Weed Technology 2011 25:38–43

Application Timing of Harvest Aid Herbicides Affects Soybean Harvest and Yield

Joseph M. Boudreaux and James L. Griffin*

Research was conducted over 2 yr to evaluate soybean response to harvest aid herbicide treatments paraquat at 0.28 kg ai ha^{-1}, paraquat with carfentrazone at 0.014 kg ai ha^{-1}, and sodium chlorate at 6.72 kg ai ha^{-1}. Indeterminate and determinate soybean cultivars were treated when moisture of seed collected from the uppermost four nodes of plants averaged 60, 50, 40, 30, and 20% (± 2%). For each soybean cultivar, the harvest aid treatment by application timing interaction was not significant, and data for harvest aid treatments were averaged. Application of harvest aid at 60% average seed moisture reduced yield for the maturity group (MG) IV indeterminate cultivar 15.4% compared with the nontreated; 100-seed weight was reduced 12.4%. Yield and seed weight were not negatively affected when harvest aid was applied at 50% average seed moisture and soybean was harvested 14 and 15 d before the nontreated control. Although planting date in the 2 yr for the indeterminate cultivar differed by 26 d, number of days from planting to harvest aid application at 50% average seed moisture was 112 and 116 d. For MG V and MG VI determinate cultivars, application of harvest aid at 60% average seed moisture reduced yield compared with the nontreated control 22 and 18.1%, respectively, and at 50% average seed moisture 15.6 and 4%, respectively; seed weight reductions of 8.9 to 33.3% accompanied the yield reductions of the two cultivars. Reduction in soybean yield and seed weight was not observed when harvest aid was applied at 40% average seed moisture, and harvest for the 2 yr was 8 and 9 d earlier for the MG V cultivar and 10 and 14 d earlier for the MG VI cultivar.
Nomenclature: Carfentrazone; paraquat; sodium chlorate; soybean, *Glycine max* L. Pers. 'Asgrow 4403 RR', 'Asgrow 5903 RR', 'Asgrow 6202 RR'.
Key words: Application timing, desiccant, determinate soybean, indeterminate soybean, seed moisture.

Se llevó a cabo una investigación durante dos años para evaluar la respuesta de la soya a los siguientes tratamientos de herbicidas auxiliares para la cosecha: paraquat a 0.28 kg ia ha-1, paraquat con carfentrazone a 0.014 kg ia ha-1 y sodium chlorate a 6.72 kg ia ha-1. Cultivares determinados e indeterminados de soya fueron tratados cuando la humedad de la semilla recolectada de los cuatro nudos superiores de los plantas promedió 60, 50, 40, 30 y 20% (+ o - 2%). Para cada cultivar de soya, la interacción entre el herbicida auxiliar de cosecha y el momento de aplicación no fue significativa, y por tal motivo, se promediaron los tratamientos de herbicidas auxiliares. La aplicación de un herbicida auxiliar de cosecha a un promedio de 60% de humedad de la semilla redujo el rendimiento para el cultivar indeterminado del Grupo de Madurez (MG) IV en 15.4%, comparado con el testigo no tratado; el peso de 100 semillas se redujo 12.4%. El rendimiento y el peso de la semilla no se vieron afectados negativamente cuando el herbicida auxiliar de cosecha se aplicó al 50% de humedad de la semilla y la soya se cosechó 14 y 15 días antes de la soya no tratada. Aunque las fechas de siembra en los dos años para el cultivar indeterminado difirió en 26 días, el número de días entre la siembra y la aplicación del herbicida auxiliar al 50% de humedad de la semilla fue 112 y 116 d. Para los cultivares determinados con MG V y MG VI, la aplicación del herbicida auxiliar de cosecha a 60% de humedad de la semilla redujo el rendimiento en 22 y 18.1% respectivamente, en comparación con el cultivar no tratado y a 50% de humedad de la semilla la reducción del rendimiento fue de 15.6 y 4% respectivamente. Reducciones de 8.9 a 33.3% en el peso de la semilla acompañaron la disminución del rendimiento de los dos cultivares. No se observó una disminución del rendimiento y el peso de la semilla cuando se aplicó el herbicida auxiliar de cosecha a 40% de humedad de la semilla y la cosecha para los dos años fue 8 y 9 días más temprana para el cultivar MG V y 10 y 14 días más temprana para el cultivar MG VI.

