4

Defining Interactions of Herbicides with Other Agrochemicals Applied to Peanut

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1. Introduction

Management strategies to protect peanut (*Arachis hypogaea* L.) from pest damage require multiple applications of fungicides, herbicides, and insecticides. Additionally, micronutrients and plant growth regulators are often applied to improve nutrient balance and to manage peanut growth and development. Over fifty active ingredients can be used to manage pests in peanut, often with more than one formulated product commercially available. Timing of application of pesticides, micronutrients, and plant growth regulators often coincide during the growing season, and co-application of these agrochemicals is desirable if pesticide, micronutrient, and plant growth regulator performance and peanut tolerance are not compromised. In addition to potential interactions related to physiological effects on plants and other organisms, application variables such as commercial formulation, adjuvant, water quality, and environmental stress can affect agrochemical compatibility.

Physical compatibility, in particular formation of precipitates in spray tanks and equipment, is a concern for farmers when co-applying agrochemicals. Defining potential interactions among these agrochemicals is important in developing appropriate weed management programs and implementing integrated pest management strategies for peanut.

Considerable research has been conducted during the last four decades to define interactions among agrochemicals (Barrett, 1993; Green, 1989; Green and Bailey, 1987; Hatzios and Penner, 1985; Putnam and Penner, 1974). Most of these reviews are focused on interactions of herbicides in mixture with other herbicides, fungicides, insecticides, nematicides, and adjuvants, in general, but not for a particular crop. Some of these reviews summarized the mechanisms responsible for the interactions of herbicides with other agrochemicals and the statistical methodology for characterization of agrochemical combinations (Barrett, 1993; Green, 1989; Hatzios and Penner, 1985; Jianhua *et al.*, 1995). Since these reviews were published, many of new agrochemicals have received registration for different crops and for other uses. Defining interactions of these new agrochemicals is important when developing pest management strategies for a cropping system. This chapter reviews some of the interactions discussed in the earlier work, but also elucidates the interactions and/or compatibility of herbicides with other agrochemicals used in peanut production systems.

2. Peanut production systems

Mechanized production systems utilize a wide range of agrochemicals to manage peanut growth and development and minimize the impact of pests on peanut yield and quality (Lynch and Mack, 1995; Sherwood *et al.*, 1995; Wilcut *et al.*, 1995). Pests that can potentially impact peanut are diverse (Table 1). Yield loss from weed interference or from damage caused by insects, diseases, and nematodes can be substantial in peanut if pest control strategies are not implemented in a timely manner.

Monocotyledonous weeds, including annual and perennial grasses and sedges, as well dicotyledonous weeds, are prevalent in peanut production systems in the United States (Webster, 2009; Wilcut *et al.*, 1995). Comprehensive herbicide programs, in combination with appropriate cultural practices, are employed to manage weeds and minimize interference and subsequent yield loss (Wilcut *et al.*, 1987a 1987b 1990 1995). Herbicides are often applied in mixtures either prior to planting (preplant incorporated in conventional tillage or preplant to emerged weeds in reduced tillage), immediately following planting (preemergence), or after peanut and weeds have emerged (postemergence) (Burke *et al.*, 2004; Clewis *et al.*, 2007; Richburg *et al.*, 1995 1996; Wilcut *et al.*, 1994a 1994b 1995).

Agrochemicals with efficacy against insects and plant parasitic nematodes are often applied in the seed furrow at planting and include organophosphate and carbamate insecticides (Brecke *et al.*, 1996; Drake *et al.*, 2009; Funderburk *et al.*, 1998; Minton *et al.*, 1990; Minton and Morgan, 1974; Riley *et al.*, 1997). In-furrow insecticides also reduce incidence of tomato spotted wilt of peanut (caused by tomato spotted wilt virus, a *Tospovirus* vectored by several species of thrips) (Brown *et al.*, 2003; Hurt *et al.*, 2003). Pyrethroid insecticides are often applied to peanut foliage to control beet armyworm, corn earworm, fall armyworm, potato leaf hopper, and two-spotted spider mites. Chlorpyrifos can be applied at pegging, 45 to 70 days after peanut emergence, to control lesser cornstalk borer (Mack *et al.*, 1989 1991) and southern corn rootworm (Brandenburg and Herbert, 1991; Chapin and Thomas, 1993).

