compared to their near-isoline without the RR trait), although this isn't adequately proven. (Bott et al., 2008; Zobiole et al., 2010a. *Cf.* D.M. Dodds, D.M. Huber & M.V. Hickman, 2002, Micronutrient levels in normal and glyphosate-resistant soybean, in *Proceedings: North Central Weed Sci. Soc.* Abstract #57: 107 (Champaign, IL). See also C.A. Rosolem, G.J.M. Andrade, I.P. Lisboa, S.M. Zoca, 2009, Manganese uptake and redistribution in soybeans as affected by glyphosate, in *Proceedings of the International Plant Nutrition Colloquium XVI* [U.C.-Davis, CA].) Paleness of RR crops following glyphosate application may be due to its strong inhibition of a chlorophyll precursor, 5-aminolevulinic acid. (Rosolem et al., 2009; Carlisle & Trevors, 1988.)

7 Reddy et al., 2008; M.C. Arregui, A. Lenardón, D. Sanchez, M.I. Maitre, R. Scotta & S. Enrique, 2003, Monitoring glyphosate residues in transgenic glyphosate-resistant soybean, *Pest Mgmt. Sci.* 60: 163-166 (following typical in-crop glyphosate application rates & timing on RR soybean, substantial glyphosate & AMPA were found in all plant parts at 7 days after application & at maturity, and correlated with number of glyphosate applications to that crop).

8 de Andréa et al., 2003. Carlisle & Trevors, 1988; Borggaard & Gimsing, 2008 (what percent of glyphosate in the soil gets converted to AMPA is unknown, since a second pathway—via C-P lyase cleaving, and subsequent conversion to phosphate & sarcosine—is known to exist in microbes, although sarcosine has never been found in glyphosate-treated agricultural soils, possibly because of sarcosine's rapid degradation to glycine & formaldehyde; some *Pseudomonas* spp degrade glyphosate via the sarcosine pathway).

9 al-Khatib, Sept. 2010; Reddy et al., 2008 ("AMPA from soil microbes in contact with root-exuded glyphosate might be translocated to shoots"—however, the authors interpreted their evidence as *not* supporting this hypothesis.)

10 S. Bott, T. Tesfamariam, G. Neumann & V. Römheld, 2009b, PowerPoint 'Glyphosate toxicity in the rhizosphere,' presented at the Institute Plant Nutrition Colloquium (Univ. of Hohenheim, Germany, 20 Nov. 2009) (slide #12); S. Bott, U. Lebender, A. Kania, D.-J. Yoon, T. Tesfamariam, Y. Ceylan, V. Römheld & G. Neumann, 2010d draft, Rhizosphere transfer of glyphosate after pre-crop herbicide application, unpublished manuscript submitted to a major journal in late 2010; Tsehaye Tesfamariam (crop nutrition physiologist, U. Hohenheim, Germany), personal communication Sept. 2010; G.F. Barry, 2009, U.S. Patent # 7,554,012 B2 (Assignee: Monsanto Technology LLC, St. Louis, MO): Plants and plant cells exhibiting resistance to AMPA, and methods for making the same,

Photo by Sebastian Bott.

All pots (unsterilized field soil, pH 5.0) were planted at the same density of wheat kernels at the same depth; glyphosate had been applied 2 days prior. Treated weeds were clipped and removed before wheat germination, so the loss of stand and vigor indicate root-to-root transfer of glyphosate. 4 L/ha = 1.7 quarts/acre of 4-lb/gallon Roundup Ultra. (Sources: Bott et al., 2009b; Bott et al., 2010d draft)

by plant foliage & stems to root tips (as well as what remains in leaves, which eventually drop onto the soil), because glyphosate is broken down so slowly within plant tissues—even in Roundup Ready crops.[11] Within hours of glyphosate application, the plants (weeds or crops, including RR crops) have translocated a significant portion to the roots,[12] where it leaks into the surrounding soil in root exudates, or is retained within the root (and other plant parts) where it may be released months or years later as the remnants slowly decompose.[13] The glyphosate in root exudates can also be transferred to nearby plants by root-to-root contact, such as when glyphosate sprayed onto row middles with a hooded sprayer makes its way into the non-RR crop (and this is also known to happen in orchards, when the weeds or cover crops between the orchard trees are sprayed with glyphosate).[14] Injury symptoms from glyphosate taken up via roots differ considerably from foliar uptake, perhaps because up to 75% of the glyphosate uptake by roots remains in young roots and can severely impair their development and function, thereby causing poor absorption and translocation of water and nutrients.[15] This phenomenon likely has caused under-recognition of glyphosate carryover injury.

Within hours of glyphosate application, the plants—including RR crops—translocate a significant portion to the roots, where it leaks into surrounding soil.

Nodulation and N-fixation by legumes can also be reduced by glyphosate, although these effects vary considerably in the field and in the lab, partly because some strains of soybean rhizobial bacteria are much more susceptible to glyphosate than others, and also because of different rates & timing of glyphosate application, and because moisture and nutrient availability also influence nodule growth and effectiveness.[16] For example, drought stress impairs the legume's ability to nodulate, and glyphosate application to RR soy-

(30 June 2009 patent issue date; filed on 7 Aug. 2002) (text following Table 17: "[AMPA] concentrations above 0.2 mM were severely inhibitory to both shoot and root elongation, indicating that AMPA may also be phytotoxic to wheat and, considering the nature of the monocot crop species as a whole, phytotoxic to other monocotyledonous crops as well as turf grasses.").

11 See, e.g., Arregui et al., 2003. Current glyphosate resistance (Roundup Ready) relies on the EPSPS-*cp4* (*aroA*) gene insertion 'event,' causing the plant to develop a variant—a second EPSPS pathway that is especially tolerant of inhibition by glyphosate, which is why so little glyphosate is actually degraded in Roundup Ready plants. Some newer gene events conferring glyphosate resistance (e.g., Pioneer's long-awaited *Gat*) cause plants to degrade glyphosate outside the EPSP route, such as by acetylation in the case of *Gat*, or by oxidation with the *Gox* gene. This would greatly reduce the loading of glyphosate into the root zone by these crops, although the weeds would still be putting glyphosate into their roots, and thus, the soil. (G.S. Johal & D.M. Huber, 2009, Glyphosate effects on diseases of plants, *Europ. J. Agron.* 31: 144-152. See also S.O. Duke & S.B. Powles, 2009, Glyphosate-Resistant Crops and Weeds: Now and in the Future, *AgBioForum* 12: 346-357.) And AMPA problems may continue.

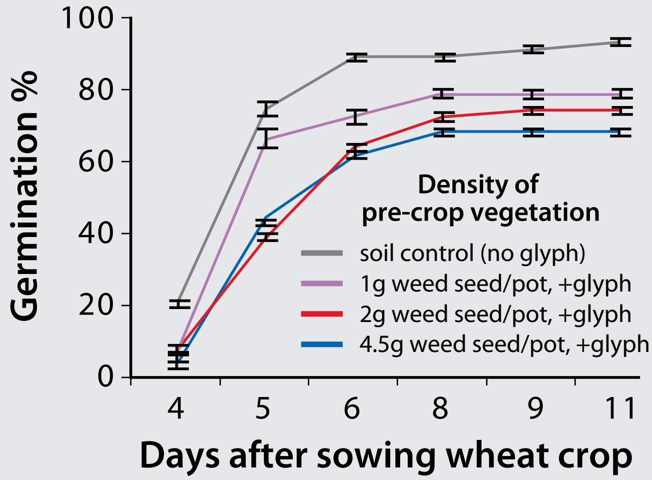
12 See, e.g., Eker et al., 2006; Lévesque & Rahe, 1992a.

13 Doublet et al., 2009; Laitinen et al., 2007; M.A. Locke, R.M. Zablotowicz & K.N. Reddy, 2008, Integrating soil conservation practices and glyphosate-resistant crops: impacts on soil, *Pest Mgmt. Sci.* 64: 457-469 (see especially the discussion of von Wirén-Lehr et al., 1997, as to the greater portion of glyphosate in plant residues being sequestered in durable components [e.g., lignins] which decompose slowly to very slowly); D. Coupland & J.C.Caseley, 1979, Presence of ^{14}C activity in root exudates and guttation fluid from *Agropyron repens* treated with ^{14}C-labelled glyphosate, *New Phytol.* 83: 17-22.

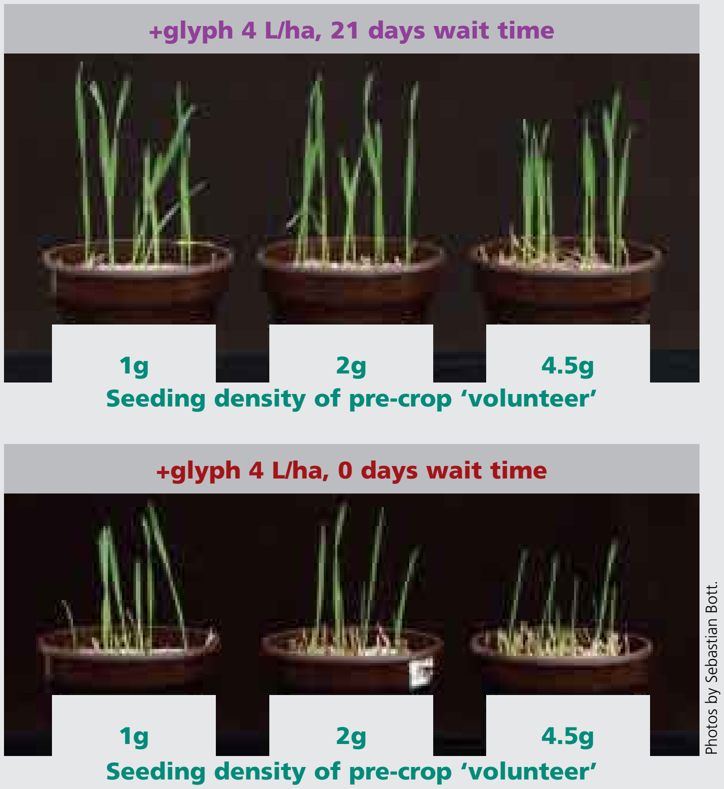
14 See, e.g., Neumann et al., 2006.

15 Bott et al., 2010d & 2010c drafts, and references therein; Bott et al., 2010a draft (excellent photos of symptoms).

16 Holländer & Amrhein, 1980; C.A. King, L.C. Purcell & E.D. Vories, 2001, Plant Growth and Nitrogenase Activity of Glyphosate-Tolerant Soybean in Response to Foliar Glyphosate Applications, *Agron. J.* 93: 179-186; K.N. Reddy, R.E. Hoagland & R.M. Zablotowicz, 2001, Effect of Glyphosate on Growth, Chlorophyll, and Nodulation in Glyphosate-Resistant and Susceptible Soybean (*Glycine max*) Varieties, *J. New Seeds* 2: 37-52; R.M. Zablotowicz & K.N. Reddy, 2004, Review: Implications of glyphosate resistant transgenic soybean on the *Bradyrhizobium japonicum* symbiosis, *J. Environ. Qual.* 33: 825-831; Laitinen et al., 2007. *Cf.* J.R. Powell, R.G. Campbell, K.E. Dunfield, R.H. Gulden et al., 2009, Effect of glyphosate on the tripartite symbiosis formed by *Glomus intraradices*, *Bradyrhizobium japonicum*, and genetically modified soybean, *Appl. Soil Ecol*. 41: 128-136 (N fixation tended to be greater with glyphosate application.) On the other hand, mycorrhizae typically don't suffer directly from glyphosate—except for the death or stunting of their host plant; evidence of both stimulation and suppression are found, apparently due to variations in climate, other soil biota, and fertility (Powell et al., 2009; Savin et al., 2007; Lévesque & Rahe, 1992a; A.L. Cerdeira, D.L.P. Gazziero, S.O. Duke, M.B. Matallo & C.A. Spadotto, 2007, Review of potential environmental impacts of transgenic glyphosate-resistant soybean in Brazil, *J. Env. Sci. Health Part B* 42: 539-549.)



In another lab experiment using unsterilized field soil with pH of 7.1, the density of vegetation—grams of 'volunteer' wheat seeds planted a few weeks prior—that got sprayed with glyphosate strongly affected the germination rate of the subsequent wheat seeds planted on the same day as the glyphosate application (0 days wait time). At *21* days wait time, no differences in germination occurred between the various vegetation levels or bare soil. (Sources: Bott et al., 2009b; Tesfamariam, Sept. 2010.)



