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Weed Management and Cotton Yield under Two Row Spacings in Conventional and Conservation Tillage Systems Utilizing Conventional, Glufosinate-, and Glyphosate-based Weed Management Systems

J. S. Aulakh, A. J. Price, and K. S. Balkcom*

A field experiment was conducted during three cropping seasons to compare weed control and cotton yield provided by conventional (CV), glufosinate resistant (LL), and glyphosate resistant (RR) weed management systems under standard (102 cm) and narrow (38 cm) row spacing grown in conventional and conservation tillage systems. The conventional tillage and/or CV cotton received a PRE application of pendimethalin. The CV, LL, and RR cotton varieties received two POST applications of pyrithiobac, glufosinate, and glyphosate, respectively, at two and four leaf cotton growth stages. A final (LAYBY) application of trifloxysulfuron was applied to 38 cm row cotton while a LAYBY POST directed spray of prometryn plus MSMA was used in 102 cm row cotton. The LL and RR weed management systems controlled at least 97% of large crabgrass, Palmer amaranth, sicklepod, and smallflower morningglory, while the CV system controlled 89, 73, and 87 to 98% of large crabgrass, smallflower morningglory, and Palmer amaranth, respectively. Sicklepod control increased from 85% in 102 cm rows to 95% in 38 cm rows in the CV herbicide system. Yellow nutsedge and pitted morningglory control exceeded 98% and was not affected by tillage, row spacing, or weed management system. Cotton yield was not affected by row spacing any year, by tillage in 2005, or by weed management system in 2004 and 2005. In 2006, yield in the RR weed management system was 27 and 24% higher than LL and CV weed management systems, respectively. In 2004, yield of conventional tillage cotton was 18% higher than conservation tillage cotton, but in 2006 the yield in conservation tillage was 12% higher than conventional tillage.

Nomenclature: Glufosinate; glyphosate; monosodium methanearsonate (MSMA); pendimethalin; prometryn; pyrithio bac; trifloxysulfuron; large crabgrass, *Digitaria sanguinalis* (L.) Scop. DIGSA; Palmer amaranth, *Amaranthus palmeri* S. Wats. AMAPA; pitted morningglory, *Ipomoea lacunosa* L. IPOLA; sicklepod, *Senna obtusifolia* (L.) H.S. Irwin & Barneby SENOB; smallflower morningglory, *Jacquemontia tamnifolia* (L.) Griseb. IAQTA; yellow nutsedge, *Cyperus esculentus* L. CYPES; cotton, *Gossypium hirsutum* L.

Key words: Cover crop, herbicide seed trait, integrated pest management.

Un experimento de campo se llevó al cabo durante tres estaciones de cosecha para comparar el control de malezas y el rendimiento del algodón proporcionado por sistemas de manejo convencionales (CV), resistentes al glufosinato (LL) y resistentes al glifosato (RR), con espacios estándares entre surcos (102 cm) y angosto (38 cm), utilizando sistemas de labranza convencional y de conservación. El algodón en el sistema de labranza convencional y/o el algodón (CV) recibieron una aplicación preemergente de pendimetalina. Las variedades de algodón CV, LL y RR recibieron dos aplicaciones posemergentes de pyrithiobac, glufosinato, y glifosato, respectivamente, en las etapas de dos y cuatro hojas de crecimiento. Una aplicación final de trifloxysulfuron se aplicó al algodón entre los surcos de 38 cm, mientras que una aplicación posemergente dirigida de prometrina más MSMA se usó entre los surcos de 102 cm. Los sistemas de manejo de malezas LL y RR controlaron al menos 97% de *Digitaria sanguinalis*, *Amaranthus palmeri*, *Senna obtusifolia* y *Jacquemontia tamnifolia*, mientras que el sistema CV controló 89, 73 y de 87 a 98% de *Digitaria*, de *Jacquemontia* y de *Amaranthus*. El control de *Senna* se incrementó de 85% en los surcos de 102 cm, a 95% en los surcos de 38 cm utilizando el sistema convencional (CV). El control de *Cyperus esculentus* e *Ipomoea lacunosa* excedió 98% y no se vio afectado por la labranza, el espacio entre surcos o el sistema de manejo de malezas. El rendimiento de algodón no se vio afectado por el espacio entre surcos en ningún año, por la labranza en 2005, ni por el sistema de manejo de malezas en 2004 y 2005. En 2006, el rendimiento obtenido con el sistema de manejo RR fue 27 y 24% más alto que con los sistemas LL y CV, respectivamente. En 2004, el rendimiento del algodón con labranza convencional fue 18% mayor que con labranza de conservación, pero en 2006 el rendimiento con labranza de conservación fue 12% mayor que con labranza convencional.