Depending on environmental and edaphic conditions and a range of agronomic and pest management practices, application of insecticides may be needed throughout the growing season to protect peanut from pest damage.

Disease, caused by viruses, bacteria, or fungi, can reduce peanut yield considerably when not controlled (Sherwood *et al*., 1995). Fungicides are applied routinely to peanut to control foliar-borne diseases, including early leaf spot, late leaf spot, and web blotch (Brenneman *et al*., 1994; Culbreath *et al*., 2008; Shew and Waliyar, 2005). Fungicides are also applied to control the soil-borne disease stem rot and Sclerotinia blight (Brenneman *et al*., 1994; Culbreath *et al*., 2008; Smith *et al*., 1992). Although variation is noted among geographical regions, years, and environmental conditions, during a typical growing season fungicides are applied either singly or in combination beginning approximately 45 days after peanut emergence and continuing throughout the remainder of the growing season, which can approach 135 or more days (Sherwood *et al*., 1995; Smith and Littrell, 1980). Fungicide programs to control early and late leaf spot and stem rot often include bi-weekly sprays during this period. Fungicides applied to control these diseases provide protection for a period of two weeks under most environmental conditions (Shew and Waliyar, 2005). The soil fumigant metam sodium is often applied to peanut to control *Cylindrocladium* black rot (Cline and Beute, 1986). A period of at least two weeks between fumigation and peanut planting is required to allow the fumigant to dissipate, making weed control prior to planting challenging under some environmental conditions, especially excessive rainfall, that allow weeds to emerge between fumigation and planting operations (Van Gundy and McKenry, 1977).

The micronutrients boron and manganese are applied routinely to optimize peanut growth and development and, in the case of boron, to ensure proper kernel development (Gascho and Davis, 1995; Harris and Brolman, 1966; Powell *et al*., 1996). Because peanut is often grown on coarse-textured soils, boron can be deficient due to leaching. Single, and in some cases, multiple applications of boron-containing foliar solutions are applied 45 to 70 days after peanut emergence (Gascho and Davis, 1995). Manganese deficiency occurs frequently in peanut because of liming to achieve a target soil pH above 6.0. Correcting a manganese deficiency is achieved by foliar applications when visible symptoms become apparent, although some growers apply manganese irrespective of plant symptomology (Powell *et al*., 1996).

Excessive vine growth of peanut can reduce row visibility at digging and vine inversion (Mitchem *et al*., 1996). Prohexadione calcium is currently the only plant growth regulator applied to manage vine growth in order to facilitate efficient digging. Prohexadione calcium inhibits gibberellin biosynthesis in responsive plants (Grossman *et al*., 1994) and is applied when 50% of vines from adjacent peanut rows have met, and an application is repeated 2 to 3 weeks later (Mitchem *et al*., 1996). This timing of application is generally 70 to 90 days after peanut emergence (Mitchem *et al*., 1996). In addition to prohexadione calcium, a wide range of products are available at the distributor level that contain micronutrient combinations, synthetic plant growth regulators, and other ingredients perceived to have value. Many of these products are not applied routinely to peanut.

3. Agrochemicals used in peanut

A diversity of pesticide active ingredients is available for peanut (Table 2) (Brandenburg, 2010; Jordan, 2010; Shew, 2010). Currently, 19 herbicide active ingredients, 16 insecticide active ingredients, and 20 fungicide active ingredients representing the major modes of action can be applied during the peanut growing season. Three fumigants, two micronutrients, and one plant growth regulator are registered for use in peanut. Within herbicide, insecticide, fungicide, and fumigant categories, a range of formulated products are available for most active ingredients. These products are often manufactured and sold through distributor networks and are numerous. Additionally, spray adjuvants are recommended with some, but not all, agrochemicals to increase performance and compatibility.

Presence of biotic and abiotic stresses often occur simultaneously during the peanut growing season, and timing of application for many agrochemicals overlap (Table 3). Practitioners prefer limiting the number of trips across fields in order to increase efficiency of managing peanut. This approach is preferable because of convenience, savings in time, reduced application costs, and freeing labor for other operations. Additionally, applying multiple pesticides with different modes of action is an important resistance management strategy for pests (Brandenburg, 2010; Jordan, 2010; Shew, 2010). This approach is feasible as long as adverse interactions, primary increased crop injury or decreased pest control, do not occur. Defining interactions among agrochemicals is important in assisting growers and their advisors as they make decisions on co-application of these products.