Same experiment as previous graph. Injury to wheat plants from glyphosate residual in roots and/or soil was worse with shorter wait times, and with heavier density of the target pre-crop vegetation. (Sources: Bott et al., 2009b; Tesfamariam, Sept. 2010.)

bean multiplies this effect.[17] Furthermore, glyphosate impairs nitrate reductase activity in many crops, including RR soybeans and RR corn, thereby hindering the plant's usage of nitrate to build proteins.[18] Glyphosate also inhibits a number of other plant enzymes.[19]

Roots themselves exude a slime (biofilm) that's a feed-trough for many soil organisms, some of which are beneficial to the plant, some benign, and some pathogenic. Glyphosate can become concentrated in these exudates, which is the precise location in the soil for pathogenic fungi & 'water mold'[20] entry into roots. Glyphosate leakage from roots can directly stimulate the pathogens' propagule germination and early growth.[21] Glyphosate also increases and alters root exudates, which benefits certain pathogens, and this effect occurs with a few other herbicides as well.[22]

However, the primary cause of the crop's greater susceptibility to disease with glyphosate exposure *is the impairment of the shikimate (EPSPS) pathway* (see fn 5), which

[17] King et al., 2001 (N content of roots + shoots decreased 18 – 20% from glyphosate application to RR soybean in greenhouse experiments; in moisture-limited *field* conditions, glyphosate application resulted in 8 – 25% yield reduction; in high-yield, abundant-moisture environments, nodulation was also impaired but the plants subsequently recovered; from observations of replications with abundant N supplied as fertilizer, the authors draw another conclusion: "the detrimental effects of glyphosate on plant growth are not limited to symbiotic N_2 fixation").

[18] See, e.g., K.N. Reddy, N. Bellaloui & R.M. Zablotowicz, 2010, Glyphosate Effect on Shikimate, Nitrate Reductase Activity, Yield, and Seed Composition in Corn, *J. Agric. Food Chem.* 58: 3646-3650.

[19] Carlisle & Trevors, 1988.

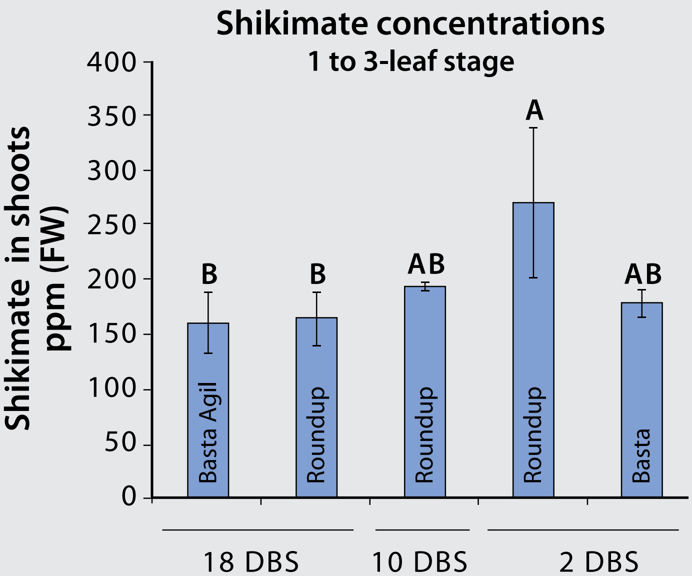
[20] 'Water mold' is outdated terminology: Although *Pythium* spp & *Phytophthora* spp were once considered fungi, they've been reclassified (via ribosome RNA) as oomycetes, most closely related to diatoms and brown algae (Plant Kingdom).

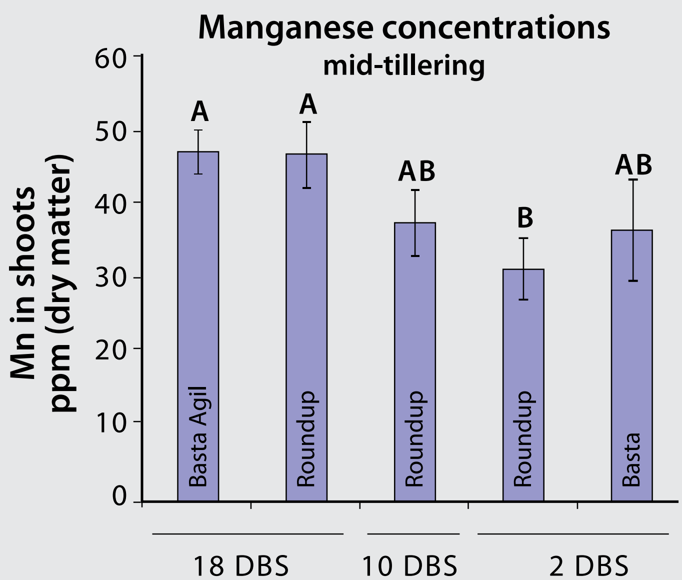
[21] L. Liu, Z.K. Punja & J.E. Rahe, 1997, Altered root exudation and suppression of induced lignification as mechanisms of predisposition by glyphosate of bean roots (*Phaseolus vulgaris* L.) to colonization by *Pythium* spp, *Physiol. & Molecular Plant Path*. 51: 111-127. See also G.S. Johal & J.E. Rahe, 1984, Effect of Soilborne Plant-Pathogenic Fungi on the Herbicidal Action of Glyphosate on Bean Seedlings, *Phytopath.* 74: 950-955; R.J. Kremer, N.E. Means & S. Kim, 2005a, Glyphosate affects soybean root exudation and rhizosphere microorganisms, *Intl. J. Analyt. Environ. Chem*. 85: 1165-1174 (glyphosate applied foliarly to soybean was exuded from roots, and also increased other root-exuded compounds and *Fusarium* spp growth, although pathogenic vs saprophytic wasn't determined); T. Krzysko-Lupicka & T. Sudol, 2008, Interactions between glyphosate and autochthonous soil fungi surviving in aqueous solution of glyphosate, *Chemosphere* 71: 1386-1391; R.J. Kremer & N.E. Means, 2005b, Herbicidal Impacts on Crop-Soil Microbial Interactions and Potential Plant Disease, in *Proceedings of Symposium on Mineral Nutrition and Plant Disease Incidence*, POTAFOS (Piracicaba-SP, Brazil, 2005). See also E.B. Nelson, 1991, in *The Rhizosphere and Plant Growth*, ed. D.L. Keister & P.B. Cregan, Kluwer Academic Publ. (Dordrecht, Netherlands) (pp. 197-209) (exudates stimulate pathogens); S. Steinkellner, V. Lendzemo, I. Langer, P. Schweiger et al., 2007, Review: Flavonoids and Strigolactones in Root Exudates as Signals in Symbiotic and Pathogenic Plant-Fungus Interactions, *Molecules* 12: 1290-1306.

[22] Lévesque & Rahe, 1992a; Kremer et al., 2005a; J. Altman & C.L. Campbell, 1977, Effect of herbicides on plant diseases, *Ann. Rev. Phytopath*. 15: 361-385. Root colonizers such as *Fusarium* spp can release compounds stimulating root exudation of compounds benefiting themselves. (D.A. Phillips, T.C. Fox, M.D. King, T.V. Bhuvaneswari & L.R. Teuber, 2004, Microbial Products Trigger Amino Acid Exudation from Plant Roots, *Plant Physiol.* 136: 2887-2894.)

is essential to the plant's 'immune system' as well as plant growth.[23] In the field, the net result of these effects—year after year—could be higher levels of certain key pathogen strains that are attracted to glyphosate-altered root exudates, and/or proliferate on glyphosate-impaired host plants, and/or proliferate due to glyphosate's suppression of pathogen-antagonistic organisms (primarily bacteria).[24] These pathogen-antagonizing microbes interfere with the pathogens' colonizing of roots, often via mechanisms such as chemical inhibition (yes, fungicides are ancient, as is chemical warfare in all of nature).

Most studies find little or no change in soil microflora populations from glyphosate applications, *although these are generally conducted in bulk soil and aren't looking at the biofilms on roots, nor at specific organisms.*[25] However, studies are becoming more sophisticated.[26] Tim Paulitz, Ph.D., an expert in plant pathogen and root interactions (USDA-ARS), puts it thusly: "Having worked with microbial populations on the roots for many years, you need at least a 1 log[arithmic] unit difference [i.e., a 10X increase, or reduction by a factor of 10] in population to show there is an effect. If you express everything on a linear scale, you can pick up





(LH graph) Elevated shikimate in the plant is an indicator the pathway was blocked due to glyphosate toxicity, i.e., shikimate wasn't being converted to essential amino acids, etc. In these no-till field trials at Tauberbischofsheim, Germany, significantly elevated shikimate was only associated with glyphosate pre-plant with a short waiting time (2 & 10 DBS = Days Before Seeding). This indicates that glyphosate's hindrance of the plant's shikimate-derived 'immune system' can cause flaring of disease under this scenario. The greatest differences in shikimate are typically detected in roots (not shoots) for soil residual glyphosate (lower levels [Bs] in graph are background or normal levels of shikimate). Basta = glufosinate, a.k.a. Liberty, Ignite. **(RH graph)** With short wait times, glyphosate pre-plant significantly reduced Mn levels in the wheat foliage. Zn levels were also significantly reduced. (Sources: Bott et al., 2009b; Tesfamariam, Sept. 2010.)

[23] Holländer & Amrhein, 1980; Carlisle & Trevors, 1988; Lévesque & Rahe, 1992a; G.S. Johal, 2007, PowerPoint presentation at IPNI Symposium: 'Mineral Nutrition & Disease Problems in Modern Agriculture: Threats to Global Sustainability?' (Paricicaba, Brazil, 20-21 Sept. 2007). With glyphosate exposure, plant shikimate levels increase as the conversion to essential amino acids is blocked; however, small increases in shikimate from *ultra-low* doses of foliar glyphosate (very slight drift, etc.) may actually cause *increased* growth—'hormesis'—of some plant species in unsterilized soil (E.D. Velini, E. Alves, M.C. Godoy, D.K. Meschede, R.T. Souza & S.O. Duke, 2008, Glyphosate applied at low doses can stimulate plant growth, *Pest Mgmt. Sci.*, 64: 489-496; Edivaldo Velini, personal communication Sept. 2010 [clarifying that unsterilized soil was used]; *Cf.* I. Cakmak, A. Yazici, Y. Tutus & L. Ozturk, 2009, Glyphosate reduced seed and leaf concentrations of calcium, manganese, magnesium, and iron in non-glyphosate resistant soybean, *Europ. J. Agron*. 31: 114-119 [ultra-low glyphosate doses impaired nutrient uptake and growth]).

[24] A.J. Termorshuizen & L.A.P. Lotz, 2002, Does large-scale cropping of herbicide-resistant cultivars increase the incidence of polyphagous soil-borne plant pathogens?, *Outlook on Agriculture* 31: 51-54; J.R. Powell & C.J. Swanton, 2008, Review: A critique of studies evaluating glyphosate effects on diseases associated with *Fusarium* spp., *Weed Res*. 48: 307-318; Kremer & Means, 2009.

[25] For studies of glyphosate's effects on general C & N transformations and other broad microbial activity indicators, see, e.g., M.A. Weaver, L.J. Krutz, R.M. Zablotowicz & K.N. Reddy, 2007, Effects of glyphosate on soil microbial communities and its mineralization in a Mississippi soil, *Pest Mgmt Sci.* 63: 388-393; R.L. Haney, S.A. Senseman, L.J. Krutz & F.M. Hons, 2002, Soil carbon and nitrogen mineralization as affected by atrazine and glyphosate, *Biol. Fertil. Soils* 35: 35-40; R.L. Haney, S.A. Senseman, R.M. Hons & D.A. Zuberer, 2000, Effect of glyphosate on soil microbial activity and biomass, *Weed Sci*. 48: 89-93; K.B. Liphadzi, K. Al-Khatib, C.N. Bensch, P.W. Stahlman, J.A. Dillie, T. Todd, C.W. Rice, M.J. Horak & G. Head, 2005, Soil microbial and nematode communities as affected by glyphosate and tillage practices in a glyphosate-resistant cropping system, *Weed Sci*. 53: 536-545. See also Carlisle & Trevors, 1988; M.C. Zabaloy, J.L. Garland & M.A. Gómez, 2008, An integrated approach to evaluate the impacts of the herbicides glyphosate, 2,4-D and metsulfuron-methyl on soil microbial communities in the Pampas region, Argentina, *Appl. Soil Ecol.* 40: 1-12 (at 10X rates, glyphosate disturbed soil microbial activity more than 2,4-D or metsulfuron); D.A. Wardle & D. Parkinson, 1991, Relative importance of the effect of 2,4-D, glyphosate, and environmental variables on the soil microbial biomass, *Plant & Soil* 134: 209-219; D.A. Wardle & D. Parkinson, 1990, Influence of the herbicide glyphosate on soil microbial community structure, *Plant & Soil* 122: 29-37.

