CONVERSION FROM COTTON TO SHORT-ROTATION WOODY CROPS: HYDROLOGIC IMPACTS

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INTRODUCTION

In the wake of a global search for new and efficient sources of energy, biomass plantations have been identified as having the potential to provide many values to society. Biomass plantations, such as short rotation woody crops (SRWCs), are being assessed for the possibility of large-scale implementation for use as a sustainable source of renewable energy. Biomass produced in these plantations could be either burned directly in incinerators to produce electricity, or the wood can be converted into methane for use as a cleaner burning liquid fuel.

Although research on the environmental impacts of SRWC systems is limited, that which is available indicates that they have the potential to provide many environmental advantages over traditional agriculture, (i.e., annual rowcrops).SRWCs have the potential to meet high standards of environmental quality on a broad range of cropland types, including certain environmentally sensitive areas (ORNL 1992). The majority of land that will be put into SRWC production will be that which has historically been used for more traditional agriculture (Grahm 1994). But SRWCs can also be considered a more robust crop for areas not well suited for traditional agriculture, such as flood- prone areas.

Overall environmental impacts of SRWs will be determined by previous land use, the particular energy crop being grown, how the crop is managed, and the overall effort made to integrate the crop with regional landscape ecology (OTA 1993; ORNL 1992). As a substitute for traditional agriculture, such as row-cropped cotton, properly managed SRWCs can help stabilize erodible soils and filter agricultural chemicals and sediments before they reach water supplies (OTA 1993). Conversely, substituting SRWCs for pasture, hay, or well managed Conservation Reserve Program lands will generally have mixed environmental impacts (OTA 1993).

Physical characteristics of SRWCs, as well as cultural practices implemented for their production, contribute to their potential environmental advantages over traditional agriculture. SRWCs require less cultivation, less traffic of heavy machinery, and generally fewer inputs of agricultural chemicals. SRWCs also have the potential to be more efficient in fertilizer use due to nutrient retention and cycling that occurs between growing seasons, a phenomenon that is negligible in traditional annual agricultural systems. Furthermore, SRWCs often have deeper and heavier rooting patterns which utilize more soil volume for water, nutrient, and agricultural chemical uptake (OTA 1993).

Perhaps the most easily recognizable impact that SRWC systems have on soil is reduced erosion. The average rotation period for SRWCs is typically 4-8 years. After harvesting, the stands will be coppiced, or regenerated from stump sprouts, and harvested repeatedly on cycles of up to 25 years (Lortz and Betters 1993). This comparatively long period of soil coverage will protect mineral soil to a much greater extent than traditional annual rowcrops. SRWC's heavy rooting patterns and annual depositions of organic matter also play key roles in reducing erosion. Furthermore, SRWCs can be harvested when soil conditions are most favorable, unlike agricultural crops that must be harvested within a certain time frame when the crop is ready.

Another environmental advantage of SRWCs is annual deposition of organic matter which often increases soil water holding capacity and is a very important source of essential nutrients. It also helps buffer soil against extremes of acidity/alkalinity (Tisdale et al. 1993). SRWCs may substantially increase soil organic matter compared with conventional rowcrops, with overall gains in productivity and soil quality (OTA 1993). Organic matter also provides a surface to which fertilizers, heavy metals, and pesticides will adhere rather than leaching through the soil (OTA 1993). This has implications for management of agricultural chemicals and reduction of possible off-site migration.

