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Herbicides used as harvest aids are applied at crop maturity to desiccate weed and crop foliage. Weeds present in the harvested crop can increase moisture content and foreign material, reducing grade and market price. Weeds can also delay the harvest operation and reduce harvest efficiency. Glyphosate can be used to desiccate weeds in glyphosate-resistant crops without concern for crop injury. Carfentrazone and pyraflufen-ethyl used as harvest aids can be effective in desiccating broadleaf weeds in corn and soybean. Paraquat, although effective on grass and broadleaf weeds when applied late season, can cause significant crop injury if applied too early. With expanded production of early maturing soybean cultivars in the mid-South (Arkansas, Louisiana, Mississippi, Missouri bootheel, and west Tennessee), presence of green stems, green pods, or green leaf retention, or combinations of these at harvest has increased. Interest in harvest aids has shifted to use as a crop desiccant. Paraquat also is an effective soybean desiccant, but application timing differs for indeterminate and determinate cultivars. Paraquat applied after soybean seed reached physiological maturity reduced number of green stems, pods, and retained green leaves present, allowing harvest to proceed 1 to 2 wk earlier than nontreated soybean. Seed moisture, foreign material, and seed damage also were reduced when paraquat was applied.

Nomenclature: Corn, *Zea mays* L.; soybean, *Glycine max* (L.) Merr.

Key words: Crop quality, desiccant, determinate soybean, grade reduction, green plant malady, harvest efficiency, indeterminate soybean, physiological maturity, preharvest application.

Traditionally, harvest aids have been used to desiccate weeds to improve crop quality and harvest efficiency. Seed moisture and foreign material in harvested soybean was increased when common cocklebur (*Xanthium strumarium* L.), hemp sesbania [*Sesbania herbacea* (P. Mill) McVaugh], ivyleaf morningglory [*Ipomoea hederacea* Jacq.), redroot pigweed (*Amaranthus retroflexus* L.), sicklepod [*Senna obtusifolia* (L.) H. S. Irwin & Barneby] (Ellis et al. 1998), and wild poinsettia (*Euphorbia heterophylla* L.), (Willard and Griffin 1993) were present at harvest. Presence of tall growing weeds, which remain green long after the crop has matured, and have climbed and wrapped around crop plants can slow harvest and reduce harvest efficiency (Burnside 1973; Burnside et al. 1969; Ellis et al. 1998; Nave and Wax 1971). Burnside (1973) reported a 19% increase in losses for soybean containing a predominance of broadleaf compared with grass weeds. In maturity group (MG) III soybean, use of paraquat plus sodium chlorate as a preharvest desiccant increased harvestability as reflected in decreased costs associated with machinery wear and labor (Griffin et al. 2003).

In recent years, use of harvest aids has become important, especially in production of early maturing soybean in the mid-South (Arkansas, Louisiana, Mississippi, Missouri bootheel, and west Tennessee). Soybean leaf retention and presence of green stems and/or green pods in fields where soybean seed are mature (green plant malady) can delay or prevent harvest (Boudreaux et al. 2007). Philbrook and Oplinger (1989) reported that soybean seed yield loss increased linearly at a rate 0.2% per day as harvest was delayed out to 42 d. Harvest aids, therefore, might have an important role in desiccating the crop and accelerating harvest. Desiccation of the crop, however, should be timed so as not to negatively affect seed fill or yield.

This paper is part of a WSSA symposium on nonherbicide uses of herbicides and will focus on herbicides used as harvest aids for desiccation of both weeds and the crop. Special emphasis is placed on the soybean green plant malady and on paraquat, which is the most widely used harvest aid and which is becoming an important component of soybean production systems in the mid-South.

