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Performance of Cropsyst Model in Rice-Wheat Cropping System

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ABSTRACT

Simulation models are available for studying the response of individual crops and cropping systems to management practices. However, since the crops growing in a system have influence on each other, there is a need to simulate the cropping system as a whole. Cropsyst (Cropping Systems Simulation Model) is a multi-year, multi-crop, daily time step cropping system simulation model to study the effect of climate, soils, and management on crop productivity and the environment. We have calibrated and validated the Cropsyst model for rice-wheat cropping system at Ludhiana. Model was calibrated using the experimental values of crop parameters, soil profile data and observed daily weather data of experimental site. The model-simulated crop growth parameters, i.e. leaf area index and biomass and yield matched well with observed data, with higher values of R^2. The simulated effects of transplanting date, irrigation were in accordance with the experimental results observed by previous researchers. The model did not simulate the puddling effect.

Key words: Cropsyst model, calibration, validation, rice-wheat system

Introduction

Simulation modeling is a modern research tool of data generation, which complements the field experiments. Detailed or desired information on crop response to soil, climate and its management variables from field experiments is a costly and time-consuming exercise. Such information can be taken by simulation modeling, which can help in further understanding crop management under different soil and climatic conditions. But, before using a simulation model some pre-requistites like calibration and validation of the model for a given crop, soil and climatic environment are required. Cropsyst is a multi-year, multi-crop cropping systems model developed by Stockle *et al.* (1994), which takes into account the effects of management.

In the central Indian Punjab, rice-wheat is a dominant cropping system. Out of the total 5.04 m ha geographic area of Punjab, rice is sown on 2.61 m ha and wheat on 3.41m ha. It contributes 40% of the state GDP and 50% of food grains to the central pool. The state average productivity of rice and wheat are 6.4 ton/ha and 4.4 ton/ha, respectively. During the last three decades, with large scale adoption of rice-wheat cropping system, the food grain production has increased by 65%. But this has resulted into over exploitation of ground water resources. Almost 80% area of Punjab falls under dark categories. Presently, Punjab agriculture has reached the plateau and shrinking water resources threaten the maintenance of the agricultural productivity and calls for enhancing crop water productivity through wet saving of water (Kijne et al., 2003) without sacrificing the yield. It is possible by adjusting the date of transplanting of paddy and deficit irrigation techniques with reduced losses in evapotranspiration.

The objectives of the present study were to (i) conduct experiments and generate crop data on rice-wheat system (under varying scenarios of dates of transplanting of paddy, irrigation scheduling and tillage) and its use in calibration of the CropSyst model, (ii) validate the calibrated model on independent data and (iii) evaluate the ability of CROPSYST model for simulating crop water productivity in relation to transplanting dates, water regimes and puddling intensity.

Materials and Methods

An experiment on rice-wheat cropping system was started during *kharif* season of the year 2004 on loamy sand soil at the Research Farm of the Department of Soils, Punjab Agricultural University, Ludhiana, (30°56′N, 75°52′E and 247 m a.s.l.), in India. Soil physical (texture, bulk density and hydraulic conductivity) and chemical (EC, pH, OC, ammonical nitrogen and nitrate nitrogen) properties of experimental field were determined up to 1.8 m with 0.15 m soil depth interval following the standard procedures. The sand, silt and clay contents were determined by the International Pipette Method, bulk density with core method, hydraulic conductivity with constant head method (Jalota *et al.*, 1998). EC was measured with solu bridge method (Chopra and Kanwar, 1976) and pH with potentiometric method (Jackson, 1973), OC by wet digestion method (Walkley and Black, 1934). Ammonical and nitrate nitrogen were determined by KCL method (Keeney, 1982). Daily weather data on maximum and minimum temperature, maximum and minimum relative humidity, wind speed and rainfall during the crop growth period were borrowed from meteorological laboratory at Punjab Agricultural University. Data on solar radiation was generated using the Climgen model.