Soybean is an economically important crop in the United States, and in 2007, 25.9 million hectares were harvested (USDA 2009). Soybean cultivars are differentiated on the basis of maturity group (MG) and adaptation to certain latitudes (McWilliams et al. 1999). Maturity groups range from 000 in the extreme northern United States to VIII in the southern Gulf Coast states. Cultivars with the lowest number designation (000 to IV) are considered indeterminate, while MG V through X are determinate cultivars (Anonymous 2009). In the mid-South, introduction of glyphosate-resistant technology in the mid-1990s promoted a shift in soybean cultivar development toward MG IV and MG V cultivars. Use of glyphosate greatly improved weed control, and the production of early maturing soybean cultivars in some years avoided late season dry weather and insect problems (D. Lanclos, personal communication).

Although both determinate and indeterminate soybean cultivars are photoperiod sensitive, they differ with respect to the extent of vegetative growth occurring after flower initiation (Pedersen et al. 2007). For determinate soybean, flowering is initiated in the middle portion of the plant and proceeds towards the top and bottom of the plant; terminal bud growth ceases when flowering begins. Although seed

DOI: 10.1614/WT-D-10-00045.1
* Research Associate and Lee F. Mason Louisiana State University Alumni Association Professor, School of Plant, Environmental, and Soil Sciences, Louisiana State University Agricultural Center, 104 Sturgis Hall, Baton Rouge, LA 70803. Corresponding author's E-mail: jgriffin@agcenter.lsu.edu

maturity on the plant might differ slightly, most seed mature at the same time. In contrast, flowering of indeterminate soybean is initiated in the lower portion of the plant and proceeds upward; terminal buds continue growing several weeks after flowering. Seed maturity can differ considerably, with bottom seed reaching physiological maturity (when seed have reached maximum dry weight) first. With the variation in seed maturation, indeterminate plants tend to retain leaf material, and stems remain green later into the growing season.

Traditionally, harvest aids have been used to desiccate weeds and increase harvest efficiency (Burnside et al. 1969; Burnside 1973; Griffin et al. 2003). Increases in foreign material and seed moisture associated with green plants and weeds present at harvest can reduce seed quality (Ellis et al. 1998; Willard and Griffin 1993). Reduction in seed quality can affect net returns to the grower. Additionally, leaving soybean plants in the field past maturity and awaiting harvest exposes seed to adverse weather conditions that can reduce yield and quality (Boudreaux and Griffin 2008). Philbrook and Oplinger (1989) reported that postponing harvest after soybean reached maturity resulted in yield losses of 0.2% per day, which was attributed to plant deterioration, grain losses, decreased harvest efficiency, and reduction of net yield.

With the shift toward earlier maturing soybean cultivars, the use of harvest aids has increased. A survey of extension soybean specialists in the mid-South in 2007 determined that 30 to 35% of soybean hectarage received a harvest aid application (D. Lanclos, personal communication). The increase in harvest aid use was related to late-season weed infestations, but in many cases, desiccation of the crop expedited harvest. Earlier harvest may allow growers to take advantage of higher market price for early delivery (Boudreaux and Griffin 2008).

Both paraquat[1] and sodium chlorate[2] are labeled as harvest aids/desiccants in soybean. For indeterminate varieties, the paraquat label states that 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 varieties, paraquat should be applied when plants are mature (i.e., soybeans are fully developed, half of the leaves have dropped, and remaining leaves are yellowing). For sodium chlorate, the label states that application should be made 7 to 10 d before anticipated harvest date, when soybean is mature and ready to harvest. Statements on application timing for both paraquat and sodium chlorate are unclear and open to interpretation. If harvest aid is applied too early and foliage is removed before all seed on the soybean plant have reached physiological maturity, significant yield losses can occur (Pedersen et al. 2007). Application of paraquat 3 and 4 wk before harvest was effective for desiccation of soybean foliage but reduced soybean yield (Whigham and Stoller 1979). Ratnayake and Shaw (1992) in Mississippi, observed that application of glufosinate or paraquat at R5 (beginning seed when seed is 3 mm long in the pod at one of the four uppermost nodes on the main stem) and R6 (full seed when pods contain a green seed that fills the pod cavity at one of the four uppermost nodes on the main stem) (McWilliams et al. 1999) reduced yield, but yield loss did not occur with application at R7 (beginning maturity when one normal pod on the main stem has reached mature pod color) or R8 (full maturity). Therefore, timing of application of harvest aid to soybean is critical.

