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논 문

Feasibility of EPIC to Assess Long-Term Water Quality Impacts for a Fast Growing Cottonwood Bioenergy Crop

Bioenergy 작물인 Cottonwood의 재배가 수질에 미치는 장기적인 영향을 평가하기 위한 EPIC 모델의 적용 가능성 검토

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초 록

화석연료의 고갈에 대비한 대체에너지 개발의 일환으로 미국의 에너지성과 TVA는 속성수인 Cottonwood를 재배하여 에너지화 하는 연구를 하고 있다. 미시시피주 Stoneville에 0.365ha 크기의 시험포 6개를 설치하고 Cottonwood와 Cotton을 재배하며 환경영향을 평가하기 위하여 유출량, 부유물질(TSS), 질산성 질소(NO_3-N), 총인(T-P) 등의 수질인자를 모니터링하고 있다. 본 연구는 EPIC 모델이 이들 수질인자들을 예측할 수 있는지를 평가하고 Cottonwood의 재배가 유출수의 수질에 미치는 장기적인 영향을 평가하기 위하여 수행되었다. EPIC 모델의 유출량 예측치는 실측치와 비교적 잘 일치하였으며, Cottonwood 시험포의 유출량은 장기적으로 Cotton 시험포의 유출량에 비하여 37% 작게 유출되는 것으로 나타났다. TSS의 예측은 재배 초기에는 잘 맞지 않았으나 Cottonwood가 성장하면서 실측치와 예측치는 비교적 잘 일치하는 것으로 나타났다. 질산성 질소와 총인의 예측치는 실측치와 잘 일치하지 않아 EPIC을 이용한 이들의 장기적인 영향의 예측에는 세심한 주의가 필요한 것으로 나타났다. EPIC 모델은 Cottonwood 시험포의 유출량과 TSS를 비교적 잘 예측하여 Cottonwood 재배가 장기적인 강우 및 TSS 유출에 미치는 영향을 평가할 수 있는 도구로 사용될 수 있다고 판단되었다.

Ⅰ. Introduction

Use of woody biomass as a feedback for generation of electricity or conversion to liquid fuels is receiving considerable attention in part because of the potential environmental benefits projected with conversion of conventional cropland to short rotation woody biomass crops. Conversion of erosive or marginally productive agricultural

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lands to woody crop production has been identified as having both environmental and economic benefits. The potential for fast growing woody crops, such as hybrid poplar, sweetgum, sycamore, and eastern cottonwood, to be grown on thousands of acres of agricultural lands necessitates identification of the potential benefits and impacts of this land use conversion on water quality, soil stability, land resources, and biota(Ranney and Mann, 1994). And the conversion of cropland to short rotation woody crops was predicted to result in reductions in runoff and soil erosion as well as reductions in nitrate, phosphorus, pesticides and herbicides in runoff and groundwater(Pimentel and Krummel, 1987; Hohenstein and Wright, 1994; Ranney and Mann, 1994).

Pimentel and Krummel(1987) estimated the erosion form short rotation woody crops to be an order of magnitude less than that from row crops, while hay land(or switchgrass) erosion was an order of magnitude less than that woody crops. The decrease in erosion with short rotation woody crops might be greater if a cover crop were used to stabilize soils during the first two growing seasons(Ranney and Mann, 1994). One of the largest impacts of cropland conversion could be upon the quantity of runoff. Woody crops have a larger leaf area than annual crops and maintain that leaf area for a considerably longer portion of the year. And their deeper rooting depth could result in substantially greater evapotranspiration and infiltration, and less potential for surface runoff. However, the critical examination about impacts of the land conversion on water quality has not been thoroughly performed.

Biomass use as an energy source in the USA is anticipated to increase to between 13% and 25% by 2030(Hohenstein and Wright, 1994). An analysis of the environmental impacts of the production system is urgently required before the biomass production systems are implemented. Field monitored data sets on fast growing herbaceous and woody biomass production systems are the best sources for the basis to estimate the environmental impacts of the systems. However, such data are expensive to obtain over an extended time frame and cannot be readily obtained for the desired ranges of conditions. Thus, the use of models to examine the potential water quality benefits of biomass production is of interest.