With proper management, SRWCs may significantly decrease non-point pollution of surface waters from agricultural practices, with attendant benefits for water quality and fish habitat (OTA 1993). In addition to having a greater capacity to utilize nitrogen, it is generally believed that SRWCs will require less nitrogen fertilizer than agricultural crops (OTA 1993, Tschaplinski et al. 1991; Ranney and Mann 1994). SRWCs will generally require less inputs of all agricultural chemicals than conventional row-crops. However, large amounts of nutrient removal per unit of biomass harvested will require some level of fertilization to sustain productivity (Tschaplinski et al. 1991). It may also be necessary at times to treat SRWCs with insecticides to control pest problems. Furthermore, research indicates that failure of these SRWC systems is likely without control of weedy vegetation during the first one or two growing seasons (Colletti et al. 1991). The greater capacity to absorb chemicals combined with overall lower chemical inputs of SRWCs provide substantial possibilities for water quality management. Highly productive SRWCs use up to 300-1000 tonnes of water per tonne of biomass grown (OTA 1993). This volume of water use could be either positive or negative, depending on location. SRWCs could provide a useful new tool for management of water tables in poorly drained areas, or a more robust crop for areas prone to flooding (OTA 1993).

The focus of this project is to explore environmental impacts of SRWCs on hydrology by quantifying and comparing hydrologic responses of cottonwood and cotton plantations. This project is designed to determine the usefulness of SRWCs, as compared to conventional cotton production, for combating soil erosion, improving quality, quantity, and timing of overland flow, intercepting inorganic nitrogen (NO_3-N, and NH_4-N) and phosphate before reaching the groundwater, management of water table depths, and improving infiltration capabilities of soil.

STUDY AREA

This study is being conducted in Stoneville, Mississippi, at the Delta Branch Agricultural Experiment Station. The study area consists of six approximately one-acre (.37 ha) plots adjacent to Deer Creek. Three of the plots were randomly chosen to be planted annually in cotton and the remaining three were planted in cottonwood (*Populus deltoides* Bartr.) SRWCs. The site is on agricultural land that is dominated by a Bosket silt loam soil, which is a fine-loamy, mixed, thermic Mollic Hapludalfs. This alluvial soil is considered highly productive for agriculture.

The land slopes gently to the west and slightly northwest, away from Deer Creek. This causes surface runoff generated on-site to flow away from the creek. Berms have been pulled up around each of the experimental plots such that overland flow generated within a plot is funneled through a 1.5 ft. H-flume that lies at the western end of each plot. These berms also prevent the entry of overland flow generated outside of the experimental plots. In addition to flumes, each plot contains four pan lysimeters (buried at a depth of 75 cm), nine 3-meter piezometers, and four neutron probe access tubes also placed to a depth of 3 meters.

Cotton was planted in three plots using conventional methods so that the crop would not differ from that found in a typical cotton plantation. Three plots were also planted with cottonwood cuttings at a spacing of 4 by 12 ft. (1.2 by 3.7 meters) within the berms, with an additional two rows of trees with the same spacing outside the berms. The extra two rows of trees on each side of the SRWCs were planted to provide uniformity within the study plots by eliminating edge effects.

METHODS

Overland flow

H-Flumes located at the western end of each plot are used to monitor the overland flow generated within the plots. Flumes are operated by Flowlink software which is connected to an ISCO 3230 bubbler-type flow meter which monitors flow depth, and an ISCO 2900 water sampler that draws water samples from a sample splitter attached to the H-flume (ISCO, Herrilberg, Switzerland).

The Flowlink software is programmed to begin sampling overland flow after 2000 liters of water have passed through a flume. Additional volumes of 2000 liters trigger the ISCO sampler to draw corresponding 500 ml samples. This process continues until either the samplers are full or the runoff event ceases. Up to 24 samples can be held within the samplers so that comparisons may be made among samples taken during various stages of the runoff event.

The Flowlink software is also used to produce hydrographs for each plot and runoff event. These hydrographs provide information on rates and timing of overland flow. By keeping the samples separate we are able to compare them to the hydrograph to check for relationships in time and flow, to peak sedimentation and nutrient export. The samples collected from the flumes by the ISCO samplers are analyzed for inorganic nitrogen (NO_3-N, and NH_4^+ -N) and ortho-phosphate using a Technicon Auto Analyzer II (Technicon Industrial Systems, Tarrytown, N.Y.)