4. Herbicide – Herbicide interactions

A considerable amount of research has been conducted to define interactions among herbicides used in peanut. Herbicides applied in combination either preplant incorporated or preemergence generally increase the spectrum of weed control or the length of residual weed control (Wilcut *et al.*, 1987b 1995). For example, pendimethalin is often applied in combination with alachlor, dimethenamid-*P*, metolachlor, or *S*-metolachlor to improve early season weed control (Bridges *et al*., 1984; Wehtje *et al*., 1988; Wilcut *et al*., 1994b 1995; Wilcut and Swann, 1990). Alachlor, dimethenamid-*P*, metolachlor, or *S*-metolachlor can be applied with diclosulam, flumioxazin, or imazethapyr preemergence to enhance weed control with a single application (Clewis *et al*., 2007; Grichar *et al.*, 1992, 1996, 2000, 2008; Scott *et al*., 2001). Combinations of preplant incorporated or preemergence herbicides currently registered for use in peanut have not been shown to increase peanut injury over either herbicide component applied alone (Wilcut *et al*., 1995). However, several herbicides that are no longer registered for peanut increased peanut injury when co-applied as compared to the herbicides applied alone (Wilcut *et al.*, 1995).

In reduced tillage systems, herbicides are needed to control winter weeds and summer annual weeds that have emerged prior to planting peanut. These herbicide applications include glyphosate, paraquat, or 2,4-D alone or in combinations with other herbicides. Combinations of glyphosate and 2,4-D broaden the spectrum of weed control compared with each herbicide applied alone (Flint and Barrett, 1989a). However, in some instances, 2,4-D can negatively affect efficacy of glyphosate, but this interaction is typically noted only on grass weeds (Flint and Barrett, 1989b). Efficacy of paraquat is generally not negatively affected by 2,4-DB (Wehtje *et al*., 1992a). Glyphosate and paraquat can also be applied with herbicides that provide residual weed control. This approach is designed to control emerged weeds and provide residual weed control prior to and following planting (Wilcut *et al.*, 1995).

Paraquat is often applied at peanut emergence or up to 28 days after peanut emergence (Carley *et al.*, 2009; Wilcut *et al.*, 1990). Other non-residual herbicides such as bentazon or acifluorfen plus bentazon as well as residual herbicides such as alachlor, diclosulam, dimethenamid-*P*, imazethapyr, metolachlor, or *S*-metolachlor are applied postemergence to broaden the spectrum of control (Askew *et al.*, 1999; Bailey *et al.*, 1999; Grey *et al.*, 2002; Grichar and Colburn, 1996). Injury associated with paraquat can be reduced by co-application with bentazon (Jordan *et al.*, 2003b; Wehtje *et al.*, 1992b). However, the chloroacetamide herbicides alachlor, dimethenamid-*P*, metolachor, or *S*-metolachlor applied with paraquat can increase peanut injury (Jordan *et al.*, 2003b). Diclosulam and imazethapyr did not affect injury potential from paraquat (Jordan *et al.*, 2003b). Weed control with these herbicide combinations generally increases depending on the weed species and size of the weed (Wilcut *et al.*, 1995). For example, bentazon and imazethapyr co-applied can increase control of emerged common cocklebur and yellow nutsedge, while control of annual grasses by paraquat can be reduced when paraquat is co-applied with bentazon (Wehtje *et al.*, 1992b; Wilcut *et al.*, 1994b). Residual control by chloroacetamide herbicides, diclosulam, and imazethapyr was not affected by paraquat applied alone or with bentazon (Grichar *et al.*, 2000; Wilcut *et al.*, 1995).