Cotton is more sensitive to weed interference during the first 8 to 9 wk of growth compared with most other row crops due to its slow initial growth (Buchanan and Burns 1970). Cotton yield and quality losses may ensue following competition by weeds for water, nutrients, sunlight, and possibly by allelopathic weed crop interaction (Frans and Chandler 1989). In the United States, pigweeds (*Amaranth* spp.) including glyphosate-resistant Palmer amaranth, morningglories (*Ipomoea* spp.), sicklepod, crabgrass (*Digitaria* spp.), goosegrass [*Eleusine indica* (L.) Gaertn.], and nutsedge (*Cyperus* spp.) are major weeds in many of the cotton-producing states (Culpepper 2006; Webster 2005).

Glyphosate-resistant (RR) cotton has become widely adopted by producers since it became commercially available in 1997 (Dill 2005; Gianessi 2005). Glufosinate-resistant (LL) cotton was introduced in 2004, but adoption of this

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technology was slow due to the lack of availability of regionally adapted cultivars (Culpepper et al. 2009; USDA-AMS 2010). Rapid adoption of RR cotton occurred also because of the lack of effective PRE herbicides in nonirrigated production systems and the narrow spectrum of control of available POST herbicides in conventional (CV) cotton (Dill et al. 2008). RR cotton is now planted on a widespread basis, imposing intensive selection pressure for the evolution of glyphosate-resistant weed populations. The current widespread occurrence of glyphosate-resistant horseweed [*Conyza canadensis* (L.) Cronq.] (Nichols et al. 2009; Owen and Zelaya 2005), ryegrass (*Lolium multiflorum* Lam.) (Bond et al. 2011), and Palmer amaranth (Culpepper et al. 2006; Norsworthy et al. 2008; Price et al. 2009) in the southeastern United States has underscored the need for the adoption of alternatives to the RR cotton system. The development of glyphosate-resistant weeds, coupled with the availability of glufosinate-resistant cotton cultivars that are well-adapted for production in the southeastern United States, have resulted in increased interest in CV and glufosinate-based cotton production programs.

Historically, cotton has been grown in 91- to 102-cm rows due to equipment configurations. Producer interest and implementation of an alternative narrow-row (38-cm rows) production system is increasing due to the potential for higher yields on less productive soils with an increased cotton plant population (Reddy et al. 2009). In narrow-row systems, more rapid canopy closure may allow for moisture conservation and weed suppression earlier in the season. Previous research indicates a potential yield increase for cotton grown in narrow rows during a dry growing season (Jost and Cothren 2000). Research to determine the effectiveness of weed management systems for narrow-row production systems could provide improved weed management strategies for growers utilizing narrow-row cotton production.

Adoption of conservation tillage was greatly accelerated with the introduction of glyphosate-resistant crop cultivars, especially in cotton (Fernandez-Cornejo and Caswell 2006). Conservation tillage cotton production in the southern United States increased from approximately 250,000 ha in 1998 to over 750,000 ha in 2002 (CTIC 2002). However, much of the row-crop agriculture in the southeastern United States remains in conventional tillage to facilitate the use of PPI and PRE herbicides and cultivation, proven methods of controlling many troublesome and herbicide-resistant weeds. The inclusion of high-residue cover crops in conservation-tillage systems can aid in weed suppression through mulch and allelopathic effects that can reduce weed seed germination and growth (Norsworthy et al. 2011; Price et al. 2006). Producers throughout the southeastern United States can effectively grow rye (*Secale cereale* L.) or other winter cereal crops as high-residue covers (4,500 kg ha^{-1} or greater), while following the recommended cover crop termination and cotton planting schedule (Price et al. 2009; Reiter et al. 2008). The use of a rye cover in conventional cotton cultivars can result in higher crop yield and a reduction in the need for POST herbicides (Price et al. 2006; Reeves et al. 2005); However, an evaluation of the effectiveness of high-residue cover crops in RR, LL, and CV weed management systems is needed. The objective of this study was to compare the weed control and cotton yield for three weed management systems, RR, LL and CV, as affected by row spacing and tillage.