Samples taken from the flumes are also analyzed for total suspended sediments. Sediment is removed from water samples by filtering measured volumes. Sediment collected from flumes after each runoff event is analyzed for total N, inorganic N, total P, and extractable P.

Sub-surface water

Pan lysimeters are used to monitor water percolating through root zones of the cotton and cottonwood plantations. Water that percolates into the pans drains into a below-ground collection container where it can be pumped to the surface, sampled, and the volume contained can be recorded. The samples collected are then analyzed for inorganic nitrogen and ortho-phosphate using an auto analyzer. Lysimeter collection is conducted after precipitation events.

Water table depths are monitored weekly using 54 piezometers spread across the study area. Groundwater samples will be collected monthly to determine levels of inorganic nitrogen and ortho-phosphate using an auto analyzer.

Four 3-meter aluminum access tubes are spaced evenly in each plot and are used to lower a Campbell Scientific Hydroprobe 503 neutron moisture gauge (Boart Longyear Co., Martinez, California) which provides weekly readings of soil moisture at sampling depths of .5, 1, 1.5, 2, 3, 4, 6, 8, and 10 feet (.15, .3, .5, .61, .91, 1.2, 1.8, 2.4, and 3 meters) or just above the water table. Neutron counts have been calibrated with gravimetric samples to determine water-volume content.

Hydrologic Balance

Water balances for each plot will be calculated using the equation $Pg=Et+\Delta S+Q$; where, Pg is gross precipitation, Et is evapotranspiration, ΔS is change in soil water storage, and Q is overland flow. Gross precipitation is measured using an ISCO 8-inch tipping-bucket raingauge placed in the open. In addition to Pg, throughfall precipitation (represented by T) is monitored by a series of portable raingauges randomly placed under the canopies in each of the experimental plots. ΔS is monitored weekly using a neutron moisture gauge and piezometers. Q is monitored by the flumes and Flowlink software. Et is assumed to be the difference between Pg and $\Delta S + Q$ ($Pg-(\Delta S+Q)=Et$). Infiltration rate (I) will be calculated as the difference in throughfall precipitation and overland flow over time and will use the following equation: $I=(T-Q)\div t$, where t is equal to the actual period of rainfall. Using T instead of Pg to calculate infiltration rate excludes any water that is intercepted by, and subsequently evaporated from, the plant canopies. Water balances will be calculated on a weekly basis.

Statistical Analysis

Data are analyzed using a completely random design with one-way analysis of variance (ANOVA) using two treatments and three replications to test for treatment effects. Analysis of variance procedures are run on plot means in order to test null hypotheses.

PRELIMINARY RESULTS

First-year data indicate that there were no significant treatment effects on volumes of water being discharged from the experimental plots. However, it is important to note that the cotton plots discharged more water in the earlier runoff events and the SRWCs discharged more water in the later events (Figure 1). Although the differences were insignificant, they were enough to affect sediment and selected nutrient fluxes.

Concentrations of NO_3-N were similar for both treatments during the initial eight months of the study (Figure 2). The SRWC tended to have slightly higher concentrations than the cotton treatment, but the differences were not statistically significant. Higher volume discharge from SRWCs during latter events, coupled with a slightly higher NO_3-N concentration during the January 6, 1996, event, resulted in a significantly higher NO_3-N flux for that event.

Ammonium -N concentrations and fluxes tended to be higher in SRWC plots during the first growing season (Figure 3). Fertilization with NH_4NO_3 in May 1995 probably contributed to the high NH_4-N flux from SRWC plots observed on May 31, 1995.

Although cotton plots tended to export higher concentrations of bioavailable-P during the first eight months, bioavailable-P flux from cotton plots was only significantly higher on May 31, 1995 (Figure 4).

