doi:10.2489/jswc.67.1.8

Water, sediment, and metolachlor transport differences between wide- and narrow-row cotton production systems

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Abstract: Planting cotton (*Gossypium hirsutum* [L.]) in narrow rather than wide rows could reduce erosion and off-site agrochemical transport, but this hypothesis needs to be evaluated under midsouth cropping conditions. Field studies were conducted near Stoneville, Mississippi, on a Dundee silty clay loam in 2006 and 2007 to evaluate sediment, water, and metolachlor (2-chloro-N-[2-ethyl-6-methylphenyl]-N-[2-methoxy-1-methylethyl] acetamide) loss in narrow (38 cm [15 in]) and wide-row (102 cm [40 in]) cotton. One day after a postemergence metolachlor application over four- to six-leaf stage cotton, 60 mm h^{-1} (2.4 in hr^{-1}) of simulated rainfall was applied until 25 min of runoff was generated per plot. Sediment loss, regardless of year, was at least 38% lower from narrow-row than wide-row cotton. Depending on year, planting cotton on narrow rows either had no effect or reduced cumulative runoff by 25%, compared to the wide-row system. Cumulative metolachlor loss was 27% higher in narrow-row relative to wide-row cotton in 2006, but the trend was reversed in 2007. Our results indicate that nearly flat seedbeds in narrow-row systems can reduce sediment loss relative to wide-row cotton planted on slightly raised seedbeds. Moreover, planting cotton in narrow rows rather than wide rows may reduce the loss of metolachlor applied postemergence if cumulative runoff is reduced in the narrow-row system and factors governing mixing-zone pesticide concentrations are similar between row spacings, primarily canopy coverage, and antecedent soil moisture conditions.

Key words: agrochemical—herbicide—metolachlor—pesticide transport—row spacing

Midsouth cotton (*Gossypium hirsutum* [L.]) has historically been grown in rows spaced 91 to 102 cm apart (35 to 40 in), but recently introduced equipment that is able to pick cotton on row spacings ranging from 38 to 102 cm (15 to 40 in) has prompted interest in narrow-row systems (i.e., 38 cm [15 in rows]). Canopy closure occurs four weeks sooner, and lint yield is approximately 20% higher in midsouth cotton grown on 38 versus 102 cm rows (15 versus 40 in rows) (Reddy et al. 2009). Higher yield potential in narrow-row cotton may encourage midsouth producers to shift from conventional row spacing. A large-scale shift from conventional to narrow-row cotton could reduce sediment and agrochemical transport to surface water bodies throughout the midsouth.

Narrow-row systems alter plant geometry and, consequently, parameters that impact runoff, erosion, and agrochemical transport, namely antecedent soil moisture and canopy coverage (Krutz et al. 2007). Reduced antecedent moisture and greater canopy coverage in narrow-row, compared to wide-row, soybean (*Glycine max* L.) was noted at the time of a postemergent metolachlor application and a subsequent simulated rainfall event (Krutz et al. 2007). The differential moisture content between row spacings was attributed to a more even distribution of plant roots in the narrow-row system, which delayed runoff inception, increased infiltration, and likely promoted the leaching of metolachlor below the mixing zone. The mixing zone is the surface 2 to 3 mm (0.08 to 0.12 in) of soil, where pesticides are entrained in runoff through a mixing-extraction process (Ahuja 1986; Leonard 1990). The metolachlor mass available for transport in surface runoff was reduced by at least 32% in narrow-row soybean due to greater canopy coverage interception and foliar absorption (Krutz et al. 2007). Reduced antecedent moisture and enhanced foliar interception/absorption in narrow-row soybean combined to decrease cumulative runoff, erosion, and metolachlor transport by approximately 40%. Similar data for cotton are not available. Therefore, the objective of this experiment was to compare effects of row spacing on runoff, erosion, and metolachlor transport when applied over the top of four- to six-leaf stage cotton.

Materials and Methods

Site Description. A two-year study was established at the USDA Agricultural Research Service Crop Production Systems Research farm, Stoneville, Mississippi (33°26´N, 90°55´W), on a Dundee silty clay loam (fine-silty mixed, thermic Aeric Ochraqualf) with a pH of 6.9, organic matter content of 1.6%, cation exchange capacity of 23 cmol$_c$ kg^{-1} soil (50.7 cmol$_c$ lb^{-1} soil), and soil textural fractions of 15% sand, 56% silt, and 20% clay (Reddy et al. 2009). Soil preparation consisted of an initial disking, subsoiling, and then bedding in the fall of the previous year. Raised beds spaced 102 cm (40 in) from the center were formed with disk hippers. The experimental area was treated with Paraquat (Gramaxone Inteon R, Syngenta Corporation, Wilmington, Delaware) at 1.1 kg a.i. (active ingredient) ha^{-1} (1.0 lb a.i. ac^{-1}) or glyphosate at 0.84 kg acid equivalent (a.e.) ha^{-1} (0.75 lb a.e. ac^{-1}) one to two weeks prior to cotton planting to kill existing vegetation. Prior to planting, raised beds were smoothed with a reel and harrow row conditioner as needed by removing a thin layer of soil from the top of the seedbed to plant cotton in 102 cm rows (40 in) and by flattening the seedbed to plant cotton on 38 cm rows (15 in).

