Influence of Application Variables on Efficacy of Manganese-Containing Fertilizers Applied to Peanut (*Arachis hypogaea* L.)

David L. Jordan*, Sarah H. Lancaster, James E. Lanier, P. Dewayne Johnson, Joshua B. Beam, Alan C. York, and Rick L. Brandenburg[1]*

ABSTRACT

Several formulations of the essential element manganese (Mn) are commercially available for application to peanut (*Arachis hypogaea* L.). Research was conducted in North Carolina to compare accumulation of Mn in peanut leaves, stems, and pods following application of water soluble manganese sulfate including 17.5% Mn (Techmangum® or Man-Gro DF®) and liquid Mn formulations including 5.0% Mn (Manganese Xtra©) or 8% Mn (Nutrisol 8% Manganese™). Experiments were also conducted to determine the influence of herbicides, adjuvants, and selected fungicide and insecticide combinations on Mn accumulation in peanut leaves. A second experiment was conducted to determine if efficacy of clethodim, imazapic, imazethapyr, lactofen, sethoxydim, and 2,4-DB was affected by Mn formulations when applied in mixture. Experiments were also conducted to determine the effect of Mn on efficacy of the fungicides azoxystrobin, chlorothalonil, pyraclostrobin, and tebuconazole. More Mn was found in leaves when dry formulations of Mn were applied compared to liquid formulations, reflecting the higher amount of actual Mn delivered per ha based on manufacturer recommendations of these products. Accumulation of Mn was higher when Mn was applied with the herbicides clethodim, imazapic, and lactofen compared with Mn alone or Mn plus 2,4-DB. Accumulation of Mn was similar for Mn alone or most combinations of Mn with fungicides and insecticides. Manganese did not affect corn (*Zea mays* L.) control by clethodim or sethoxydim; large crabgrass [*Digitaria sanguinalis* (L.) Scop.] control by clethodim; Palmer amaranth [*Amaranthus palmeri* (S.) Wats.] control by imazethapyr; sicklepod [*Senna obtusifolia* (L.) Irwin and Barneby] control by imazapic, imazethapyr, or 2,4-DB; or tall morningglory [*Ipomoea purpurea* (L.) Roth] control by imazapic. In contrast, common ragweed (*Ambrosia artemisiifolia* L.) control by lactofen was reduced by dry manganese but not the 8% liquid solution. Peanut canopy defoliation was similar when the fungicides azoxystrobin, chlorothalonil, pyraclostrobin, or tebuconazole individually were compared alone, with Mn, or Mn plus the insecticide lambda cyhalothrin.

Key Words: agrochemical compatibility, foliar fertilizers, micronutrient, weed management.

Manganese (Mn) is an essential element needed for peanut (*Arachis hypogaea* L.) growth and development (Gascho and Davis, 1995) serving as a cofactor in kinase and transferase enzymatic reactions in plants (Horst, 1986). Deficiencies of Mn are often associated with production on high pH soils (Gascho and Davis, 1995) but can be corrected with Mn-containing fertilizers applied topically (Gascho and Davis, 1995).

A variety of commercial formulations of Mn are available, with the range of elemental Mn applied per unit area varying considerably when these products are applied at the manufacturer's suggested use rates. Furthermore, some manufacturers with lower concentrations of manganese claim that absorption of Mn is enhanced by their formulation. Determining the relative difference in the amount of elemental Mn accumulation in plant tissue following foliar application of Mn fertilizer is important in determining which formulation is the most beneficial for use in peanut. The influence of pesticides and adjuvants on absorption of boron, a micronutrient often applied topically to peanut, into peanut leaves has been reported previously (Jordan *et al.,* 2006). However, research is limited with respect to the influence of agrochemicals traditionally used in peanut on absorption of Mn.

