Chapter 7

Parameterization of the GPFARM-Range Model for Simulating Rangeland Productivity

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Abstract

One of the major limitations to rangeland model usage is the lack of parameter values appropriate for reliable simulations at different locations and times. In this chapter we seek to show how the GPFARM-Range, a rangeland model, which has been previously parameterized, tested, and validated for the central locations of the Great Plains, could be reparameterized to extend its domain of application to other locations of the Plains. Two main parameter determination methods are proposed: (i) manual adjustment of default parameter values and (ii) direct empirical parameter determination from some experimental data. It was recommended that in view of the level of information and expertise required for the second method, at this point the users should follow the first method—comparing the simulated output with observed data in a statistical sense such that the sum of squared deviations between the simulated and observed is minimized. It is noteworthy, however, that the published literature is a major source of data that could be used for parameterizing models. A number of texts are suggested for consultation to assist in the empirical determination of parameter values. It is shown that by varying the default values of only a few key parameters, the GPFARM-Range model could simulate forage growth under varying weather and grazing conditions at Miles City, located in northern part of the Great Plains.

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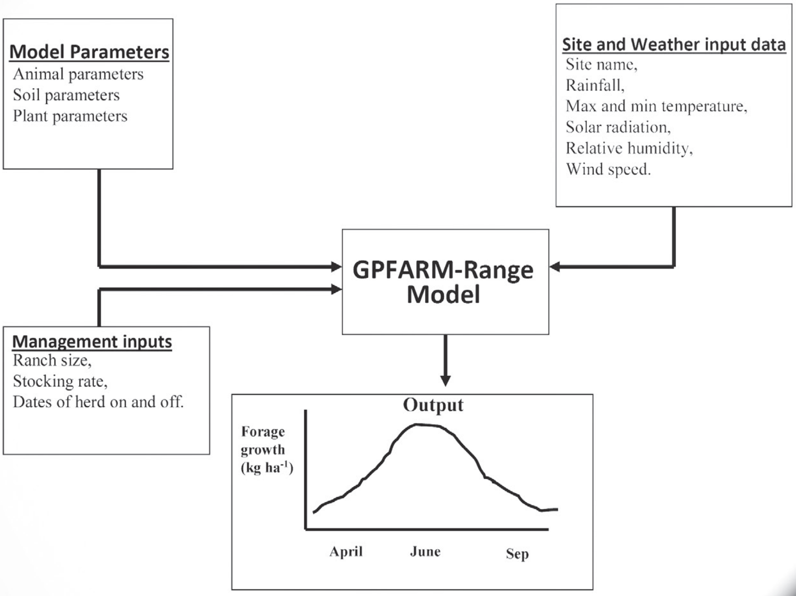

Model Parameters
Animal parameters
Soil parameters
Plant parameters
Site and Weather input data
Site name,
Rainfall,
Max and min temperature,
Solar radiation,
Relative humidity,
Wind speed.
GPFARM-Range Model
Management inputs
Ranch size,
Stocking rate,
Dates of herd on and off.
Output
Forage growth (kg ha-1)
April
June
Sep

Rangelands comprise about 50% of the world's land area. They occur largely in low rainfall zones and on marginal lands and have diverse vegetation types, including (i) natural grasslands, (ii) deserts shrublands, (iii) savanna woodlands, (iv) forests, and (v) tundras. These vegetation types comprise mixtures of C3 and C4 species. Economically, rangelands are primarily used for grazing ruminants. However, rangelands also offer a range of ecosystem goods and services, such as wildlife habitat, water supply, and conservation of nature.

Most rangelands have been studied to understand the ecology of the system. Studies have focused on vegetation composition and its dynamics, hydrology, and landscape processes. Since the maintenance of rangeland productivity is at the heart of the ranch and animal husbandry industry, it is of interest to understand what factors affect it and how management could be used to sustain this productivity. Therefore, by far, the rangelands have been studied with economic motives, as the source of forage for domesticated animals, which form a vital component of human nutrition. The major aspects of rangelands currently being studied by grazing experimental stations include range species and primary production (Derner and Hart, 2007), pest infestation, invasion of poisonous plants (Blumenthal et al., 2005), and soil fertility and water relations (Heitschmidt et al., 1999, 2005).