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Narrow-row bed height in both years was less than 1.3 cm (0.5 in), while bed height in wide row beds was 5.0 cm (2 in) in 2006 and 7.6 cm (3 in) in 2007.

Glyphosate resistant cotton, DP164 B2RF (Deltapine, Memphis, Tennessee), was planted at a density of 126,000 plants ha^{-1} (51,030 plants ac^{-1}) on April 19, 2006, and April 30, 2007, in both narrow and wide-row systems. Narrow and wide-row cotton were planted with a John Deere 1730 Planter (Deere and Co., Moline, Illinois) and a MaxEmerge 2 Planter (Deere and Col, Moline, Illinois), respectively.

Metolachlor formulated as Sequence (Syngenta Crop Protection, Greensboro, North Carolina) was applied at a nominal application rate of 1.26 kg a.i. ha^{-1} (1.13 lb a.i. ac^{-1}) with 8,003 flat fan spray tips (Spraying Systems Co., Wheaton, Illinois) from a height of 48 cm (19 in) above the cotton canopy with a compressed air, tractor-mounted sprayer delivering 140 L ha^{-1} (15 gal ac^{-1}) at 206 KPa (4,300 lb ft^2). The metolachlor application rate was verified by arranging four 7 cm (2.75 in) diameter filter paper spray targets (Whatman no.2, Whatman Inc., Clifton, New Jersey) on the soil surface adjacent to each plot.

Rainfall Simulations. Microplots, 2.03 m wide and 2.43 m long (6.7 × 8 ft), were centered over the beds and were delineated with aluminum frames pressed approximately 10 cm (3.9 in) into the soil surface. The 2.43 m side was positioned parallel to the bed and in the center of each row, while the 2.03 m side was perpendicular to the bed as described previously (Krutz et al. 2007). Wide-row microplots contained one row of cotton, while narrow-row plots contained two rows of cotton. All microplots had an average slope of 1% and contained one wheel track and one furrow. Antecedent soil water content was determined gravimetrically on surface soil samples collected adjacent to the plot at two depths, 0 to 7.6 cm (0 to 3 in) and 7.6 to 25.4 cm (3 to 10 in). Canopy coverage at the time of herbicide application and simulated rainfall was determined using digital imagery (Purcell 2000). An oscillating nozzle rainfall simulator delivered a nominal rainfall intensity of 60 mm h^{-1} (2.4 in hr^{-1}) (Meyer and Harmon 1979), which has return frequency of 10 to 25 y for this area of Mississippi. Rainfall simulations were initiated 1 d after metolachlor application and continued until 25 min of runoff was generated per plot. All runoff generated during the simulation was captured in a holding tank positioned on the downslope end of the plot. Runoff rate was determined manually by recording the water height in the holding tank at 60 s intervals. The initial liter of runoff and those obtained at 5, 10, 15, and 20 min after runoff inception were collected in 1 L (33.8 fl oz) glass bottles. All glass bottles were sealed with Teflon-lined screw caps, were placed on ice, and were transferred to the laboratory refrigerator within 1 h of completing the simulation.

Field Foliar Washoff. Prior to applying simulated rainfall, the aboveground portions of a cotton plant were clipped at the soil surface from an area adjacent to the runoff plot, and an aboveground portion of a cotton plant was clipped at the soil surface in the plot after the simulation. Foliage was rinsed for 5 min in 1 L (33.8 fl oz) glass jars containing 250 mL (8.45 fl oz) of water, and the water was analyzed for metolachlor.

Sample Preparation and Analysis. Total sediment in runoff was determined by transferring a 200 mL (6.76 fl oz) aliquot of a well-shaken runoff sample into a tared beaker and recording the weight of the residue after oven drying. Filter paper spray–targets were extracted 1 h after collecting by shaking 24 h with 25 mL (0.85 fl oz) of methanol, and then a 1 mL (0.34 fl oz) aliquot was removed for analysis. Runoff samples were thoroughly shaken, and 10 mL (0.34 fl oz) subsamples were removed and fortified with terbuthazine at 5 ug mL^{-1} (5 parts per million [ppm]) as an internal standard. Subsamples were then extracted using a 3 mL (0.1 fl oz) C_{18} solid phase extraction column (Bakerbond, JT Baker Phillipsburg, Pennsylvania) preconditioned with 4 mL (0.135 fl oz) of methanol followed by 4 mL of distilled water. The column was eluted with 2 mL (0.68 fl oz) of methanol under negative pressure, and the extract was dried to 1 mL under a stream of nitrogen. Components of all extracts were identified and quantified using a Waters 2695 HPLC separations module (Waters Corporation, Milford, Massachusetts) equipped with a Waters 996 photodiode array detector (Waters Corporation, Milford, Massachusetts). The HPLC was fitted with a 2.1 mm [0.8 in] diameter by 150 mm [5.9 in] length Waters Symmetry C_{18} column (Waters Corporation, Milford, Massachusetts). The mobile phase solvents were HPLC–grade and consisted of acetonitrile and water (55:45 v/v). Mobile phase flow rate was constant at 1.0 mL min^{-1} (0.03 oz min^{-1}). The method detection limit, based on the low concentration standard (0.1 μg mL^{-1} in each calibration) was 10.0 μg L^{-1}.