Herbicides Used As Harvest Aids

Glyphosate. Glyphosate is a nonselective, systemic herbicide that inhibits 5-enolpyruvyl shikimate-3-phosphate (EPSP) synthase (Senseman 2007). Plant growth is inhibited soon after application, followed by general foliar chlorosis and necrosis within 4 to 7 d for highly susceptible grasses and within 10 to 20 d for less susceptible species. Glyphosate is ineffective on glyphosate-resistant crops but can negatively affect growth and yield of other crops (Ellis and Griffin 2002; Ellis et al. 2003). In regard to glyphosate use as a harvest aid, the label states that in corn, application should be made at 35% grain moisture or less and when corn is physiologically mature (Anonymous 2009a). In cotton (*Gossypium hirsutum* L.), glyphosate should be applied after sufficient bolls have developed to produce desired yield. In soybean, glyphosate should be applied for weed control after pods have set and lost all green color.

Prior to the introduction of glyphosate-resistant crops, application of glyphosate 3 wk before soybean harvest reduced soybean yield (Azlin and McWhorter 1981; Whigham and Stoller 1979). Reduction in soybean seed weight and progeny emergence and vigor have been reported when glyphosate was applied before soybean reached physiological maturity (Jeffery et al. 1981). Glyphosate is very effective in preharvest desiccation of grain sorghum [*Sorghum bicolor* (L.) Moench] (Bovey et al. 1975; Gigax and Burnside 1976). Glyphosate was more effective than paraquat in reducing grain sorghum leaf and stem moisture and grain moisture was 13% or less 1 wk after treatment (Bovey et al. 1975).

Glyphosate also has been evaluated as a late-season treatment to reduce weed seed production and viability. Application of glyphosate at initial seed set (prior to physiological maturity) in hemp sesbania and sicklepod reduced seed production per plant around 85% (Clay and Griffin 2000). Using seed collected

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from glyphosate-treated plants, hemp sesbania seedling emergence was reduced 94%. In other research, application of glyphosate to sicklepod during seed development reduced seed production and subsequent seedling emergence (Isaacs et al. 1989; Ratnayake and Shaw 1992b). Bennett and Shaw (2000) reported a negative effect on pitted morningglory seed production following preharvest application of glyphosate, but observed no adverse effect on sicklepod or hemp sesbania seed production.

Carfentrazone. Carfentrazone inhibits protoporphyrinogen oxidase (Protox) (Senseman 2007). Carfentrazone is a contact, nonresidual herbicide used for control of broadleaf weeds. Initial symptoms are observed within hours after application and death within a few days. Carfentrazone is labeled as a harvest aid in corn, soybean, and other crops to desiccate broadleaf weeds such as morningglories, pigweeds, and velvetleaf (*Abutilon theophrasti* Medik.) (Anonymous 2009b). Application should be made when the crop is mature and grain has begun to dry down. Spray volume should be sufficient to provide complete coverage of foliage, a minimum of 93 L ha^{-1} for ground application and 47 L ha^{-1} for aerial application. In most cases, carfentrazone is applied in combination with paraquat (Griffin et al. 2004). Because coverage of weed foliage is critical, carfentrazone generally has not been effective on large morningglory vines.

Pyraflufen-ethyl. Pyraflufen-ethyl, like carfentrazone, is a Protox inhibitor and a contact herbicide causing rapid desiccation of foliage in the presence of light (Senseman 2007). Pyraflufen-ethyl is labeled in potatoes (*Solanum tuberosum* L.) for desiccation of foliage, vines, and broadleaf weeds, and in cotton after sufficient bolls have developed to produce desired yield (Anonymous 2009d). In soybean, increased control of pitted morningglory and hemp sesbania was observed when pyraflufen-ethyl was applied with glyphosate compared with glyphosate applied alone (Scroggs et al. 2006). Soybean yield, however, was reduced with higher rates of pyraflufen-ethyl.