Traditionally, field observations involving destructive biomass harvests from quadrats or along transects and soil sampling are used to determine rangeland productivity. Increasingly, nondestructive methods have been developed that estimate biomass from leaf area (determined using remote sensors), canopy height measurement, or from weighted plate measurements (Ganguli et al., 2000). Over the years, the use of nondestructive methods such as moisture meters for soil measurement has also increased compared with the traditional soil augering.

However, due to the high labor demands, increasing cost, and time and location specificity of field observations, modeling approaches are now emerging as additional methods for the assessment of rangeland productivity. In particular cases, where it is desired to predict rangeland productivity in space and time to gain a foreknowledge of the range condition under varying management to match stocking rates to forage availability, or to assess the effect of future changes in climate on rangeland productivity, models have been found to be more appropriate tools (National Resource Models in the Rangelands, 2004). Several models have now been developed for rangeland management studies. One important range model is the Simulation of Production and Utilization of Rangelands, or SPUR (Hanson et al., 1987), and this model has been used by many researchers to assess forage growth and cattle production in the Great Plains of the United States. The model was further enhanced into SPUR II (Hanson et al., 1992). The SPUR models provided a good foundation for the development of a broader agricultural production model for cultivated crops and forage and animal production, referred to as the Great Plains Framework for Agricultural Resource Management (GPFARM) Decision Support System (DSS) (Ascough et al., 2007; Shaffer et al., 2000). Later, the components of GPFARM DSS that simulated rangeland forage growth and cattle production were extracted to form the basis of a new model now called the GPFARM-Range model. Details of the new GPFARM-Range model can be found in Andales et al. (2005, 2006). Information on the soil properties, potential evapotranspiration, water balance, and chemical transport modules are similar to those of GPFARM DSS publications (see Andales et al., 2003). The GPFARM-Range has been validated for some central locations of the Great Plains of the United States (Andales et al., 2005, 2006)

The purpose of this chapter is to present the GPFARM-Range model with a focus on how it could be parameterized and applied to simulate rangeland productivity at other locations of interest within the Great Plains of the USA or elsewhere.

The GPFARM-Range Model

Model Description

The GPFARM-Range is an object-oriented model written in Java. It comprises several modules that describe the growth of up to five forage functional groups and animal types (e.g., cattle). The model requires information about the sites, animal types, weather variables, and management as inputs and several animal–soil–plant parameters for execution (Fig. 7–1). Parameters are constants that describe the behavior of a system under varying environmental conditions. Their values can be either hard-coded in the models or read from parameter files. For example, the relative growth rate, RGR, which is the relative increase in mass per unit mass per unit time (kg kg^{-1} d^{-1}), is a simple growth parameter that is often used to describe the growth of a range plant. More detailed physiological models would require parameters such as the radiation use efficiency (RUE) or the photosynthetic efficiency rate. Parameter values are derived from detailed experimental data, and a host of them have been published in the literature. Input variables, on the other hand, are external to the model and include environmental variables (e.g., temperature, radiation, rainfall, and initial soil and plant conditions) and

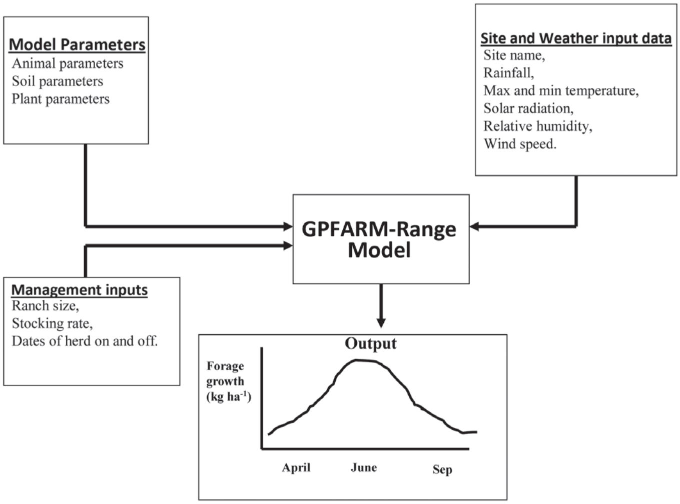


Fig. 7–1. Schematic diagram of the GPFARM-Range model.

management factors (e.g., stocking rates) that interact with the parameters and process descriptions to predict behavior of the system.