Materials and Methods

Field experiments were conducted from 2003 through 2006 at the E.V. Smith Research Center, Field Crops Unit near Shorter, AL, on a Compass sandy loam soil (coarse-loamy, siliceous, subactive, thermic Plinthic Paleudult). The experimental area contained long-term conservation and conventional tillage plots prior to establishment of this experiment and the respective tillage treatments remained in place throughout the experiment duration. Treatments were arranged as a split-split-plot design in a randomized complete block with four replications. Main plots consisted of two row spacings (38 or 102 cm), each containing three different cotton cultivars weed management subplots: a CV cultivar with corresponding herbicide treatments, a RR cultivar with glyphosate-based herbicide treatments, and an LL cultivar with glufosinate-based herbicide treatments (See Table 1 for specific herbicide treatments for each weed management system). Plots were then subdivided further into sub-subplots containing tillage system (conventional or conservation tillage). Herbicides were applied with a CO_2-pressurized backpack sprayer with Teejet[1] AI11002VS flat fan nozzles with a pressure of 180 kPa calibrated to deliver 140 L ha^{-1}.

Within conservation tillage plots, a rye cover crop was drill-seeded at 101 kg ha^{-1} in 17-cm row spacings in late October of each year. The conservation tillage experimental area was subsoiled just following cover crop seeding to eliminate any subsurface soil compaction, with the exception of 2003. In the early spring of each year, 22 to 34 kg ha^{-1} N as an ammonium nitrate solution[2] was applied to rye to enhance biomass production. Two random 0.5-m^2 samples of aboveground rye biomass were harvested from each main plot approximately 3 wk prior to cotton planting. Averaged over conservation tillage replications, oven-dried weights of aboveground biomass for 2004, 2005, and 2006, were 3,940, 3,430, and 5,000 kg ha^{-1}, respectively. Conservation tillage plots were terminated with glyphosate[3] at 840 g ae ha^{-1} and rolled with a three-section straight crimping bar roller.[4] Surface tillage in the conventional tillage plots consisted of multiple spring disk operations and a field cultivator operation to level and firm the soil prior to cotton planting. In the conservation tillage plots, cotton was direct-seeded through rye residue.

Cotton cultivars planted in this experiment included FM-966[5] as the CV cultivar, FM-960 RR[5] as the RR cultivar, and FM-966 LL[5] as the LL cultivar. The experimental area received 47 kg N ha^{-1} prior to cotton planting; an additional 67 kg N ha^{-1} was side-dressed as urea-ammonium nitrate.[6] The cotton planting dates were May 25 in 2004 and May 17 in 2005 and 2006. A drill was used to plant 38-cm row cotton at 259,300 seeds ha^{-1} while 102-cm row cotton was planted at 197,600 seeds ha^{-1}.

Pendimethalin[7] PRE at 930 g ai ha^{-1} was applied to CV, RR, and LL weed management systems in conventional tillage plots as well as the conventional weed management system in

Table 1. Tillage systems, weed management systems, herbicides and application timing, and herbicide rates used.[a]

Tillage system	Weed management system[b]	Herbicides and timing	Rate g ha ^{1}
Conventional	CV	Pendimethalin PRE fb pyrithiobac at two- and four-leaf stages	930 fb 36 fb 36
	LL	Pendimethalin PRE fb glufosinate at two- and four-leaf stages	930 fb 470 fb 470
	RR	Pendimethalin PRE fb glyphosate at two- and four-leaf stages	930 fb 1,100 fb 1,100
Conservation	CV	Pendimethalin fb pyrithiobac at two- and four-leaf stages	930 fb 36 fb 36
	LL	Glufosinate at two- and four-leaf stages	470 fb 470
	RR	Glyphosate at two- and four-leaf stages	1,100 fb 1,100

[a] A LAYBY application of trifloxysulfuron at 71 g ai ha ^{1} was applied to 38-cm row cotton and a POST-directed spray application of prometryn at 1,120 g ai ha ^{1} plus MSMA at 597 g ai ha ^{1} was applied to 102-cm row cotton.