Sodium Chlorate. Sodium chlorate is used as a preharvest desiccant in several crops to include cotton, soybean, and corn (Senseman 2007). It is a strong oxidizing agent in plants and also can act to block protein sulfation. Sodium chlorate is absorbed readily into foliage, causing rapid desiccation. The sodium chlorate label states that spray volume should be 187 to 280 L ha^{-1} for ground application and 37 to 93 L ha^{-1} for aerial application.[4] Weather conditions that favor good defoliation are high temperature, high humidity, low wind velocity, and high to adequate soil moisture. Plant conditions that favor good defoliation are ample fertility and moisture, and complete insect control. Leaves should be green and turgid. Sodium chlorate often is applied with paraquat as a harvest aid (Ellis et al. 1998; Griffin et al. 2003).

Paraquat. Paraquat inhibits photosynthesis at photosystem I (Senseman 2007). Rapid wilting and desiccation occurs within several hours of application in full sunlight. Complete foliar necrosis occurs within 1 to 3 d. The paraquat label in cotton states to apply when 75% of bolls are open (Anonymous 2009e). Desiccation of weeds with paraquat has improved soybean harvest efficiency and crop quality (decreased foreign material and moisture) for soybean delivered to the elevator (Boudreaux and Griffin 2008). Paraquat in combination with sodium chlorate applied 5 to 7 d prior to harvest generally increased harvestability but did not consistently increase soybean yield (Griffin et al. 2003).

Application of paraquat to desiccate soybean leaves 3 to 4 wk before harvest, prior to seed reaching physiological maturity, reduced soybean seed weight and yield (Whigham and Stoller 1979). Soybean yield was reduced with paraquat applied at the R5 and R6 growth stages (Fehr and Caviness 1977), but not at R7 or R8 (Ratnayake and Shaw 1992a). When grain sorghum was desiccated with paraquat at around 30% seed moisture, the crop was harvested when seed moisture reached 20%, which was 5 to 7 d earlier compared to nontreated sorghum (Gigax and Burnside 1976).

The paraquat label differentiates between indeterminate and determinate soybean with regard to application timing (Anonymous 2009e). For indeterminate cultivars, application should be made when at least 65% of the seed pods have reached a mature brown color or when seed moisture is 30% or less. For determinate cultivars, application should be made when plants are mature, i.e., beans (*Phaseolus vulgaris* L.) are fully developed, 50% of leaves have dropped, and remaining leaves are yellowing. Spray volume should be 187 L ha^{-1} for ground application and 47 L ha^{-1} for aerial application. Although written to assure crop safety, the label is confusing with respect to application timing.

History of Weed Control Programs and Soybean Production in the Mid-South

Soybean varieties representing MG V, VI, and VII were planted in the mid-South in the 1980s and 1990s. During that time period, weeds were a major limiting factor to soybean production. Morningglory species (including pitted [*Ipomoea lacunosa* L.], entireleaf [*Ipomoea hederacea* var. *integriuscula* A. Gray], and ivyleaf) were particularly troublesome and, in cases where climbing and wrapping of soybean plants occurred, combine harvest was impeded or impossible. The herbicide paraquat was used to desiccate weed foliage and improve harvest efficiency. The introduction of Roundup Ready technology in the mid-1990s promoted a shift in soybean cultivar development programs for the mid-South toward MG IV (indeterminate) and MG V (determinate) varieties. Use of glyphosate greatly improved weed control and production of early maturing soybean varieties in some years avoided late-season dry weather and insect problems (Griffin 2003).

Although both determinate and indeterminate soybean varieties are photoperiod-sensitive, they differ with respect to the extent of vegetative growth occurring after flower initiation. For determinate soybean, flowering is initiated in the middle of the plant and proceeds both acropetally and basipetally; terminal bud growth ceases when flowering begins. Although there can be some slight difference in seed maturity on the plant, most seed mature at the same time. In contrast, flowering of indeterminate soybean is initiated at the bottom of the plant and proceeds acropetally; terminal buds continue to grow several weeks after flowering. There can be considerable difference in seed maturity, with bottom seed reaching physiological maturity first. With the variation in seed maturation, plants tend to retain leaf material and stems remain green longer. Harvest aids might have an important role in desiccating the crop to expedite harvest. Earlier harvest allows growers to take advantage of higher market price for early delivery (Boudreaux and Griffin 2008). The feeling among many in the mid-South is that a harvest aid application should be a standard practice in a soybean production system, particularly with MG IV soybean varieties.

