I_APEX Calibration and Validation Using Research Plots in Tifton, Georgia

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Introduction

The agricultural computer model I_APEX (Interactive Agricultural Policy Environmental eXtender) was calibrated and validated for runoff and percolation hydrology as well as movement of pesticides off the edge of the field and leaching into the soil. Model simulations were compared with 2000-2001 observed results from USDA Agricultural Research Service research plots in Tifton, Georgia (Bosch et al, 2005; Potter and Bosch, unpublished, 2006). Two herbicides were applied in this study: fluometuron, a highly mobile pesticide, and pendimethalin which does not tend to leach, but will readily leave the edge of the field in both soluble runoff form and adhered to soil particles. Both were applied to fields being used for growing cotton (*Gossyplum hirsutum L.*).

I_APEX is being used to assess agricultural practices including pesticide use in the Conservation Effects Assessment Project (CEAP). CEAP began in 2003 as a multi-agency endeavor to quantify environmental benefits of conservation practices used by farmers participating in selected United States Department of Agriculture (USDA) Conservation Programs. Regarding CEAP pesticides, I_APEX assesses potential risk to humans and aquatic wildlife.

I_APEX, which uses APEX (Williams, 2006) as its core model, is an extension of the continually evolving Environmental Policy Integrated Climate model (EPIC, Williams, 2006). EPIC allows modeling of one field per simulation where APEX can perform simulations on contiguous fields and small watersheds. EPIC has been used extensively in many field and watershed studies (Bernardos et al., 2001; Rinaldi, 2001; Apezteguia et al., 2002; and many others). The model has also been calibrated and validated by Chung et al. (1999), Wang et al. (2006) and others.

Since its inception in 1996, APEX has been used in dozens of studies to evaluate the impact of agricultural practices (e.g., Ramanarayanan et al., 1997; Gassman et al., 2002; and Harman et al., 2004). In addition to this calibration/validation study, APEX has previously been calibrated/validated by Flowers et al. (1996) and others, and is currently being evaluated in other efforts by Wang (unpublished).

Materials and Methods

Site Description

Three replicate 0.14-ha plots (approximately 58 meters long and 24 meters wide) were studied at the University of Georgia Gibbs Farm facility in Tift County, Tifton, Georgia (31^0 26' N, 83^0 35' W). The plots were used to grow cotton with a winter rye cover crop (*Secale cereale L.*). The soil was Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) which contains a restrictive argillic layer (relatively greater clay content) about 15 cm deep, and a slope of about 3.5%. Texture in the A horizon consists of approximately 87% sand, 7% silt and 6% clay, and a 0.51% organic carbon content.

In early April of 2000 and 2001 the rye cover crop was killed with glyphosate (1.1 kg ha^{-1}), followed by poultry manure broadcast applied at 4.5 Mg ha^{-1}. Each plot was conventionally tilled and bedded. Cotton was planted the first week in May in 91 cm rows on center and defoliated and picked in mid-September. The plots were sprinkler irrigated according to the schedule presented in Table 1.

Table1: Irrigation Schedule on Tifton Plots

Date	**Depth (mm)**
May 5, 2000	9.1
May 23, 2000	20.3
July 3, 2000	25.4
July 18, 2000	25.4
July 21, 2000	25.4
May 4, 2001	25.4
May 11, 2001	25.4
May 18, 2001	25.4
June 21, 2001	25.4
June 27, 2001	25.4
July 10, 2001	25.4
July 18, 2001	25.4
Aug. 24, 2001	25.4
Aug. 30, 2001	25.4

The herbicides fluometuron and pendimethalin were tank-mixed and applied by a tractor-mounted ground boom 24 hours after cotton planting. In crop year 2000, fluometuron was applied at 0.89 kg ha^{-1} and pendimethalin at 0.69 kg ha^{-1}. During 2001, fluometuron was applied at 1.46 kg ha^{-1} and 42 days post planting at 1.1 kg ha^{-1} while pendimethalin was applied only after planting at 0.95 kg ha^{-1}.