The objective of this research was to determine the effects of paraquat and sodium chlorate applied to indeterminate and determinate soybean on the basis of seed moisture in the top of the crop canopy on yield, seed weight, and harvest date. Because in some cases harvest aids are applied to desiccate morningglory (*Ipomoea* spp.), paraquat was applied with carfentrazone[3] to document any possible antagonism.

Materials and Methods

Experiments were conducted in 2006 and 2007 at the Central Research Station, Ben Hur Research Farm in Baton Rouge, LA, on a Mhoon silty clay loam (fine-silty, mixed, nonacid, thermic Typic Fluavaquent) with 1.9% organic matter (OM) and pH of 6.3. Experiments were conducted each year with the use of MG IV indeterminate 'Asgrow 4403RR' and MG V 'Asgrow 5903RR' and MG VI 'Asgrow 6202RR' determinate soybean cultivars. In 2006, MG IV and V soybean was planted May 12 and MG VI soybean was planted on June 19. In 2007, MG IV soybean was planted on April 16 and MG V and VI soybean was planted May10. For each experiment both years, soybean was planted in prepared seedbeds following soybean the previous year. Row spacing consisted of three drills (38 cm apart) under the tractor with the outside drills 76 cm apart at a seeding rate of 56 kg ha^{-1}.

The experimental design was a randomized complete block with 16 treatments arranged in a three by five augmented factorial with a nontreated control (no harvest aid) included for comparison. Treatments were replicated four times and plot size was 1.5 by 9.1 m. Factor one consisted of the harvest aid treatments: paraquat at 0.28 kg ai ha^{-1}, paraquat at 0.28 kg ha^{-1} with carfentrazone at 0.014 kg ai ha^{-1}, and sodium chlorate at 6.72 kg ai ha^{-1}. A nonionic surfactant[4] at 0.25% v/v was added to all paraquat treatments. Treatments were applied at a spray volume of 140 L ha^{-1} with a CO_2-pressurized backpack sprayer at 172 kPa.

The second factor was application timing. Harvest aid treatments were applied when moisture content of seed collected from pods at the four uppermost nodes of plants averaged 60, 50, 40, 30, and 20% (± 2%). Application timing based on seed moisture was chosen because, for indeterminate soybean, the paraquat label states that application should be made at seed moisture of 30% or less. For both the indeterminate and determinate varieties, the most immature seed would be located in the top of the crop canopy. To determine seed moisture, pods were hand shelled, and seed were weighed (wet weight), oven-dried for 24 hr (dry weight), and re-weighed to calculate average moisture percentage. The three center rows of each plot were mechanically harvested with a plot combine when seed moisture was near 13% (harvest maturity). At harvest, 95% of the soybean leaves had dropped and 90% of stems had reached a mature brown color. Seed yield was adjusted to 13% moisture and expressed as a percent change compared to the yields of the respective nontreated controls (4,152 kg ha^{-1}

Table 1. Harvest aid application and harvest information for 2006 and 2007 and the effect of harvest aid application timing on yield and seed weight of MG IV 'Asgrow 4403RR' indeterminate soybean.[a,b]

	2006				2007					
% moisture[c]	Application date	DAP to application	Harvest date	DAA to harvest	Application date	DAP to application	Harvest date	DAA to harvest	Yield[d,e]	Seed weight[d,e]
		No.		No.		No.		No.	% change	g (100 seed)$^{-1}$
60	Aug 31	111	Sep 15	15	Jul 26	101	Aug 13	18	−15.4 b	12.7 c
50	Sep 5	116	Sep 15	10	Aug 6	112	Aug 13	7	−3.0 a	14.0 a
40	Sep 12	123	Sep 20	8	Aug 15	121	Aug 20	5	−1.3 a	14.2 a
30	Sep 19	130	Sep 26	7	Aug 20	126	Aug 25	5	−2.9 a	13.9 a
20	Sep 22	133	Sep 29	7	Aug 24	130	Aug 28	4	+1.1 a	13.9 a
Nontreated	—	—	Sep 29	—	—	—	Aug 28	—	0 a	14.5 a

[a] Harvest aid treatments included paraquat at 0.28 kg ai ha^{-1}, alone and with carfentrazone at 0.014 kg ai ha^{-1}, and sodium chlorate at 6.72 kg ai ha^{-1}. Data were averaged for the harvest aid treatments. Soybean planted May 12, 2006, and April 16, 2007.