Determining compatibility of agrochemicals is important when developing pest management strategies for peanut. Interactions of graminicides with herbicides that control broadleaf weeds and purple nutsedge (*Cyperus rotundus* L.) and yellow nutsedge (*Cyperus esculentus* L.) in peanut have been evaluated (Burke *et al.,* 2004). Additionally, compatibility of agrochemicals including fungicides and insecticides routinely applied to peanut has been defined partially (Lancaster *et al.,* 2005a 2005b; Jordan *et al.,* 2003). Beam *et al.* (2002)

[1]Professor, former Graduate Assistant, former Graduate Assistant, Research Specialist, former Graduate Assistant, William Neal Reynolds Professor, Department of Crop Science, North Carolina State University, Box 7620, Raleigh, NC 27695; and William Neal Reynolds Professor, Department of Entomology, North Carolina State University Box 7613, Raleigh, NC 27695. Current address of S. R. Lancaster: Department of Plant and Soil Sciences, Oklahoma State University, 368 Ag Hall, Stillwater, OK 74078.

*Corresponding author (e-mail: david_jordan@ncsu.edu)

reported possible interactions of prohexadione calcium, a plant growth regulator applied to peanut to manage vine growth, with herbicides, insecticides, fungicides, foliar fertilizers, and other plant growth regulators registered for use in peanut. Manganese did not affect efficacy of prohexadione calcium in their research.

Reduced herbicide efficacy may be a result of chemical interactions in the spray solution. Cations in the spray solution can adversely affect efficacy of glyphosate and sethoxydim (Nalewaja *et al.,* 1991; Wanamarta *et al.,* 1993). In these situations, efficacy of some herbicides can be improved by the addition of ammonium sulfate prior to herbicide placement in the spray solution (Wanamarta *et al.,* 1993). Bailey *et al.* (2002) reported that lignin and chelated formulations of Mn reduced control of common lambsquarters (*Chenopdium album* L.), large crabgrass, morningglory spp. (*Ipomoea* spp.), and smooth pigweed (*Amaranthus hybridus* L.) by glyphosate. Bernards *et al.* (2005) reported that antagonism of glyphosate by Mn varied when comparing Mn formulations. Additionally, increasing the rate of glyphosate or applying glyphosate and Mn sequentially, partially or completely eliminated antagonism on some but not all weed species (Bailey *et al.,* 2002; Bernards *et al.,* 2005; Poston *et al.,* 2005). However, interactions of fertilizers containing Mn with herbicides other than glyphosate that are commonly used in peanut have not been clearly defined.

Timing of application of fungicides, insecticides, and Mn often coincide, and determining interactions of these agrochemicals will be important in making good decisions on pest management in peanut. Although research has demonstrated that boron does not affect efficacy of fungicides (Jordan *et al.,* 2006), similar research has not been conducted with Mn.

Determining which formulations of Mn provide the most elemental Mn in plants will help when attempting to correct deficiencies with a wide range of commercially available products. Additionally, determining if Mn affects pesticide efficacy or if agrichemicals will affect Mn absorption can assist practitioners as they develop appropriate production and pest management strategies for peanut. Research was conducted to determine (1) differences in Mn accumulation in peanut leaf tissue when various commercially available Mn products are applied, (2) influence of pesticides and adjuvant on Mn accumulation in peanut, and (3) the effect of Mn on disease and weed control when co-applied with fungicides, herbicides, and insecticide.

Materials and Methods

Influence of formulation on Mn accumulation in peanut tissue. The experiment was conducted in two separate fields located near Edenton, NC during 2001 both on a Roanoke silt loam soil (clayey, mixed, thermic, Typic Ochraquepts) and in two separate fields at the Upper Coastal Plain Station during 2007 on a Goldsboro loamy sand soil (fine-loamy, mixed, semiactive, thermic, Typic Hapludults). The cultivar NC-V 11 (2001) (Wynne *et al.,* 1991) or VA 98R (2007) (Mozingo *et al.,* 2000) was seeded at a rate to establish an in-row population of 5 plants/m on 91-cm rows. Plot size was two rows by 5 m. A non-treated row separated each plot.

Treatments in 2001 consisted of no Mn, a dry formulation of Mn sulfate (Techmangum®, 19% S and 32% Mn sulfate monohydrate, Erachem Mexico, Veracruz, Mexico) at 2.8 kg/ha (17.5% actual Mn), and a liquid complex of Mn containing 5.0% Mn formulated at 1.10 kg Mn/L (Manganese Xtra©, Custom Agricultural Formulations, Fresno, CA) at 0.12 L/ha. In 2007, treatments consisted of no Mn or Mn formulations containing 8% Mn (NutriSol 9% Manganese™, Coastal Agrobusiness, Inc., Greenville, NC) at 1.16 L/ha or Mn sulfate (Man-Gro DF®, Tetra micronutrients, The Woodlands, TX) at 2.8 kg/ha (17.4% actual Mn). These rates are consistent with those recommended by the manufacturer and typically applied by peanut producers in North Carolina. Manganese was applied during flowering in late July.