EPIC(Environmental Policy Integrated Climate formerly Erosion-Production Impact Calculator) was developed to assess the effect of soil erosion on productivity and predict the effects of management decisions on soil, water, nutrient and pesticide movement and their combined impact on soil loss, water quality and crop yields for areas with homogeneous soils and management (Williams et al., 1997). EPIC has been applied to numerous projects related to agricultural production, soil erosion and environmental quality, and publications and references about EPIC were well documented (Mitchell, 1998). Runoff, soil erosion and total suspended solids(TSS) discharge, nitrate loss(NO_3-N) in runoff, and total phosphorus(T-P) loss are some of the variables that EPIC can estimate. These variables are considered key elements in managing and controlling non-point source pollutant discharges from rural agricultural fields.

The objective of this study was to investigate EPIC's ability to assess the long-term impacts of fast growing cottonwood production system on water quality at the edge of fields by comparing monitored and predicted data. The analysis of EPIC's ability to estimate these parameters will be an indication of its ability to predict the long-term environmental impacts of the fast growing bioenergy crops on water quality. The results may be used to help develop environmentally sound biomass production systems and predict the long-term water quality impacts of the systems.

Ⅱ. Methods

The Tennessee Valley Authority(TVA), the U.S. Department of Energy's Bioenergy Feedstock Development Program(BFDP), and cooperating universities are currently investigating biomass production systems to develop cost-effective production methods for biomass crops that protect soil and water quality as an alternative to agricultural crop production. Plot scale studies at three locations in the southeastern US with various herbaceous and woody crops were designed to estimate the local and regional impacts of the biomass production systems on water quality at the edge of field and some of the monitoring research results were reported(Green et al., 1996; Houston, 1996; Malik et al., 1996; Thornton et al., 1996; Tolbert et al., 1997a; Tolbert et al., 1997b).

Among the monitored data sets at the three locations, data sets collected at the Delta Research and Extension Center site at Stoneville, Mississippi, were chosen to model with EPIC. Six experimental runoff plots of 0.365 ha each were established at the center. Two treatments of cotton(Gissypium hirsutum L.) and cottonwood(Populus deltoides Bartr) were randomly assigned to the 6 plots. Cotton was the control plot and cottonwood plots were designed to compare to the control plot and to assess the impact of the biomass production systems on water quality at the edge of field. Cottonwood cuttings were established at a spacing of 1.2m within each row by 3.6m between each row in February and March, 1995. Management of cotton followed typical local practices. Runoff volume, sediment and nutrient transport have been monitored on an event basis for about 3 years since the tree crop establishment in early 1995. An earth berm about 50cm in height was constructed around each plot to hydrologically isolate the plots from surrounding fields, and H-flume systems were set up to measure runoff from each plot.

The soil at the Delta Research and Extension Center is Bosket silty loam and is a highly productive alluvial soil(Mitchell, 1997) with an average slope of 0.2%. The Center areas have been under cotton cultivation for at least 15 years. Detailed experimental procedures and some of the monitoring results were reported by Tolbert et al.(1997b). The runoff and water quality variables measured were event based runoff volume, total suspended solids(TSS), nitrate nitrogen(NO_3-N) and total phosphorus(T-P, dissolved). Summarized runoff plot configuration, treatment, and fertilizer application rates are shown in Tables 1 and 2, respectively.

〈Table 1〉 Runoff plot treatment at the Delta Research and Extension Center at Stoneville, Mississippi, USA

Plot No.	Area (ha)	Slope (%)	Treatment
1	0.365	0.13	Cotton
2	0.365	0.22	Cottonwood
3	0.365	0.10	Cottonwood
4	0.365	0.12	Cotton
5	0.365	0.13	Cottonwood
6	0.365	0.19	Cotton

〈Table 2〉 Annual N and P fertilizer application rates for experimental plots at the Delta Research and Education Center at Stoneville, Mississippi, USA

Year	N fertilizer (kg/ha)		P fertilizer (kg/ha)	
	Cotton	Cottonwood	Cotton	Cottonwood
1995	112	112	0	0
1996	112	112	0	0
1997	112	57	0	0
Total	336	281	0	0

EPIC is a data intensive program and requires many model parameters which are either readily available from the builtin data bases or simulated. Model input data for crops, soil, and tillage were chosen from the data bases. Maximum and minimum temperatures, solar radiation, relative humidity, and wind velocity were simulated and rainfall input data was collected at the experimental site. For runoff and soil erosion, the SCS CN method and the small watershed version of MUSLE options were chosen, respectively (Mitchell, 1998). Other site specific and management data were provided based on the study site field data (Tolbert, 1998).