[26] See, e.g., J. Kuklinsky-Sobral, W.L. Araújo, R. Mendes, A.A. Pizzirani-Kleiner & J.L. Azevedo, 2005, Isolation and characterization of endophytic bacteria from soybean (*Glycine max*) grown in soil treated with glyphosate herbicide, *Plant & Soil* 273: 91-99.

statistical difference, but it does not mean much biologically." Paulitz continues, "The other problem with microbial studies, until now, has been a lack of tools to look at specific groups. Techniques such as FAME, T-RFLP, etc., look at broader groups, and cannot differentiate between pathogenic strains versus common saprophytes [living on dead tissue, and not strongly pathogenic]. DNA methods can differentiate, but only for a few reference strains, and you still need to know what *proportion* of the hundreds of colonies are the pathogenic ones. We now have the molecular tools to do this much more efficiently (pyrosequencing) . . . but with culturing, we can only see about 1% of the microbes in the soil."[27]

In non-RR crops, glyphosate appears to promote *Gaeumannomyces graminis* (take-all in wheat), *Pythium* spp ('damping off' of cotton, sunflowers, soybean, milo, corn, wheat, etc.), *Phytophthora sojae* (damping off & root rot of soybeans), *Rhizoctonia solani* (bare patch of wheat; damping off & root rot of soybean, canola, field pea), and *Colletotrichum lindemuthianum* (anthracnose of dry bean).[28] Furthermore, glyphosate may make crops susceptible to *Pythium*, *Phytophthora*, and *Fusarium* strains that normally *aren't* pathogenic.[29] Some evidence exists for glyphosate's flaring of *Fusarium* pathogens, including *F. graminearum* & *F. avenaceum* (wheat head scab [a.k.a. head or 'ear' blight]; lentil & canola wilt), as well as *F. culmorum* & other *Fusarium* spp (crown rot of wheat,[30] canola, stalk rot of corn & milo, etc.), *Fusarium solani* f. sp. *glycine* (Sudden Death Syndrome of soybeans), and *F. oxysporum* f. sp. *lentis* (lentil &

Photo by Brian C. Selle.

A corn plant in Missouri succumbs to *Fusarium* crown/stalk rot, although *Fusarium* infection often gets underway via damage ('nicks') of roots or mesocotyls from *Pythium* or *Rhizoc*, or from nematode or wireworm incursion. Glyphosate often worsens susceptibility to these diseases.

[27] Tim Paulitz (rhizosphere pathologist, USDA-ARS), personal communication Sept.-Oct. 2010. Paulitz further explains, "For example, the *Fusarium* in the Kremer and Means study could have been common saprophytes—they didn't take the final step of differentiating. In fact, this is what Kremer and Means recommend at the end of their paper." (discussing Kremer & Means, 2009; see also Kremer & Means, 2005b; N.E. Means, R.J. Kremer, C. Ramsier, 2007, Effects of glyphosate and foliar amendments on activity of microorganisms in the soybean rhizosphere, *J. Environ. Sci. Health Part B* 42: 125-132). Paulitz explains: "Pathogenic and non-pathogenic isolates of *Fusarium oxysporum* and *F. solani* look identical in culture. The only way to distinguish them is to inoculate them back on plants. Unfortunately, even with molecular techniques, we cannot easily distinguish them. For example, with *F. oxysporum*, there are non-pathogenic forms, but also what they call 'forma speciales,' and each one has a very narrow host range. For example, f. sp. *cucumerinum* goes to cucumber, f. sp. *spinaceae* goes to spinach, etc. But you have no way of knowing this unless you inoculate plants. The genetic difference between pathogens and non-pathogens, or between f. speciales, is so small—it may just be one or a few genes or gene islands, and no one has devised a reliable method to do this yet." Paulitz, Sept.-Oct. 2010; Bob Kremer (USDA-ARS), personal communication Oct. 2010 (clarifying that DNA analysis was conducted by ARS in Peoria, IL, but the determination of saprophytic vs pathogenic was deferred, although file samples were retained).

[28] Johal & Rahe, 1984; Lévesque & Rahe, 1992a; Lévesque et al., 1992b; Johal, 2007; Liu et al., 1997; R.C. Descalzo, Z.K. Punja, C.A. Lévesque & J.E. Rahe, 1998, Glyphosate treatment of bean seedlings causes short-term increases in *Pythium* populations and damping off potential in soils, *Appl. Soil Ecol*. 8: 25-33; P. Mekwatanakarn & K. Sivasithamparam, 1987a, Effect of certain herbicides on saprophytic survival and biological suppression of the take-all fungus, *New Phytol*. 106: 153-159; P. Mekwatanakarn & K. Sivasithamparam, 1987b, Effect of certain herbicides on soil microbial populations and their influence on saprophytic growth in soil and pathogenicity of take-all fungus, *Biol. Fertil. Soils* 5: 175-180 (take-all antagonists were suppressed by glyphosate). *Cf*. R. Harikrishnan & X.B. Yang, 2002, Effects of Herbicides on Root Rot and Damping-off Caused by *Rhizoctonia solani* in Glyphosate-Tolerant Soybean, *Plant Disease* 86: 1369-1373. *Cf.* Termorshuizen & Lotz, 2002, and references therein (glyphosate *suppression* of *Rhizoctonia solani*). Some of the variability amongst studies of glyphosate x disease interaction is due to micronutrient availability, soil pH and redox potential, as well as which pathogen antagonists are present (if any). (Powell & Swanton, 2008.)

[29] Lévesque & Rahe, 1992a; Carlisle & Trevors, 1988 (also, *Pseudomonas syringae* p.v. *glycinea* became pathogenic to soybeans).

[30] Actually, most of the *Fusarium* spp causing crown rot of wheat or barley can also cause head scab. Interestingly, glyphosate's flaring of *F. culmorum* in quackgrass and the resulting disease outbreak in the following barley crop was first documented in the late 1970s. However, the increased incidence of *Fusarium* spp on weed roots after glyphosate treatment didn't always translate into damage in subsequent crops. (Lévesque & Rahe, 1992a; J.M. Lynch & D.J. Penn, 1980, Damage to cereals caused by decaying weed residues, *J. Sci. Food Agric*. 31: 321-324.) In a correlation study of a large number of farmers' fields, glyphosate application in the 18 months* preceding a wheat or barley crop was found to be the most important agronomic factor in the incidence of *Fusarium* head scab & crown rot. (M.R. Fernandez, R.P. Zentner, P. Basnyat, D. Gehl, F. Selles & D. Huber, 2009, Glyphosate associations with cereal diseases caused by *Fusarium* spp in the Canadian Prairies, *Europ. J. Agron*. 31: 133-143. *See comments on this study in Powell & Swanton, 2008 [fields receiving glyphosate in the previous "18 months" most likely received glyphosate within 1 – 2 months of seeding].)

canola wilt).[31] Glyphosate's flaring of *Fusarium* diseases *in RR crops* has long been suspected, but most studies find little or no effect.[32] Conversely, glyphosate may suppress *Bipolaris sorokiniana* (=*Cochliobolus sativus*), the pathogen causing common root rot of wheat & barley, although no-till itself seems to suppress it independently of glyphosate usage, and this pathogen may simply be crowded out by *Fusarium*, *Rhizoctonia*, and *Pythium* spp which are favored.[33] Some crop diseases do not appear affected by glyphosate.[34]

% Mortality on Bean Seedlings
12 Days After Treatment with Glyphosate

	Control	+ Pythium	+ Pythium + Ridomil
Sterilized Soil	0	100	0
Vermiculite	0	100	0
Unsterilized Soil	100	100	88

Glyphosate makes plants more vulnerable to disease: It relies heavily on soil-borne pathogens ("glyphosate synergists") for herbicidal efficacy, as shown in this classic experiment by Johal in the early 1980s. Adding Ridomil—a systemic pesticide specific for oomycetes ("OH-uh-MY-seets," formerly 'water molds') such as *Pythium*—prevented this pathogen from restoring the herbicidal activity of glyphosate on seedlings growing in sterilized soil or soil-less media (vermiculite), but not in unsterilized soil where *Fusarium* and other non-oomycete pathogens were naturally present. (Source: Johal, 2007.)

A complication for many of the field studies (and a few of the greenhouse studies), is the 'dislocated-pathogen' or 'green-bridge' effect—which probably occurs as much belowground as aboveground—wherein killing the vegetation with herbicides (or clipping) causes the pathogen inhabitants to seek a new home: the freshly planted crop. If the killed vegetation is significant, and the pathogen load in the soil is conducive, the green-bridge effect can overshadow any direct glyphosate injury on the new crop (although the two are intertwined, and exacerbate each other).[35] Experiments clearly show that both exist. For instance, far more crop injury to sunflowers occurred with glyphosate applied to a preceding ryegrass cover crop versus the same rate being applied to the soil without ryegrass, and incorporated with tillage. Meanwhile, the treatment with an equal density of ryegrass, but terminated by clipping it near the soil line, had good sunflower growth—so the injury *wasn't* due to the cover crop being there (or being recently killed), but was instead a result of glyphosate being moved into the ryegrass roots & biofilms before it died, and thereby remaining highly available for uptake by the sunflowers.[36] These methods rule out green-bridging as the cause, wherein soil-borne

[31] Lévesque & Rahe, 1992a; Johal & Rahe, 1984; Johal, 2007 (in pioneering work in the 1980s, Johal showed that what kills glyphosate-treated plants in unsterilized high-clay, wet soils was usually *Pythium*, while in drier sandy loams it was *Fusarium*). See also J.M. Meriles, S. Vargas Gil, R.J. Haro, G.J. March & C.A. Guzmán, 2006, Glyphosate and Previous Crop Residue Effect on Deleterious and Beneficial Soil-borne Fungi from Peanut-Corn-Soybean Rotations, *Phytopath*. 154: 309-316.

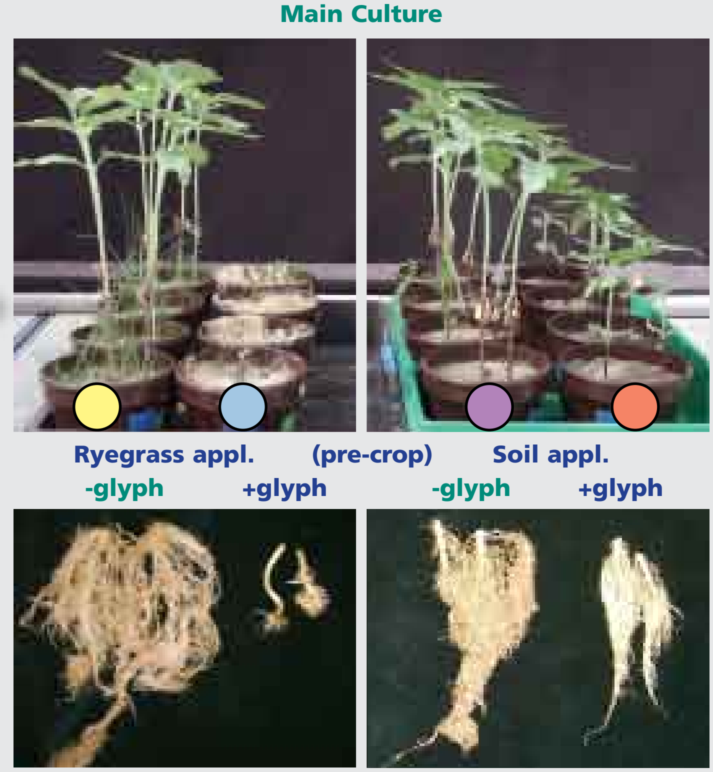
[32] Powell & Swanton, 2008 (although commenting that researchers may be "underestimating the effect of glyphosate on crop disease" by maintaining weed-free conditions); V.N. Njiti, O. Myers Jr., D. Schroeder & D.A. Lightfoot, 2003, Roundup Ready Soybean: Glyphosate Effects on *Fusarium solani* Root Colonization and Sudden Death Syndrome, *Agron. J*. 95: 1140-1145 (during 2 yrs of field plot studies at multiple locations, with 10 RR soybean varieties across 4 maturity groups, no differences were found in any SDS parameters with glyphosate versus without); S. Sanogo, X.B. Yang & P. Lundeen, 2001, Field Response of Glyphosate-Tolerant Soybean to Herbicides and Sudden Death Syndrome, *Plant Dis*. 85: 773-779 (glyphosate increased *Fsg* infection one year, but not the other; across years, there was an increase in SDS severity with acifluorfen (Blazer), glyphosate, and imazethapyr (Pursuit) compared to lactofen (Cobra, Phoenix) and the control); Powell & Swanton, 2008, and studies therein. *Cf.* S. Sanogo, X.B. Yang & H. Scherm, 2000, Effects of Herbicides on *Fusarium solani* f. sp. *glycines* and Development of Sudden Death Syndrome in Glyphosate-Tolerant Soybean, *Phytopath.* 90: 57-66 (across 4 varieties and 3 *Fsg* isolates, and many replicated experiments in greenhouse studies, the incidence of SDS was highest with glyphosate application, and decreased in the order of glyphosate >imazethapyr >lactofen >control, in comparing both 1X and 2X of recommended rates; a non-RR variety with glyphosate application died more quickly when inoculated with *Fsg* than did the non-inoculated). Also *cf.* Kremer & Means, 2009 (at 10 days after treatment in 2003, *Fusarium* colonies were 10 times greater on RR corn roots as compared to the nil-glyphosate treatment of the same hybrid, although no determination of whether these were pathogenic or saprophytic [see fn 27]; study originally described by Means, 2004 in Ph.D. dissertation). Also *cf.* N.E. Means & R.J. Kremer, 2007, Influence of Soil Moisture on Root Colonization of Glyphosate-Treated Soybean by *Fusarium* Species, *Comm. Soil Sci. & Plant Analysis* 38: 1713-1720 (highest *Fusarium* colonization of RR soybean roots occurred with glyphosate application, and at the maximum soil moisture content tested).