Analyses were performed for soluble pesticide in runoff and percolation. Surface runoff was collected using ISCO samplers installed in flumes at the edge of each plot. Percolation was collected through a drainage tile system installed at the 1200 mm depth. Very few analyses were performed for pesticide sorbed to soil particles leaving the edge of the field, and were not modeled in this study. A more thorough description of methods used at the Tifton site can be found in Potter et al. (2004) and Bosch et al. (2005).

Model Simulation

I_APEX was employed to characterize the Tifton plots. The model required recorded daily temperature (minimum and maximum), precipitation and relative humidity. Wind speed and direction and solar radiation were based on monthly mean values gathered for the Tifton area. Detailed soil properties were obtained from Bosch and Potter (unpublished) and from the Natural Resources Conservation Service (NRCS) Tifton soil interpretive record GA0001. Hydrology balance was performed using the stochastic, varying NRCS Runoff Curve Number method. Evapotranspiration was determined using the Hargreaves equation within the APEX model.

Pesticide soil half-lives were those previously determined for the Tifton site by Potter (personal communication, 2006). Pendimethalin Koc was estimated to be 16,000 mL g^{-1} based in part on the range found in the literature and analyses by Potter (personal communication, 2007) at this site. All other pesticide properties were from the ARS/NRCS/University of Massachusetts Extension Pesticide Properties database (December, 2006) and are presented in Table 2.

I_APEX simulations determined surface runoff, and percolation water at the 1200 mm depth. Soluble pesticide mass losses in g ha^{-1} were modeled in both surface runoff and percolate.

Calibration was performed by adjusting the evapotranspiration coefficient and exponent used in the Hargreaves equation to best represent Tifton plot monitored data, based on graphic optimization. Additionally, an optimal RCN was determined by adjustment at the inception of numerous runs to best reflect soil and soil management conditions by graphic comparison of modeled runoff versus observed.

A summary of the Tifton site data and model simulation data is shown in Table 2.

Table 2: Parameter Values Used in I_APEX Simulation

Parameter Name	**Value**
Time Period Modeled	2000-2001
Weather	Daily local precipitation, temperature, relative humidity
Plot length	58 meters
Plot width	24 meters
Field slope	0.035
Hydrologic condition	Good
Irrigation ratio	0.1
Runoff Curve Number (RCN)	84
RCN method	Stochastic, varying
Tile drainage depth	1200 mm
Evapotranspiration equation	Hargreaves PET
Hargreaves PET coefficient	0.0032
Hargreaves PET exponent	0.6
Soil type	Tifton LS
Crop	Cotton
Fertilizer	Poultry litter
Pesticides	Pendimethalin, Fluometuron
Pendimethalin properties	Water solubility: 0.275 mg L^{-1} Koc: 16,000 mL g^{-1} Soil half-life: 96 days Foliar half-life: 30 days Foliar washoff fraction: 0.4
Fluometuron	Water solubility: 110 mg L^{-1} Koc: 100 mL g^{-1} Soil half-life: 75 days Foliar half-life: 30 days Foliar washoff fraction: 0.5