In 2001, ten leaves consisting of four leaflets per leaf were removed at random from the top one-third of the peanut canopy 6 h (0.25 d), 2, and 14 d after application and were subjected to a 30 second leaf wash in 1 L tap water. Stems and pods were removed from three randomly selected plants within a plot for Mn determination 14 d after application. In 2007, ten leaves were removed from each plot 7 d after application as described previously and subjected to a 30 second wash in 1 L tap water. Leaf, stem, and pod tissue were dried and ground to pass through a 1 mm screen prior to Mn concentration determination using a Perkin Elmer 3300 Argon Plasma Emission Spectrophotometer (Perkin Elmer, Sulton, CN).

In both experiments, Mn was applied using a CO_2-pressurized backpack sprayer calibrated to deliver 145 L/ha using 8002 regular flat fan nozzles (Spraying Systems Co., Wheaton, IL) at 275 kPa. Adjuvant was not included. The experimental design was a randomized complete block with treatment replicated 3 or 4 times. Data for Mn accumulation (mg Mn/kg tissue) were subjected to analyses of variance and means separated using Fisher's Protected LSD test at $P \leq 0.05$.

Influence of adjuvants, fungicides, herbicides, and insecticides on Mn accumulation in peanut tissue. Experiments were conducted during 2008 at the Peanut Belt Research Station in two separate fields with the peanut cultivar Perry (Isleib *et al.,* 2003). Plot size was one row (96-cm spacing) by 3 m with one non-treated row separating treated rows.

In one experiment, treatments consisted of a dry formulation of Mn (Super Mangro) at 2.8 kg/ha (17.4% Mn) applied alone or with azoxystrobin (230 g ai/ha), chlorothalonil (1,260 g ai/ha), pyraclostrobin (175 g ai/ha), and tebuconazole (230 g ai/ha). Manganese was also applied with these fungicides combined with the insecticide lambda cyhalothrin at 18 g ai/ha. Additional treamtments included lambda cyhalothrin and Mn applied in mixture without fungicide and a no-Mn control was included. In a second experiment, treatments consisted of the same formulation and rate of Mn applied alone or with nonionic surfactant (Induce nonionic surfactant, Helena Chemical Co., Memphis, TN) at 0.25% (v/v), crop oil concentrate (Agri-Dex nonionic spray adjuvant™, Helena Chemical Co., Memphis, TN) at 1.0% (v/v), clethodim at 110 g ai/ha plus crop oil concentrate, imazapic at 70 g ai/ha plus nonionic surfactant, lactofen at 280 g ai/ha plus crop oil concentrate, and 2,4-DB at 280 g ai/ha without adjuvant. A non-treated control was included in both experiments. Treatments were applied using a CO_2-pressurized backpack sprayer calibrated as described previously.

The experimental design was a randomized complete block with four replications. Twenty leaves that were present at the time of application were removed from the top half of the canopy 7 d after application. Leaves were subjected to a one minute wash in tap water as described previously. Leaf tissue was blotted, air dried, and the concentration of Mn determined as descried previously. Data for Mn accumulation (mg Mn/kg tissue) were subjected to analysis of variance and means were separated using Fisher's Protected LSD test at $p \leq 0.05$.

Influence of Mn formulation on efficacy of postemergence herbicides. The experiment was conducted at the Cherry Research Farm located near Goldsboro, NC in 2001 on a Wickam sandy loam (fine-loamy, mixed, semi-active, thermic, Typic Hapludults). The experiment was also conducted at the Central Crops Research Station located near Clayton, NC in 2002 on a Geliad sandy loam soil (clayey, kaolinitic, thermic, Aquic Hapludults). Experiments were established in tilled fallow areas without a peanut crop. Plot size was 2 by 5 m.