The GPFARM-Range model requirements are grouped into four classes: (i) site and weather inputs, (ii) animal parameters, (iii) soil parameters, and (iv) plant parameters. Each of these classes is discussed in greater detail below.

Inputs and Parameters

Site and Weather Inputs

The site information required for running the GPFARM-Range model include the site name and the Cartesian coordinates, namely latitude and longitude. The weather input variables constitute the external drivers of the GPFARM-Range model. Daily input data are required for rainfall amount (mm) and duration (h), maximum and minimum temperature (°C), solar radiation (Langleys), wind velocity ($m\ s^{-1}$), and relative humidity (%). The weather data can be historical or forecast and must be available for all the years for which the simulations are to be run. The site coordinates are helpful to estimate some weather variables, such as solar radiation, if measured data are not available

Animal Parameters and Input Variables

Animal parameters enable the prediction of animal growth and weight gain during the season. The parameters relate to the animal types currently on the range. For example, for cattle, parameters include the various groups such as open cows, pregnant cows, calves, heifers, steers and bulls, as well as their initial weight, daily forage intake rate, and forage utilization efficiency. Input variables for the animal component include stocking rate, the forage use criterion ("useCrit"), which specifies the fraction of total forage available for grazing. Setting the "useCrit" to zero implies no grazing whereas a fraction of 0.5 would represent the "take half leave half" rule. Further input variables include the details of the grazing events, that is, the dates when the animals were on and off the rangeland. Table 7–1 summarizes the major parameters of the animal module.

Soil Parameters

The soil parameters enable the simulation of the soil water balance and other soil processes. As with the site description, it is useful to specify the general classification (according to U.S. soil taxonomy) of the soil, although this information is not directly used in the model execution. There are two sets of parameters: the hydrologic group, which relates to the soil surface condition (e.g., crusting, soil albedo, and residue cover) and affects the simulation of evaporation, and the soil profile group, which comprises the detailed description of the properties for each soil layer. As shown on Table 7–2, the parameters include soil layers and layer thickness, sand and clay percentages, bulk density, saturated soil water content, saturated hydraulic conductivity, the air-entry value, and the pore-size distribution index for each layer. The latter soil water related parameters are estimated from soil texture and bulk density if measured data are not provided. These parameters are used to simulate the distribution of soil water with time and depth, using the Darcy descriptions for soil water flow simulation.

Plant Parameters

Plant parameters enable the simulation of forage development and growth in rangelands. As indicated earlier, rangelands have many plant species growing in a mixture, and it is not practicable to simulate the development and growth of each individual species. For convenience, species are classified into functional groups, based on their major physiological similarities. In the GPFARM-Range model, all the C4 graminoids are grouped into warm season grasses (WSG), and the C3 ginoids into cool season grasses (CSG). Three other recognized functional groups are the legumes, the forbs, and the shrubs. Each of these groups has distinctive parameters for development and growth (Table 7–3).

Plant development is expressed in terms of physiological, rather than chronological, time. The main development stages recognized are (i) emergence or green up, (ii) anthesis, (iii) senescence, and (iv) maturity, and the duration of each stage is expressed as growing degree days (GDD). The calculation of GDD requires knowledge of functional-group specific cardinal temperatures, namely

Table 7–1. Some animal parameter values for Central Plains Experiment Research Station, Nunn, CO.

Parameter	Cow	Calf	Heifer	Bull
Mature weight, kg	544	–	–	500
Daily feed requirement, kg head^{-1}	7.7	3.8	7.7	7.7
Weight gain rate, kg d^{-1}	1.4	0.5	0.5	1.4
Feed utilization efficiency, kg kg^{-1}	0.6	0.6	0.6	0.6

Table 7–2. Example of soil parameters for Central Plains Experiment Research Station, Nunn, CO.