Results and Discussion

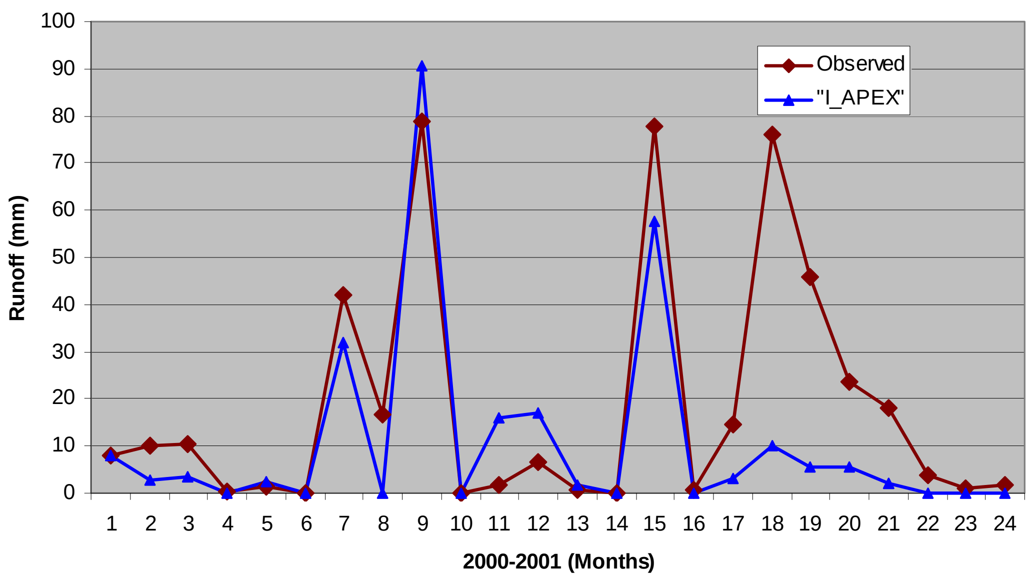
It was determined that the most appropriate RCN assignment at the inception of the run was 84 with allowance for stochastic and land use RCN variation during the run. The soil, Tifton LS has a B hydrologic soil group rating. Under good hydrologic soil conditions, conventional tillage and growing a row crop such as cotton, the expected RCN range of B soils would be 78 to 82. Employing a greater RCN leads to increased water runoff relative to percolate. Given the restrictive argillic layer in Tifton LS, it would be expected that increased runoff would occur. It is therefore not surprising that the optimal model curve number would be in the higher end of the B hydrologic soil group RCN range or slightly exceed it. The Hargreaves coefficient and exponent values of 0.0032 and 0.6, respectively, are those expected for a hot climate and were found to provide the best representation of the Tifton weather data in these simulation runs as well as based on earlier APEX modeling using Tifton weather data (Williams, personal communication, 2006).

Monthly comparisons were made of hydrology and pesticide losses using two years (2000-2001) of monitored daily data.

Runoff

As shown in Figure 1, close correlation was found between observed and simulated results for most of the 24-month period. Monthly simulated data were within 2% to 50% of monitored results until May of 2001. At that time simulated data diverged from the greater observed values. The differential increased in June, 2001 when observed levels reached about 75 mm versus only 10 mm in simulated results (a factor of 7.5). In July, 2001 that factor reached a maximum of about nine with 45 mm and five mm shown for observed and simulated results respectively.

Figure 1. Runoff from Tifton Research Plots: I_APEX Versus Observed Data



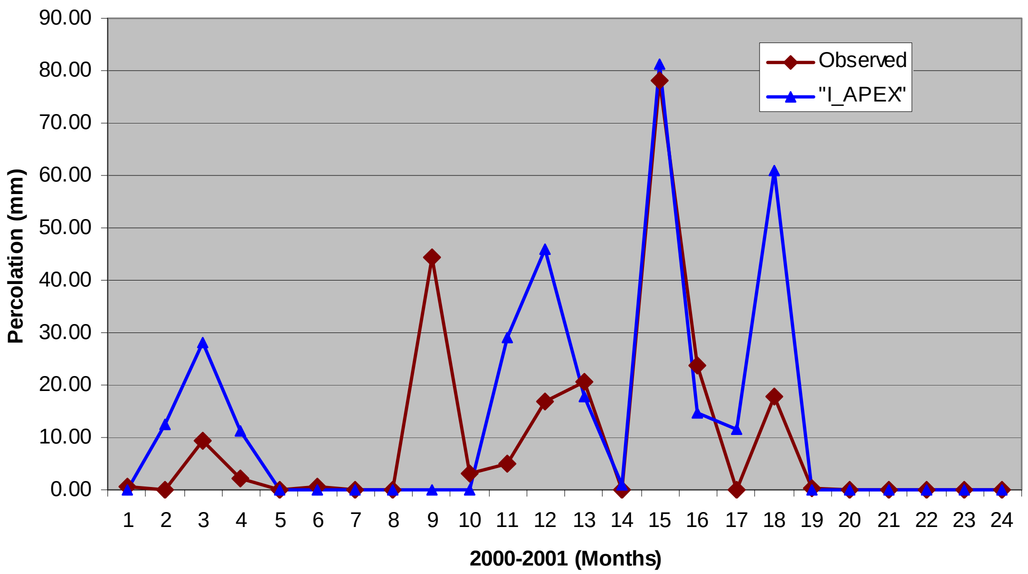
By October- December, 2001, close correlation was found once again. Overall, close agreement was found for 19 of the 24 months. One likely explanation for the deviation during the summer months of 2001 might be due to the fact that APEX uses a daily time step for precipitation. During the summer months in Tifton, storm precipitation can be intensive with 2 cm or more per hour. Actual runoff in these cases would be expected to be greater than simulated runoff in that a daily simulated rain event of 2 or 3 cm would have a much greater period of time to infiltrate into the soil. Numerous substantial rain events were recorded during the Tifton summer of 2001. In June for example, there were eight precipitation events with 1.6 to 2.2 cm. While during July, two major events were observed of 4.0 cm and 2.2 cm. Later in the summer during August, two more events were recorded of about 2 cm each.