[33] Fernandez et al., 2009, and numerous references therein. For *Pythium* and *Fusarium* spp dominance of root colonization after glyphosate exposure, see, e.g., C.A. Lévesque, J.E. Rahe & D.M. Eaves, 1993, Fungal colonization of glyphosate-treated seedlings using a new root plating technique, *Mycological Res.* 97: 299-306; C.A. Lévesque, J.E. Rahe & D.M. Eaves, 1987, Effects of glyphosate on *Fusarium* spp: its influence on root colonization of weeds, propagule density in the soil, and crop emergence, *Can. J. Microbiol*. 33: 354-360; Johal, 2007.

[34] E.g., white mold (*Sclerotinia sclerotiorum*), leaf rust, etc. (Termorshuizen & Lotz, 2002; Powell & Swanton, 2008; Cerdeira et al., 2007; see also Locke et al., 2008, and references therein.)

[35] R.W. Smiley, A.G. Ogg Jr. & R.J. Cook, 1992, Influence of glyphosate on *Rhizoctonia* root rot, growth, and yield of barley, *Plant Disease* 76: 937-942 (in the Pacific Northwest, USA, glyphosate applications for spring cereals were safest when applied 3 – 6 wks ahead of planting; *Pythium* and *Fusarium* spp were also infesting roots in these trials); Paulitz, Sept. 2010; T.C. Paulitz, R.W. Smiley & R.J. Cook, 2002, Minireview: Insights into the prevalence and management of soilborne cereal pathogens under direct seeding in the Pacific Northwest, U.S.A., *Can. J. Plant Path.* 24: 416-428 (perhaps more than other pathogens, *Pythium* is favored by green-bridging; it primarily colonizes seeds and roots under moist to saturated conditions, and can infect seeds within 24 – 48 hrs, killing or stunting the seedling, or enfeebling the plant; soils with high clay content and low pH allow greater *Pythium* infection, since low pH suppresses microbes that compete with *Pythium*; fresh seed is important in preventing *Pythium*, because as a seed ages, cells in the seed coat die, which attract this pathogen); Günter Neumann (plant nutrition physiologist, U. Hohenheim, Germany), personal communication Sept. 2010 ("green-bridge effects can cause severe problems but this may hold particularly true for plants previously weakened by hidden glyphosate toxicity."); Descalzo et al., 1998. See also M.K. Kawate, S.G. Colwell, A.G. Ogg & J.M. Kraft, 1997, Effect of glyphosate-treated henbit (*Lamium amplexicaule*) and downy brome (*Bromus tectorum*) on *Fusarium solani* f. sp. *pisi* and *Pythium ultimum*, *Weed Sci.* 45: 739-743. *Note the negligible or absent crop rotation in the trials showing large green-bridge effects.*

[36] Tesfamariam et al., 2009a (sunflower root & shoot biomass were reduced by 90% following glyphosate-terminated ryegrass when planting occurred the same day as the glyphosate application; sunflower Mn levels were reduced up to 80% where glyphosate was applied to the ryegrass); Tesfamariam, 2009b.



Sunflowers following either ryegrass (one set terminated by glyphosate; another by clipping near the soil line) or planted into bare soil (with and without glyphosate). Green-bridging of soil-borne pathogens such as *Rhizoc* can be ruled out, since the sunflowers following ryegrass killed by clipping didn't exhibit growth reduction. This experiment used two soil types, a sandy Arenosol with pH 4.5 ($CaCl_2$), and a calcareous subsoil with pH 7.6 ($CaCl_2$); glyphosate injury occurred in both. (Sources: Bott et al., 2009b; Tesfamariam, Sept. 2010; Tesfamariam, 2009b; Bott et al., 2009a.)

Photos by Tsehaye Tesfamariam.

pathogens such as *Rhizoctonia* or *Pythium* spp could've been dislocated from dying ryegrass roots onto sunflower roots. Instead, the injury was entirely due to glyphosate carryover, and other studies support this conclusion—that glyphosate & AMPA soil carryover damage occurs independently from green-bridging.[37]

Even without green-bridging, the overall trend is for greater plant disease with glyphosate exposure, since crucial plant defense mechanisms (phenolics) derived from the shikimate pathway are blocked.[38] (And glyphosate is the only herbicide to block the shikimate 'immune system' of plants.) Indeed, *it takes as much as 10- to 47-fold more glyphosate to kill any given plant species in sterilized (autoclaved) field soil as compared to unsterilized soil*.[39] The pathogens involved are often called "herbicide synergists" or "glyphosate synergists."

Most glyphosate in the soil degrades via a variety of microbes, especially certain groups of bacteria (e.g., many *Pseudomonas* spp), but also including some fungi and actinomycetes.[40] With repeated glyphosate

[37] Bott et al., 2010a draft; Bott et al., 2010b draft (soybeans injured by pre-crop glyphosate onto ryegrass); Tesfamariam et al., 2009a; Barry, 2009; Mekwatanakarn, 1987a & 1987b (sprayed onto soil, glyphosate as well as a mix of paraquat + diquat increased take-all). See also the graphs on pp 540-541 where Basta (glufosinate) was used as a comparison burndown (also available at http://escholarship.org/uc/item/25v599pr [Bott et al., 2009a]).

[38] See, e.g., Termorshuizen & Lotz, 2002, and references therein (crop diseases increased due to glyphosate). The phytoalexins (anti-microbial substances) responsible for some of the plant's active defense are derived from the phenylpropanoid pathway, which acquires nearly all of its precursors from the shikimate pathway. (Lévesque & Rahe, 1992a; Johal & Rahe, 1984; Descalzo et al., 1998; Powell & Swanton, 2008.) And for several diseases, another mechanism involved is lack of available Mn at the infection site due to glyphosate's activity: The plant's lignification process, which normally would curb disease growth—in part by 'walling off' the infection site—is impaired by low Mn conditions, as well as by the disruption of the shikimate pathway which produces lignin precursors. (Lévesque & Rahe, 1992a; Johal, 2007.)

[39] Johal & Rahe, 1984 (the dominant pathogens in unsterilized field soil were *Pythium* and *Fusarium* spp, and adding these individually to autoclaved soil restored the herbicidal effectiveness of glyphosate; furthermore, this effect was blocked by Ridomil in the case of the *Pythium*-only treatment, but not in unsterilized field soil with multiple pathogens); C.A. Lévesque, J.E. Rahe & D.M. Eaves, 1992b, The effect of soil heat treatment and microflora on the efficacy of glyphosate in seedlings, *Weed Res.* 32: 363-373 (to further prove the point, no differences were found with applications of *2,4-D* or *paraquat* in sterilized vs unsterilized soil). See also Descalzo et al., 1998 (the lethal dose of glyphosate was 100-fold higher with a weakly pathogenic strain of *P. coloratum* versus a more aggressive strain of *P. ultimum* when inoculated onto dry beans in sterilized soil; regardless of being treated with glyphosate or paraquat or merely heat-killed, freshly killed bean roots added to the soil caused a 10-fold increase in *P. ultimum* vs control [no beans] which persisted from 3 to 21+ days after treatment; *subsequent sunflowers grown in the same pots had the most damping off where beans were killed by* glyphosate).

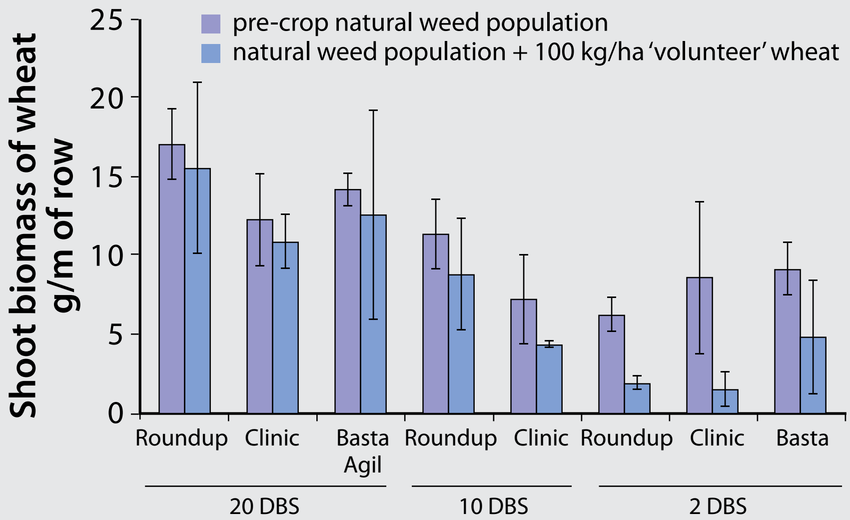
[40] Borggaard & Gimsing, 2008. A few scientists think that glyphosate in root biofilms suppresses several important PGPR, Plant Growth-Promoting Rhizobacteria, such as *Pseudomonas fluorescens* (Kremer & Means, 2009, and references therein) which is a known antagonist to fungal pathogens, and *Fusarium* in particular. However, other studies show *no* inhibition of *P. fluorescens* by glyphosate. (E. Zboinska, B. Lejczak & P. Kafarski, 1992, Organophosphate Utilization by the Wild-Type Strain of *Pseudomonas fluorescens, Appl. Env. Microbiol.* 58: 2993-2999.) Furthermore, most other plant-beneficial *Pseudomonas* spp—including many of the 'fluorescent pseudomonads'—are tolerant of glyphosate and can actually use glyphosate as a nutrient source. (Zboinska et al., 1992; Powell & Swanton, 2008; Borggaard & Gimsing, 2008). Glyphosate in RR crops is theorized to decrease PGPR living *inside* roots, stems, and leaves (endophytes). (Kuklinsky-Sobral et al., 2005.)

applications, the soil microbial degradation rate might be slowed,[41] unchanged,[42] or accelerated.[43] Although you'd think the microbial degradation would be fastest on soils with diverse, high biological activity (total microbial biomass), one study found correlation only with *Pseudomonas* spp levels.[44] Degradation is typically the most rapid in warm & continually moist conditions, as in the tropics and subtropics, and slower in colder or drier climates.[45]

Glyphosate & AMPA are slowly desorbed (released) from soil particles and go back into solution.

And what about the glyphosate & AMPA that get bound onto soil particles? —These compounds are slowly desorbed (released) and go back into soil solution, and this process can be accelerated by applying phosphorus (P) fertilizers, since phosphate and glyphosate (and AMPA) bind to some of the same sorption sites on soil particles, especially iron and aluminum in their trivalent cation forms: Fe^{+++} and Al^{+++}.[46] *The release (resolubilization) of glyphosate and AMPA from the soil by application of modest amounts of P fertilizers can cause significant damage to newly planted crops,* and this may readily occur in the field since P application and the sorbed glyphosate & AMPA occur primarily in the upper few inches of soil.[47] Furthermore, P application causes roots to proliferate near the P band or granule, which is where the glyphosate desorption is taking place.

Some soils adsorb glyphosate much more strongly, and release it more slowly, such as those with 2:1 clays, or with high levels of iron & aluminum in conjunction with low P status.[48] The role of soil pH is



Field trial at Starzach, Germany. Shoot biomass of the winter wheat crop was greatly reduced with shorter waiting times for glyphosate (Roundup Ultra = 4 lbs/gallon, Clinic = 3 lbs/gallon, but active ingredient rates per hectare were matched), and also reduced with *glufosinate* (Basta)—which may indicate that at least some of the growth suppression is from increased disease pressure due to 'green-bridging' (dislocated pathogens from dying vegetation, including soil-borne pathogens). And/or glufosinate, or an adjuvant, may itself be damaging to wheat plants when applied very close to planting—although for most soils and conditions, it's less damaging to newly sown crops than glyphosate. (In the graph, yield reduction associated with Basta at 2 DBS was primarily due to insufficient weed control, not herbicide toxicity.) Basta Agil contains a 'fop' grass herbicide, whereas 'Basta' contains only glufosinate—again, yield loss was due to inadequate weed control. (Sources: Bott et al., 2009b; Bott et al., 2010d draft; Tesfamariam, Sept. 2010; Bott, Oct. 2010.)