[b] Abbreviations: CV, conventional cotton cultivar–weed management system; LL, glufosinate-resistant cotton; RR, glyphosate-resistant cotton; fb, followed by.

conservation tillage plots immediately following planting. RR and LL weed management systems received no PRE application in the conservation tillage treatments. Two POST applications of glyphosate at 1,100 g ha ^{1}, glufosinate[8] at 470 g ai ha ^{1}, or pyrithiobac[9] at 36 g ai ha ^{1} were made to RR, LL, and CV systems, respectively, at the two-leaf and again at the four-leaf cotton growth stages (Table 1). A LAYBY application of trifloxysulfuron[10] at 71 g ai ha ^{1} was applied to 38-cm spaced cotton while a LAYBY POST-directed spray (PDS) application of prometryn[11] at 1,120 g ai ha ^{1} plus MSMA[12] at 597 g ai ha ^{1} was applied to the 102-cm spaced cotton. A nontreated check was included for comparison. Cotton from two 2-m ^{2} sections within each plot, excluding nontreated, was hand-harvested on October 4, 2004, October 11, 2005, and October 11, 2006, respectively.

Weed control was evaluated in 2005 and 2006 only. Visual estimates of weed control were made 14 d after POST treatments and 21 d after LAYBY treatments based on a scale of 0 to 100%, where 0 indicated no control and 100 indicated complete control (Frans et al. 1986). Weed control data from the evaluation at 21 d after the LAYBY were used in statistical analysis.

Weed control and yield data were analyzed using the MIXED procedure in SAS[13] and the LSMEANS PDIFF option to distinguish between treatment means (Littell et al. 2006). In the weed control ANOVA model, row spacing, weed management system, tillage, and the interactions among row spacing, weed management system, and tillage were treated as fixed effects while year, replication, row spacing × replication, weed management system × row spacing × replication were considered random. In the yield ANOVA model, year, row spacing, weed management system, tillage, and the interactions among row spacing, weed management system, and tillage were treated as fixed effects while replication, year × replication, row spacing × replication, weed management system × row spacing × replication were considered random. Treatment differences were considered significant if $P \leq 0.05$. Means were compared, where appropriate, using Fisher's Protected LSD test at the 5% level.

Results and Discussion

Weed Control. The predominant weed species in this study were large crabgrass (10 m ^{2}), Palmer amaranth (50 m ^{2}), pitted morningglory (5 m ^{2}), sicklepod (30 m ^{2}), smallflower morningglory (5 m ^{2}), and yellow nutsedge (20 m ^{2}). Sicklepod and Palmer amaranth were present in 2006 only. Row spacing, weed management system, and tillage system did not affect control of yellow nutsedge and pitted morningglory, which exceeded 97% for all management systems (data not shown). Large crabgrass control was affected only by the weed management systems. The CV weed management system provided 89% control of large crabgrass while RR and LL weed management systems resulted in 98% control (Table 2). Similar results were seen with smallflower morningglory, which differed only in respect to weed management systems (Table 2). Greater than 90% control of large crabgrass has been reported with early POST application of glufosinate (Gardner et al. 2006; Wesley et al. 2007); similar results have been noted with glyphosate or glufosinate POST followed by a residual PDS (Culpepper and York 1999; Price et al. 2008b). Increased grass weed control with glyphosate or glufosinate can be achieved with multiple applications since weeds may not be completely controlled by one application. Moreover, new cohorts may emerge following a single application of nonresidual glyphosate and glufosinate. Therefore, weed management systems that include residual herbicides at LAYBY will provide increased weed control (Beyers et al. 2002; Price et al. 2008b; Tharp and Kells 2002; Vencill 2002; Wiesbrook et al. 2001).

There was a weed management system × tillage interaction for Palmer amaranth control. The CV weed management system under conservation tillage resulted in 98% Palmer amaranth control in conservation tillage but only 87% in the conventional tillage system (Table 3). This is likely due to a combination of row-middle weed suppression by cover crop residue and adequate activation of pendimethalin (Price et al. 2005, 2006, 2008a). This differs from Clewis et al. (2004) who found no weed control differences when comparing

Table 2. Effect of weed management system on large crabgrass and smallflower morningglory control.[a,b]

	Weed management system[c]			
Weed species	CV	LL	RR	LSD (0.05)
	——% ——			
Large crabgrass	89	98	98	3
Smallflower morningglory	73	99	98	24

[a] Data pooled over years, tillage system, and row spacing.