Percolation Water Retrieved by Tile Drainage

Monthly correlation of modeled and observed percolation water at 1200 mm (depth of tiles) was not as tight of a fit as runoff values. In the early months of 2000, I_APEX output exceeded observed data by a factor of about three. In September, a spike of about 45 mm due to a tropical storm is shown for the observed data, where modeling did not indicate significant percolation until October. During the fall of 2000, modeled output exceeded monitoring by a factor of about three. Overall for the year, percolation discrepancy was very small.

In 2001, correlation was very close except for May and June. May modeled water was about 11 mm while no significant monitored water had been collected. In June, I_APEX percolate reached 60 mm while observed was only 18 mm. These greater percolate values with modeled data coincide with greater observed runoff during May and June. In total, the 2001 modeled percolate was slightly higher than observed values.

Figure 2. Percolation at 1200 mm from Tifton Research Plots: I_APEX Versus Observed Data



Pesticide Movement

Pendimethalin

With its high Koc of 16,000 mL g^{-1}, pendimethalin readily sorbs to soil organic carbon. The surface soil organic carbon was reported to be about 0.51% on a weight basis. Using this value, the pendimethalin partition coefficient (kd) on soil was estimated to be 80. This high kd resulted in virtually zero pendimethalin percolating at the 1200 mm depth in both monitoring and modeled results. This same high Koc would enable pendimethalin to readily bind to sediment leaving the edge of the field and running off in solubilized form as well. Soluble runoff movement was analyzed and compared to modeled output in Figure 3.