[b] Abbreviations: DAP, days after planting; DAA, days after application; MG, maturity group.

[c] Average seed moisture (±2%) for seed collected from the four uppermost nodes of plants. Seed moisture was determined on the basis of weight loss for dried seed.

[d] Yield and seed weight data were averaged across 2 yr.

[e] Means within a column followed by the same letter are not significantly different ($P \leq 0.05$). Yield for the nontreated control was 4,152 kg ha^{-1}.

for MG IV; 3,991 kg ha^{-1} for MG V; 3,809 kg ha^{-1} for MG VI). Seed weight expressed in grams per 100 seed (g [100 seed]$^{-1}$) was also determined. Because of late season problems with Cercospora leaf blight (*Cercospora kikuchii*), a fungicide application of pyraclostrobin at 0.22 kg ai ha^{-1} plus thiophanate-methyl at 0.78 kg ai ha^{-1} was made in 2007 on both MG V and MG VI soybean at R3, beginning when a pod on the upper four nodes is 5 mm long (McWilliams et al. 1999). Fungicide application in 2007 did not appear to delay senescence of soybean plants. In 2006, wet weather conditions delayed harvest of MG VI soybean treated with harvest aid at 20 and 30% seed moisture and for the nontreated control.

Because in this study a quantitative series of treatments (application timing based on seed moisture) were evaluated, data were analyzed initially using regression. To understand the nature of the response and also to predict responses for each soybean cultivar to timing of harvest aid application, sum of squares in the ANOVA was partitioned to determine linear and quadratic effects. From previous research and on the basis of the paraquat label, soybean yield is not affected when paraquat harvest aid is applied to soybean at 30% seed moisture. Our interest was in determining if harvest aid can be applied earlier when seed moisture is greater than 30% without negatively affecting yield. Highly significant linear and quadratic responses were observed for each soybean cultivar. For the linear response, soybean yield decreased with increasing seed moisture leading one to conclude that it would never be safe to apply a harvest aid in soybean. Using the quadratic response, one would conclude that soybean yield was greater when harvest aid was applied at 20, 30, and 40% seed moisture compared with no harvest aid application. The responses generated by regression analysis, although statistically significant, cannot be supported biologically.

Data for each of the soybean cultivars were subjected to the Mixed Procedure in SAS (2003). Years, replications (nested within years), and all interactions containing either of these effects were considered random effects (Carmer et al. 1989). Harvest aid and application timing were considered fixed effects. Considering years as an environmental or random effect permits inferences about treatments to be made over a range of environments (Carmer et al. 1989; Hager et al. 2003). Type III statistics were used to test the fixed effects. For the seed yield and seed weight data for each experiment, harvest aid treatment by application timing interaction was not significant; therefore, data were averaged across harvest aids. Least square means were used for mean separation at $P \leq 0.05$. Letter groupings were converted with the PDMIX800 macro in SAS (Saxton 1998).

Results and Discussion

For both indeterminate and determinate soybean cultivars, the harvest aid treatment by application timing interaction was not significant and data for harvest aid treatments were averaged. Therefore, the harvest aid treatments were equally effective in desiccating soybean foliage, and application of carfentrazone with paraquat was not antagonistic. Carfentrazone is active on broadleaf weeds, especially morningglory, and could be applied with paraquat to enhance control of morningglory and other troublesome broadleaf weeds not adequately controlled by paraquat (Griffin et al. 2004).

MG IV Indeterminate Soybean. Soybean was planted 26 d earlier in 2007 than in 2006. For the harvest aid timing treatments, the 10% (± 2) average loss in soybean seed moisture between applications occurred within 3 to 10 d depending on year and environmental conditions (Table 1). For the 60% average seed moisture application, harvest aid was applied on August 31 in 2006 and on July 26 in 2007. Although harvest aid application was 36 d earlier in 2007, the difference between years in days after planting (DAP) to harvest aid application at 60% average seed moisture was only 10 d. When harvest aid was applied at 50% average seed moisture or less, the difference in DAP to harvest aid application between years was no more than 4 d.