Total 12 treatments in 48 plots of size 6.5m x 4m were replicated in quadruplicate in a randomized block design. The treatments included three dates of transplanting viz. May 26 (D_1), June 10 (D_2) and June 25 (D_3), two irrigation regimes viz. continuous flooding of 15 days after transplanting followed by intermittent irrigation at 2 days interval (I_2); and continuous flooding for 15 days after transplanting followed by intermittent irrigation at 4 days interval (I_4) and two tillage treatments viz. puddling two times (P_2) and four times (P_4). Puddling was done by running cultivator in the standing water followed by planking. Seedlings of 30 days old nursery of variety PR-118 were transplanted on three dates of transplanting with spacing of 20 cm between row to row and 15 cm between hill to hill. At each date of transplanting, 40 kg N ha^{-1} and 30 kg P_2O_5 ha^{-1} and 30 kg K_2O ha^{-1} were applied at the time of transplanting. Second and third (40 kg ha^{1} each) and additional dose (30 kg ha^{-1}) of N were applied at 22, 43 and 70 days after transplanting to D_1, D_2 and D_3 dates of transplanting. To control weeds (*Phalaris minor* L.) Butachlor 50EC 3000 ml ha^{-1} was applied two days after transplanting. Monocrotophos (1400 ml ha^{-1}), Chloropyriphos (2.5 1 ha^{-1}), Padan (18 kg ha^{-1}), Indofill-45 (1250 g ha^{-1}) and Tilt 25EC (500 ml ha^{-1}) were used periodically to control insects and diseases. Amount of water applied as irrigation was measured with the Parshal Flume. During the crop growing season, periodic biomass (leaf and stem separately), and leaf area were monitored at 30 days interval. Leaf area was determined with image analyzer. At harvest of the crop, paddy yield, and straw yield were monitored.

After paddy harvest, four treatments in wheat comprising of combinations of tillage and crop residues were imposed. The treatments were (i) clean conventional tillage (2 discings + 2 cultivators and one planking) without paddy residue (ii) conventional tillage (2 discings +2 cultivators and no planking) with paddy residue burnt (2.5 t/ha) (iii) paddy residue incorporated (2.5 t/ha) and (iv) no tillage with paddy residue (2.5 t/ha) at the surface. Prior to seeding, the field was irrigated with 100 mm of water as pre-sowing irrigation. The land was tilled 2 times with a disc and spring tyne harrow and followed by leveling for preparation of seed beds. A uniform application of 26.2 kg of P as single superphosphate and 50 kg of K as Muriate of potash ha^{-1} were drilled at the time of seeding. Fertilizer N at a uniform rate (120 kg ha^{-1}) was applied in two equal splits; half at seeding and the remaining 30 days later (with first irrigation). The wheat crop was sown with seed drill on November 11 and was harvested in the third week of April.

The experiment on rice was repeated during the year 2005 for validation of the model. In this experiment the treatments and management practices were kept same as in the experiment conducted during 2004.

The model was calibrated by using the observed data on morphology, phenology, growth and harvest parameters from the experiment conducted during the year 2004 for this cultivar in the crop file. The other parameters for the crop file were taken as default with slight adjustments. These adjustments were made within the range from the experience or reported by other researchers so that it matched the periodic crop growth in terms of phonological stages, biomass production, leaf area index and crop yield. The crop parameters used in the model are given in Table 1. During the first step of calibration, simulated phonological stages (germination, flowering and maturity) were matched with the observed data by adjusting the heat units. Location and files were prepared using the actually observed data for that experimental site. The calibrated model was validated on an independent experiment conducted during the year 2005.