Depth	Bulk density	Clay	Sand	Saturated soil water content	Saturated hydraulic conductivity	Air-entry value	Soil pore-size distribution index
cm	g cm^{-3}	——— % ———		cm^3 cm^{-3}	cm h^{-1}	cm	
7	1.45	15.00	71.05	0.45	2.59	14.66	0.32
15	1.45	15.00	71.05	0.45	2.59	14.66	0.32
41	1.44	24.29	54.04	0.39	0.43	28.08	0.25
56	1.45	22.50	53.84	0.39	0.43	28.08	0.25
86	1.48	11.50	71.79	0.45	2.59	14.66	0.32
116	1.48	11.50	71.79	0.45	2.59	14.66	0.32
152	1.48	11.50	71.79	0.45	2.59	14.66	0.32

the base, optimum, and maximum temperatures. Because rangeland forage is not sown, there is no definite sowing date. For modeling convenience, the GDD value is calculated from January 1 until the occurrence of a particular stage for a given functional group.

Forage growth is controlled by the functional group-specific relative growth rate (RGR), temperature, and soil water availability. Growth is initiated by translocation of root biomass reserves to shoots at the beginning of the growing season. The proportion of the various functional groups in the mixture governs the contribution of each functional group to the overall forage growth. The senescence of both the above- and below-ground biomass adds to soil carbon and nitrogen and determines the fertility status of the range.

Running the Model using Default Parameters

To facilitate model execution, the GPFARM-Range model is equipped with a Microsoft Office Excel interface for input and output. Three Excel worksheets enable the user to input location specific information for running the model. These are (i) the "Input" sheet, (ii) the "Weather" sheet, and (iii) the "Events" sheet. The "Input" sheet provides all the default parameters for each model component: site, animal, soil, and plant (Fig. 7–2 and 7–3). The "Weather" sheet provides the daily weather variables for the location of interest. The "Event" sheet provides informa-

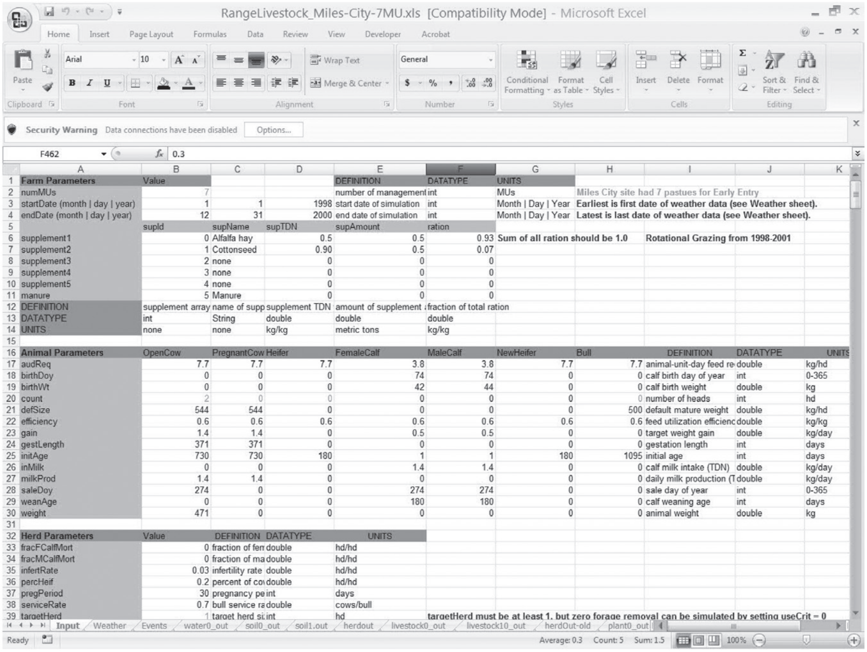
Table 7–3. Example of plant parameters for Central Plains Experiment Research Station, Nunn, CO.