Co-application of postemergence herbicides with efficacy against dicotyledonous weeds and sedges generally increases control of weeds or broadens the spectrum of control compared with components of the mixture applied alone (Green, 1989; Hatzios and Penner, 1985; Jianhua *et al.*, 1995; Wilcut *et al.*, 1995). In contrast, efficacy of clethodim and sethoxydim, often referred to as graminicides, can be reduced when applied in mixture with herbicides that control dicotyledonous weeds and sedges (Culpepper *et al.*, 1998 1999; Grichar, 1991; Jordan and York, 1989; Minton *et al.*, 1989; Mueller *et al.*, 1989; Myers and Coble, 1992; Vidrine *et al.*, 1995). The interaction of bentazon and sethoxydim is one of the most notable examples of reduced graminicide efficacy caused by a herbicide that controls dicotyledonous plants and sedges (Rhodes and Coble, 1984a 1984b; Wanamarta and Penner, 1989; Wanamarta *et al.*, 1989). Annual and perennial grass control by sethoxydim is reduced by bentazon through reduced absorption of sethoxydim into grasses (Rhodes and Coble, 1984b; Wanamarta and Penner, 1989; Wanamarta *et al.*, 1989). The mechanism of reduced control is associated with physical interactions of the herbicides in the spray solution prior to reaching the target weed (Penner, 1989; Thelen *et al.*, 1995). Acifluorfen and imazethapyr also can reduce efficacy of clethodim and sethoxydim (Burke and Wilcut, 2003; Grichar, 1991; Lassiter and Coble, 1987; Myers and Coble, 1992). In contrast to reduced grass control when these herbicides are co-applied, control of dicotyledonous plants and sedges is not reduced by clethodim and sethoxydim (Dotray *et al.*, 1993; Holshouser and Coble, 1990; Isaacs *et al.*, 2003). Efficacy of clethodim can also be reduced by acifluorfen, acifluorfen plus bentazon, bentazon, imazethapyr, imazapic, lactofen, and 2,4-DB (Grichar *et al.*, 2002; Myers and Coble, 1992; York *et al.*, 1993). The magnitude of reduced efficacy can be minimized or eliminated by applying the herbicides sequentially, increasing the graminicide rate, or applying more efficacious adjuvants (Burke *et al.*, 2004; Jordan, 1995; Myers and Coble, 1992; Wanamarta and Penner, 1989; Wanamarta *et al.*, 1989). Grass species, plant size, and plant stress also can affect the magnitude of negative interactions (Green, 1989; Hatterman-Valenti *et al.*, 2006). York and Wilcut (1995) reported that bentazon reduced control of yellow and purple nutsedge by imazethapyr.

Chloroacetamide herbicides can be applied postemergence without injuring peanut (Grichar *et al*., 1996, 2008; Jordan *et al*., 2003b). While these herbicides provide residual control of grasses and some dicotyledonous and sedge weeds, they do not control weeds that have emerged (Foy and Witt, 1997; Grichar *et al*., 2000; Richburg *et al*., 1995). These herbicides can be applied with herbicides that have efficacy against emerged weeds. Dimethenamid-*P* and *S*-metolachlor did not reduce grass control by the graminicides clethodim or sethoxydim or the dicotyledonous and sedge herbicides acifluorfen, acifluorfen plus bentazon, or imazapic (Grichar *et al*., 2000; Wilcut *et al*., 1995). However, visible injury caused by acifluorfen increased when acifluorfen was applied with chloroacetamide herbicides (Jordan *et al*., 2003b). Johnson *et al*. (1993) reported that injury from postemergence application of paraquat was not increased when following several chloroacetamide herbicides applied at planting, in contrast with injury observed when the herbicides were co-applied.

5. Herbicide – Insecticide interactions

Timing of application of herbicides and insecticides overlap during much of the growth cycle of peanut (Table 3). As with other crops, potential interactions between herbicides and insecticides applied in the seed furrow to control thrips and suppress plant parasitic nematodes can occur (Hauser *et al*., 1976 1981). Acephate and aldicarb applied in the seed furrow at planting did not affect injury potential of peanut following postemergence application of acifluorfen plus bentazon or bentazon; however, the insecticide phorate applied in the seed furrow enhanced visible injury associated with bentazon, although this injury was generally transient (Swann and Herbert, 1999). Although interactions of nicosulfuron (Bailey and Kapusta, 1994; Morton *et al*., 1994; Rahman and James, 1993) and pyrithiobac-sodium (Allen and Snipes, 1995) increased injury in corn (*Zea mays* L.) and cotton (*Gossypium hirsutum* L.), respectively. However, chlorpyrifos applied at planting did not affect peanut response to diclosulam, *S*-metolachlor, or flumioxazin applied preemergence or acifluorfen, acifluorfen plus bentazon, imazapic, or paraquat plus bentazon applied postemergence (Jordan *et al*., 2008). Efficacy of graminicides can be affected by insecticides applied to peanut. Carbaryl and dimethoate applied postemergence in combination with sethoxydim reduced annual grass control; no adverse effect was noted when acephate was mixed with sethoxydim (Byrd and York, 1988). Pyrethroid insecticides did not affect efficacy of postemergence herbicides (Allen and Snipes, 1995).