Quality Control. Recovery of metolachlor from fortified filter paper used for spray targets was 93 ± 1% (n = 8). Field application rates were adjusted based on spray target recovery. Metolachlor was below the method detection limit in all field blank water samples collected from the simulator holding tank before each rainfall event, and the concentration of metolachlor was below the method detection limit in all laboratory blanks. Matrix-fortified samples were prepared by adding 0.4 mL (0.014 fl oz) of 50 μg mL^{-1} metolachlor solution to 10 mL (0.34 fl oz) of field blank sample. The average recovery of metolachlor from these samples was 110 ± 12% (n = 12). Field runoff samples were not adjusted for recovery.

Data Calculations. Herbicide and sediment concentrations were multiplied by the volume of runoff represented by the samples taken for analysis, and the results were summed to give total loads. Estimates for cumulative mass loss were obtained by multiplying the average concentration for each time step by the corresponding runoff volume. Average concentrations in the portion of the runoff that were not analyzed were estimated by fitting the data to nonlinear regression models in Sigma Plot 9.0. The mass of metolachlor intercepted by the cotton canopy was calculated by multiplying herbicide mass applied (kg ha^{-1}) by the cotton canopy coverage at the time of application (Beyerlein and Donigian 1979). Herbicide mass available for washoff 1 d after herbicide application was calculated by multiplying water extractable metolachlor (g plant^{-1}) by the plant density (plants ha^{-1}) (Wauchope et al. 2004). The mass of metolachlor remaining on the crop canopy following rainfall simulation was calculated by multiplying water extractable herbicide following the simulated rainfall event (g plant^{-1}) by the plant density (plants ha^{-1}) (Wauchope et al. 2004). Herbicide mass unavailable for washoff (% of applied) was calculated as follows: unavailable = [(intercepted – prerainfall) / Intercepted] × 100. The herbicide mass washed off (% of applied) was calculated as follows: washoff = [(prerainfall – postrainfall) / mass applied] × 100.

Statistical Analysis. Analysis of variance for all evaluated parameters was performed in Proc Mix (SAS version 9.1, SAS Institute

Table 1

Antecedent soil moisture at two depths from wide- and narrow-row cotton established in Stoneville, Mississippi, in 2006 through 2007 prior to simulated rainfall. Soil moisture level can be compared with least significant difference ($LSD_{0.05[year \times spacing \times depth]} = 2.348$).

	2006		2007	
Depth (cm)	Narrow (%)	Wide (%)	Narrow (%)	Wide (%)
0 to 7.6	11.17* (1.05)†	9.28 (2.21)	6.99 (0.43)	7.19 (1.79)
7.6 to 25.4	17.67 (0.95)	16.09 (0.41)	12.28 (1.55)	12.91 (1.37)

* Mean of three replicates.

† Standard deviation.

Inc., Cary, North Carolina). The simulated rainfall rate, time-to-runoff, canopy coverage, metolachlor mass applied, metolachlor mass intercepted by canopy, metolachlor mass recovered prerainfall, metolachlor mass recovered postrainfall, metolachlor mass unavailable for washoff, and metolachlor mass washed off the cotton were analyzed as a split-plot with three replications of each treatment. Year was the whole plot, and row spacing was the subplot. Antecedent soil moisture data were analyzed as a split-split plot, with three replications of each treatment. Year was the whole plot, row spacing was the subplot, and sampling depth was the sub-sub plot. Cumulative runoff, runoff rate, sediment runoff concentration, cumulative sediment loss, metolachlor runoff concentration, and cumulative metolachlor loss were analyzed as a split-split plot with year as the whole plot, row spacing as the subplot, and sampling time as the sub-sub plot. Least square means were calculated, and mean separation ($p \leq 0.05$) was produced using PDMIX800 in SAS, which is a macro for converting mean separation output to letter groupings (Saxton 1998).

Results and Discussion

Hydrology. Differences in plant geometry and root distribution between wide- and narrow-row cotton did not alter antecedent soil moisture or time to runoff for the growth stages evaluated, four- to six-leaf stage (tables 1 and 2). This denotes equivalent water use and/or evapotransportation rates between narrow- and wide-row cotton at the four- to six-leaf stage (table 1). There is limited potential, therefore, for row spacing to alter time to runoff for cotton during growth stages ranging from emergence to the six-leaf stage (table 2). These data are contrasted with those for soybean and peanut where

Table 2

Metolachlor applied, simulated rainfall applied, and time to runoff for wide- and narrow-row cotton established in Stoneville, Mississippi, in 2006 and 2007. Year main effect for all parameters was significant at $p < 0.05$.

	2006			2007		
Parameter	Wide	Narrow	Pooled	Wide	Narrow	Pooled
Metolachlor applied (kg ha^{-1})	0.94* (0.08)†	0.98 (0.06)	0.96b‡	1.19 (0.01)	1.21 (0.03)	1.20a
Rainfall applied (mm)	23.7 (0.6)	24.3 (0.6)	24.0b	26.2 (1.3)	27.5 (2.8)	26.8a
Time to runoff (min)	3.7 (0.6)	4.3 (0.6)	4.0b	6.2 (1.3)	7.5 (2.8)	6.8a

* Mean of three replicates.

† Standard deviation.

‡ Means within a row that are followed by the same letter are not significantly different across years at $p \leq 0.05$.