Graphical comparison, coefficient of determination, and the Nash-Sutcliffe Efficiency(Nash and Sutcliffe, 1970) were used to evaluate EPIC's ability to predict the measured variables. Because all of the runoff events and associated variables were not monitored during the study, the evaluations between measured and predicted values were based on the measured and matching predicted values.

Ⅲ. Results and Discussion

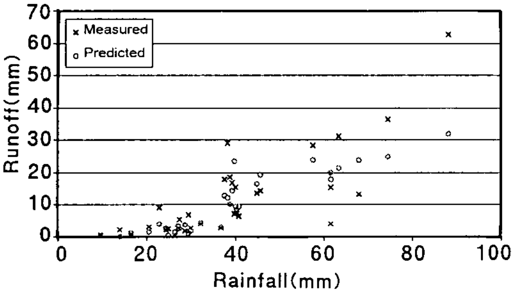
1. Runoff

Measured runoff from both cotton and cottonwood plots did not show a significant difference during the 3-year study. However, measured runoff from cotton plots tended to be larger than that from cottonwood plots when rainfall became increased beyond 60 mm/day.

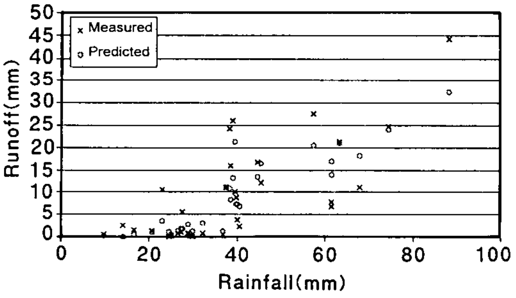
Measured and predicted runoff from both cotton and cottonwood plots agreed reasonably well<Fig. 1 and Fig. 2>. However, for both treatments measured runoff varied more widely than predicted runoff and tended to become larger than predicted runoff when rainfall was higher than 70 mm/day. Both the coefficient of determination and the Nash-Sutcliffe Efficiency showed a good association between measured and predicted runoff<Table 3>. Annual sums(mm) and differences(%) of measured and predicted runoff also showed a good fit<Table 4>. The sum of predicted runoff was computed only where there was a matching field measured runoff at the same date.

〈Table 3〉 The coefficient of determination and the Nash-Sutcliffe Efficiency between measured and predicted variables at the Delta Research and Education Center, Stoneville, MS

Treatment	Runoff	TSS	NO_3-N	T-P
Coefficient of determination				
Cotton	0.61	0.02	0.11	0.26
Cottonwood	0.71	0.64	0.00	0.13
Nash-Sutcliffe efficiency				
Cotton	0.59	-6.64	-14.11	-2.75
Cottonwood	0.71	-20.37	-83.13	-0.66



〈Fig. 1〉 Measured and predicted runoff from cotton plots at the Delta Research and Education Center, Stoneville, MS



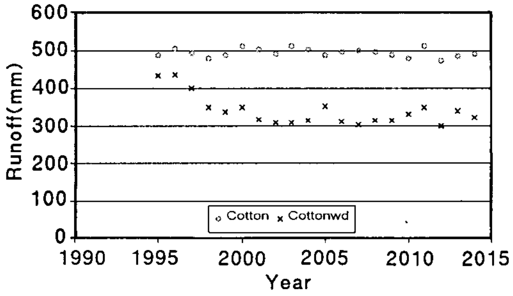
〈Fig. 2〉 Measured and predicted runoff from cottonwood plots at the Delta Research and Education Center, Stoneville, MS