[b] Weed ratings not recorded for 2004.

[c] Abbreviations: CV, conventional cotton cultivar/weed management system; LL, glufosinate-resistant cotton/weed management system; RR, glyphosate-resistant cotton/weed management system.

Table 3. Interaction of weed management system and tillage system on Palmer amaranth control.[a,b]

Weed management system[c]	Tillage system	
	Conventional	Conservation
	%	
CV	87	98
LL	97	98
RR	99	98
LSD(0.05)	4	

[a] Data combined over years.

[b] Weed ratings not recorded for 2004.

[c] Abbreviations: CV, conventional cotton/weed management system; LL, glufosinate-resistant cotton/weed management system; RR, glyphosate-resistant cotton/weed management system.

conventional tillage with a low residue strip-tillage system. The effectiveness of RR and LL weed management systems was similar between the two tillage systems (Table 3). The RR and LL weed management systems generally provided similar control of Palmer amaranth, which exceeded 97%. Glyphosate has been documented to be more effective on Palmer amaranth than glufosinate if Palmer amaranth is more than 7.6 cm tall or under drought stress (Beyers et al. 2002; Coetzer et al. 2002; Corbett et al. 2004). Our results support those of Clewis et al. (2004), who reported more than 90% control of Palmer amaranth with a broad-spectrum herbicide followed by pyrithiobac.

For sicklepod control, there were interactions of row spacing by weed management system, row spacing by tillage and weed management system by tillage (Tables 4 and 5). Sicklepod control was higher in 38-cm row spacing than 102-cm row spacing. At 102-cm row spacing, the RR and LL weed management systems controlled 98% of sicklepod, compared with 89% under CV weed management. Wesley et al. (2007) also achieved greater than 90% control of sicklepod with glufosinate.

In the row spacing by tillage interaction under conventional tillage, 99% sicklepod control was attained with 38-cm row spacing, which differed from 94% control with 102-cm row spacing. The increase in control in the narrow-row, CV weed management system may be attributed to shading provided by early canopy closure typically observed in narrow row systems. At 102-cm row spacing, 98% sicklepod control was higher under conservation tillage than the 94% attained under

Table 4. Interaction of weed management system and row spacing on sicklepod control.[a,b]

Weed management system[c]	Row spacing		
	38-cm	102-cm	LSD (0.05)
	%		
CV	95	85	5
LL	98	99	
RR	95	99	

[a] Weed ratings not recorded for 2004.

[b] Data averaged over 2005 and 2006.

[c] Abbreviations: CV, conventional cotton/weed management system; LL, glufosinate-resistant cotton/weed management system; RR, glyphosate-resistant cotton/weed management system.

Table 5. Interaction of weed management system, tillage, and row spacing by tillage on sicklepod control.[a,b]

Treatment	Tillage system	
	Conventional	Conservation
	%	
Weed management system[c]		
CV	93	98
LL	98	98
RR	98	98
LSD(0.05)	2	
Row spacing		
38-cm	99	98
102-cm	94	98
LSD(0.05)	2	

[a] Weed ratings not recorded for 2004.

[b] Data averaged over 2005 and 2006.

[c] Abbreviations: CV, conventional cotton/weed management system; LL, glufosinate-resistant cotton/weed management system; RR, glyphosate-resistant cotton/weed management system.

conventional tillage. In the tillage by weed management system interaction, the CV, RR, and LL weed management systems under conservation tillage resulted in 98% sicklepod control, higher than the 93% attained in the conventional weed management system under conventional tillage (Table 4).