Table 3

Cumulative runoff from wide- and narrow-row cotton established in Stoneville, Mississippi, in 2006 and 2007. Year by spacing ($p = 0.0001$) and year by time ($p = 0.0002$) interactions were significant.

	2006			2007		
Time (min)	Narrow (mm)	Wide (mm)	Pooled (mm)*	Narrow (mm)	Wide (mm)	Pooled (mm)
0	0.0† (0.00)‡	0.0 (0.00)	0.0	0.0 (0.00)	0.0 (0.00)	0.0
5	1.5 (0.43)	1.3 (0.33)	1.4	0.2 (0.08)	0.7 (0.34)	0.5
10	3.9 (0.49)	3.6 (0.38)	3.7	1.5 (0.83)	2.6 (0.41)	2.1
15	6.5 (0.51)	6.3 (0.24)	6.4	3.5 (1.21)	4.8 (0.29)	4.1
20	9.5 (0.45)	9.3 (0.36)	9.4	5.7 (1.38)	7.5 (0.19)	6.6
25	10.3 (0.59)	10.2 (0.37)	10.3	7.0 (1.24)	8.3 (0.21)	7.6
Pooled§	6.4	6.1		3.6	4.8	

* Runoff values pooled over narrow- and wide-row cotton within year (2006 or 2007) can be compared within time with least significant difference ($LSD_{0.05[year \times time]} = 0.60$).

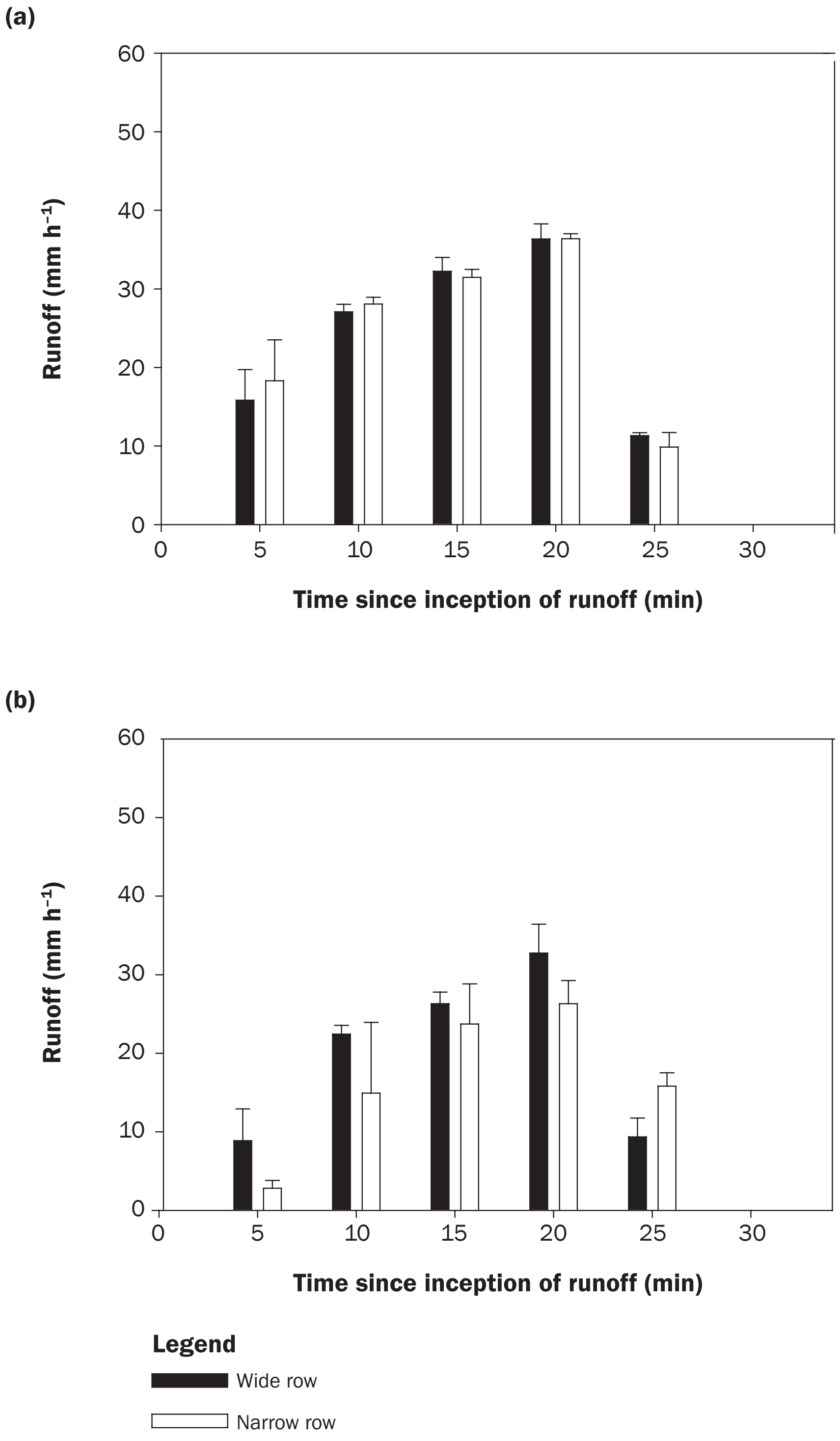
† Mean of three replicates.