<Fig. 3> shows 20-year long-term runoff simulation for both cotton and cottonwood plots. The simulation was based on the measured rainfall of 1,606mm in 1995 and other weather variables were simulated by EPIC. Runoff simulated from cotton plots remained the same over time; while runoff from cottonwood plots gradually decreased for the first 4 years and then stabilized. Annual runoff from cottonwood plots after runoff stabilization was about 37% less than that from cotton plots, meaning that the conversion from cotton to cottonwood culture may significantly reduce runoff and runoff related non-point pollutant discharges from agricultural lands. The reduced runoff from cottonwood plots might be attributed to increased infiltration due to a deep root system developed by the cottonwood over time. The predicted dry weights of cottonwood roots and shoots increased from 1.5ton/ha and 2.37ton/ha at the end of 1995 to 33.9ton/ha and 62.83ton/ha at the end of 1999, respectively. Extensive root development might loosen the soil and dense foliage and fallen leaves protect the soil from the

〈Table 4〉 Annual comparison between measured and predicted runoff at the Delta Research and Education Center, Stoneville, MS

Year		1995	1996	1997	Total
Annual rainfall (mm)		1,606.7	1,410.0	1,419.7	4,436.4
Rainfall (mm) for analysis[1]		357.9	709.4	181.9	1,249.2
No. event runoff measured		7	19	9	35
Cotton	Measured (mm)	129.4	191.1	65.6	386.0
	Predicted (mm)	118.0	165.7	48.1	331.7
	Diff (%)[2]	8.8	13.3	26.7	14.1
Cottonwood	Measured (mm)	113.6	134.2	53.6	301.4
	Predicted (mm)	108.5	135.8	38.4	282.7
	Diff (%)[2]	4.5	-1.2	28.3	6.2

1 Part of annual rainfall that caused the measured runoff for analysis
2 Diff(%) = (Measured-Predicted)/Measured*100



〈Fig. 3〉 **Results of 20-year runoff simulation for cotton and cottonwood plots at the Delta Research and Education Center, Stoneville, MS for the same yearly rainfall of 1,606mm**

surface sealing, resulting in increase of infiltration.

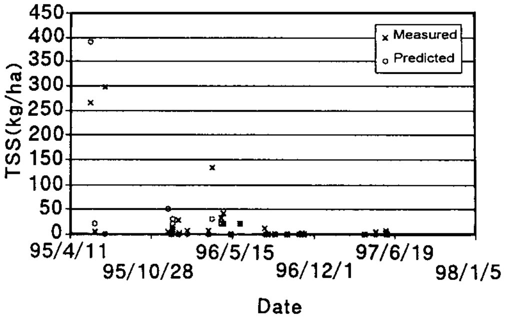
2. Total Suspended Solids (TSS)

Measured TSS discharges from cotton plots were generally greater than those from cottonwood plots. Measured TSS discharges from cottonwood plots tended to decrease with time while those from cotton plots did not. Measured TSS discharges from cotton and cottonwood plots were less than 520kg/ha and 300kg/ha, respectively, except for two extreme cases which occurred at cotton plots after bedding preparation and prior to planting and were 2,810kg/ha and 1,071 kg/ha. No unusual TSS discharge was observed at cottonwood plots.

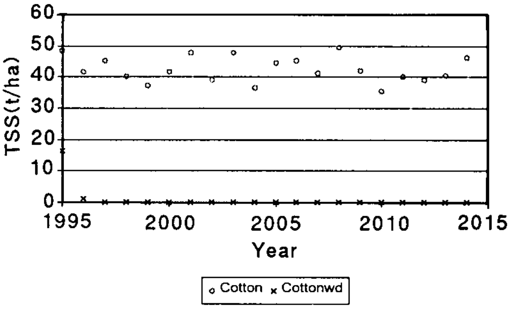
Measured and predicted TSS discharges from cotton plots did not fit well and varied widely. For both measured and predicted TSS, the recent soil disturbance such as field cultivation and bedding preparation significantly increased TSS discharges if rainfall followed shortly. Both the coefficient of determination and the Nash-Sutcliffe efficiency between measured and predicted TSS from cotton plots were small because of the wide variation. Measured and predicted TSS discharges from cottonwood plots fit reasonably well although a few large differences were observed at the beginning of the study<Fig. 4>. The differences decreased with time and from the middle of 1996, both the measured and predicted TSS discharges from cottonwood plots were less than 10kg/ha while many of the measured and predicted TSS discharges from cotton plots were more than 500kg/ha. The magnitudes of both measured and predicted TSS from cottonwood plots were generally much smaller than those from cotton plots. The coefficient of determination between measured and predicted TSS from cottonwood plots showed a reasonable association but the Nash-Sutcliffe efficiency was very low<Table 3>.