Surface-runoff concentration and loss of total P from cotton plots was consistently higher during the initial study period (Figure 5). This is probably associated with consistently higher concentrations and export of total suspended sediments observed in the cotton plots during the same period. Four of the initial eight runoff events produced significantly higher concentrations of TSS in the cotton plots and two of the initial eight runoff events produced significantly higher TSS fluxes (Figure 6).

SUMMARY

This paper presents an overview of expected environmental benefits of SRWCs when compared with conventional agricultural row crops. A newly established study comparing cotton production with short -rotation eastern cottonwood production has been implemented at the Delta Branch Experiment Station in Stoneville, Mississippi, to assess hydrologic and soil responses when cotton sites are converted to cottonwood. Preliminary results from first-year surface runoff data suggests higher export of TSS and total P from cotton plots than from short-rotation cottonwood plots. However, reliable environmental-impact comparisons between the two systems will require continued data collection throughout the rotation of the SRWC.

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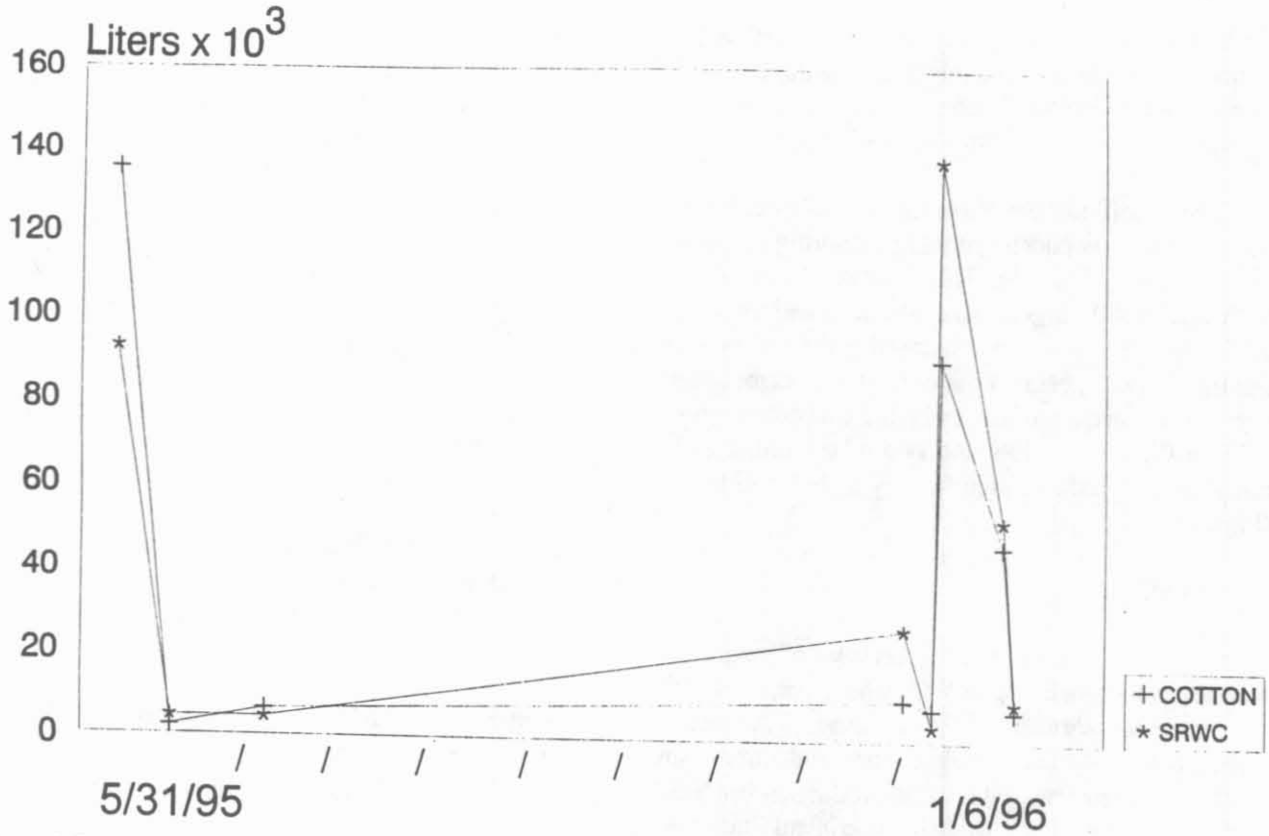

Figure 1. First-year effects of cotton and short-rotation cottonwood on surface runoff.