‡ Standard deviation.

§ Runoff values pooled over time can be compared across row-spacing and year with $LSD_{0.05(year \times spacing)} = 0.60$.

Figure 1

Runoff rate from wide- and narrow-row four- to six-leaf stage cotton established on a Dundee silty clay loam (fine-silty, mixed thermic Aeric Ochraqualf) near Stoneville, Mississippi, in (a) 2006 and (b) 2007. Nominal rainfall intensity was 60 mm h^{-1}. Error bars denote one standard deviation. Year by row spacing by sampling time interaction was significant at $p = 0.0162$. Least significant difference ($\text{LSD}_{0.05[\text{year} \times \text{spacing} \times \text{time}]} = 5.3$).



narrow- or twin-row systems increased time to runoff relative to conventional row spacing (Krutz et al. 2007; Shelton et al. 1986; Truman and Williams 2001).

A differential response in cumulative runoff and runoff rate between the row spacings occurred across years (table 3; figure 1). In 2006, cumulative runoff and runoff rate were independent of row spacing. In 2007, cumulative runoff and runoff rate from wide-row cotton were at least 25% higher than that of narrow-row cotton. We propose that cumulative runoff differences between row spacings across years arose from an interaction between antecedent soil moisture level and root channel distribution at the time of runoff-generating rainfall. That is, as antecedent moisture decreases, more evenly distributed root channels within narrow-row systems have greater potential to increase infiltration rates relative to wide-row systems. Future laboratory experiments are required to elucidate this mechanism. We conclude that cumulative runoff from four- to six-leaf stage narrow-row cotton will likely be equivalent to or less than that of wide-row systems, which is similar to results for corn (*Zea mays* L.), dry bean (*Phaseolus vulgaris* L.), grain sorghum (*Sorghum bicolor* [L.] Moench), peanut (*Arachis hypogaea* L.), soybean, and sugarbeat (*Beta vulgaris* L.) (Adams et al. 1978; Colvin and Laflen 1981; Krutz et al. 2007; Mannering and Johnson 1969; Shelton et al. 1986, Sojka et al. 1992; Truman and Williams 2001).

Sediment Transport. Planting narrow-row cotton on flat seedbeds rather than slightly raised seedbeds, as is common for wide-row systems, has potential to reduce erosion rates across the midsouth. The runoff sediment concentration and cumulative sediment losses were at least 38% lower in narrow-row rather than wide-row cotton, regardless of the year (table 4; figure 2). Similar results were noted for corn, dry bean, grain sorghum, peanut, soybean, and sugar beets. Lower sediment loss in narrow-row cotton than in wide-row systems under conditions of those experiments was attributed to greater canopy coverage and/or reduced cumulative runoff (Adams et al. 1978; Colvin and Laflen 1981; Krutz et al. 2007; Mannering and Johnson 1969; Shelton et al. 1986, Sojka et al. 1992; Truman and Williams 2001). Under the conditions of our experiment, however, canopy coverage in narrow-row cotton was either less than or equivalent to that of wide-row cotton at the growth stages evaluated (table 5). Reduced sediment loss in narrow-row cotton cannot be attributed, therefore, to greater canopy coverage and reduced rainfall impact. A plausible explanation for lower erosion rates from narrow-row cotton relative to wide-row cotton is bed height. Truman and Bradford (1993) reported less erosion from cotton planted flat relative to cotton planted on raised beds (Truman and Bradford 1993). Moreover, as canopy coverage increases in narrow-row cotton relative to wide-row cotton at later growth stages (Reddy et al. 2009), we suspect an additive interaction between canopy coverage and bed height from approximately 8 to 11 weeks after planting. Simulated rainfall experiments occurring during this window are required if this interaction is to be confirmed.

Spray Rate Validation. Within a year, metolachlor recovered from spray targets was not different between narrow- and wide-row cotton (table 2). Metolachlor concentration pooled over row spacing was 76% of the nominal application rate in 2006 and 95% of the nominal application rate in 2007. Spray target data confirm that metolachlor transport differences between row spacings within year are associated with a treatment effect and not variations in herbicide deposition. Thus, measured deposit amounts were used to calculate foliar interception at the time of application and off-site loss as a fraction of metolachlor applied within year.

Table 4

Sediment concentration in runoff from wide- and narrow-row cotton established in Stoneville, Mississippi, in 2006 and 2007. Year by row spacing interaction was significant at p = 0.0001).

	2006		2007	
Time (min)	Narrow (g L^{-1})	Wide (g L^{-1})	Narrow (g L^{-1})	Wide (g L^{-1})
0	0.0* (0.0)†	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
5	5.0 (1.6)	7.6 (2.0)	4.7 (0.9)	15.7 (4.0)
10	5.4 (2.0)	9.1 (3.3)	4.8 (1.7)	19.1 (6.2)
15	5.2 (2.3)	9.1 (3.5)	6.0 (2.3)	19.6 (4.6)
20	5.3 (2.5)	8.2 (3.3)	4.9 (2.0)	19.7 (5.9)
Pooled‡	5.2	8.5	5.1	18.5

* Mean of three replicates.

† Standard deviation.

‡ Sediment concentration pooled over time can be compared across row spacing and year with least significant difference ($LSD_{0.05[\text{year} \times \text{spacing}]}$ = 1.72).