[41] de Andréa et al., 2003; Weaver et al., 2007.

[42] A.L. Gimsing, O.K. Borggaard, O.S. Jacobsen, J. Aamand & J. Sorensen, 2004, Chemical and microbiological soil characteristics controlling glyphosate mineralisation in Danish surface soils, *Appl. Soil Ecol.* 27: 233-242; Borggaard & Gimsing, 2008 (no adaptation of soil biota to glyphosate exposure).

[43] A.S.F. Araújo, R.T.R. Monteiro, R.B. Abarkeli, 2003, Effect of glyphosate on the microbial activity of two Brazilian soils, *Chemosphere* 52: 799-804 (glyphosate applications during the previous 6 to 11 years sped up microbial degradation of glyphosate as compared to orchards and fields with no previous glyphosate application); See also J.P. Quinn, J.M.M. Peden & R.E. Dick, 1988, Glyphosate tolerance and utilization by the microflora of soils treated with the herbicide, *Appl. Microbiol. Biotech.* 29: 511-516; Carlisle & Trevors, 1988, and references therein.

[44] Borggaard & Gimsing, 2008 (no correlation between general microbial activity and glyphosate degradation). *Cf.* Araújo et al., 2003.

[45] See, e.g., Cerdeira et al., 2007; Borggaard & Gimsing, 2008.

[46] Bott et al., 2010a draft, and references therein. See also P. Laitinen, 2009, Fate of the organophosphate herbicide glyphosate in arable soils and its relationship to soil phosphorus status, Ph.D. dissertation (presented 4 Sept. 2009 at Univ. of Kuopio); Gimsing et al., 2004; Borggaard & Gimsing, 2008 (phosphate and glyphosate not always competitive for adsorption, i.e., some sites bind preferentially to one or the other).

[47] Bott et al., 2010a draft (also, live plant roots release chelators that may solubolize soil-bound glyphosate).

[48] Laitinen, 2009; Piccolo et al., 1994; Carlisle & Trevors, 1988. Some studies show the potential for short-term carryover damage from glyphosate in the soil and crop residues appears to be lessened on calcareous soils, which is thought to be due to high calcium levels complexing and immobilizing the glyphosate and preventing the formation of AMPA, i.e., calcareous soils will sorb more glyphosate for longer periods, although it is released so slowly as to reduce the immediate risk of injury to subsequent vegetation, yet there would be greater opportunity for glyphosate and AMPA to accumulate with repeated application over the long term. (Bott et al., 2008; Neumann, 2006; Bott et al., 2010a draft.) However, some microbial degradation of glyphosate occurs even while it is sorbed onto iron oxides and other binding sites. (Borggaard & Gimsing, 2008.) Further note that low Mn availability in the soil can impair both biological and non-biological processes which degrade glyphosate & AMPA. (Borggaard & Gimsing, 2008.)

unclear, with disparate findings.[49] Scientists in Germany compared 5 diverse soils and reported a 0.46 correlation of higher sand content with greater plant injury in non-RR soybean due to glyphosate uptake from the soil (applied 10 days pre-plant), as measured by aboveground soybean biomass; soil acidity was 0.77 correlated with plant injury; greater P fertilizer availability was 0.57 correlated with injury (across a range of P rates, plus a control).[50] The correlations were weakened by one of the soils apparently having completely degraded the glyphosate to AMPA in the 10 days of incubation* before seeds were sown, *which did indeed reduce seed germination by 40%*.[51] (*Perhaps due to soil biology differences.) Previously, one of the researchers had summarized the evidence as to 'safe' wait times for planting crops after glyphosate application as: "Zero to 3 weeks for wet, light soils with a fast turn-over of weed roots (e.g., in Brazil); 4 – 8 weeks for wet, heavy calcareous soils with a slower turn-over of weed roots; *but might be* up to 1 year for dry sandy soils as [are] widespread in Israel; 1.5 – 3.0 years for cold soils with [very slow] turn-over of weed roots as in . . . Canada [original emphasis]."[52]

Part II: Now What?

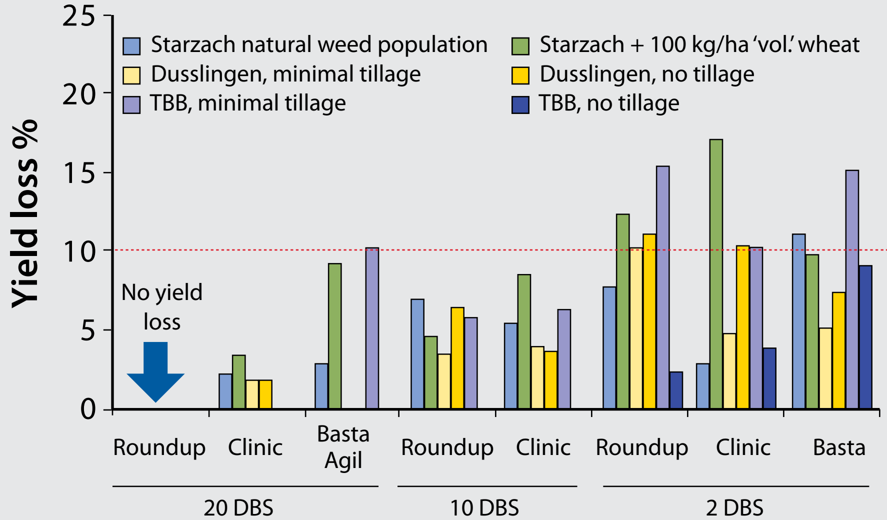
TECHNIQUE

The accumulated evidence tends to show that pre-plant glyphosate isn't as harmless to crops as previously thought, with its lingering ill effects on crop germination, vigor, nutrient availability, and disease potential. Nor is post-emerge glyphosate on RR crops quite as safe as what most in the ag sector think. While the full truth is yet to be learned, it would be unwise to ignore this current state of knowledge.

Assuming the conclusions of these studies are true, the implications are far-reaching. Some nutrient deficiencies (e.g., manganese) induced or worsened by glyphosate can be prevented or alleviated in an affordable, practical way with pre-plant or early post-emerge sprays (e.g., EDTA), or via manganese fertilizers placed in the seed row, or side-band. However, other nutrient deficiencies are much more difficult to overcome (e.g., *magnesium*). And all of these remedies add directly to the cost of using glyphosate.

Other issues are far less tractable: Glyphosate soil residual impairs crop rooting (see graphs on p 544), which causes poor drought tolerance, along with subpar uptake of nutrients—particularly those highly dependent on root interception (e.g., P, Mg). Plus, the impaired N utilization due to glyphosate interference with nitrate reductase (necessary to create protein).

Plant diseases cause a large amount of lost profit each year, even without any flaring from glyphosate. The cost comes not only from yield reduction, but also from failed stands, and from less vigorous crops needing more



At all field sites and treatments, the highest wheat yields were with long wait times. Short wait times for glyphosate caused 3 – 17% yield loss at these locations, and these yield losses from glyphosate are typical according to the scientists involved in numerous experiments such as this one. Further summarizing their many field trials, one of the scientists stated that Roundup almost always caused the most damage (perhaps due to its 'tallow amine'—POEA, polyoxyethylene amine—surfactant loading more glyphosate into the pre-crop weeds), i.e., Roundup typically caused significantly more damage than either generic glyphosate or Basta. In min-till, the tillage was at time of sowing, in the "upper few centimeters." At one trial site, no-till was associated with more yield loss than minimum-till from pre-plant glyphosate and glufosinate, while at the other site, min-till had more yield loss from the herbicides than did no-till. (Sources: Bott et al., 2009b; Bott et al., 2010d draft; Tesfamariam, Sept. 2010; Neumann, Sept. 2010; Carlisle & Trevors, 1988.)

[49] By manipulating soil pH and P content of several Greek soils, the researchers concluded that soil acidity contributed more to glyphosate adsorption than did initial P level. (C.N. Giannopolitis & V. Kati, 2009, Effect of superphosphate fertilizer on glyphosate adsorption by four Greek agricultural soils, *Hellenic Plant Protection J.* 2: 23-32.) And yet several other studies show *decreased* glyphosate sorption at higher pH, *except* when the higher pH was achieved by liming. (Borggaard & Gimsing, 2008, and references therein.) Research in Brazil found negligible effects of soil pH on glyphosate sorption. (Cerdeira et al., 2007.) Also, studies of plant damage from glyphosate carryover usually show less injury on high-pH soils, most likely due to stronger glyphosate adsorption in the soil. (Bott et al., 2010a draft; also see previous fn.) *Cf.* V. Römheld, 2007, PowerPoint presentation at IPNI Symposium (Paricicaba, Brazil, 20-21 Sept. 2007) (shikimate was 7-fold higher in soybean following ryegrass killed with glyphosate versus no glyphosate on the *calcareous* soil, but not the acidic soil). Also *cf.* Carlisle & Trevors, 1988, and references therein (soil pH has little effect on either sorption or degradation).

[50] Bott et al., 2010a draft (expression of plant injury associated with elevated shikimate in the *root* tissue); Sebastian Bott (crop nutrition physiologist, U. Hohenheim, Germany), personal communication Oct. 2010 (soils used in this study were from Brazil, west Africa, Bavaria & Germany).

[51] Bott et al., 2010a draft (no elevation of shikimate levels in the plants grown in these pots indicated no glyphosate had been taken up).

[52] Römheld, 2007 (his 1.5 – 3.0 yr estimate probably derives from Fernandez: see fn 30 comment).

'rescue' treatments for things that otherwise would've been overcome. The costs further multiply when considering that the enfeebled crop allows more nutrients to leach, and provides less protection for the soil (fewer roots, and less stubble). Glyphosate's soil activity certainly appears to amplify the problems with seedling disease (and diminished vigor of the survivors), while AMPA contributes directly to reduced germination from the outset.

Any effective burndown at seeding time can trigger belowground green-bridge effects.

There aren't any silver bullets for managing many of the diseases discussed in Part I. Top-notch seed-applied fungicides help, as does using only the highest vigor seed. Attention to seed placement helps. So does careful nutrient management. In other words, do everything possible to baby the crop along, to mitigate as many stresses as possible. And you might still fail in going headlong against heavy pathogen pressure, especially with the other adverse effects of glyphosate & AMPA thrown in. Remember, crop stresses multiply.

While all the tools in the preceding paragraph are of value regardless of which herbicide program is used, we ought to get serious about cutting back on glyphosate usage anyway. Weed populations with glyphosate resistance are exploding (e.g., kochia, marestail, Palmer pigweed), to the point where, in some areas, glyphosate is no longer used for anything except at low rates for a non-selective grass killer—in other words, approximately back to where we were 20 years ago when Monsanto's Roundup (the only glyphosate available then) was $70/gallon. Yet there were tremendously successful no-tillers in that era, and with far fewer herbicide options available to them than we have now (and no herbicide-resistant crops). *I wouldn't want to be without glyphosate in the toolkit*, but I think it's time we backed away from using glyphosate multiple times per year, every year, and from using higher rates just because it seems so inexpensive compared to other herbicides, or because we've gotten complacent on adjuvants (e.g., AMS 'substitutes'), or because we've gotten accustomed to seeing the weeds die within a few days at the higher doses.

Photo by Keith Thompson.

Infections such as *Pythium, Rhizoc* & *Fusarium* often kill the seedling before it ever emerges. Low seed vigor contributed in this case.

One way to eliminate a lot of glyphosate usage in the spring is to apply residual herbicides in the late fall, especially ones that target the weeds for which you'd be inclined to use glyphosate in the spring. For corn and milo, this could be accomplished by applying atrazine (or simazine for corn) in the fall (where this practice is legal), preferably tank-mixed with 2,4-D and/or dicamba. Or you might hold the triazines until springtime, using them for synergistic tankmixes with broad-spectrum 'burndown' products such as paraquat (e.g., Gramoxone Inteon, generics), or Ignite (glufosinate; previously called 'Liberty' in the USA)—a chemistry without the toxicity hazard to the applicator that paraquat has. Ignite is rather weak on grasses (it can be tank-mixed with Select), and paraquat isn't great on grasses either—at least not by itself anyway. Both these chemistries require high gallonage, and work better with sunlight & warmth. Liquid N fertilizer or generous AMS also help.

Jill Clapperton: "This glyphosate research is telling us that we need to use less chemical, use more plant properties, increase diversity, and _think_."

Don't try to get by with air-induction nozzles: Flat fan (or Turbo Tees) nozzles are a necessity. Note, however, that *any* effective burndown can trigger green-bridge effects (as can tillage of vegetated fields at seeding time), and that neither Ignite nor paraquat is a truly safe haven for avoiding the direct stimulation of pathogens, nor for avoiding harming the pathogen's antagonists,[53] although both chemistries appear to offer advantages over glyphosate in these regards.