Results and Discussion

Observed Field Results

The physical and chemical properties of the experimental site showed that the soil was loamy sand throughout the profile. Higher bulk density and lower hydraulic conductivity were observed in 0-30 cm soil layer compared to other layers. The observed meterorological data during the growing season of paddy-2004 indicated that total rainfall was 314 mm, 329 mm and 293 mm and pan evaporation was 702 mm, 665 mm and 588 mm for D_1, D2 and D3 dates of transplanting. In D1, D2 and D3 treatments the total amount of irrigation applied, irrespective to puddling treatments, was 405 cm, 420 cm and 390 cm in I_2 and 248 cm, 255 cm and 233 cm in I_4 treatments. These values seems to be on higher side than those reported by Singh et al. (1997) because of

Table 1. Crop parameters of rice and wheat used for calibration of the Cropsyst model

	Paddy	Wheat
Estimated from the experiment		
GDD emergence (°C-d)	1	100
GDD flowering (°C-d)	1100	1400
GDD grain filling (°C-d)	1500	1675
GDD phonological maturity (°C-d)	1700	1825
Maximum of LAI m^2 mn^{-2}	9.0	7.0
Fraction of LAI at maturity	1.0	0.8
Maximum rooting depth (m)	1.0	1.8
Unstressed harvest index	0.50	0.40
Standard		
Base temperature (°C)	15	3.5
Cut off temperature (°C)	35	35
Phenological sensitivity to water stress	1.0	1.0
Light to biomass conversion (g M J^{-1})	4.0	3.30
Maximum water uptake (mm d^{-1})	10	5
Critical leaf water potential (J kg^{-1})	-1000	-1000
Wilting leaf potential (J kg^{-1})	-1500	-1000
Harvest sensitivity during flowering	0	0.05
Harvest index during grain filling	0	0.05
Calibrated		
Biomass-transpiration coefficient (k Pa kg m^{-3})	8.0	7.0
ET crop coefficient	1.2	1.3
At/Pt ratio where canopy growth ceases	0.20	0.20

the reason that the experiment was conducted on coarse textured untraditional paddy soils, which was recently brought under paddy and also the growing season of 2004 was comparatively more drier than the normal. The rainfall was less than 50% of the normal. Unlike traditional paddy soils, hard pan did not exist in the sub surface of these soils and the applied water infiltrated quickly i.e. 8-10 hours. That is why, more irrigation water was required to keep the soil wet. The effect of puddling intensity meant to keep water standing did affect the grain yield. These results indicate that irrespective of puddling intensity I_4 saved 150-165 cm of irrigation water compared to I_2. The effects of puddling intensity and irrigation interval on periodic biomass, periodic leaf area index, grain yield and harvest index were non-significant for all dates of transplanting.

Model Calibration

The calibrated model was implemented to generate data on periodic biomass and LAI and yield of the paddy and wheat. The model out put on these parameters matched excellently with the observed data for paddy (Figure 1a) and wheat (Figure 1b) during the year 2004. The simulated yield of paddy averaged over treatments was 8.4±0.3 t ha^{-1} compared to observed yield of 9.1± 0.4 t ha^{-1}. The linear regression between simulated and observed values forced to zero intercept gave slope nearer to one with higher coefficient of correlation. The RMSE was 8% of the mean observed yield.