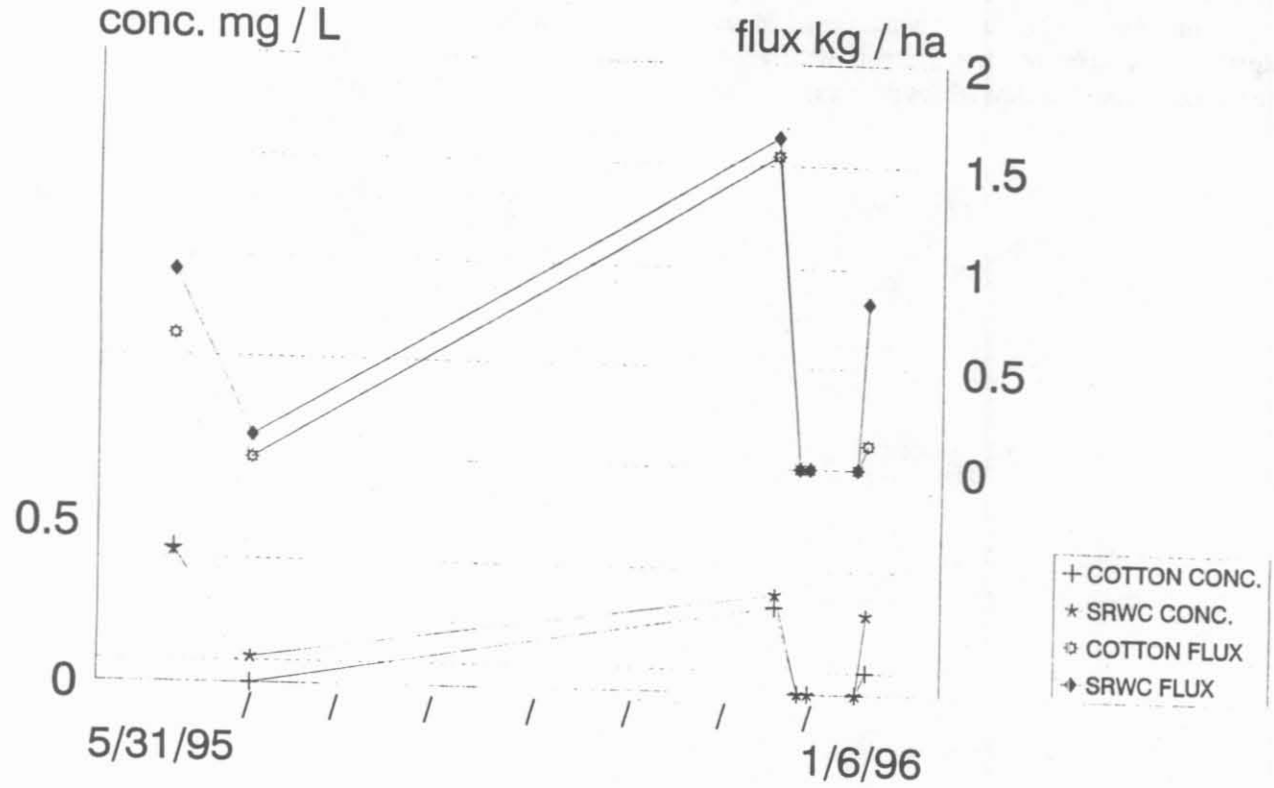

Figure 2. First-year effects of cotton and short-rotation cottonwood on nitrate-N in surface runoff.