6. Herbicide – Fungicide interactions

Similar to herbicides and insecticides, timing of application of postemergence herbicides and fungicides to control foliar and soil-borne diseases overlap considerably during the peanut growing season (Table 3). Fungicides are applied beginning approximately 45 days after peanut emergence and can be applied until a few weeks prior to digging and vine inversion. Efficacy of clethodim and sethoxydim can be reduced by co-application with copper-containing fungicides or azoxystrobin, chlorothalonil, and pyraclostrobin (Jordan *et al*., 2003a; Lancaster *et al*., 2005a 2008). Fluazinam and tebuconazole did not reduce grass control compared with graminicides applied alone (Jordan *et al*., 2003a; Lancaster *et al*., 2005a 2005b). Efficacy of herbicides that control dicotyledonous and sedge weeds is not generally affected by fungicides (Jordan *et al.*, 2003a). As was noted for interactions of herbicides, weed species and size and plant stress can affect the magnitude of interactions between herbicides and fungicides (Jordan *et al.*, 2003a).

Although not used in peanut, efficacy of glyphosate was not affected by azoxystrobin, pyraclostrobin, or tebuconazole (Grichar and Prostko, 2009). Weed control by metribuzin, rimsulfuron, and thifensulfuron-methyl applied to tomato (*Lycopersicon esculentum* Mill.) was not affected by azoxystrobin or pyraclostrobin (Robinson and Nurse, 2008). However, pyraclostrobin increased tomato injury from thifensulfuron-methyl when co-applied (Robinson and Nurse, 2008). Chlorothalonil increased persistence of metolachlor in soil although cyproconazole, flutriafol, and tebuconazole did not affect dissipation of metolachlor (White *et al.*, 2009).

7. Herbicide – Micronutrient interactions

Boron and manganese are the primary micronutrients applied to peanut. Occasionally, these can affect herbicide performance. For example, efficacy of clethodim and imazethapyr was reduced by micronutrients for some, but not all, weeds evaluated (Jordan *et al.*, 2006; Lancaster *et al.*, 2005b).

8. Herbicide – Plant growth regulator interactions

Prohexadione calcium is the primary plant growth regulator available for use in peanut. Efficacy of the herbicides acifluorfen, acifluorfen plus bentazon, bentazon, imazethapyr, imazapic, lactofen, and 2,4-DB was not affected by prohexadione calcium (Beam *et al.*, 2002). However, other plant growth regulator products developed by agrochemical distributor chains are numerous and have not been evaluated sufficiently to make recommendations on compatibility with herbicides.

9. Co-application of multiple components

The previous discussion focused on co-applications that have only two components. However, there is considerable interest in compatibility of three or more pesticides, micronutrients, adjuvants, or plant growth regulators and their impact on pest control and crop management. With respect to weed control, efficacy of clethodim, sethoxydim, and 2,4-DB were compared when these herbicides were applied alone or with fungicides and insecticides (Jordan *et al.*, 2003a; Lancaster *et al.*, 2005a 2005b). Although results often supported previous findings with components from two groups of pesticides, no clear relationships were established with respect to combinations of three or more pesticides (Lancaster *et al.*, 2005a 2005b). More recently, research is being conducted to compare herbicide efficacy with mixtures containing various levels of fungicide, insecticide, micronutrient, or adjuvant (Chahal *et al.*, 2009a 2009b).