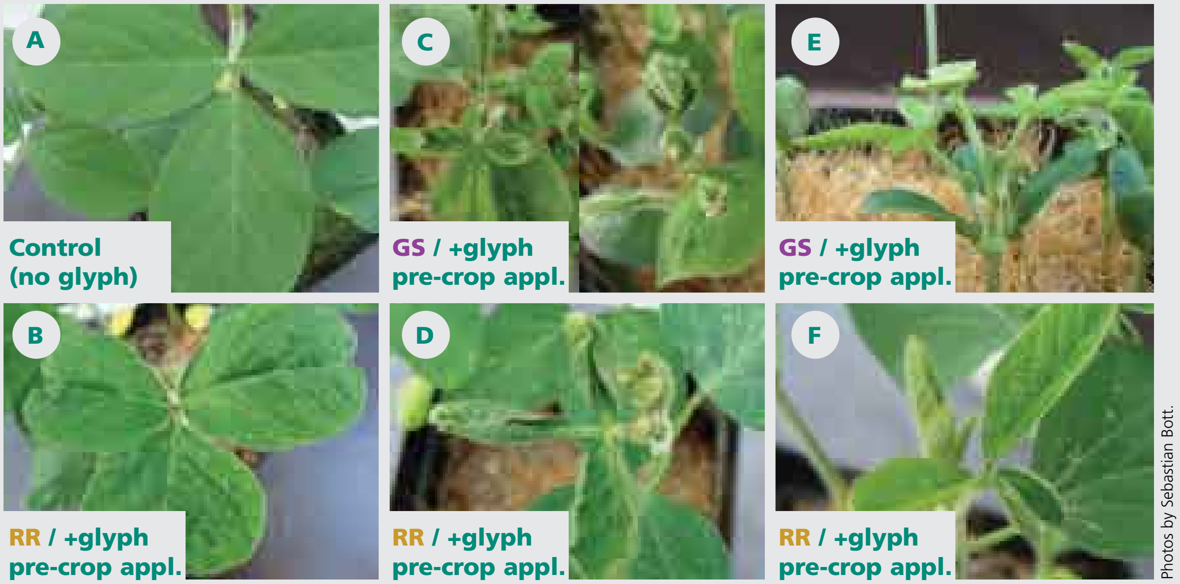
For soybeans, you might use pre-plant metribuzin (e.g., Sencor)—another triazine—or any other chemistry suitable for your winter weed spectrum. For springtime burndowns ahead of broadleaf crops, grass herbicides such as

[53] See, e.g., Termorshuizen & Lotz, 2002, and references therein; Mekwatanakarn & Sivasithamparam, 1987b. *Cf.* Lévesque et al., 1984 (pathogenic soil-borne fungi dramatically increased the herbicidal activity of glyphosate, while 2,4-D & paraquat didn't show any change). Also, glufosinate does have minor, short-lived herbicidal activity in the soil under certain conditions (sandy soils) on highly susceptible species (e.g., tomatoes).

clethodim (Select) or quizalofop (Assure) may become standard components of tankmixes to kill 'cheatgrass' and other winter grasses, as well as volunteer corn, milo, etc.[54]

A major concern resulting from these studies is glyphosate's use in terminating cover crops: For causing glyphosate injury to subsequent crops, the greatest risk is from spraying it onto a dense canopy of vegetation, be it weeds or a growing crop (either a RR crop, or a non-RR crop being terminated for replant, etc.). So, you'd prefer to avoid killing a nice thicket of cover crop with glyphosate and then planting a susceptible crop immediately into that seedbed—at least if you wanted to improve the odds that a truly vigorous crop would be forthcoming.[55] Crops highly sensitive to *foliar* glyphosate include wheat, barley, rye, sunflowers, some of the millets, non-RR corn, oats, etc. *Non*-RR soybeans and some other legumes, as well as *non*-RR cotton, are less sensitive (and RR soys are 50x less sensitive yet), and sensitivity to *root*-uptake glyphosate appears to follow the same pattern amongst species.[56] As for green-bridging (regardless of herbicide used), this can largely be avoided by careful choice of cover-crop species. Properly done, cover crops offer many advantages, and if your climate & cash crops dictate that, to be effective, the cover must be grown until close to seeding of the cash crop, I wouldn't let green-bridge concerns get in the way (but remember, choose your species wisely, and—if necessary—control volunteer from the preceding cash crop; and use seed treatments to help keep *Pythium* at bay).

The introduction of glyphosate, and later, RR crops, prompted a huge shift of acres to no-tillage cropping around the world. Glyphosate offers substantial advantages in efficacy, economics, ease of management, and safety during handling—all of which are very real. But as the totality of evidence shows, we must now weigh these factors against the potential for yield loss in current and future crops, simply for having used glyphosate. Although the wisest course of action is to reduce glyphosate usage, especially for certain timings, we must keep the risks in perspective, both with glyphosate and its alternatives (for instance, many growth-regulator herbicides can also cause crop injury when applied too close to planting).



Control soybeans (**A**) without glyphosate pre-plant were normal. Damage to both RR and non-RR ('GS') soybeans (**B – F**) occurred when glyphosate was applied to a pre-crop of ryegrass with a 5-day wait time until soybeans were sown, while no damage occurred when the same dose was mixed into the soil (no ryegrass), demonstrating the effect was due to root-to-root transfer of glyphosate. Non-RR soybean had considerably more damage, and far greater shikimate levels. No shikimate detected for soil application. These symptoms are frequently mistaken for growth-regulator herbicide injury in the field. (Source: Bott et al., 2010b draft.)

[54] We might have unrealized (unknown) harmful effects from these alternative herbicides, which is quite possible. But we do know that clethodim (Select) and fomesafen (Reflex/Flexstar) don't cause the *Fusarium* root colonization or nutritional problems associated with glyphosate, since those herbicides were applied yearly to the control plots in Kremer's studies (same RR varieties, but no post-emerge glyphosate). (Kremer & Means, 2009.) And the same can be said for atrazine on corn, from Kremer's work. Elsewhere, in extensive testing with 3 RR varieties, less incidence of SDS (*Fusarium solani*) occurred with lactofen and imazethapyr than with glyphosate, and soybean growth was greater with Pursuit applied post-emerge than with glyphosate. (Sanogo et al., 2000.) In field trials and greenhouse studies, *Rhizoctonia solani* root rot incidence on RR soybeans was highest with pendimethalin (Prowl) pre-emerge, while glyphosate, lactofen, and imazethapyr post-emerge had only very slightly elevated root rot compared to no herbicide (but weed free). (Harikrishnan & Yang, 2002 [pendimethalin also reduced stands substantially in the greenhouse].) For a more comprehensive perspective, Lévesque & Rahe, 1992a, reviewed the literature and found that various diseases either weren't affected, or were actually *decreased*, by the pre-plant application of alachlor, trifluralin, diquat, paraquat, and dicamba. Perhaps not so surprisingly, since no chemistry impairs the shikimate pathway like glyphosate does.

[55] Several other phenomena can reduce vigor of a subsequent crop planted into a thick cover crop that has been terminated by non-glyphosate methods, including nutrient sequestration (available nutrients were taken up by the cover crop, which won't be mineralized [released] until many months later), allelopathic compounds, shading, and excessive drying of soils.

[56] Bott et al., 2010c draft (sensitivity of root exposure to glyphosate: non-RR soybean < non-RR corn < wheat). See also W.A. Pline, J.W. Wilcut, K.L. Edmisten & R. Wells, 2002, Physiological and morphological response of glyphosate-resistant and non-glyphosate-resistant cotton seedlings to root-absorbed glyphosate, *Pest. Biochem. Physiol.* 73: 48-58.

Jill Clapperton, Ph.D., soil ecologist and land-use consultant, comments on the glyphosate issue: "This is a big *system* problem! I think it really stems around the desire to make a complex system simple: one chemical, continuous corn, or continuous wheat. How often do you hear: 'I don't have time to think.' Actually, *not* taking the time to think and plan *is* the issue. We let the FSA, NRCS, 'organic' inspector, consultants, and university extension think. Nothing wrong with having people around you to provide new info, but in the end, it is the responsibility of the farmer to think and plan his and/or her farm." Clapperton continues, "This glyphosate research is telling us that we need to use less chemical, use more plant properties, increase diversity, and *think*. All chemicals have an effect on the ecosystem and ecosystem function; it is more about how we manage to mitigate or minimise the short- and long-term effects."

Part III: Field Observations

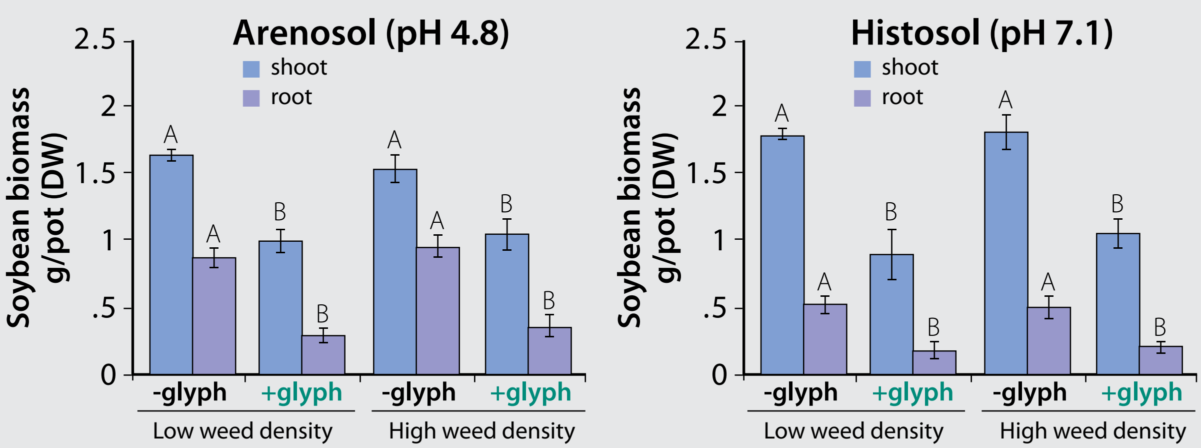
PERSPECTIVE

While I'd read several research articles over the years implicating glyphosate as contributing to manganese (Mn) deficiency in RR soybeans, delving into this recent evidence (mostly published 2008 – 2010) hit me square between the eyes. Simply put, this research *could* explain some vexing questions that had arisen in my mind during the past 10 – 12 years of field observations. (However, correlation does not prove causation, so take this with a few grains of salt.)

First, I had been noticing an unusual amount of crown roots and brace roots being knocked out by *Fusarium* spp since '99 (all my observations herein were from no-till, generally long-term no-till, in Kansas). It occurred more frequently in corn or milo planted into wheat stubble—and in all cases, glyphosate was applied multiple times to keep the wheat stubble 'clean' during the summer/fall, and sometimes with additional glyphosate applied pre-plant or pre-emerge (almost always in the case of milo). In some cases, severe yield losses occurred from seedling disease and stalk rots, along with standability problems. I kept asking questions, sending samples to labs, etc., and about all I could decipher was that we needed higher quality seed along with very good protectants (fungicides and insecticides) on the seed, in addition to vigilance in avoiding planting too deep (or too shallow) and in avoiding overpacking the soil above the seed. And hope that it didn't rain—I had already noticed way back in the mid-'90s that our no-till soybean & wheat stands suffered if it rained just after planting, and I thought it was caused by reduced soil oxygen levels slowing germination, stressing the seed, and flaring the fungal pathogens. But a major culprit might have been the direct injury of glyphosate and/or AMPA being mobilized to the seed by the rain, or perhaps the *Fusarium*, *Rhizoc*, and *Pythium* levels that had been stacked against us by repeatedly killing vegetation with glyphosate in those fields (and often just ahead of planting). Selection happens!

I had already noticed back in the mid-'90s that no-till soybean & wheat stands suffered if it rained just after planting.

Second, I had been noticing very poor wheat foliage growth (low vigor) and lousy rooting in the fall, both in the 2d-year ('stacked') wheat and in the wheat after soybeans. Rarely did the wheat roots appear healthy. Since virtually all my clients' soybeans have been RR since ~ '99 or so, with plentiful glyphosate applications, both as burndowns and in-crop, I can see why—if significant glyphosate & AMPA are



Same experiment as photos on previous page. In non-RR soybean, both root and shoot biomass (28 DAS) were dramatically inhibited by glyphosate that was applied to ryegrass 5 days prior to soybean sowing. On the sandy Arenosol, the ryegrass took 7 – 10 days longer to die from glyphosate as compared to the clayey, high-pH Histosol. The more rapid ryegrass death on the Histosol may have caused greater soybean injury since the ryegrass roots were likely releasing glyphosate more quickly. *Note that soybean root biomass was decreased by ~ 60% with glyphosate pre-plant onto the ryegrass versus ryegrass killed by clipping (no glyphosate), and this effect undoubtedly causes poor nutrient uptake and more susceptibility to drought in the field*. Different letters indicate statistical significance at P ≤ 0.05. (Source: Bott et al., 2010b draft.)