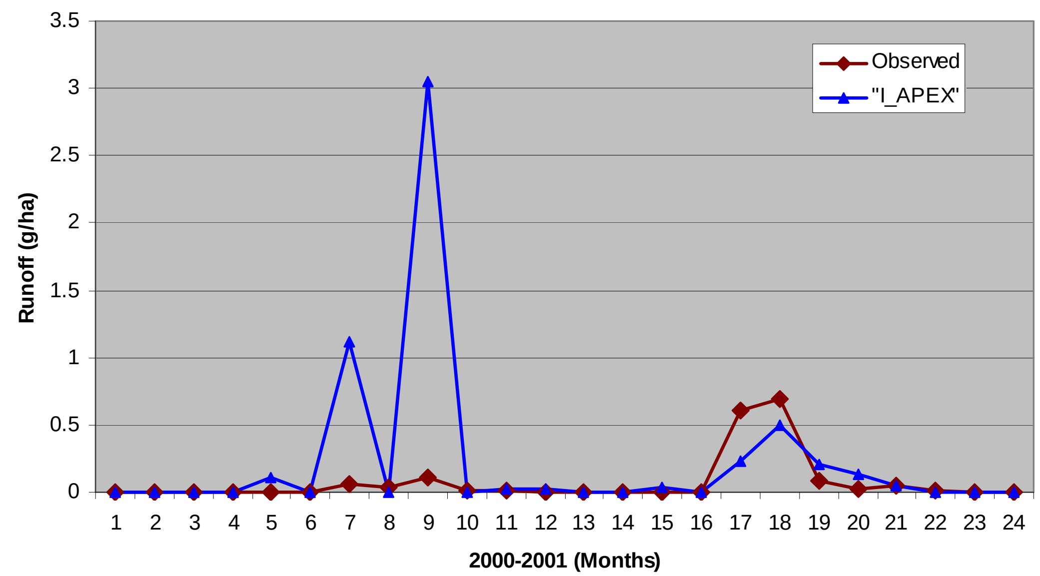


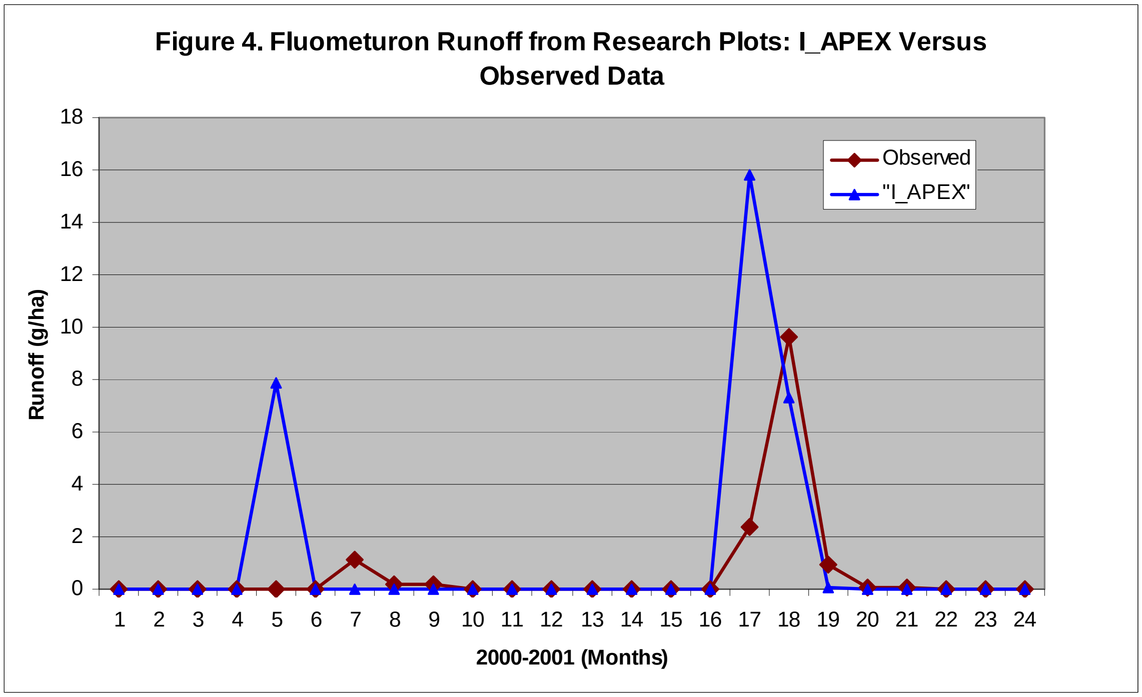
Figure 3. Pendimethalin Soluble Runoff from Research Plots: I_APEX Versus Observed Data

Pendimethalin was broadcast applied on May 2nd of both 2000 and 2001. Runoff losses occurred during the five months post application. In July and September of 2000, minimal Pendimethalin runoff of about 0.2 g ha^{-1} was observed where the model predicted significantly more Pendimethalin runoff (but still relatively low) with 1.1 g ha^{-1} and 3 g ha^{-1} for these months, respectively. The 2001 Pendimethalin runoff losses were much closer with the combined May-June observed losses equaling 1.3 g ha^{-1} compared to model results indicating a 0.4 g ha^{-1} combined loss.