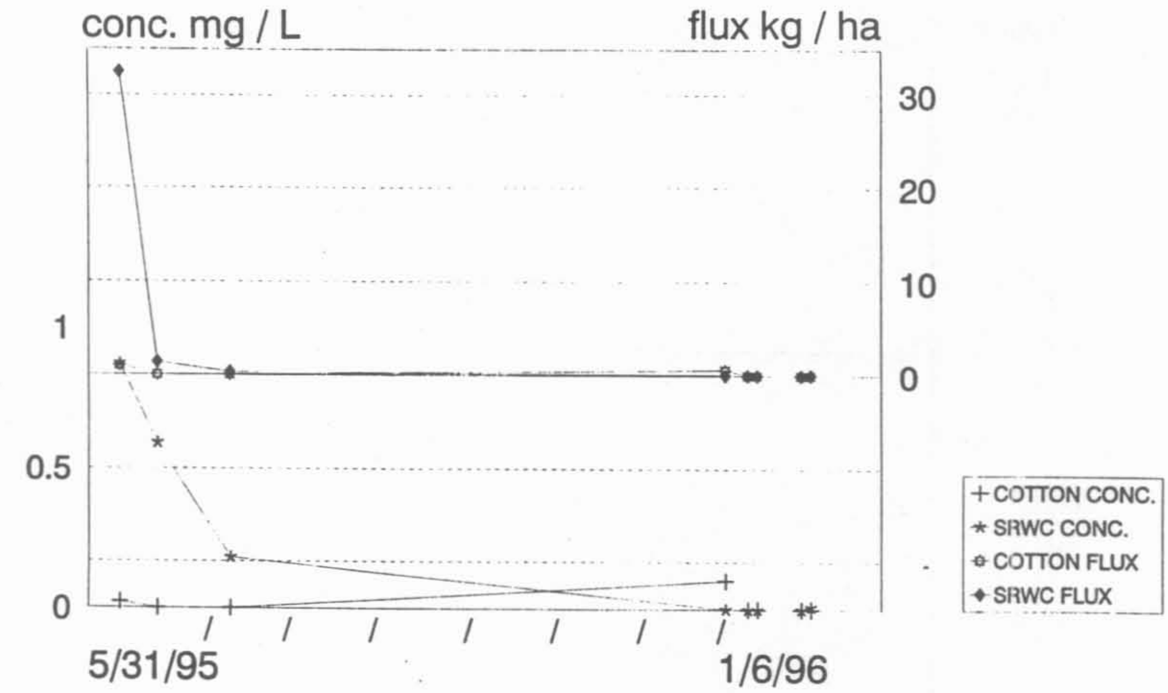

Figure 3. First-year effects of cotton and short-rotation cottonwood on ammonium-N in surface runoff.