Model performance

The performance of the CROPSYST model was tested on an independent experiment at Ludhiana during the year 2005 for estimation of ET and paddy yield under varying dates of transplanting, water regimes and puddling intensities. The time trend and cumulative ET at the end of the growing period were identical to PET. The simulated ETs in the treatments of two water regimes (I_2 and I_4) and two puddling intensities (P_2 and P_4) were at par. However, differences in ETs under different dates of transplanting were dramatic. The cumulative ET during the growing season of paddy decreased with delaying the transplanting date. For example, ET was 84, 75 and 67 cm for May 26, June 10 and June 25 transplanted paddy. The corresponding values of open pan evaporation during the respective periods were 6 cm, 10 cm and 14 cm less than the ET values. These simulated results of 1.16 times higher ET than open Pan-evoporation confirm the observations of Tomer and Otoole (1980), who reported 1.2 times higher ET under paddy compared to open pan evaporation. The time trends and magnitude of the model simulated periodic plant growth parameters like biomass and leaf area index satisfactorily matched the experimental observations (Figure 2). The effects of transplanting date, water regime on paddy yield observed in the experiment were reflected in the simulated results also. The overall simulated paddy yield was 9.1±0.5 t ha^{-1} which was close to the observed yield of 8.9±0.2 t ha^{-1}. The value of the slope was closer to one and R^2 was also satisfactorily higher 0.84. The RMSE was 6% of the observed mean. The additional statistical analysis was performed after separating the data into dates of transplanting. The simulated yields (averaged over water regimes and puddling intensity) for May 25, June 10 and June 25 were 8.4±0.1 t ha^{-1}, 9.1±0.01 t ha^{-1} and 9.6±0.0 t ha^{-1} compared to he observed yields of 9.2±0.1 t ha^{-1}, 8.8±0.0 t ha^{-1} and 8.8±0.1 t ha^{-1} respectively. Similarly simulated yield for I_2 and I_4 water regimes were 8.9±0.5 t ha^{-1} and 9.1±0.05 t ha^{-1} compared to the observed 8.9±0.3 t ha^{-1} and 9.0±0.06 t ha^{-1}.

These results indicate that the model is as equally accurate and represents the response to weather and water regimes. However, as expected it does not respond to effect of puddling intensity because the phenomena of break down of aggregation and settling particles effects has not been incorporated into the model. It has also been mentioned by the modeler that the tillage system in the present version of the model affects the residue fate only but does not impact the soil physical properties. The model simulated results complement the experimentally observed results. Whatsoever deviations observed to have occurred were due to the variability in the field experimentation and must be kept in mind when comparing the field data (Pannkuk *et al.*, 1997).