Fluometuron

Fluometuron was applied the first week of May in 2000 and 2001, and was additionally applied 42 days after planting in 2001. Fluometuron properties make it prone to both runoff and percolate losses. It dissolves readily with a water solubility of 110 mg L^{-1} and remains in the environment for extended periods having a soil half-life of 75 days. Its Koc of 100 mL g^{-1} indicates that it will readily percolate into the soil, and will not sorb tightly to soil particles leaving the edge of the field.

As shown in Figure 4, observed runoff losses in 2000 were only found to occur in July with about one g ha^{-1}. Modeled 2000 losses occurred entirely in May with 7.9 g ha^{-1}. For the year, modeled losses exceeded observed losses by a factor of about eight.



In 2001, losses occurred primarily in May and June for both modeled and monitored data. May observed loss was approximately 2.3 g ha^{-1} which was exceed by modeled data of 15.8 g ha^{-1}. June losses were very close with observed mass loss at 9.6 g ha^{-1} and I_APEX output displaying a runoff loss of 7.2 g ha^{-1}. The combined 2001 losses were about 13 g ha^{-1} observed losses and modeled losses totaling about 23 g ha^{-1} or about 1.8 times the observed.

Percolation movement was generally predicted by the model to be lower than monitoring findings as shown in Figure 5. This is not surprising considering that the mass balance with modeled surface runoff was greater than observed losses. Monitored losses showed a spike in September, 2000 with 25 g ha^{-1} that was not predicted by the model. However, loss correlation from October, 2000 – December, 2001 was quite good. Figure 5 indicates that losses occurred from November, 2000 to July, 2001. The combined observed losses during this period was about 34 g ha^{-1} compared to modeled losses of 27.6 g ha^{-1}. It is notable that significant losses were found by both methods during November, 2000-January, 2001. This suggests a relatively long residence time in the soil since only one fluometuron application was made on May 2nd. The pesticide half-life was reported to be 75 days.

Annual Results

Additional insight of the calibration/validation was made by comparing the means of the two years data as shown in Table 3. Relatively good agreement is shown for both hydrology and pesticide mass losses. Simulated runoff water was only a factor of 0.6 from observed data, while simulated percolation water was greater than observed by a 1.4 factor. This led to a total water movement ratio (Simulated/Observed) of 0.9. Soluble runoff modeling overestimated pendimethalin and fluometuron by 3.2 and 2.2 times respectively, while underestimating fluometuron percolation by half.