The annual sum of predicted TSS discharges from cotton plots was generally much larger than that of measured TSS discharges<Table 5>. The differences between annual sums of measured and predicted TSS discharges from cottonwood plots were not as large as that of cotton plots. The magnitude of TSS discharge from cottonwood plots was very small and decreased with time.

<Fig. 5> shows 20-year long-term TSS simulation for both cotton and cottonwood.



<Fig. 4> Measured and predicted TSS from cottonwood plots at the Delta Research and Education Center, Stoneville, MS



<Fig. 5> Results of 20-year TSS simulation for cotton and cottonwood plots at the Delta Research and Education Center, Stoneville, MS

<Table 5> Annual comparison between measured and predicted TSS at the Delta Research and Education Center, Stoneville, MS.

Year		1995	1996	1997	Total
Cotton	No. of measure	6	19	6	31
	Measured (kg/ha)	637.4	5,067.2	811.6	6,516.2
	Predicted (kg/ha)	3,820.0	9,410.0	3,820.0	17,050.0
	Diff (%)[1]	-499.3	-85.7	-370.7	-161.7
Cottonwood	No. of measure	6	17	5	28
	Measured (kg/ha)	299.3	308.2	13.9	621.4
	Predicted (kg/ha)	510.0	110.0	0.0	620.0
	Diff (%)[1]	-70.4	64.3	100.0	0.2

1 Diff(%) = (Measured-Predicted)/Measured*100

Annual TSS discharges from cotton plots maintained the same magnitude throughout the simulation. However, annual TSS discharges from cottonwood plots decreased to zero in 3 years. The oscillation might be caused by different weather conditions generated by EPIC except for rainfall that had a fixed value of 1,606 mm.

3. Nitrate-Nitrogen (NO_3-N) and Total Phosphorus (T-P)

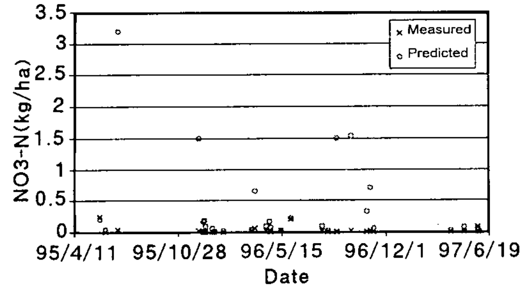
Measured NO_3-N losses from both cotton and cottonwood were not significantly different although cotton plots lost slightly more NO_3-N than cottonwood plots. N fertilizer applied to both cotton and cottonwood plots were not much different during the 3-year study<Table 2> and thus, NO_3-N losses from both plots were thought to be similar. Measured NO_3-N losses ranged from 0 to 0.337kg/ha for cotton plots and 0 to 0.241 kg/ha for cottonwood plots except for one extreme event. The extreme NO_3-N loss of 4.33kg/ha occurred from the cottonwood plots when 44.7mm rainfall with 16.6mm runoff occurred(5/3/97) within two days of N fertilizer application(57 kg/ha).

Predicted NO_3-N losses from both cotton and cottonwood plots were generally much greater than measured NO_3-N losses <Fig. 6>. The magnitudes of predicted NO_3-N losses from cotton and cottonwood plots ranged from 0 to 2.13kg/ha and 0 to 3.19 kg/ha, respectively. The coefficient of determination and the Nash-Sutcliffe efficiency were very low. Annual sums of predicted and measured NO_3-N losses were very different from each other.