In the first set of experiments at Goldsboro during 2001, treatments consisted of clethodim (140 g/ha), imazapic (70 g /ha), imazethapyr (70 g ai/ha), sethoxydim (220 g ai/ha), and 2,4-DB (220 g/ha) applied alone, with dry manganese sulfate (Techmangum®), or with a liquid formulation (Manganese Xtra©) at rates described previously. Herbicides were applied in separate experiments and were repeated in different fields during the same year. Imazethapyr was applied when Palmer amaranth was 40 to 60 cm in height. Imazapic, imazethapyr, and 2,4-DB were applied when sicklepod was 15 cm in height. Tall morningglory had 6 to 10 leaves when imazapic was applied. Clethodim and sethoxydim were applied to corn that was 25 cm in height.

In a second set of experiments conducted during 2007, common ragweed control by lactofen at 280 g ai/ha and large crabgrass control by clethodim at 140 g/ha were compared in separate experiments at the Upper Coastal Plain Research Station near Rocky Mount on the Goldsboro loamy sand soil described previously. The experiment was conducted in two adjacent fields and herbicides were applied alone or with manganese sulfate (Man-Gro DF®) at 2.8 kg/ha or liquid Mn (NutriSol 9% Manganese™) at 1.16 L/ha when common ragweed was 15 to 20 cm in height and large crabgrass was 10 to 15 cm in height.

Crop oil concentrate (Agri-Dex spray adjuvant™) at 1.0% (v/v) was applied with clethodim and sethoxydim. Nonionic surfactant (Induce nonionic surfactant™) at 0.25% (v/v) was applied with imazapic, imazethapyr, lactofen, and 2,4-DB. Treatments were applied using a CO_2-pressurized backpack as described previously.

Visual estimates of percent weed control were determined 2 wk after application using a scale of 0 to 100% where 0 = no control and 100 = complete control. Foliar chlorosis, necrosis, and plant stunting were used when making the visual estimates. The experimental design was a randomized complete block with 3 or 4 replications. Means for visual estimates of percent control were separated using Fisher's Protected LSD Test at $p \leq 0.05$.

Influence of Mn and lambda cyhalothrin on efficacy of fungicides. The experiment was conducted during 2008 at the Peanut Belt Research Station in two separate fields with the peanut cultivar Perry. Plot size was one row (96-cm spacing) by 5 m with one non-treated row separating treated rows.

Treatments consisted of a dry formulation of Mn (Man-Gro DF®) applied alone at 2.8 kg/ha, with the fungicides azoxystrobin (230 g/ha), chlorothalonil (1,260 g/ha), pyraclostrobin (175 g/ha), and tebuconazole (230 g/ha), and with these fungicides co-applied with the insecticide lambda cyhalothrin at 18 g/ha. Fungicides and lambda cyhalothrin were also

Table 1. Manganese (Mn) accumulation in peanut leaf leaves, stems, and pods when applied as two Mn formulations during 2001.[a]

Manganese treatment	Spray solution	Manganese accumulation: Leaf tissue, Days after application (2001)[b] 0.25	2	14	2001[b] Stems	Pods
	mg Mn/L	mg Mn/kg tissue				
No Mn	0.02	3 c	0 c	0 b	0 b	0 a
5.0% Mn[c]	2352	42 b	86 b	26 b	5 ab	1 a
Manganese sulfate[d]	6394	144 a	208 a	87 a	7 a	1 a

[a]Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p \leq 0.05$. Data are pooled over two experiments.

[b]Leaves were subjected to a 30 s wash in 1 L tap water. Stems and pods were collected 14 d after treatment.

[c]Liquid formulation of Mn containing 5.0% Mn formulated at 1.10 kg/L applied at 0.12 L/ha.

[d]Dry formulation (Techmangum®) of Mn sulfate containing 17.5% Mn applied at 2.8 kg/ha.

applied alone. A non-treated control was also included. Treatments were applied using a CO_2-pressurized backpack sprayer as described previously.

The experimental design was a randomized complete block with four replications. The percentage of peanut canopy defoliated due to early leaf spot caused by *Cercospora arachidicola* Hori and late leaf spot caused by *Cercospora personatum* Berk. and Curtis incidence was recorded in early October within one week of peanut harvest using a scale of 0 to 100 where 0 = no defoliation and 100 = defoliation of the entire peanut canopy. Data for percent canopy defoliation were subjected to analysis of variance and means were separated using Fisher's Protected LSD test at $p \leq 0.05$.