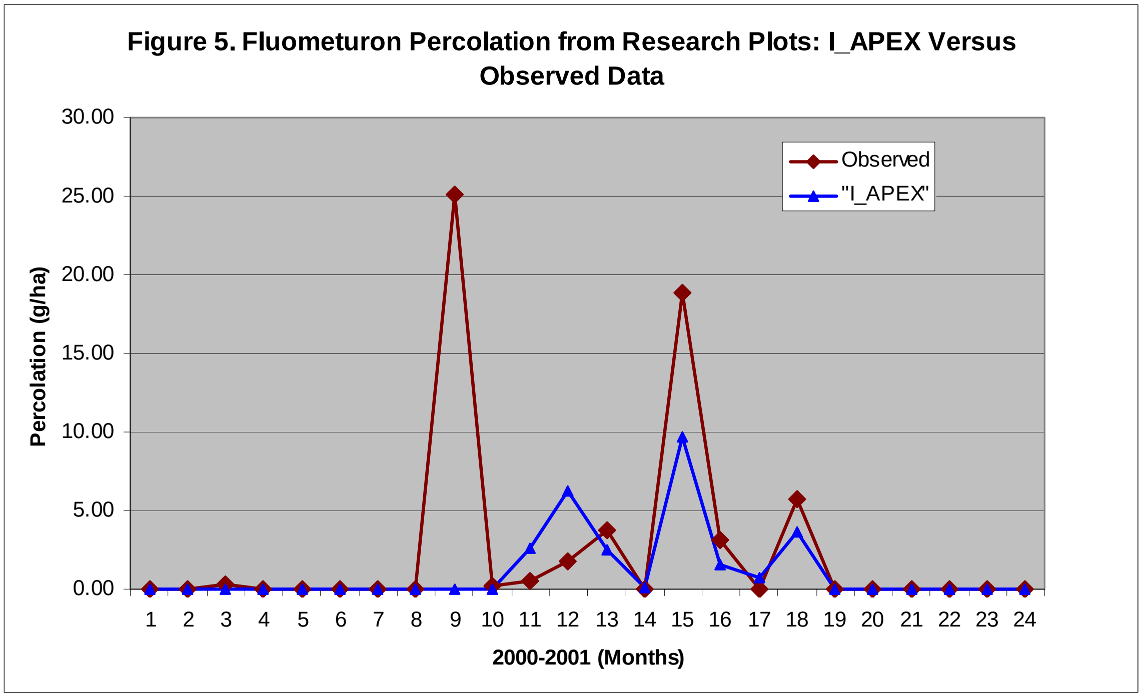


Table 3: Annual Means of Observed and Simulated Results

Parameter Name	**Observed**	**Simulated**	**Ratio (Simulated/ Observed)**
Runoff water at edge of field	220.14 mm	128.93 mm	0.6
Percolation water at 1200 mm depth	111.57 mm	157.03 mm	1.4
Total water movement	331.7 mm	286 mm	0.9
Pendimethalin runoff	0.85 g ha^{-1}	2.74 g ha^{-1}	3.2
Pendimethalin percolation	0 g ha^{-1}	0 g ha^{-1}	0
Fluometuron runoff	7 g ha^{-1}	15.52 g ha^{-1}	2.2
Fluometuron percolation	29.66 g ha^{-1}	13.53 g ha^{-1}	0.5

Summary and Conclusions

1. The I_APEX model was calibrated and validated with two years (2000-2001) of hydrologic and pesticide movement data from Tifton, GA research plots.
2. Three replicate 0.14 ha plots were used that contained Tifton LS with a 15 cm deep argillic layer.
3. Cotton was grown in the summers followed by winter rye cover crops.
4. The herbicides pendimethalin and fluometuron were applied to the fields each year.

5. An NRCS Runoff Curve Number of 84 was found to provide the best hydrologic balance between runoff and percolation. RCN was varied during the run stochastically and in accordance with land use (conventional tillage and row crop).
6. Evapotranspiration was determined using the Hargreaves equation. The Hargreaves coefficient of 0.0032 and exponent of 0.6 were found to be most suitable for the hot summer Tifton weather.
7. Monthly runoff water comparison between the model and observed data was very good except in the summer of 2001 when observed exceeded model values by a factor of about 7.5. The annual runoff water simulated/observed ratio was about 0.6.
8. Percolation water was more variable monthly than runoff with simulated results generally being greater than observed data. The annual means of percolate water indicated a 1.4 ratio of simulated to observed values.
9. Pendimethalin mass loss in runoff was greater in simulated data in the summer of 2000. The 2001 soluble runoff losses were similar for both modeled and observed data. Annual mean comparison indicated a 3.2 ratio of simulated to observed data. Pendimethalin was broadcast applied as opposed to soil incorporation. Given this, a considerable fraction likely volatilized from the Tifton plots considering that pendimethalin has a significant vapor pressure of 4 mPa, a fairly long half-life of 40 days, and a high Koc of 16,000 mL g^{-1} that would tend to keep the pesticide near the soil surface. Since I_APEX does not account for volatilization as a loss pathway, this may in part explain the relatively greater runoff concentrations modeled compared to monitored runoff. Pendimethalin was not found to percolate due to its high Koc.
10. Simulated runoff mass loss of fluometuron was greater than observed levels. All of the simulated and observed losses occurred within three months of the applications. Annual mean ratio of simulated to observed values was 2.2. Fluometuron percolation was the opposite with most monitored losses exceeding those that were simulated. The annual mean ratio of simulated to observed was 0.5. These annual fluometuron loss comparisons indicate that simulated losses were within a factor of two of the monitored levels.
11. Overall, the calibration and validation showed that I_APEX provided estimates of water and herbicide losses that were in relatively close agreement with measured data.

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