Parameter	Description	Warm season grasses	Cool season grasses	Legumes	Shrubs	Forbs
emergGDD, °C d	Growing degree days from January 1 to green up	50	80	105	89	105
senGDD, °C d	Growing degree days from January 1 to senescence	1200	1200	1335	1877	1188
matureGDD, °C d	Growing degree days from January 1 to maturity	1600	2200	1855	2300	1865
maxGrowthRate, kg kg^{-1} d^{-1}	Maximum relative growth rate	0.26	0.25	0.17	0.17	0.17
propPop	Proportion of functional group in forage	0.64	0.23	0.00	0.04	0.07
respRate, kg kg^{-1} d^{-1}	Respiration rate	0.04	0.04	0.04	0.04	0.04
senRate, kg kg^{-1} d^{-1}	Senescence rate	0.018	0.013	0.005	0.001	0.001
rootBiomass, kg ha^{-1}	Initial root biomass	7168	2576	0	672	784
foragePref, 0–1	Preference for forage by grazing animals	0.4	0.9	0.9	0.2	0.1
waterStresssSen, 0–1	Sensitivity to water stress	0.15	0.30	0.6	0.45	0.18
tempBase, °C	Base temperature	8	3	3	4	3
tempOpt, °C	Optimal temperature	27	22	20	21	23
tempMax, °C	Maximum temperature	41	36	35	36	35

tion on grazing events, such as the dates of herd on and off the rangeland. Data from these sheets can be edited by the user and are used by the Java program to simulate several animal, soil, and forage growth attributes.

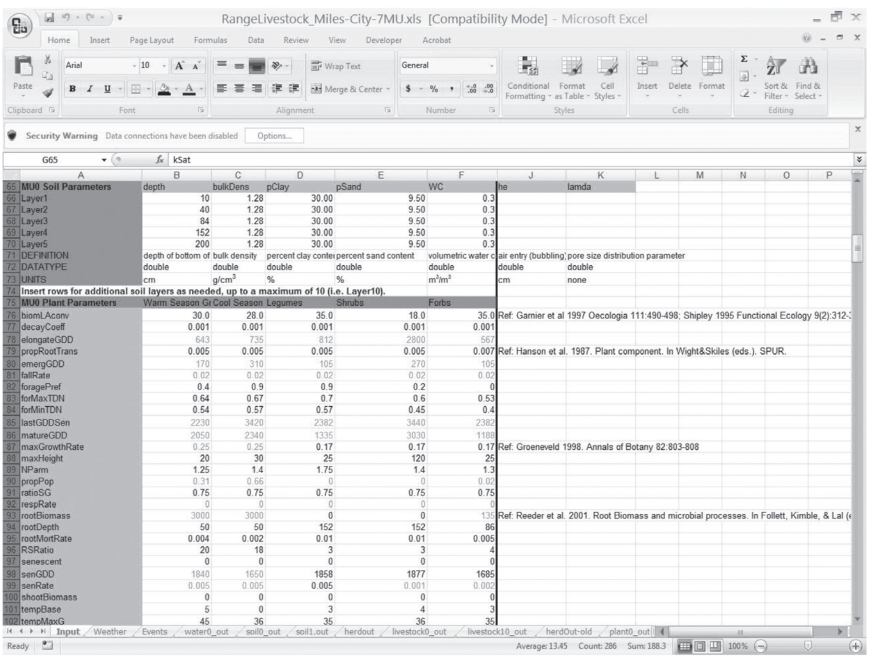
The results from the model simulations are also output to the same Excel interface. The animal weight gain, soil water distribution with time and depth, and forage growth during the simulation period are output on the Excel sheets "herd.out," "water.out," and "plant.out," respectively. A typical output of the forage growth at Central Plains Experiment Research Station (CPER) at Nunn, CO for four functional groups is shown in Fig. 7–4.