Results and Discussion

Influence of formulation on Mn accumulation in peanut tissue. In 2001, the concentration of Mn in leaf tissue was the highest when manganese sulfate was applied regardless of harvest date (Table 1). When compared at 0.25 and 2 d after application, the 5.0% liquid Mn formulation increased Mn concentration in leaves compared with non-treated peanut. However, there was no difference in Mn concentration when comparing these two treatments by 14 d after treatment. Manganese formulation did not affect Mn concentration in stems (Table 1). However, the concentration of Mn was also similar when comparing the 5% liquid formulation with non-treated peanut. Accumulation of Mn in pods was similar regardless of Mn treatment (Table 1). In 2007, there was no difference in Mn accumulation in leaf tissue when comparing non-treated peanut with the 8% Mn formulation (Table 2). However, Mn accumulation increased from 286 mg Mn/kg tissue (non-treated and 8% Mn formulation) to 338 mg Mn/kg tissue when Mn sulfate was applied.

These data suggest that liquid formulations of Mn applied at the manufacturer's suggested use rate do not result in increases in Mn accumulation in all instances. In contrast, Mn sulfate at the rate recommended by the manufacturer consistently increased the amount of Mn in leaf tissue. This result was not surprising when comparing the amount of Mn applied in these formulations in 2001 (Table 1). Approximately 2.7 times as much Mn was delivered per ha when applied as Mn sulfate, and this resulted in approximately 3.4 times the amount accumulated at 0.25 and 14 d after application and 2.4 times the amount accumulated at 2 d after treatment. These data suggest that when a Mn deficiency occurs, practitioners should be aware that some liquid Mn products applied at rates recommended by the manufacturer may not increase Mn concentration appreciably. Convenience is often cited by practitioners as the reason for using liquid products rather than dry materials such as Mn sulfate delivered in the formulated products Technangum® or Man-Gro DF®. Cost of

Table 2. Manganese (Mn) accumulation in peanut tissue 7 days after application of two Mn formulations during 2007. [a]

Manganese forumulation	Manganese accumulation[b]
	mg Mn/kg tissue
Non-treated control	236 b
8% Mn[c]	236 b
Manganese sulfate[d]	338 a

[a]Means followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p \leq 0.05$. Data are pooled over two experiments.

[b]Leaves were subjected to a 30 s wash in 1 L tap water when harvested 7 d after application.

[c]Liquid formulation of Mn containing 8.0% Mn applied at 1.16 L/ha.

[d]Dry formulation of Mn (Man-Gro DF®) containing 17.5% Mn applied at 2.8 kg/ha.

Table 3. Influence of adjuvants and herbicides on manganese (Mn) accumulation in peanut leaves 1 wk after application in 2008.[a]

Manganese[b]	Adjuvant[c]	Herbicide[d]	Manganese accumulation[e]
			mg Mn/kg tissue
-	-	-	114 d
Manganese sulfate	-	-	228 c
Manganese sulfate	Crop oil concentrate	-	390 b
Manganese sulfate	Nonionic surfactant	-	446 ab
Manganese sulfate	Crop oil concentrate	Clethodim	388 b
Manganese sulfate	Crop oil concentrate	Lactofen	519 a
Manganese sulfate	Nonionic surfactant	Imazapic	349 b
Manganese sulfate	-	2,4-DB	240 c

[a]Means followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p \leq 0.05$. Data are pooled over two experiments.
[b]Dry formulation of Mn (Man-Gro DF®) containing 17.5% Mn applied at 2.8 kg/ha.
[c]Crop oil concentrate and nonionic surfactant applied at 1.0% (v/v) and 0.25% (v/v), respectively in 140 L/ha.
[d]Clethodim, lactofen, imazapic, and 2,4-DB applied at 140 g/ha, 240 g/ha, 70 g/ha, and 220 g/ha, respectively.
[e]Leaves were subjected to a 1 minute wash in 1 L tap water 7 days after application.

liquid and dry formulations of Mn is often competitive when these products are applied at rates applied in these experiments. However, when Mn deficiencies are apparent, rates higher than those recommended by the manufacturer for 5% and 8% liquid formulations used in these experiments may be needed. At the rates used in these experiments, dry Mn sulfate may be the most appropriate formulation when applied at 2.8 kg/ha.