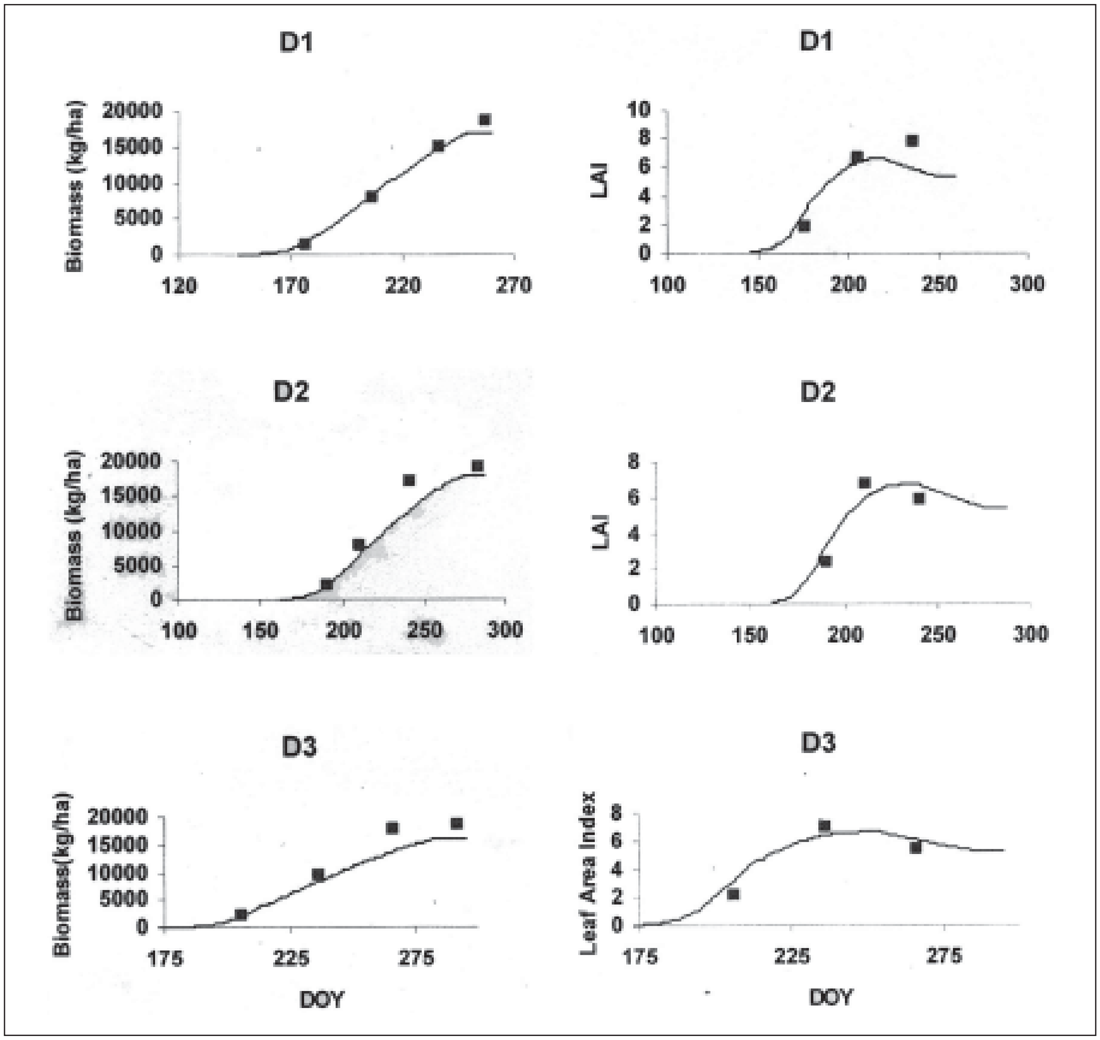

Fig. 1a. Simulated (line) and observed (point) biomass and leaf area index for different dates of transplanting in paddy during 2004