10. Herbicide effects on other agrochemicals

The focus of this review has been the impact of agrochemicals used in peanut on herbicide efficacy. However, defining the impact of herbicides on insect and disease control and response of peanut to micronutrient and plant growth regulator applications is important. Preliminary research has shown that the herbicides clethodim and 2,4-DB do not affect performance of chlorothalonil, pyraclostrobin, or the prepackage combination of prothioconazole plus tebuconazole (Chahal *et al*., 2009a 2009b). Paraquat and 2,4-DB did not affect chlorothalonil efficacy (Choate *et al*., 1998). Katan and Eshel (1973) discussed possible mechanisms of interactions among herbicides and pathogens. With respect to peanut, Baysinger *et al*. (1999) reported that sporulation of early leaf spot was reduced by acifluorfen and lactofen. In-vitro, chlorothalonil efficacy against early blight (*Alerternaria solani*) was reduced by metribuzin while susceptibility of *Pseudo cercospera herpotrichoides* to cyproconazole increased following exposure to dicamba, bromoxynil, or ioxynil (Kataria and Gisi, 1990; Levesque and Rahe, 1992).

The influence of the postemergence herbicides clethodim, imazapic, lactofen, and 2,4-DB on boron and manganese absorption into peanut leaves was evaluated, and results suggested that while herbicides could affect accumulation of boron and manganese in leaf tissue, the adjuvant associated with these herbicides may have been the primary factor in influencing absorption (Jordan *et al*., 2006 2009a).

11. Application variables that can affect interactions

A wide range of application variables can affect interactions of herbicides with other agrochemicals. Adjuvant selection, herbicide rate, commercial formulation, active ingredient, length of time between applications of components, spray volume, water quality, weed species, and environmental conditions can affect interactions of agrochemicals. For example, the negative effect of bentazon was reduced by including ammonium sulfate and other more efficacious adjuvants with clethodim and sethoxydim (Jordan, 1995: Jordan and York, 1989; Penner, 1989; Wanamarta and Penner, 1989; York *et al*., 1990). Applying a higher rate of the herbicide that may be adversely affected can compensate for interactions (Chernicky and Slife, 1986; Rhodes and Coble, 1984a 1984b). Differential response to clethodim was noted when applied with different formulations of chlorothalonil (Jordan *et al*., 2003a). Increasing the interval between applications of components of the mixture can overcome negative interactions, especially herbicide-herbicide interactions (Green, 1989; Grichar and Boswell, 1987; Putnam and Ries, 1967). Applying graminicides in higher spray volumes can exacerbate the negative influence of herbicides and fungicides on weed control by graminicides (Buhler and Burnside, 1984; Jordan *et al*., 2003a; Kells and Wanamarta, 1987). Water quality, in particular presence of cations that can form complexes in the spray solution, can influence the propensity of herbicides to perform poorly in pesticide combinations (Buhler and Burnside, 1983a 1983b; Hatzios and Penner, 1985; Sandberg *et al*., 1978; Stahlman and Phillips, 1979; Thelen *et al*., 1995; Whisenant and Bovey, 1993; Wills and McWhorter, 1985).

Environmental conditions that affect plant response to agrochemicals can influence the magnitude of interactions. Negative effects of interactions associated with efficacy of systemic herbicides, especially graminicides, are exacerbated when grasses are stressed and physiological processes that reduce absorption and translocation occur (Burke *et al*., 2004; Burke and Wilcut, 2003; Green, 1989; Wanamarta and Penner, 1989; Wanamarta *et al*., 1989).

12. Challenges of defining interactions and making recommendations

Major challenges in recommending practices associated with interactions of herbicides with other agrochemicals include the diversity of products available, the diversity of weeds present in the field that can vary in response to herbicides, differences in water quality within and across production regions, and adjuvant recommendations associated with herbicides versus other agrochemicals. Compounding these complex variables is the unpredictable response often observed due to environmental conditions. Additionally, new active ingredients are being marketed that have not been evaluated for possible interactions, and as patents expire, some of these active ingredients are formulated differently from the product receiving the initial registration. The extensive number of possible combinations, especially when multiple components are considered, is challenging from a research standpoint when considering the logistics of research trials needed to address possible interactions. Although attempts are made to establish research trials in a manner similar to practitioner operations, techniques associated with maintaining spray solutions and applying materials with small-plot equipment differ from commercial applications and adds to the challenges in research.