Photo by Volker Römheld.

On a farm in Germany in 2006, only glyphosate was applied pre-plant, yet where the sprayer overlapped, the cover-crop never emerged or was stunted.

indeed plant-available months after application as shown by several scientific studies (see Part I). Almost always for us, the 2d-year wheat would've had one or more glyphosate applications within a couple weeks of planting, or perhaps even the day of planting. Now, of course there are always confounding factors, but weakened vigor due to residual glyphosate in the soil never occurred to me—everyone in the ag world was *sure* it was so strongly bound to the soil that it had no residual effect. Only the rarest of scientists had ever thought about the fate of glyphosate that had entered the vegetation, and, until recently, no one suspected that glyphosate or its metabolites remained in roots (and other plant parts) and that as these decayed, those compounds become available for uptake by the next crop.

What was really bothering me was that the disease and poor growth problems seemed to be getting worse in many cases. Indeed, the really stellar wheat yields occurred mostly in the first couple years of no-till for any given field—assuming it was reasonably well cared-for under the previous tillage regime. And, under long-term no-till, wheat after RR soybeans (which followed milo) often had more drought susceptibility than expected. (My primary theory was inadequate fertility causing the yield stagnation or reduction, which I still contend is a major factor, but certainly isn't the whole truth. It's apparently much more complicated than that. However, almost all cropland suffers from net export of secondary and micronutrients—removal in grain exceeds replenishment, thus causing deficits for crops. More intensive cropping with no-till accelerates this process, plus the exacerbation of the effect by net sequestration in soil OM of *all* nutrients.)

Crown rot in winter wheat has also plagued many no-tillers across Kansas, especially in '09. Several species of *Fusarium* cause crown rot, with the most aggressive being *F. pseudograminearum* and *F. culmorum*. We also seemed to be having more head scab issues, but mostly I blamed this on the cooler, wetter weather patterns in Kansas and Oklahoma at wheat pollination during the '06 – '09 timeframe (temperatures in this region are often warm enough at wheat heading to prevent major head scab outbreaks). Whether repeated glyphosate application has anything to do with these, I don't know, but the science (Part I) has me seriously considering it as a possibility.

Another thing that was a bit troubling to me was the flaring of *Phytophthora* in soybeans, which sometimes resulted in some sizeable patches being devoid of plants by mid-summer (or at most, a few stunted stragglers). I thought it was just dumb luck—we didn't pay enough attention to this characteristic when choosing varieties. But glyphosate usage could explain it (and/or the RR trait itself).

Another oddity was that sometimes a sunflower, wheat, or millet stand would simply be 'missing' where the sprayer overlapped during the burndown, when the only thing in the sprayer was glyphosate and adjuvants. Since I was 'sure' it wasn't the glyphosate, I chalked it up to surfactant toxicity, or perhaps due to small amounts of residues in the spray tank (SUs in particular). Now, I'm convinced it's due to AMPA and glyphosate itself.

Photos by Sebastian Bott.

Reduced wheat growth and chlorosis resulting from low levels of glyphosate supplied to roots for a few hours in hydroponics. Another symptom is needle-like leaves, as well as slowed growth. These symptoms are often observed in the field with glyphosate intoxification of wheat by root uptake. '-glyph' = no glyphosate (control), which grew normally. (Sources: Bott et al., 2009b; Bott et al., 2010d draft.)

Finally, we had begun having lots of problems with nutrient deficits, some of which supposedly never occurred in this part of the world (and some of that is just naïve unwillingness to go test these things). Some of the deficiencies (e.g., zinc) were probably due to soil depletion from nutrient export at harvest, in addition to sequestration of nutrients as soil organic matter built under good no-till management. However, residual glyphosate is likely playing a role here, too.

One of the most puzzling deficiencies is magnesium (Mg), which certainly shouldn't be deficient in our crops when we often have 20 or 30% Base Saturation of our soil's CEC occupied by Mg ions. Yet the plants *were* Mg deficient. In some cases, this was induced by inadequate N levels, but not always. However, some studies do show that Mg uptake is impaired by residual effects of glyphosate. Hmm, another hypothesis to seriously consider.

Dwayne Beck: "*All* pesticides and herbicides—even the natural ones—have unintended or undefined consequences."

Manganese (Mn) deficiency has also become much more prevalent in no-till crops across the region, and particularly on certain soil types under long-term no-till. It became conspicuous in RR corn, and had been troubling us for some time on those soils. Our RR soybeans, wheat, milo, and other species were also being hurt by Mn deficiency, although the symptoms and tissue test results were usually less obvious than in corn.

With the recent scientific advances, perhaps some light has been shed on these mysteries—even if it will be awhile before we're fully fluent in the new management that may be required to avoid these problems. Good management is always subject to change . . . .

To summarize, *occasional* use of glyphosate may be a reasonably good choice from a cropping systems standpoint, so long as the timing and rates are carefully chosen. Dwayne Beck, Ph.D., Dakota Lakes Research Farm, who has engaged his sharp mind on this topic for many years, gives us the wide-angle view: "*All* pesticides and herbicides—even the natural ones—have unintended or undefined consequences. The real problem is that there is not enough money in researching these things [pesticides] as compared to the money spent promoting them . . . . I am not against these products, but the less often we have to use any one chemistry, the better . . . . Diverse crop rotation plays a part in ensuring the chemistries are not abused."

And just to be abundantly clear: While the problems with glyphosate appear to be quite significant for certain crops and timings, I am in no way suggesting that tillage is a viable alternative: The soil degradation from tillage is ultimately catastrophic for civilizations.[57]

The author gratefully acknowledges the helpful comments on drafts of this article by: Jill Clapperton, Ph.D. (Earthspirit Consulting); Rolf Derpsch (consultant, Paraguay / Germany); John Grove, Ph.D. (U. Kentucky); Günter Neumann, Ph.D. (U. Hohenheim, Germany); Ken Nixon (farmer, science enthusiast); Tim Paulitz, Ph.D. (USDA-ARS, Pullman, Wash.); Raymond C. Ward, Ph.D. (Ward Labs); Nigel Wilhelm, Ph.D. (S. Australia Res. & Develop. Inst.); and two weed scientists who wish to remain anonymous.

[57] See *Leading Edge*'s April '09 issue: 'Cropland Degradation,' and references therein. See also D.R. Montgomery, 2007, *Dirt: The Erosion of Civilizations*, U. Calif. Press. (although he endorses some entirely unscientific and imprudent ag fads of our era).

Glyphosate-Resistant Marestail:
Dwindling Options for No-till Soybeans?

by Matt Hagny

TECHNIQUE

There *was* successful no-till soybean production before Roundup Ready; it was just a bit more awkward, and you had to be timely. There are plenty of options yet. E.g., burndowns with Ignite, or with paraquat mixtures, preferably with 2,4-D ester added (delay planting accordingly) and/or dicamba (longer planting delays). Sharpen (Kixor) has limited ability to kill small marestail, but only if MSO (methylated seed oil) is used. Sharpen has some residual activity, but rather little at the rate labeled and considered safe for soybeans pre-plant.

FirstRate is a wonderful ALS product that came out in the mid-'90s before RR dominated the market, although some ALS-resistant marestail have shown up in areas of the USA. However, most (but not all) marestail populations in Kansas & nearby states are still susceptible to it (as of 2010), if sprayed before the plants get too large (more than ~ 10 inches), and using the proper adjuvants, etc. FirstRate also has excellent soil activity against ALS-susceptible marestail when used as a pre-plant, often as a premix: Authority First (a.k.a. Sonic).

Photo by Dallas Peterson, KSU.

The farmer on the RH side had some issues with marestail control in soybeans (likely due to glyphosate resistance), while the field on the LH side had excellent control. (Details!) Both fields were no-till.

For both burndown and residual, Sencor (metribuzin) pre-plant is still effective on most populations. Although if you use atrazine on your corn & milo in the rotation, you're using the same mode of action and putting a lot of selection pressure on weed populations, and some triazine-resistant populations of marestail already exist in the eastern USA, and suspected in Kansas.

For all of these chemistries, it's best to get control of the marestail before they get large (starting to bolt) and tough to kill. Late fall or early spring applications with 2,4-D plus dicamba are becoming more necessary, whether or not long-residual products are included in the mix. This reduces the need for high rates (and fingers crossed) at planting.

If things got bad enough (and no new products came to market), we could go back to planting on wider rows and running hooded sprayers between the rows. (Not a pleasant thought, but this is done on a huge percentage of Australia's crops.) But I suspect that Monsanto's dicamba-resistant soybeans (coming in 2013 ?) and LibertyLink soys (on the market currently, and tolerant to Ignite) will buy us time for other chemistries and herbicide-resistant crops to be developed.

The key is to make wise use of the tools at hand to slow the development & spread of resistance, and to keep the marestail populations under control on your own land (usually 99+% of the weeds in a field come from weeds setting seed in that field, and a single marestail plant can produce 300,000+ seeds). More diverse crop rotations and cover crops (where appropriate) certainly help, as well as doing everything possible to achieve adequate stands and vigorous growth of both cash crops and covers. Ultra-low soil disturbance and heavy mulch cover go a long way toward keeping the marestail emergence rate down. (Further reading: 'Marestail Menace,' Sept. '07 issue.)

The Payoff

by Matt Hagny

Holzwarth was the cover story for the Sept. '04 issue.

As of our '04 interview, Ralph Holzwarth (Gettysburg, SD) was doing well, and his careful positioning—both in technology as well as long rotations and good agronomy—is now paying off nicely. Says Ralph, "Our yields keep going up. . . . We're a lot more aggressive with our yield goals now: We try to push a little harder with the inputs. And we're trying to stretch the rotations."

Ralph tries to be in wheat only 2 years out of 5, instead of 2 out of 4. Although he was already doing some of this in '04, the longer rotation now encompasses most of his acres. And on some of his best soils, he's pushed it out to a 6-year rotation, such as corn >>field pea >>corn >>soy >>s.wheat >>w.wheat. His 5-year rotation is stacked wheat, stacked corn, then either sunflower or soybean. "We're growing more soybeans now: The yields are getting better. Sunflowers fill in on the fields that are rocky." As for the field peas, "We only have 7 or 8% of our acres in peas. The last two springs ['09 & 2010], it was too wet to get them planted into wheat stubble, so we had to jump out of that. Our peas only go into corn stalks now."

The long rotational breaks provide advantages, as Ralph describes, "If I stay out of wheat for 3 – 4 years, I'm thinking we have a 5 – 10 bu/a yield increase." He also reports that his 2d-year corn is 'only' 5 – 10 bu/a less than his corn into wheat stubble, which he finds entirely satisfactory in the scheme of things, since it requires less investment (no wheat stubble to keep clean in the fall), and allows more time away from wheat. 'Cheatgrass' continually motivates Ralph to stretch the rotations, and in one case he did 6 consecutive years of corn, soybeans, and peas to get a field cleaned up. His cropping intensity, and yields, are astonishing for an area that was 1/3 summerfallow a mere 20 years ago.

Holzwarth is now precision on everything—auto-steer, RTK, variable-rate (VR) phosphorus and N on wheat & corn, plus VR population on corn. He has about half his fields zoned. "We've gotten pretty aggressive with planting rates for corn: We push for 120 – 180 bu/a [avg. 155], and we've hit it the last few years. But not every year," he hastens to add. He says they won't make those yields in 2010, having not had any rain since the 4th of July. He recounts the tough years, "It was so dry in '06, nothing much mattered anyway. The corn completely burned up. It was so dry, we only harvested about half our wheat that year." He continues, "I'm sure glad we had no-till, or else the whole countryside woulda blowed away." (His county is over 90% no-till, among the highest in the nation.)

"Our yields keep going up."

Ralph uses a JD 1895 drill with a 3-tank cart to apply most of his N for wheat at seeding, which works well in his climate. All his spring wheat also gets stream-bar N with the sprayer to get higher protein in the grain. He runs Cargill's MESZ (all granules contain N, P, S, and Zn) for pop-up on both wheat and corn (towing the cart behind the planter to supply the dry fertilizer). Ralph intends to fine-tune his fertilizer program further: "We've been doing some leaf analysis to figure out what we're missing." As a result, he's now using boron, and experimenting with copper. (On a related note, his better soils are now up to 4.5 – 5.0% OM in the upper 6 inches.)

Ralph's planter setup hasn't changed much, but the interesting thing is that everyone in his area who'd converted to 20-inch spacing has abandoned it: "They just can't get the residue to flow, especially on rows with transport wheels." He doesn't want to create 'self-directed' problems: "When I'm trying to get things done in the field, I don't want to be plugging. Why do that to yourself?"