Influence of adjuvants, fungicides, herbicides, and insecticides on Mn accumulation in peanut tissue. The concentration of Mn in tissue following application of Mn with the adjuvants crop oil concentrate or nonionic surfactant or with clethodim, imazapic, lactofen, or 2,4-DB applied with the appropriate adjuvant was higher than Mn concentration in non-treated peanut (Table 3). With the exception of 2,4-DB, applying Mn with either adjuvant or herbicide with the appropriate adjuvant increased Mn concentration over Mn alone. Absorption of Mn was higher when Mn was applied with lactofen and crop oil concentrate compared with clethodim and crop oil concentrate. However, differences in adjuvant selection prevent accurate comparisons of Mn concentration among other herbicide treatments.

Absorption of Mn was higher when Mn was applied with fungicides alone or with lambda cyhalothrin compared with Mn alone (Table 4). Although some differences were noted when

Table 4. Influence of fungicides and the insecticide lambda cyhalothrin on manganese (Mn) accumulation in peanut leaves 1 wk after application in 2008.[a]

Manganese[b]	Fungicide[c]	Insecticide[d]	Manganese accumulation[e]
			mg Mn/kg tissue
-	-	-	38 d
Manganese sulfate	-	-	235 bc
Manganese sulfate	Azoxystrobin	-	220 bc
Manganese sulfate	Chlorothalonil	-	274 ab
Manganese sulfate	Pyraclostrobin	-	290 ab
Manganese sulfate	Tebuconazole	-	227 bc
Manganese sulfate	Azoxystrobin	Lambda cyhalothrin	238 bc
Manganese sulfate	Chlorothalonil	Lambda cyhalothrin	280 ab
Manganese sulfate	Pyraclostrobin	Lambda cyhalothrin	337 a
Manganese sulfate	Tebuconazole	Lambda cyhalothrin	247 bc
Manganese sulfate	-	Lambda cyhalothrin	195 c

[a]Means followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p \leq 0.05$. Data are pooled over two experiments.
[b]Dry formulation of Mn (Man-Gro DF®) containing 17.5% Mn applied at 2.8 kg/ha.
[c]Azoxystrobin, chlorothalonil, pyraclostrobin, and tebuconazole were applied at 230, 1,260, 175, and 230 g/ha, respectively.
[d]Lambda cyhalothrin applied at 18 g/ha.
[e]Leaves were subjected to a 1 minute wash in 1 L tap water.

Table 5. Weed control with postemergence herbicides applied alone or with three formulations of manganese (Mn).[a,b]

Manganese treatment	Weed control						
	Corn		Palmer amaranth	Sicklepod			Tall morningglory
	Clethodim	Sethoxydim	Imazethapyr	Imazapic	Imazethapyr	2,4-DB	Imazapic
	%						
No Mn	100 a	89 a	66 a	95 a	48 a	72 a	80 a
5.0% Mn[c]	100 a	92 a	66 a	96 a	45 a	71 a	82 a
Manganese sulfate[d]	100 a	92 a	64 a	96 a	46 a	73 a	77 a
Number of experiments	2	2	3	2	2	4	2

[a]Means for each weed species and herbicide combination followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p \leq 0.05$. Data are pooled over experiments.

[b]Clethodim, imazapic, imazethapyr, sethoxydim, and 2,4-DB applied at 140, 70, 70, 220, and 220 g/ha, respectively. Clethodim and sethoxydim applied with crop oil concentrate at 1.0% (v/v). Imazapic and imazethapyr applied with nonionic surfactant at 0.25% (v/v).

[c]Liquid formulation of Mn containing 5.0% Mn formulated at 1.1 kg/L applied at 0.12 L/ha.

[d]Dry formulation of Mn sulfate (Techmangum©) containing 17.5% Mn applied at 2.8 kg/ha.

comparing across fungicide treatments, there was no difference in absorption of Mn when comparing application with fungicide alone or fungicide with lambda cyhalothrin (Table 4).