When harvest aid was applied at 60% average seed moisture, yield was reduced an average of 15.4% and seed weight was reduced 1.8 g (100 seed)$^{-1}$ (12.4%) (Table 1). Reduction in yield and seed weight indicates that not all seed within the top of the crop canopy had reached physiological

Table 2. Harvest aid application and harvest information for 2006 and 2007 and the effect of harvest aid application timing on yield and seed weight of 'Asgrow 5903 RR' MG V determinate soybean.[a,b]

	2006				2007					
% moisture[c]	Application date	DAP to application	Harvest date	DAA to harvest	Application date	DAP to application	Harvest date	DAA to harvest	Yield[d,e]	Seed weight[d,e]
		No.		No.		No.		No.	% change	g (100 seed)$^{-1}$
60	Sep 1	112	Sep 15	14	Aug 22	105	Sep 12	21	−22.0 c	10.2 e
50	Sep 5	116	Sep 20	15	Aug 31	114	Sep 12	12	−15.6 b	11.2 d
40	Sep 12	123	Sep 26	14	Sep 13	127	Sep 25	12	−1.5 a	12.9 c
30	Sep 19	130	Sep 26	7	Sep 22	136	Sep 29	7	+2.2 a	13.6 c
20	Sep 26	137	Oct 3	7	Sep 27	141	Oct 3	6	+2.5 a	14.3 b
Nontreated	—	—	Oct 3	—	—	—	Oct 3	—	0 a	15.3 a

[a] Harvest aid treatments included paraquat at 0.28 kg ai ha^{-1}, alone and with carfentrazone at 0.014 kg ai ha^{-1}, and sodium chlorate at 6.72 kg ai ha^{-1}. Data were averaged for the harvest aid treatments. Soybean was planted May 12, 2006, and May 10, 2007.

[b] DAP, days after planting; DAA, days after application; MG, maturity group.

[c] Average seed moisture (± 2%) for seed collected from the four uppermost nodes of plants. Seed moisture was determined based on weight loss for dried seed.

[d] Yield and seed weight data were averaged across 2 yr.

[e] Means within a column followed by the same letter are not significantly different ($P \leq 0.05$). Yield for the nontreated control was 3,991 kg ha^{-1}.

maturity (R6.5) at the time of application. At R6.5, all normal pods on the four uppermost nodes would have pod cavities filled with soybeans, and soybeans would be separating from the white membrane inside the pod (Boudreaux and Griffin 2008). Moisture content of seed at physiological maturity would be around 50%. In this research, harvest aid application timing was based on average moisture of seed collected from the top four nodes of plants. At 60% average seed moisture, considerable variation in seed maturation was observed, and reduction in both yield and seed weight was expected. Additionally, at the 60% average seed moisture timing, few leaves had begun to turn yellow and all pods were green. In dry bean (*Phaseolus vulgaris* L.), 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 until 50% of soybean pods were yellow, crop yield reduction was not observed (Ratnayake and Shaw 1992). In the present study, application at 50% average seed moisture did not negatively affect soybean yield and seed weight. Soybean was harvested 10 and 7 d after application (DAA) in 2006 and 2007, respectively, and 14 and 15 d before the nontreated controls.

Delaying harvest aid application until 40% average seed moisture had no negative effect on yield, and soybean was harvested both years around 9 d earlier than the nontreated controls. The paraquat label states that application should be made to indeterminate soybean at 30% seed moisture or less and 15 d before harvest. The sodium chlorate label states that application should be made 7 to 10 days before anticipated harvest date. In the present study, harvest aid application at 30% average seed moisture was safe to soybean, but soybean was harvested, depending on year, 4 and 7 DAA, a violation of the paraquat label. Research shows that harvest aid can be safely applied at 50% average seed moisture, accelerating harvest by 14 and 15 d, which in 1 yr would have been in violation of the paraquat label. Strict adherence to the paraquat label with application at 30% seed moisture and harvest 15 d later in the present study would have eliminated any value in regard to earlier harvest. It should be noted that in this research, plots were weed free and harvest aid was applied to desiccate the crop and accelerate harvest. In situations where weeds are present, 15 d may be needed for weeds to completely dry down to improve harvest efficiency. In the present study, no attempt was made to document the value of harvest aid for improvement in crop quality (decreased foreign material or seed damage) or harvest efficiency.