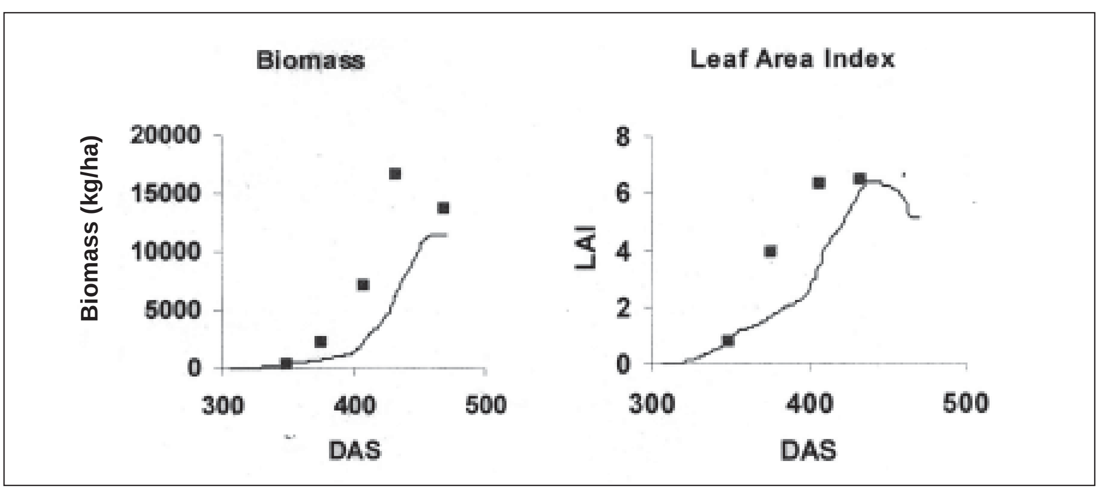

Fig. 1b. Simulated and observed periodic biomass and leaf area index in wheat

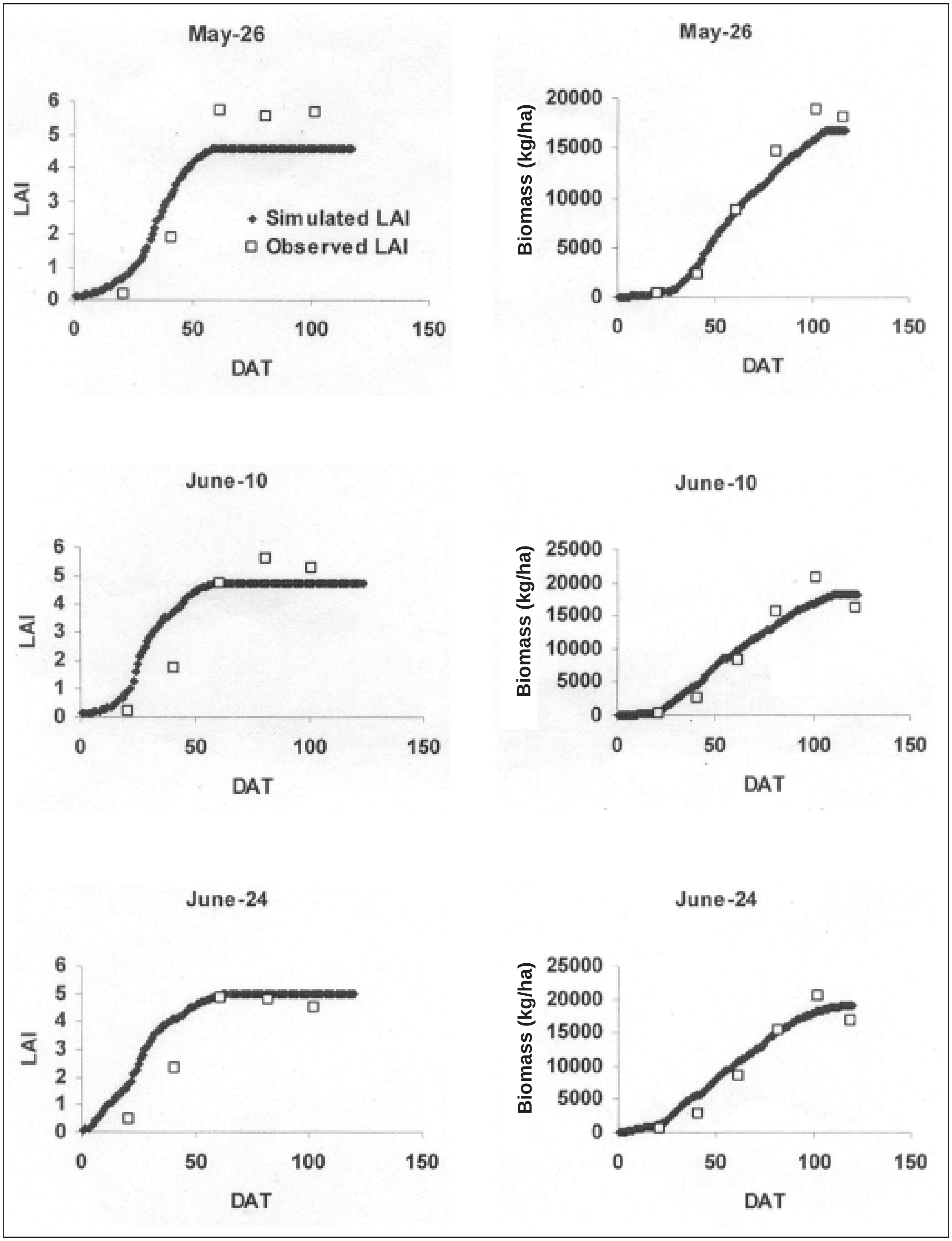

Fig. 2. Simulated and observed periodic leaf area index and biomass in paddy transplanted at different dates during 2005

From the practical point of view, the results suggest that water productivity in rice can be enhanced mainly by adjusting the transplanting date. In the present study the water productivity values for May 26, June 10 and June 25 transplanted paddy were 1.0, 1.18 and 1.34 kg m^3, respectively. The enhanced water productivity in delayed transplanted paddy was due to reduction in ET while the yield remained unaffected.

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