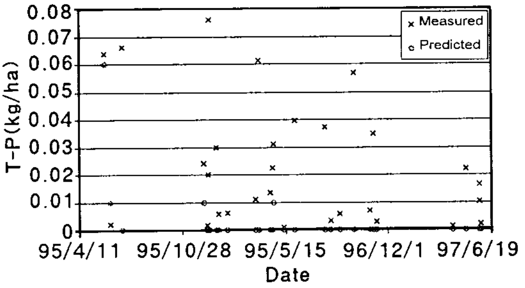
Measured T-P losses from cotton plots tended to be higher than the losses from cottonwood plots. Large T-P losses were generally observed when large TSS discharges occurred. Measured T-P losses from both cotton and cottonwood plots were 0~0.191 kg/ha and 0~0.076 kg/ha, respectively.

Measured and predicted T-P losses from cotton plots did not fit well and predicted T-P losses were generally greater than measured T-P losses. However, predicted T-P losses from cottonwood plots were generally smaller than measured T-P losses. Both measured and predicted T-P losses from cotton plots were widely scattered, while the T-P losses from cottonwood plots decreased with time<Fig. 7>. The magnitude of predicted T-P losses from cottonwood plots was much smaller than that from cotton plots. Predicted T-P losses from cottonwood plots ranged from 0 to 0.01 kg/ha except for one event that was 0.06 kg/ha, while predicted T-P losses from cotton plots ranged 0 to 0.27 kg/ha. The coefficient of determination and the Nash-Sutcliffe efficiency were very low. The annual sums of predicted T-P losses from cotton plots were larger than measured T-P losses while annual sums of predicted T-P losses from cottonwood plots were smaller than measured T-P losses.

EPIC's ability to predict NO_3-N and T-P losses from both cotton and cottonwood plots was not satisfiable in this study and



〈Fig. 6〉 Measured and predicted NO_3-N from cottonwood plots at the Delta Research and Education Center, Stoneville, MS



〈Fig. 7〉 Measured and predicted T-P from cottonwood plots at the Delta Research and Education Center, Stoneville, MS

the model calibration might not be good enough to simulate long-term NO_3-N and T-P losses from the plots. It was suggested either to improve EPIC's ability before applying it to predict NO_3-N and T-P losses or to exercise carefully if EPIC is used to assess NO_3-N and T-P losses for cotton and cottonwood production system.

IV. Conclusions

The ability of EPIC to assess the long-term impacts of a fast growing cottonwood bioenergy production on water quality at the edge of fields was investigated. Two treatments(cotton as control and cottonwood) were randomly assigned to six 0.365ha runoff plots(3 replications each) established at the Delta Research and Education Center, Stoneville, Mississippi, and the 6 plots were monitored from May 1995 to the end of 1997. Characteristics of runoff, total suspended solids(TSS), nitrate-nitrogen (NO3-N) and total phosphorus(T-P) were analyzed with respect to treatments and obtained the following results:

1. Predicted runoff from both cotton and cottonwood plots fit reasonably well with measured runoff. The coefficient of determination and the Nash-Sutcliffe efficiency showed a good association between measured and predicted runoff. Annual sums of measured and predicted runoff also showed a good fit. A 20-year long-term simulation showed that runoff from cottonwood plots was about 37% less than that from cotton plots. It indicates that the conversion of land from cotton to cottonwood culture may significantly reduce runoff and runoff associated non-point pollutant discharges from agricultural fields and improve water quality in rural watersheds.

2. Predicted TSS discharges from cottonwood plots fit relatively well with measured TSS discharges as the magnitudes of both predicted and measured TSS decreased with time. Measured TSS discharge from cotton plots was larger than that from cottonwood plots. A 20-year long-term simulation showed that yearly TSS discharges from cottonwood plots decreased to zero in 3 years while yearly TSS discharges from

cotton plots oscillated between 35 to 49 ton/ha.

3. Measured and predicted NO_3-N and T-P losses did not fit well. It was suggested either to improve EPIC's ability before applying it to assess NO_3-N and T-P losses or to exercise carefully if it is used to assess NO_3-N and T-P losses for cotton and cottonwood production system.

4. EPIC was able to reasonably predict runoff from both cotton and cottonwood plots. EPIC's ability to predict TSS discharges from cottonwood plots was also relatively good. EPIC predicted poorly NO_3-N and T-P losses from both cotton and cottonwood plots. Since EPIC has a good ability to predict runoff and TSS discharge, EPIC may be used to assess the effect of land conversion from cotton to a cottonwood production system on runoff and TSS discharge.

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