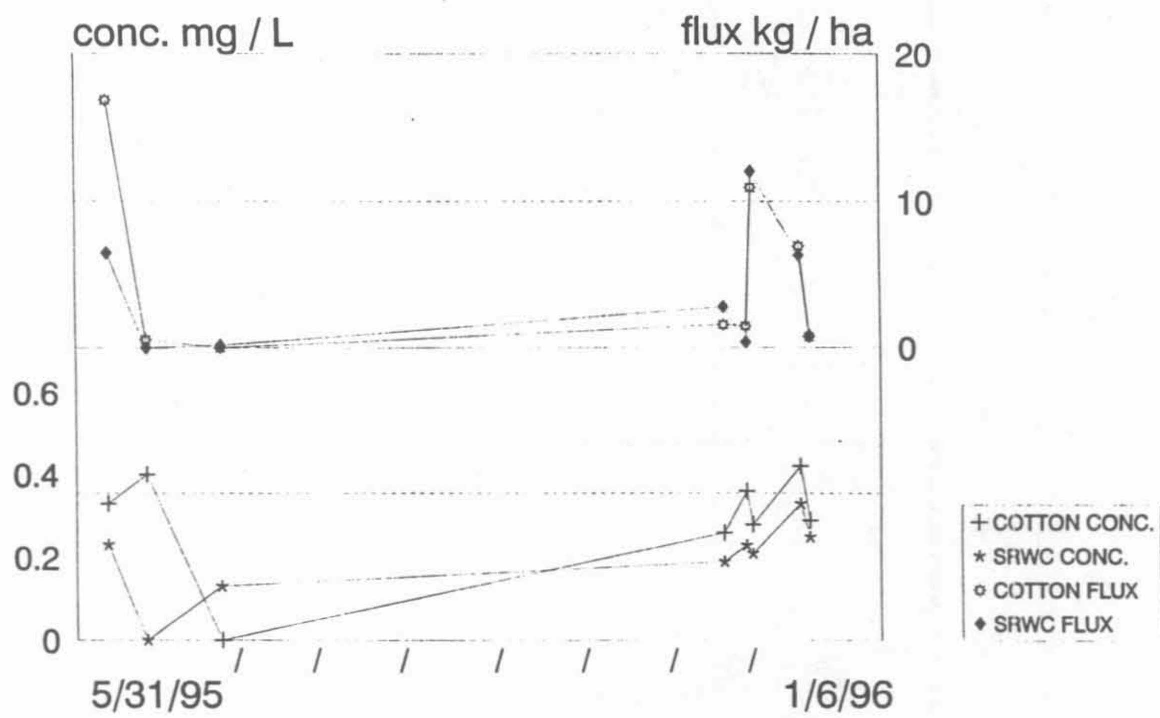

Figure 4. First-year effects of cotton and short-rotation cottonwood on bioavailable-P in surface runoff.