Ralph comments that he's gone to a Shelbourne stripper head, which would further aggravate residue flow for planting corn into heavy winter wheat stubble. But he further notes that cover crops might solve the problem: "They've got a lot of merit—something that I strongly think we need to fit into the farm. The concept makes a lot of sense." (He dabbled with covers this year.)

Ralph emphasizes the progress in his 2 decades of no-till: "Things work a lot better than 10 or 20 years ago: We don't bog down in wet soils. Equipment has gotten better—more options."

Ralph's farm has continued to expand significantly in recent years, with Ralph's incisive weighing of risks and rewards, and willingness to push the envelope. Ralph & Betty's son, Ted, returned to the farm in '09, and Ralph thinks this is quite a payoff in itself.

Adapt & Thrive

by Lisa Brown Jasa

In 1983, Chris Clausen began no-tilling in the rolling hills of northeast Nebraska, about 40 miles southeast of Norfolk, and now farms about 1,900 acres. “Twenty-five years ago, I would never have dreamt I could farm the number of acres I am without more labor. It’s phenomenal what technology has done. . . . Labor for my farm is a one-man show.” —Although he does get a little help at harvest from a few part-timers after they get off from their day jobs at 5 p.m., and from his 83-year-old father, LaVern. Chris’ wife, Lisa, has her own off-farm job, but she helps occasionally with running shuttles around, etc. Chris elaborates, “The labor savings on no-till is tremendous. Some farmers in the area who swore they’d never go to no-till have now converted their operations, and it’s due to labor.”

Currently, the Clausen farm is in a corn >>soybean, or corn >>corn >>soybean rotation, although Chris also grew wheat from ’04 to ’07. He’s primarily dryland, although about 30% of his farm is irrigated by pivots. And he does have a couple small bottomland fields that are gravity irrigated (he rebuilds the ridges about every 6 or 7 years—the only tillage to be seen on his farm in the last 20 years).

Chris has fine-tuned his operation, developing a prescription plan for each field, based on soil type, slope, and how various practices, hybrids, and inputs have performed. He explains, “I have currently progressed to grid sampling and yield mapping: I’m trying to build soil fertility levels in all areas of a field. So I started using variable-rate [VR] fertilizer application to help achieve higher yields and lower input costs.” Chris uses 2.5-acre grids, and has his fertilizer supplier VR-apply dry phosphorus, zinc, and sulfur to those grids with a floater. He also has lime applied by grid, as a separate application. Chris learned long ago about liming: “We quickly found out that incorporation wasn’t needed.” Phosphorus application was another puzzle for Chris in the early years of no-till, but he’s made his peace with the question: Pop-up, plus surface application, are the most practical and effective methods in his estimation.

Lessons from the ’80s on lime: “We quickly found out that incorporation wasn’t needed.”

Normally for dryland fields, Chris applies 30% of his nitrogen with the planter, and the remainder is sprayed onto the surface with pre-plant herbicides. “We don’t have a problem with losing residue too quickly.” —His cool climate doesn’t cause residues to decompose as rapidly, which allows liquid nitrogen to be sprayed onto the residues. On irrigated acres, Chris applies 30% with the planter, 50% with a surface spray, and 20% through the pivot. With the planter, the products applied are 4 to 5 gallons of 10-34-0 in the seed row, along with a pint of zinc sulfate (10% Zn), and 30 – 40 lbs/a of nitrogen dribbled 2 – 3 inches to the side, via a self-designed stainless steel tube aiming the liquid behind the closing wheel.

Even with a plan, each year requires adjustments, and some years more than others. In 2010, Chris had to modify his fertilization plans after 14 inches of rain fell during the first three weeks of June, causing flooded bottomlands, and leaching and/or denitrifying his applied nitrogen. “I tried more side-dressing this year and will do a lot more in the future. By getting it into the soil later in the season, we could keep from losing that nitrogen with a heavy rainfall. I didn’t see any signs of nitrogen deficiency in the side-dressed fields, but had some yellowing in

Photo by Chris Clausen.

Chris planting into heavy corn stalks: No problem!

other fields until the plants rooted deep enough to reach the displaced nitrogen [and/or until mineralization and soil aeration caught up with plant demand for nitrogen]." For side-dressing, Chris used a rig with coulters and high-pressure nozzles. However, "I won't side-dress all my corn, because I can't get it all done on time."

Along the Way

Over the years, Clausen has seen changes in equipment, seed, herbicides, fertilizer placement and other technologies that have advanced no-till. When he started farming, Chris says, "There was a lot of wasted time sitting on a tractor and field cultivator." For his farm, the no-till adoption began by planting a few fields of corn directly into soybean stubble in '83, which worked well, and he & LaVern continued to expand that practice. By '87, Chris tried a Great Plains drill for soybeans, going directly into corn stalks: "Dad thought I was crazy." Why not put the soybeans in with the planter? Chris explains that soybean herbicides were quite limited at the time, so they truly needed the quick canopy of the narrow rows of a grain drill: "Back in those days, getting good weed control in no-till soybeans was tricky. Herbicide management was a whole different story before Roundup Ready crops." Reflecting further, "Roundup was $80/gallon in the '80s, so you only used a little bit for burndowns, and used other chemistries for everything else."

Clausens liked what they were seeing with no-till. Chris reflects, "We saw that we could reduce erosion and have equal yields as compared to tillage, and better yields [with no-till] in dry years. Plus, no-till provided cleaner fields." LaVern was a big believer in soil conservation measures, and was using a reduced-tillage system already in the '60s, notes Chris, "He could see right away that no-till had some merit and has been really supportive."

In '88 and '89, Chris was contemplating purchasing a Tye or Great Plains drill with a heavy coulter cart, but was leery of the investment and what he suspected would be high-maintenance, so he held off. Then he heard that Deere was coming out with a different type of no-till drill, which was the 750 model. Chris bought one in 1990, the first year they were fully marketed (a few were out in '89). Chris describes the result as "wonderful," and states that this was truly the missing piece to let him go 100% no-till, which they did in '90.

Mid-1980s no-till: "We saw that we could reduce erosion and have equal yields as compared to tillage, and better yields [with no-till] in dry years. Plus, no-till provided cleaner fields."

Clausen likes what no-tilling has done for his soil structure, as well as the improved water infiltration on their 6 – 12% slopes of silty clay loams. "Fifteen years ago my son and I went out to collect runoff water samples after a fast 3-inch rain. It was not a surprise to see cleaner water samples from no-till fields compared to conventionally tilled fields. What was surprising was that after collecting the conventional samples, we had to wait 15 minutes before there was any runoff in the no-till fields, and then it was much less." When questioned about the runoff causing rills to form in continuous no-till, Chris replies that it's been negligible.

The benefits to soil structure and quality are particularly evident when Chris compares two of his fields—one that had previously been tilled for many decades, and another that had been in native grass and tilled *once* in the 1930s before being planted to brome. Clausen bought the latter field in 1997 and has been no-tilling it ever since. This field is 4.8% organic matter, more than twice the average for long-term tillage fields in his area. "The first year, I no-tilled soybeans into the field and saw a 10 – 15% yield increase over similar soils and fields in the area."[1]

Photos by Lisa Clausen.

Clausen's '09 corn, planted into rye which had been drilled into '08 soybean stubble. The rye was killed out several weeks prior to corn planting, which apparently avoided any major allelopathy problems.

[1] *Editors' Note: The yield advantage might be due to lower disease pressure since the field had never grown soybeans previously. Also, there would've been better soil nutrient status on this tract versus older cropland with its greater nutrient removal in harvested grain.*

More Technological Advances

For planter technology, Chris notes that the introduction of Keeton seed firmers and new closing wheels have helped ensure successful stands. Knowing which new option is worth the investment, however, takes some testing. When he's looking at planter enhancements: "I buy enough for one row and test how it performs in the field. If I like it, I'll outfit the planter." He plants with a 16-row Orthman bar outfitted with Deere XP row units on 30-inch spacing, having added non-floating straight-tooth row cleaners, Keetons with Mojo wires, and Thompson closing wheels with toe-out wedges. He's ran this setup for several years and is quite pleased with it in a broad array of conditions, although he'd like to upgrade to a full set of Yetter SharkTooth row cleaners at some point. One item that didn't work for Chris was the Reduced Inner Diameter (RID) gauge wheel tires.

Photo by Chris Clausen.

Clausen's 2010 soybeans establishing amongst a carpet of cornstalks. Clausen says, "Herbicide management was a whole different story before Roundup Ready crops. But it's made people complacent. They're not as timely in their spraying."

For soybeans, Chris uses both the planter and his JD 750 drills on a Houck hitch (he's owned several different 750s). However, Chris' current plan is to sell the drills and trade his planter for a 15-inch planter configuration. Since he abandoned wheat in '07, he figures there's no need for the drill, although he does want the quick canopy of soybeans in rows narrower than 30-inch, hence the 15-inch planter idea. He grew corn on 20-inch rows from '96 to 2000, but the disease pressure in the corn was troublesome—although he thinks that better hybrids and more affordable fungicides may make this row spacing feasible again, and he'd really like to have the quick canopy. Regardless of the new planter's row spacing, Chris plans to add VR seeding capability.

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At harvest, Clausen uses a JD 9760 combine that he outfitted with a high-performance Redekop chopper. The factory spreader wasn't performing as well as he'd like with the 35-foot soybean head, but he's been pleased with the wide, even distribution of the Redekop.

For weed control, Chris is a big proponent of switching herbicide chemistries to reduce the development of herbicide resistance. He uses only a single application per crop-year of any herbicide chemistry, including glyphosate. For soybeans, he uses a non-glyphosate pre-plant application (e.g., Authority Assist + 2,4-D), and then a post-emerge application of glyphosate. With corn, he uses a pre-emergence such as acetochlor (Harness, Surpass & generics), followed by a post application of glyphosate (often with a half rate of Callisto to clean up marestail and giant ragweed).

Chris comments that glyphosate-resistant marestail are now showing up in his area. He knows why: "Weed control got a lot easier with Roundup Ready crops. But it's made people complacent. They're not as timely in their spraying." He suspects that his knowledge and discipline from the pre-Roundup-Ready era will serve him well in coming years.

Before corn and soybean prices shot up in '08, Clausen included wheat in his crop rotation and would plant several hundred acres to cover crops after wheat, including proso millet, foxtail millet, lentils, sorghum-sudan, and canola. Now, without wheat in the rotation, Chris is more challenged to make cover crops fit.

In the fall of '08, Chris aerially seeded rye and radish into 40 acres of soybeans that were just starting to turn

Photo by Chris Clausen.

Clausen's self-crafted fertilizer tube on the back of his planter closing bracket.

yellow. He sprayed out the cover crop during the third week of April for corn, and it planted beautifully in early May: the best conditions on his farm. In '09, he did the same thing, and sprayed out this cover crop on April 20, 2010, but the field was still muddy and difficult to plant on May 10. However, he notes that this field was newly acquired and had only 4 years of no-till history, and that the winter of '09/'10 was far wetter than the previous winter. But regardless of the cause, next year he may wait and spray out the cover closer to corn planting to allow it to use more soil moisture. (*Editors: However, he may have allelopathy problems with rye being killed out close to corn planting.*)

Both Sides of Advice

Clausen credits his building a successful farming operation to information-sharing and his openness to innovation, and recommends a similar philosophy to others thinking about adopting no-till. When Clausen is asked for general advice, he tells new no-tillers to be patient. "In the first six to eight weeks after emergence, especially in cold, wet springs, corn plants can look smaller and yellower than in conventionally tilled fields. The crop looks like it's suffering. They need to remember that the crop isn't made in May—it's made in August. When it's hot and dry in August, no-till fields will outcompete and yield equally as well or better than conventional fields." (*Editors: The slower growth of no-till corn is primarily due to cooler temps in the mulch cover, while the yellowing or paleness is likely a nutrient deficiency.*)

When Clausen started no-tilling in 1983, it was still new to the area. In the next few years, the number of no-till acres in the area grew, along with a good base of people who were willing to share their ideas, their problems, and their solutions. That informal sense of community continues today: "We don't need to reinvent the wheel each time one of us looks at trying something new. We learn from each other."

Clausen remarks, "I like to surround myself with knowledgeable people. A farmer wears a lot of hats and it's hard to be an expert in every area. Know the right people and hire the right people, whether it's an agronomist or a financial expert. It will make you more successful in the long run."

We're Back!

We sincerely apologize for being MIA. Due to unavoidable circumstances, *Leading Edge* had to take a year's sabbatical following the publication of the April '09 issue. But we're back! And we've been assembling top-notch content for future issues.* *You will get every issue for which you've paid*. We intend to maintain our schedule now—as we did for the first 9 years of publication—with issues in the Winter, Spring, and Fall (~ Jan., April, and Sept.).

* January 2011 issue: Jill Clapperton's Part II, Pesticides & Soil Biology

No-till On The Plains

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