One reasonable criticism of the current approach to defining interactions, which is dictated by the number of combinations and the logistics of experimentation, is the lack of defining the impact of interactions on the larger context of the production system. For example, when a reduction in weed control by a fungicide occurs, how detrimental to peanut yield and economic value is this reduction when considering alternatives to prevent the interaction from occurring? Also, dose response curves are often used to define interactions of pesticides, and while these can be more informative than selection of a single rate of the components in the mixture, the number of treatment combinations required for this approach is often not feasible because of resource constraints.

13. Future research

A considerable knowledge base has been developed to define interactions of herbicides with other agrochemicals with respect to weed control in peanut. However, the effect of herbicides on performance of fungicides and insecticides is limited but no less important than defining impacts on herbicide efficacy. As new active ingredients and new formulations of active ingredients become available, additional research will be needed to define interactions among these agrochemicals. Although interactions of herbicide-herbicide combinations have been defined broadly and in some cases in detail, research elucidating the mechanism of reduced control associated with co-application of fungicides, insecticides, or plant growth regulator and micronutrients is limited (Duke *et al.*, 2007). Finally, determining the impact of interactions in the overall production system would be beneficial.

Pest	Latin bionomical and authority
Weeds[a]	
Bermudagrass	*Cynodon dactylon* (L.) Pers.
Bristly starbur	*Acanthospermum hispidum* DC.
Broadleaf signalgrass	*Urochloa platyphylla* (Nash) R.D. Webster
Common cocklebur	*Xanthium strumarium* L.
Common lambsquarters	*Chenopodium album* L.
Common ragweed	*Ambrosia artemisiifolia* L.
Crabgrass spp.	*Digitaria* spp.
Crowfootgrass	*Dactyloctenium aegyptium* (L.) Willd.
Eclipta	*Eclipta prostrata* L.
Florida beggarweed	*Desmodium tortuosum* (Sw.) DC.
Florida pusley	*Richardia scabra* L.
Goosegrass	*Eleusine indica* (L.) Gaertn.
Hairy indigo	*Indigofera hirsuta* Harvey
Jimsonweed	*Datura stramonium* L.
Johnsongrass	*Sorghum halepense* (L.) Pers.
Morningglory spp.	*Ipomoea* spp.
Nutsedge spp.	*Cyperus* spp.
Palmer amaranth	*Amaranthus palmeri* S. Wats.
Pigweed spp.	*Amaranthus* spp.
Prickly sida	*Sida spinosa* L.
Sicklepod	*Senna obtusifolia* (L.) H.S. Irwin & Barneby
Spurge spp.	*Chamaesyce* spp.
Texas millet	*Urochloa texana* (Buckl.) R. Webster
Tropic croton	*Croton glandulosus* var. septentrionalis Muell.-Arg.
Insects[b]	
Beet armyworm	*Spodoptera exigua* Hübner
Corn earworm	*Heliothis zea* Boddie
Lesser cornstalk borer	*Elasmopalpus lignosellus* Zeller

Pest	Latin bionomical and authority
Southern corn rootworm	*Diabrotica undecimpunctata* Howardi
Thrips	*Frankliniella* spp.
Diseases[c]	
Aspergillus crown rot	*Aspergillus niger*
Botrytis	*Botrytis cinerea* Pers.
Cylindrocladium black rot	*Cylindrocladium parasiticum* Crous, Wingfield, and Alfenas
Early leaf spot	*Cercospora arachidicola* Hori
Late leaf spot	*Cercosporidium personatum* Berk. & Curtis
Pythium	*Pythium* spp.
Rhizoctonia limb rot	*Rhizoctonia solani* Kuhn
Sclerotinia blight	*Sclerotinia minor* Jagger
Spotted wilt	Tomato spotted wilt, caused by a *Tospovirus*
Stem rot	*Sclerotium rolfsii* Sacc.
Web blotch	*Phoma arachidicola* Marasas, Pauer, and Boerema
Plant parasitic nematodes[c]	
Lesion nematode	*Pratylenchus brachyurus*
Northern root knot	*Meloidogyne hapla*
Peanut root knot	*Meloidogyne arenaria*
Ring	*Criconemella ornata*
Sting	*Belonolaimus longicaudatus*
Two-spotted spider mite[b]	*Tetranychus urticae* Koch

[a]Webster, T. M. 2009. Weed survey – southern states. Proc. South. Weed Sci. Soc. 62:509-524.
[b]Brandenburg, R. L. 2010. Peanut insect management. Pages 85-102 *in* 2010 Peanut Information. North Carolina Cooperative Extension Service Publication AG-331.
[c]Shew, B. B. 2010. Peanut disease management. Pages 103-130 *in* 2010 Peanut Information. North Carolina Cooperative Extension Service Publication AG-331.