Cotton Yield. Since the year effect was significant, yield data were analyzed by year. Higher cotton yield was recorded in 2005 followed by 2004 and 2006 (Table 6). Dry growing conditions in 2006 resulted in very low yield. Narrow-row cotton (38-cm) yields were similar to standard-row (102-cm) cotton during all the 3 yr. These results are similar to the findings of Boquet (2005) who found no yield advantage of narrow rows over standard rows. Bauer et al. (2003) also reported inconsistent yield response of ultra-narrow-row cotton (less than 25 cm) to tillage system. Weed management systems did not affect cotton yield during 2004 and 2005. In 2006, yield in the RR weed management system was 24 and 26% higher than CV and LL weed management systems, respectively. In contrast, recent results in areas with

Table 6. Effect of weed management and tillage systems on cotton yield.[a]

Treatment	Cotton yield		
	2004	2005	2006
	$kg\ ha^{-1}$		
Weed management system[b]			
Conventional	2,530	3,890	1,760
LL	2,520	3,570	1,730
RR	2,470	3,930	2,190
LSD (0.05)	NS	NS	210
Tillage system[c]			
Conventional	2,720	3,780	1,780
Conservation	2,300	3,820	2,010
LSD (0.05)	160	NS	160

[a] Abbreviations: LL, glufosinate-resistant cotton/weed management system; RR, glyphosate-resistant cotton/weed management system; NS, not significant.

[b] Data averaged over tillage system and row spacing.

[c] Data combined over weed management system and row spacing.

glyphosate-resistant Palmer amaranth have shown higher yield from LL cotton than RR cotton due to improved control of resistant amaranth in LL cotton (Culpepper et al. 2009).

Tillage systems affected cotton yield in 2004 and 2006 (Table 5). In 2004, the conventional tillage system produced 18% more cotton than conservation tillage. However, under drought conditions in 2006, conservation tillage produced 13% more cotton than the conventional tillage system, which may be attributed to increased retention of soil moisture under the rye cover crop (Daniel et al. 1999; Unger and Vigil 1998).

In this study, the RR weed management system resulted in higher cotton yield than the CV and LL systems. Cotton yield response to tillage system varied among years, with conservation tillage yielding more than conventional tillage during a dry year. Weed control under the narrow and standard row spacings was similar in most instances except for sicklepod, where higher control was achieved at 38-cm row spacing than 102-cm row spacing in a conventional weed management system. Both herbicide-resistant weed management systems demonstrated higher efficacy for the control of large crabgrass, sicklepod, smallflower morningglory, and Palmer amaranth. The LL and RR weed management systems provided 98% large crabgrass control, $\geq$ 97% Palmer amaranth, $\geq$ 98% sicklepod, and $\geq$ 98% smallflower morningglory control. The CV weed management system under conservation tillage controlled Palmer amaranth and sicklepod 98% compared with 87% and 93%, respectively, in a conventional tillage system. Our results show that glufosinate applied twice at two- and four-leaf cotton followed by a LAYBY application could provide weed control comparable to glyphosate regardless of row spacing and tillage system. Furthermore, LL technology may be an effective tool for controlling glyphosate-resistant Palmer amaranth. However, there is need to enhance the yield potential of LL varieties to increase adoption of this technology.

Sources of Materials

[1] CO_2 pressurized backpack sprayer, Spraying Systems, Co., North Avenue and Schmale Road, Wheaton, IL 60189.

[2] Ammonium nitrate solution, Simplot plant nutrients, Boise, ID.

[3] Glyphosate, Roundup Weathermax®, Monsanto Company, St. Louis, MO.

[4] Three section straight bar roller, Bigham Brothers, Inc., Lubbock, TX.

[5] FiberMax® brand FM 966, FM 960 RR, and FM 966 LL, Bayer Crop Science, Research Triangle Park, NC.

[6] Urea ammonium nitrate solution, Terra Industries Inc., Terra Centre 600 Fourth Street, Sioux City, IA 51101.

[7] Pendimethalin, Prowl®, BASF Ag. Products, Research Triangle Park, NC.

[8] Glufosinate, Ignite®, Bayer Crop Science, Research Triangle Park, NC.

[9] Pyrithiobac, Staple®, DuPont Ag. Products, Wilmington, DE.

[10] Trifloxysulfuron, Envoke®, Syngenta Crop Protection, Inc., Greensboro, NC.

[11] Prometryn, Caparol®, Syngenta Crop Protection, Inc., Greensboro, NC.

[12] Monosodium acid methanearsonate, MSMA®, Drexel Chem ical Company, Memphis, TN.

[13] Statistical Analysis Systems®, version 9.2, SAS Institute, Inc., Cary, NC.

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