Field Foliar Washoff. Metolachlor intercepted by the canopy rapidly becomes unavailable for foliar washoff and, consequently, subsequent off-site transport. Independent of year or row spacing, at least 92% of the metolachlor intercepted by the cotton canopy was unavailable for rainfall washoff 1 day after application (table 5). Similar results were noted for metolachlor intercepted by soybean and toxaphene, a lipophilic, nonpolar pesticide, intercepted by cotton (Krutz et al. 2007; McDowell et al. 1985). The behavior of these nonpolar pesticides is contrasted with that of polar compounds, where at least 90% of the mass intercepted by crop canopies is available for rainfall washoff 1 d after application (Matocha et al. 2006; Wauchope et al. 2004; Caseley and Coupland 1980; Cohen and Steinmetz 1986; Pick et al. 1984; Sundaram 1990; Willis et al. 1992; Reddy et al. 1994; Reddy and Locke 1994). The differential response between polar and nonpolar pesticides in relation to their rainfall washoff arises from the propensity of lipophilic, nonpolar pesticides to penetrate waxes at the leaf surface, thereby becoming difficult to dislodge by rainfall washoff (Leonard 1990; Krutz et al. 2007). Therefore, cropping systems that increase canopy coverage at the time of pesticide application can reduce off-site transport of these lipophilic, nonpolar compounds. This mechanism, however, will likely not be significant in reducing the transport of ionic herbicides applied over the top of the cotton

Table 5

Canopy coverage (Coverage) at the time of herbicide application, mass of metolachlor intercepted by cotton canopy (Intercepted), metolachlor mass available for wash-off from cotton canopy twenty-four hours after application (Prerainfall), metolachlor available for wash-off following simulated rainfall event (Postrainfall), metolachlor intercepted by cotton canopy unavailable for rainfall wash-off (Unavailable), and metolachlor washed off cotton canopy during simulated rainfall event (washoff). Year by row spacing interactions were significant at $p \leq 0.05$ for all parameters. Means within column can be compared with least significant difference ($LSD_{0.05[\text{year} \times \text{spacing}]}$) within a given column.

	2006		2007		
Parameter	Narrow	Wide	Narrow	Wide	$LSD_{0.05}$
Coverage (%)	18.00* (1.59)†	24.92 (6.88)	32.13 (4.07)	29.60 (2.76)	4.757
Intercepted (kg ha^{-1})	0.18 (0.03)	0.23 (0.07)	0.38 (0.05)	0.35 (0.04)	0.039
Prerainfall (g ha^{-1})	12.88 (5.57)	3.14 (3.39)	7.38 (0.75)	3.14 (1.09)	5.944
Postrainfall (g ha^{-1})	0.66 (0.18)	0.15 (0.05)	0.39 (0.04)	0.72 (0.14)	0.174
Unavailable (% intercepted)	92.26 (4.58)	98.71 (3.12)	98.10 (0.10)	97.40 (0.48)	4.756
Washoff (% applied)	1.28 (0.66)	0.33 (0.34)	0.58 (0.10)	0.70 (0.08)	0.689