Influence of Mn formulation on efficacy of postemergence herbicides. Corn control by clethodim and sethoxydim; large crabgrass control by clethodim; Palmer amaranth control by imazethapyr; sicklepod control by imazapic, imazethapyr, and 2,4-DB; and tall morningglory control by imazapic was not affected by Mn regardless of formulation (Table 5). In contrast, common ragweed control was lower when lactofen was applied with Mn sulfate compared with no Mn or the 8% Mn solution (Table 6). These results are comparable to those obtained by Jordan *et al.* (2006), who reported no effect of boron on efficacy of imazapic, 2,4-DB, clethodim, and sethoxydim; but, efficacy of imazethapyr was reduced by boron.

Influence of Mn and lambda cyhalothrin on efficacy of fungicides. The highest level canopy defoliation was noted when fungicide was not applied (Table 7). When comparing efficacy of fungicides alone, defoliation ranged from 14 to 31% and did not differ (Table 7). Likewise, there was no difference in fungicide efficacy when fungicides were applied with Mn or when comparing application with Mn and lambda cyhalothrin (Table 7). When comparing within a specific fungicide, canopy defoliation was similar when the fungicide was applied alone, with Mn, or with Mn plus lambda cyhalothrin (Table 7).

Collectively, results from these experiments suggest the amount of Mn in the formulated product and the application rate are the determining factors for increasing Mn concentration in peanut leaves. Growers should select a product that delivers adequate amounts of Mn when applications are needed to correct a Mn deficiency. In most cases, fungicides and insecticides did not affect Mn accumulation in leaf tissue. In contrast, adjuvants alone or with herbicides often increased Mn accumulation compared with Mn

Table 6. Common ragweed and large crabgrass control by herbicides applied alone or with two manganese (Mn) formulations during 2007.[a]

Manganese treatment	Common ragweed control by lactofen	Large crabgrass control by clethodim
	%	
No Mn	57 a	87 a
8% Mn solution[b]	58 a	91 a
Mn Manganese sulfate[c]	51 b	90 a

[a]Means within a weed species followed by the same letter are not significantly different according to Fisher's protected LSD test at $p \leq 0.05$. Data are pooled over two experiments for both herbicides.

[b]Liquid formulation of Mn containing 8.0% Mn applied at 1.16 L/ha.

[c]Dry formulation of Mn (Man-Gro DF®) containing 17.5% Mn applied at 3.4 kg/ha.

Table 7. Influence of manganese (Mn) and the insecticide lambda cyhalothrin on peanut canopy defoliation in 2008.[a]

Manganese[b]	Fungicide[c]	Insecticide[d]	Canopy defoliation
			%
-	-	-	51 a
Manganese sulfate	-	-	29 a–d
-	Azoxystrobin	-	14 cd
-	Chlorothalonil	-	31 a–d
-	Pyraclostrobin	-	23 bcd
-	Tebuconazole	-	20 cd
Manganese sulfate	Azoxystrobin	-	31 a–d
Manganese sulfate	Chlorothalonil	-	46 a
Manganese sulfate	Pyraclostrobin	-	30 a–d
Manganese sulfate	Tebuconazole	-	29 a–d
Manganese sulfate	Azoxystrobin	Lambda cyhalothrin	32 abc
Manganese sulfate	Chlorothalonil	Lambda cyhalothrin	45 ab
Manganese sulfate	Pyraclostrobin	Lambda cyhalothrin	31 a–d
Manganese sulfate	Tebuconazole	Lambda cyhalothrin	48 a
-	-	Lambda cyhalothrin	37 abc

[a]Means followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p \leq 0.05$. Data are pooled over two experiments.

[b]Dry formulation of Mn (Man-Gro DF®) containing 17.5% Mn applied at 2.8 kg/ha.

[c]Azoxystrobin, chlorothalonil, pyraclostrobin, and tebuconazole were applied at 230, 1,260, 175, and 230 g/ha, respectively.

[d]Lambda cyhalothrin applied at 18 g/ha.

[e]Leaves were subjected to a 1 minute wash in 1 L tap water.

alone. Manganese did not affect efficacy of the herbicides clethodim, imazapic, imazethapyr, lactofen, sethoxydim, or 2,4-DB or the fungicides azoxystrobin, chlorothalonil, pyraclostrobin, or tebuconazole. Therefore, growers can apply these products simultaneously without concern of reduced control of weeds and disease. However, Mn sulfate reduced efficacy of lactofen on common ragweed; therefore these products should be not be co-applied to avoid reduced weed control.

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