MG V Determinate Soybean. Soybean was planted both years in May within 2 d of one another. Fungicide applied at R3 in 2007 did not appear to delay senescence of soybean plants. Previous research has shown delayed maturity associated with late season fungicide application in soybean (Padgett et al. 2003; Potter 2005). Depending on the year and environmental conditions, the 10% (± 2) average loss in soybean seed moisture between the harvest aid timing treatments occurred within 4 to 13 d (Table 2). For the two years, DAP to application of individual harvest aid treatments differed by no more than 7 d. For the 2 yr, for each application timing treatment, soybean was harvested within 8 d of one another. Additionally for the 2 yr, DAA to harvest for each of the application timing treatments was within 7 d of one another.

When harvest aid was applied at 60% average seed moisture, yield was reduced 22% on average, and seed weight was reduced 5.1 g (100 seed)$^{-1}$ (33.3% reduction) (Table 2). Application at 50% average seed moisture reduced yield 15.6% and seed weight 4.1 g (100 seed)$^{-1}$ (26.8%). Soybean yield was not negatively affected when harvest aid was applied at 40% average seed moisture or less; however, a seed weight reduction was observed. By delaying harvest aid application until 40% average seed moisture, soybean was harvested for the 2 yr 14 and 12 DAA and 7 and 8 d before the nontreated controls. Soybean was harvested 7 DAA when harvest aid application was delayed until 30% average seed moisture. The paraquat label states that for determinate soybean, application should be made when plants are mature with soybeans fully developed, half of the leaves have dropped, and remaining leaves are yellowing and that 15 d be allowed between application and harvest. As also noted for indeterminate

Table 3. Harvest aid application and harvest information for 2006 and 2007 and the effect of harvest aid application timing on yield and seed weight of 'Asgrow 6202 RR' MG VI determinate soybean.[a,b]

	2006				2007					
% moisture	Application date	DAP to application	Harvest date	DAA to harvest	Application date	DAP to application	Harvest date	DAA to harvest	Yield[d,e]	Seed weight[d,e]
		No.		No.		No.		No.	% change	g (100 seed)$^{-1}$
60	Sep 19	92	Oct 3	14	Sep 10	123	Sep 26	16	−18.1 c	12.6 c
50	Sep 26	99	Oct 9	13	Sep 16	129	Sep 26	10	−4.0 b	14.4 b
40	Oct 3	106	Oct 10	7	Sep 26	139	Oct 3	7	+2.2 a	15.1 ab
30	Oct 9	112	Oct 24	15	Oct 1	144	Oct 6	5	+1.2 a	15.4 a
20	Oct 13	116	Oct 24	11	Oct 7	150	Oct 13	6	+1.2 a	15.8 a
Nontreated	—	—	Oct 24	—	—	—	Oct 13	—	0 a	15.8 a

[a] Harvest aid treatments included paraquat at 0.28 kg ai ha^{-1}, alone and with carfentrazone at 0.014 kg ai ha^{-1}, and sodium chlorate at 6.72 kg ai ha^{-1}. Data were averaged for the harvest aid treatments. Soybean was planted June 19, 2006, and May 10, 2007.

[b] DAP, days after planting; DAA, days after application; MG, maturity group.

[c] Average seed moisture (±2%) for seed collected from the four uppermost nodes of plants. Seed moisture was determined based on weight loss for dried seed.

[d] Yield and seed weight data were averaged across 2 yr.

[e] Means within a column followed by the same letter are not significantly different ($P \leq 0.05$). Yield for the nontreated control was 3,809 kg ha^{-1}.

soybean, delaying paraquat application for determinate soybean based on the label would negate any benefit to earlier harvest.

MG VI Determinate Soybean. In 2006 because of wet weather, planting was delayed until June 19. Soybean was planted May 10 in 2007, 40 d earlier than in 2006. Fungicide applied at R3 in 2007 did not appear to delay senescence of soybean plants. For the harvest aid timing treatments the 10% (± 2) average loss in soybean seed moisture occurred within 4 to 10 d, depending on year and environmental conditions (Table 3). For the 2 yr, DAP to application for individual harvest aid treatments differed by 30 to 34 d (Table 3). When harvest aid was applied at 60, 50, or 40% average seed moisture for the 2 yr, soybean was harvested within 7 d of one another. When harvest aid was applied at 30% and 20% average seed moisture, harvest was delayed because of weather problems in 2006 and harvest date differed between the 2 yr by 18 and 11 d.