Table 1. Common and scientific names for major pests found in peanut in the United States.

Herbicides	Insecticides	Fungicides	Fumigants	Plant growth regulators
Acifluorfen	Acephate	Azoxystrobin	Dichloropropene plus chloropicrin	Prohexadione calcium
Alachlor	Aldicarb	Basic copper sulfate	Metam sodium	
Bentazon	*Bacillus thuringiensis*	Boscalid	1,3 dichloropropene	
Carfentrazone	Carbaryl	Chlorothalonil		
Clethodim	Chlorpyrifos	Dodine		
Diclosulam	Disulfoton	Fludioxomil		
Dimethenamid-*P*	Esfenvalerate	Fluoxastrobin		
Ethafluralin	Fenpropathrin	Flutolanil		
Flumioxazin	Gamma-cyhalothrin	Mancozeb		
Glyphosate	Indoxacarb	Mancozeb and copper hydroxide		
Imazapic	Lambda-cyhalothrin	Mefenoxam		
Imazethapyr	Malathion	Metconazole		
Lactofen	Methomyl	Pentachloronitrobenzene (PCNB)		
Metolachlor	Phorate	Propiconazole		
Paraquat	Propargite	Prothioconazole		
Pendimethalin	Spinosad	Pyraclostrobin		
Sethoxydim		Sulfur		
S-metolachlor		Tebuconazole		
Sulfentrazone		Thiophanate methyl		
2,4-DB		Trifloxystrobin		

[a]Brandenburg, R. L. 2010. Peanut insect management. Pages 85-102 *in* 2010 Peanut Information. North Carolina Cooperative Extension Service Publication AG-331.
[b]Jordan, D. L. 2010. Weed management in peanuts. Pages 55-83 *in* 2010 Peanut Information. North Carolina Cooperative Extension Service Publication AG-331.
[c]Shew, B. B. 2010. Peanut disease management. Pages 103-130 *in* 2010 Peanut Information., Peanut Information 2010. North Carolina Cooperative Extension Service AG-331.

Table 2. Pesticide active ingredients registered for use in peanut in the United States during 2010.[a,b,c]

	April	May	June	July	August	September
Weeds						
Dicotyledonous	■	■	■	■	■	
Monocotyledonous	■	■	■	■	■	
Insects						
Beet armyworm				■	■	
Corn earworm				■	■	
Lesser cornstalk borer				■	■	
Southern corn rootworm			■	■		
Tobacco thrips	■	■				
Diseases						
Aspergillus crown rot	■	■				
Botrytis					■	■
Cylindrocladium black rot	■	■				
Cercospora spp.			■	■	■	■
Pythium	■	■				
Rhizoctonia limb rot				■	■	
Sclerotinia blight					■	■
Spotted wilt	■	■				
Stem rot				■	■	
Web blotch				■	■	■
Plant parasitic nematodes	■	■				
Two-spotted spider mite				■	■	
Nutrient deficiency						
Boron			■	■		
Manganese			■	■		
Peanut vine management						
Prohexadione calcium				■	■	

Table 3. Biotic and abiotic stresses and approximate timing of management that can occur in peanut during the growing season in the United States.

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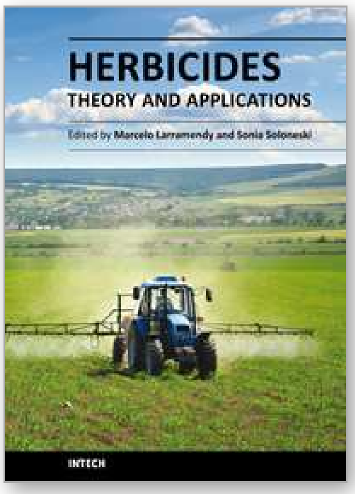

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