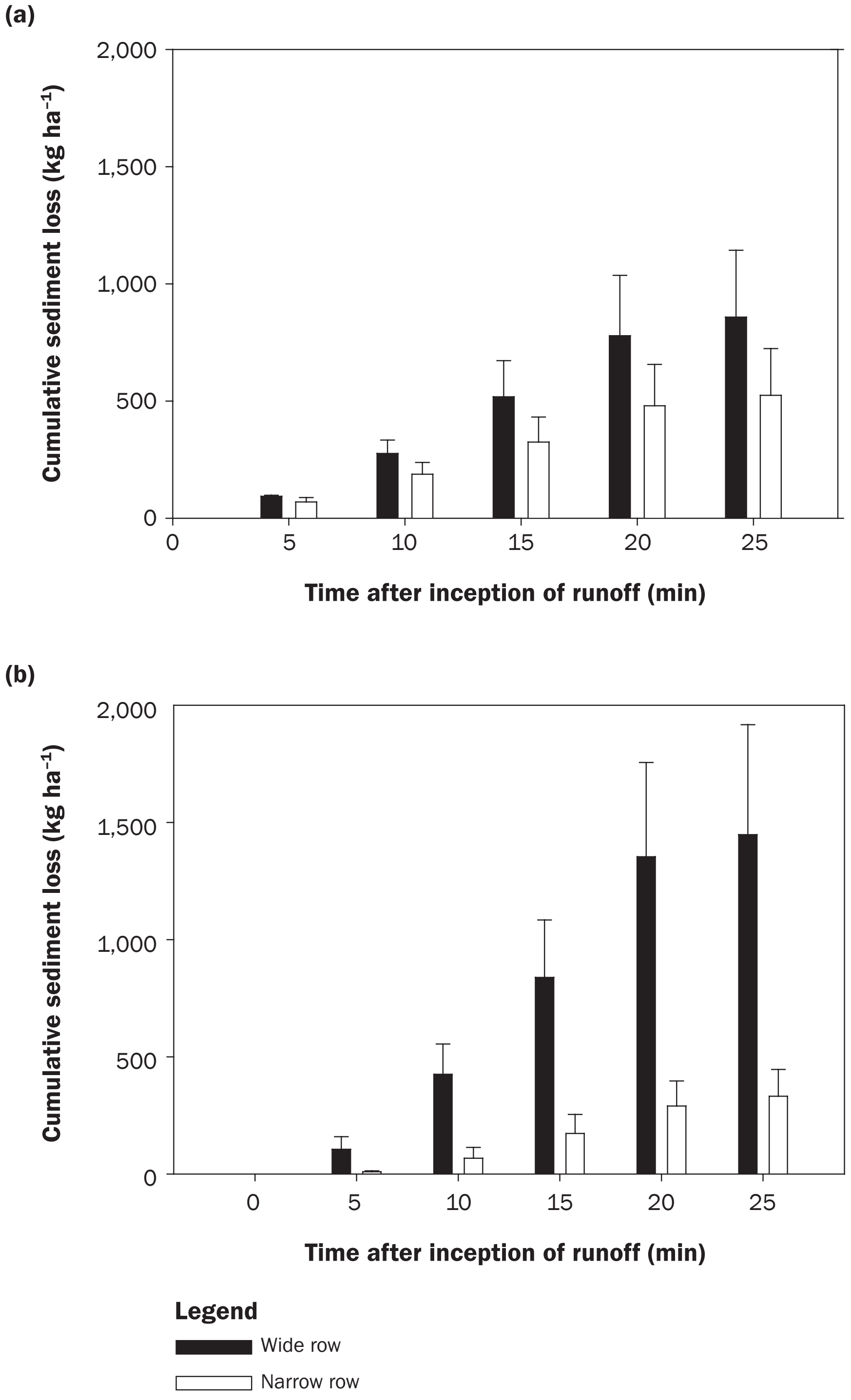
Notes: Intercepted = canopy coverage at time of herbicide application (fraction) × herbicide mass applied (kg ha^{-1}). Prerainfall herbicide concentration = water extractable herbicide 24 h after herbicide application (g $plant^{-1}$) × plant density (plants ha^{-1}). Postrainfall = water extractable herbicide immediately following simulated rainfall event (g $plant^{-1}$) × plant density (plants ha^{-1}). Unavailable = [(intercepted – prerainfall) / intercepted] × 100. Washoff = [(prerainfall – postrainfall) / mass applied] × 100

* Mean of three replicates.

† Standard deviation.

Figure 2

Cumulative sediment loss from wide- and narrow-row four- to six-leaf stage cotton established on a Dundee silty clay laom (fine-silty, mixed thermic Aeric Ochraqualf) near Stoneville, Mississippi, in (a) 2006 and (b) 2007. Nominal rainfall intensity was 60 mm h^{-1}. Error bars denote one standard deviation of three replicates. Year by row spacing by sampling time interaction was significant at $p < 0.0001$. Least significant difference ($LSD_{0.05[year \times spacing \times time]}$ = 201).



canopy due to their tendency to be readily washed off leaf surfaces.

A differential response in cotton canopy coverage and metolachlor intercepted by the canopy occurred across years (table 5). In 2006, canopy coverage and metolachlor intercepted by the canopy were at least 1.3-fold higher in wide-row cotton relative to narrow-row cotton. Conversely, in 2007, canopy coverage and metolachlor intercepted by the canopy were not different between row spacings. Thus, canopy coverage in narrow-row cotton will not be greater than that of wide-row systems from the time of planting up to at least the six-leaf stage, which is near the last time that metolachlor can be applied over the top of cotton. As the herbicide mass reaching the soil surface is inversely proportional to canopy coverage at the time of application (Beverlein and Donigian 1979), lack of differentiation in canopy coverage between row spacings indicates limited potential for narrow-row cotton to reduce metolachlor's mixing-zone concentration via foliar interception from growth stages ranging from planting to at least the six-leaf stage. However, this mechanism could be critical in reducing the off-site loss of other nonpolar, agrochemicals applied from approximately 8 to 11 weeks after planting due to approximately 50% greater canopy coverage in narrow-row relative to wide-row cotton (Reddy et al. 2009).

Metolachlor Transport in Runoff. Independent of row spacing, initial pesticide concentration in both narrow- and wide-row cotton was higher in 2007 than 2006 (Krutz et al. 2007) (tables 1, 2, and 6). Pooled over years, metolachlor runoff concentration in narrow-row cotton was at least 1.4-fold higher than that of the wide-row system from runoff inception until 5 min into the runoff event. From 10 min after runoff inception until runoff ceased, pesticide concentration was not different between row spacings. Consequently, cumulative runoff from narrow-row cotton receiving a postemergence application of a nonpolar pesticide at or prior to the six-leaf stage must be reduced relative to wide-row systems if pesticide transported in surface runoff is to be curtailed.

Differences in metolachlor runoff concentration between row spacings are likely a function of canopy coverage and leaf overlap at the time of pesticide application and rainfall. Higher metolachlor concentration in runoff from narrow-row relative to wide-

Table 6

Metolachlor concentrations in runoff from simulated rainfall in wide- and narrow-row cotton established in Stoneville, Mississippi, in 2006 and 2007. Year by time (p = 0.0006) and row spacing by time (p = 0.0003) interactions were significant.