When harvest aid was applied at 60% average seed moisture, yield was reduced an average of 18.1% and seed weight was reduced 3.2 g (100 seed)$^{-1}$ (20.3%) (Table 3). Application at 50% average seed moisture reduced yield 4.0% and seed weight 1.4 g (100 seed)$^{-1}$ (8.9%). Soybean yield and seed weight, however, were not negatively affected when harvest aid was applied at 40% average seed moisture or less. By delaying harvest aid application until 40% average seed moisture, soybean was harvested for the 2 yr 7 d after application and 10 and 14 d before the nontreated controls. Because of wet weather, soybean treated with harvest aid at 30% average seed moisture in 2006 was harvested the same day as the nontreated controls and, in 2007, 7 d before the nontreated controls. Based on this study, the paraquat harvest interval of 15 d was not met when harvest aid was applied at 40% average seed moisture or less.

In conclusion, yield reductions were not observed when the harvest aid treatments of paraquat, paraquat plus carfentrazone, or sodium chlorate were applied to MG IV indeterminate soybean at 50% average seed moisture and to MG V and VI determinate soybean at 40% average seed moisture. The greater flexibility in application with the indeterminate cultivar is because the most immature seed (seed that have not reached physiological maturity) are present in the top of the plant. For determinate soybean the most immature seed would be present in both the top and bottom of the plant. It is not practical that growers quantify soybean seed moisture by collecting and drying seed in order to determine the appropriate application timing for a harvest aid. Of importance is that, regardless of whether an indeterminate or determinate cultivar is grown, yield reduction can be avoided if harvest aid is applied when on the uppermost nodes of the main stem, pod cavities have completely filled and all seed are separating from the white membrane inside the pod (around 50% seed moisture and at R6.5). Delaying harvest aid application until all plants in the field have one normal pod on the main stem that has reached its mature pod color (R7) (McWilliams et al. 1999) would further assure that yield would not be reduced.

Paraquat and sodium chlorate can be used to desiccate weeds and the crop. The product label states that soybean should not be harvested prior to 15 d after application of paraquat and 7 to 10 d after sodium chlorate. The label for carfentrazone states that soybean can be harvested 3 d after application. For situations in which morningglory vines are present, a combination of paraquat and carfentrazone can be effective in desiccating both the crop and weeds, but 15 d may be needed to fully desiccate vines (Griffin et al. 2004). In this study when harvest aid was applied at the ideal application timing, the crop was harvested 7 to 14 d after application and depending on cultivar, 7 to 15 d before the nontreated controls. Strict adherence to the paraquat 15-d harvest interval would negate the benefit of earlier harvest. Application of harvest aid can also improve harvest efficiency (Burnside et al. 1969; Burnside 1973; Griffin et al. 2003) and crop quality (Ellis et al. 1998; Willard and Griffin 1993), resulting in increased net return (Boudreaux and Griffin 2008).

In recent years in the mid-South, soybean production has shifted to early maturing cultivars. The incidence of the soybean green plant malady has also increased, in which, although soybean seed are mature and ready to harvest, leaf

retention and presence of green stems and pods can delay harvest (Griffin et al. 2010). It may be beneficial in a soybean production system that harvest aid be applied as a preventative measure to enhance desiccation of soybean and to decrease variability among plants within a field. Improved harvest efficiency and earlier harvest could also be added advantages to harvest aid application.

Sources of Materials

[1] Gramoxone Inteon product label, Syngenta Crop Protection Inc., P.O. Box 18300, Greensboro, NC 27419-8300.

[2] Sodium chlorate defoliant–desiccant product label, Helena Chemical Co., 225 Schilling Boulevard, Suite 300, Collierville, TN 38017.

[3] Aim product label, FMC Corporation, Agricultural Products Group, 1735 Market Street, Philadelphia, PA 19103.

[4] Induce product label, Helena Chemical Co., 225 Schilling Boulevard, Suite 300, Collierville, TN 38017.

Acknowledgments

The authors thank the staff of the Central Station, Ben Hur Research Farm, for their assistance with this research. The Louisiana Soybean and Grain Research and Promotion Board provided partial funding for this research.

Literature Cited

Anonymous. 2009. Soybean Production in Mississippi. Mississippi State University. http://msucares.com/index.html. Accessed: July 28, 2010. http://www.ag.ndsu.edu/pubs/plantsci/rowcrops/a1174/a1174w.htm

Boudreaux, J. M. and J. L. Griffin. 2008. Harvest aids in indeterminate and determinate soybeans—application timing and value. Louis. Agri. 51:26–27.