Soybean Green Plant Malady

Over the last few years in the mid-South, it is not uncommon to see soybean plants with green leaves, green stems, and/or green pods in fields of mature soybean. The severity can range from just a few plants present to entire fields affected. The problem is more prevalent in indeterminate varieties but also occurs in determinate varieties. The malady has been linked to stinkbug injury (Boethel et al. 2000), fungicide application, and environmental/stress factors. The recent introduction of Asian soybean rust (*Phakopsora pachyrhizi*) to the southern United States and the proliferation of other diseases have resulted in increased fungicide use. It is common in Louisiana to experience a delay in harvest in soybean fields when a foliar fungicide has been applied because soybean plants retain green leaves longer than nontreated plants (Padgett et al. 2003). Both triazole and strobilurin fungicides have caused plants to retain lower canopy leaves several days longer than nontreated plants (Potter 2005).

In preliminary research conducted in 2008 in Louisiana, green pods at harvest were decreased when insecticide was applied to control stinkbugs (J. M. Boudreaux, unpublished data). Soybean green leaf retention, green stems, and green pods at harvest were increased when fungicide was applied. Application of paraquat as a harvest aid decreased soybean green leaf retention and green stems. The presence of green plant material in fields of mature soybean can delay harvest, increase moisture, and affect foreign material and seed damage, resulting in significant dockage and decreased crop value (Boudreaux et al. 2007).

When a harvest aid such as paraquat or sodium chlorate is applied, rapid desiccation of foliage occurs. If applied before seed have reached physiological maturity, yield loss can occur. In dry bean, a harvest aid applied when 7% of the pods had yellowed reduced seed yield 19 to 22% (Wilson and Smith 2002). When harvest aid application was delayed in soybean until 50% of pods were yellow, crop yield reduction was not observed (Ratnayake and Shaw 1992a).

Paraquat Harvest Aid Research in Louisiana

Soybean seed are considered physiologically mature at approximately 50% moisture. This corresponds to R6.5 growth stage when all normal pods on the four uppermost nodes would have pod cavities filled and beans in the pods are separating from the white membrane inside the pod (Fehr and Caviness 1977). In research to evaluate application timing of paraquat as a harvest aid in soybean, average seed moisture was determined for seed collected from the top four nodes of plants (Boudreaux et al. 2007; Boudreaux and Griffin 2008). Paraquat can be applied safely to indeterminate MG IV soybean when seed moisture from the uppermost four nodes averages 50% or less. This application corresponded to approximately 115 d after planting in either mid-April or mid-May. Soybean was harvested 7 to 10 d after herbicide was applied at 50% seed moisture and 14 d earlier than the nontreated. For determinate MG V soybean, paraquat can be applied safely when seed moisture from the uppermost four nodes averages 40% or less. This application corresponded to around 125 d after planting in mid-May. Soybean was harvested 12 to 14 d after the herbicide was applied at 40% seed moisture and 7 to 8 d earlier than the nontreated. Application timing is more flexible for indeterminate soybean varieties because the most immature seed are present only in the top of the plant. In contrast, for determinate varieties, the most immature seed are present at both the top and bottom of the plant.

Harvest aids vary in their ability to desiccate weeds and their effect on the crop. Timely application of a harvest aid can allow for earlier harvest, improve harvest efficiency, and might improve crop quality. With the increased production of indeterminate, early maturing soybean varieties in the mid-South, use of a harvest aid for crop desiccation could become an important component of soybean production systems.

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