	Interactions (mg L^{-1})			
	Year × time*		Spacing × time†	
Time (min)	2006	2007	Wide	Narrow
0	0.00‡ (0.00)§	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
5	0.75 (0.21)	1.01 (0.25)	0.73 (0.24)	1.03 (0.21)
10	0.35 (0.10)	0.61 (0.08)	0.43 (0.08)	0.52 (0.16)
15	0.22 (0.05)	0.43 (0.05)	0.32 (0.03)	0.33 (0.10)
20	0.15 (0.03)	0.32 (0.05)	0.25 (0.04)	0.22 (0.07)
$LSD_{0.05}$	0.225#		0.226**	

* Metolachlor concentration in surface runoff is pooled over narrow-row and wide-row cotton within year, 2006 and 2007.

† Metolachlor concentration in runoff is pooled over year within row spacing, narrow and wide row.

‡ Mean of six replicates.

§ Standard deviation.

\# Least significant difference (LSD) for year by time interaction.

** LSD for spacing by time interaction.

Table 7

Cumulative metolachlor loss in dissolved phase of surface runoff from wide-row and narrow-row cotton established in Stoneville, Mississippi, in 2006 and 2007. Year by row spacing interaction was significant at p = 0.0001.

	2006		2007	
Time (min)	Narrow (% of applied)	Wide (% of applied)	Narrow (% of applied)	Wide (% of applied)
0	0.0* (0.0)†	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
5	2.2 (0.5)	1.6 (1.1)	0.3 (0.1)	0.5 (0.1)
10	3.6 (0.8)	2.5 (1.4)	1.1 (0.7)	1.6 (0.1)
15	4.4 (0.9)	3.2 (1.5)	1.9 (0.9)	2.5 (0.2)
20	5.0 (0.9)	3.8 (1.7)	2.5 (0.9)	3.4 (0.4)
25	5.1 (0.8)	3.9 (1.7)	2.7 (0.9)	3.5 (0.4)
Pooled‡	4.1	3.0	1.7	2.3

* Mean of three replicates.

† Standard deviation.

‡ Cumulative metolachlor loss pooled over time can be compared among row spacing and years with least significant difference ($LSD_{0.05[\text{year} \times \text{spacing}]}$ = 0.23).

row cotton was not associated with factors affecting mixing zone concentration and extraction because pesticide mass applied, pesticide reaching soil surface immediately following application, and time to runoff were not different between row spacings (tables 2 and 5). However, we did note that leaves from four- to six-leaf stage cotton from adjacent plants were overlapping only in the wide-row system. This may indicate that leaf overlap serves as a mechanism to reduce rainfall washoff and subsequent transport in surface runoff. Our 2006 data supports this hypothesis in that metolachlor washoff was 3.9-fold higher in narrow-row relative to wide-row cotton (table 5). Controlled laboratory studies are required to confirm this hypothesis, however.

A differential response in cumulative metolachlor loss occurred between years (table 7). In 2006, cumulative metolachlor loss was 1.4-fold higher from narrow-row relative to wide-row cotton. We attributed greater metolachlor loss from narrow-row cotton in 2006 to factors known to increase pesticide mixing zone concentrations and subsequent herbicide concentrations in runoff (e.g., lower canopy coverage and greater metolachlor washoff in narrow-row relative to wide-row cotton [table 5]), coupled with equivalent water loss between systems (table 3). Conversely, in 2007, metolachlor transport from wide-row cotton was 1.4-fold higher than that of the narrow-row system (table 7). In 2007, however, factors governing mixing zone pesticide concentration (e.g., canopy coverage, metolachlor intercepted by the canopy, time to runoff, and metolachlor washoff) were similar between row spacings (tables 2 and 5). Concurrently, cumulative pooled runoff from narrow-row cotton was 1.3-fold lower than that of the wide-row system (table 3; figure 1). Combining the 2006 and 2007 pesticide runoff data indicates that planting cotton in narrow rows rather than wide rows may reduce the off-site loss of metolachlor applied at or prior to the six-leaf stage if cumulative runoff is reduced in the narrow row system and factors governing mixing-zone pesticide concentrations are equivalent between systems.

Summary and Conclusions

Results from this two-year simulated rainfall study indicate that erosion and loss of nonpolar pesticides applied over the top of four- to six-leaf narrow-row cotton can be reduced relative to wide-row systems if specific criteria are met. First, converting from wide-row to narrow-row cotton alters planting geometry whereby roots and root channels are more evenly distributed in the narrow-row system. If more uniformly distributed roots decrease antecedent moisture and/or facilitates greater infiltration, then runoff rate and cumulative runoff will be lower in narrow-row relative to wide-row cotton. Second, switching from raised-bed, wide-row cotton to flat-bed, narrow-row systems reduces runoff sediment concentration and cumulative sediment loss by 39%, even if there is no differentiation in groundcover or antecedent soil moisture between row spacings. Finally, off-site losses of nonpolar pesticides may be curtailed if factors that reduce mixing-zone pesticide concentration (i.e., canopy coverage at the time of pesticide application, foliar absorption, and time to runoff) are lower in narrow-row than wide-row cotton. Our microplot data indicate that converting from wide-row to narrow-row cotton may reduce water, sediment, and herbicide loss throughout the midsouth Cotton

Belt. Future research on narrow-row systems conducted at the field and watershed scales is required to confirm this hypothesis, however.

Disclaimer

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA.

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