Burnside, O. C. 1973. Influence of weeds on soybean harvesting losses with a combine. Weed Sci. 21:520–523.

Burnside, O. C., G. A. Wicks, D. D. Warnes, B. R. Somerhalder, and S. A. Weeks. 1969. Effect of weeds on harvesting efficiency in corn, sorghum, and soybeans. Weed Sci. 17:438–441.

Carmer, S. G., W. E. Nyquist, and W. M. Walker. 1989. Least significant differences for combined analyses of experiments with two- and three-factor treatment designs. Agron. J. 81:665–672.

Ellis, J. M., D. R. Shaw, and W. L. Barrentine. 1998. Soybean (*Glycine max*) seed quality and harvesting efficiency as affected by low weed densities. Weed Technol. 12:166–173.

Griffin, J. L., J. M. Boudreaux, and D. K. Miller. 2010. Herbicides as harvest aids. Weed Sci. 58:355–358.

Griffin, J. L., C. A. Jones, L. M. Etheredge, Jr., W. E. Judice, and D. Y. Lanclos. 2004. An overview of harvest aid research in sugarcane, soybeans, and corn. Proc. South. Weed Sci. Soc. 57:14.

Griffin, R. M., D. H. Poston, D. R. Shaw, and M. C. Smith. 2003. Economics of preharvest desiccants in maturity group III soybean. Proc. South. Weed Sci. Soc. 56:274–275.

Hager, A. G., L. M. Wax, G. A. Bollero, and E. W. Stoller. 2003. Influence of diphenylether herbicide application rate and timing on common waterhemp (*Amaranthus rudis*) control in soybean (*Glycine max*). Weed Technol. 17:14–20.

McWilliams, D. A., D. R. Berglund, and G. J. Endres. 1999. Soybean Growth and Management. North Dakota State University Ext. Serv. Pub. A1174. http://www.ag.ndsu.edu/pubs/plantsci/rowcrops/a1174/a1174.pdf. Accessed: July 28, 2010.

Padgett, B., R. Schneider, and K. Whitam. 2003. Foliar-applied fungicides in soybean disease management. Louis. Agri. 46:7–9.

Pedersen, P., S. Kumudini, J. Board, and S. Conley. 2007. Soybean growth and development. Pages 41–47 *in* A. E. Dorrance, ed. Using Foliar Fungicides to Manage Soybean Rust. Columbus, OH: Department. of Plant Pathology Extension Publication, The Ohio State University, http://www.oardc.ohio-state.edu/Soyrust/2007edition/10-SoybeanGrowthandDevelopment.pdf. Accessed: March 11, 2010.

Philbrook, B. D. and E. S. Oplinger. 1989. Soybean field losses as influenced by harvest delays. Agron. J. 81:251–258.

Potter, B. 2005. Triazole and strobilurin foliar fungicide effects on soybean disease suppression, senescence and yield. http://swroc.cfans.umn.edu/SWMNPEST/05publications/05foliareffects.pdf. Accessed: July 2, 2009.

Ratnayake, S. and D. R. Shaw. 1992. Effects of harvest-aid herbicides on soybean (*Glycine max*) seed yield and quality. Weed Technol. 6:339–344.

[SAS] Statistical Analysis Systems. 2003. SAS 9.1. Cary, NC: SAS Institute.

Saxton, A. M. 1998. A macro for converting mean separation output to letter groupings in Proc Mixed. Pages 1243–1246 *in* Proceedings of the 23rd SAS Users Group International. Cary, NC: SAS Institute.

[USDA] U.S. Department of Agriculture. 2009. 2007 Census of Agriculture. USDA AC-07-A-51. http://www.agcensus.usda.gov/Publications/2007/Full_Report/index.asp. Accessed: March 11, 2010.

Whigham, D. K. and E. W. Stoller. 1979. Soybean desiccation by paraquat, glyphosate, and ametryn to accelerate harvest. Agron. J. 71:630–633.

Willard, T. S. and J. L. Griffin. 1993. Soybean (*Glycine max*) yield and quality responses associated with wild poinsettia (*Euphorbia heterophylla*) control programs. Weed Technol. 7:118–122.

Wilson, R. G. and J. A. Smith. 2002. Influence of harvest-aid herbicides on dry bean (*Phaseolus vulgaris*) desiccation, seed yield, and quality. Weed Technol. 16:109–115.

Received March 18, 2010, and approved October 25, 2010.