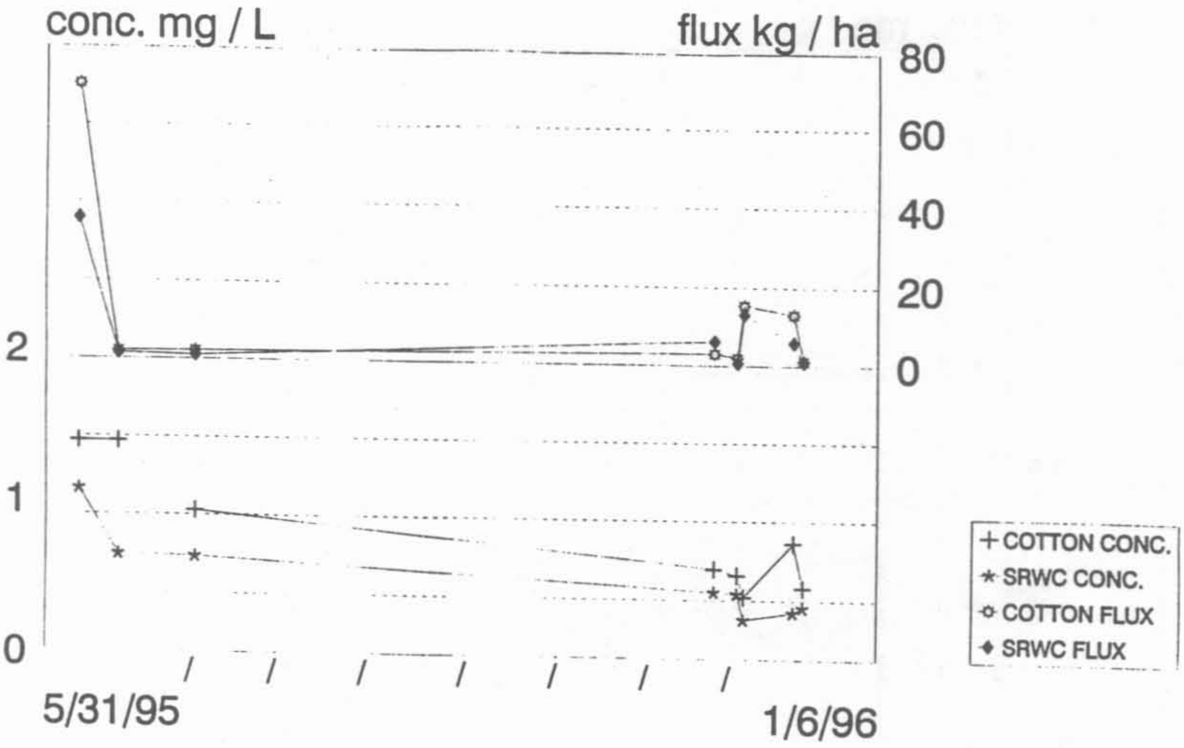

Figure 5. First-year effects of cotton and short-rotation cottonwood on total-P in surface runoff.

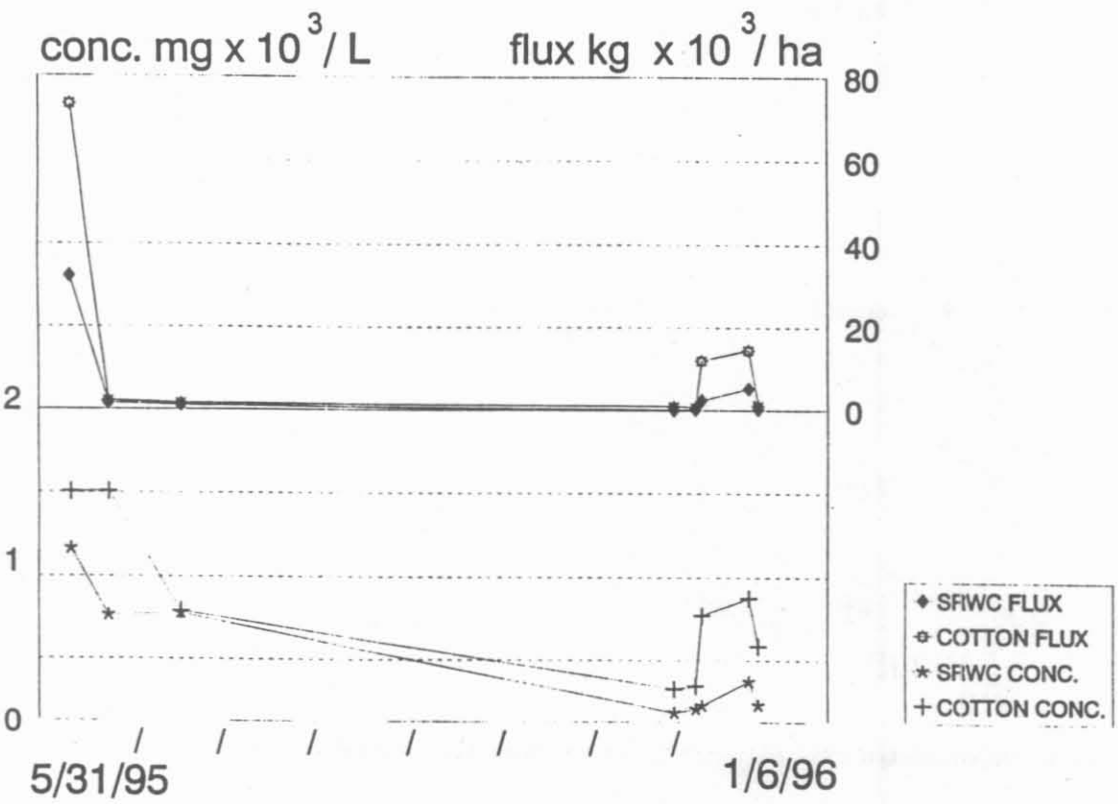

Figure 6. First-year effects of cotton and short-rotation cottonwood on TSS in surface runoff.