An important question relates to how well a model performs in simulating the behavior of the soil–plant–animal system. This is often determined by comparing simulated results with observations. The agreement is based on statistical procedure. There are several statistical criteria for judgment, but the most com-



	A	B	C	D	E	F	G	H	I	J	K
1	Farm Parameters	Value			DEFINITION	DATATYPE	UNITS				
2	numMUs	7			number of management	int	MUs	Miles City site had 7 pastues for Early Entry			
3	startDate (month | day | year)	1	1	1998	start date of simulation	int	Month | Day | Year	Earliest is first date of weather data (see Weather sheet).			
4	endDate (month | day | year)	12	31	2000	end date of simulation	int	Month | Day | Year	Latest is last date of weather data (see Weather sheet).			
5		supId	supName	supTDN	supAmount	ration					
6	supplement1	0	Alfalfa hay	0.5	0.5	0.93	Sum of all ration should be 1.0		Rotational Grazing from 1998-2001		
7	supplement2	1	Cottonseed	0.90	0.5	0.07					
8	supplement3	2	none	0	0	0					
9	supplement4	3	none	0	0	0					
10	supplement5	4	none	0	0	0					
11	manure	5	Manure	0	0	0					
12	DEFINITION	supplement array	name of supp	supplement TDN	amount of supplement	fraction of total ration					
13	DATATYPE	int	String	double	double	double					
14	UNITS	none	none	kg/kg	metric tons	kg/kg					
15											
16	Animal Parameters	OpenCow	PregnantCow	Heifer	FemaleCalf	MaleCalf	NewHeifer	Bull	DEFINITION	DATATYPE	UNITS
17	audReq	7.7	7.7	7.7	3.8	3.8	7.7	7.7	animal-unit-day feed re	double	kg/hd
18	birthDoy	0	0	0	74	74	0	0	calf birth day of year	int	0-365
19	birthWt	0	0	0	42	44	0	0	calf birth weight	double	kg
20	count	2	0	0	0	0	0	0	number of heads	int	hd
21	defSize	544	544	0	0	0	0	500	default mature weight	double	kg/hd
22	efficiency	0.6	0.6	0.6	0.6	0.6	0.6	0.6	feed utilization efficienc	double	kg/kg
23	gain	1.4	1.4	0	0.5	0.5	0	0	target weight gain	double	kg/day
24	gestLength	371	371	0	0	0	0	0	gestation length	int	days
25	initAge	730	730	180	1	1	180	1095	initial age	int	days
26	inMilk	0	0	0	1.4	1.4	0	0	calf milk intake (TDN)	double	kg/day
27	milkProd	1.4	1.4	0	0	0	0	0	daily milk production (T	double	kg/day
28	saleDoy	274	0	0	274	274	0	0	sale day of year	int	0-365
29	weanAge	0	0	0	180	180	0	0	calf weaning age	int	days
30	weight	471	0	0	0	0	0	0	animal weight	double	kg
31											
32	Herd Parameters	Value	DEFINITION	DATATYPE	UNITS						
33	fracFCalfMort	0	fraction of fem	double	hd/hd						
34	fracMCalfMort	0	fraction of ma	double	hd/hd						
35	infertRate	0.03	infertility rate	double	hd/hd						
36	percHeif	0.2	percent of co	double	hd/hd						
37	pregPeriod	30	pregnancy pe	int	days						
38	serviceRate	0.7	bull service ra	double	cows/bull						
39	targetHerd	1	target herd si	int	hd	targetHerd must be at least 1, but zero forage removal can be simulated by setting useCrit = 0					

Fig. 7–2. Excel interface focused on the animal input spreadsheet for the Miles City, MT location.



	A	B	C	D	E	F	J	K
65	MU0 Soil Parameters	depth	bulkDens	pClay	pSand	WC	he	lamda
66	Layer1	10	1.28	30.00	9.50	0.3		
67	Layer2	40	1.28	30.00	9.50	0.3		
68	Layer3	84	1.28	30.00	9.50	0.3		
69	Layer4	152	1.28	30.00	9.50	0.3		
70	Layer5	200	1.28	30.00	9.50	0.3		
71	DEFINITION	depth of bottom of	bulk density	percent clay conte	percent sand content	volumetric water c	air entry (bubbling)	pore size distribution parameter
72	DATATYPE	double	double	double	double	double	double	double
73	UNITS	cm	g/cm³	%	%	m³/m³	cm	none
74	Insert rows for additional soil layers as needed, up to a maximum of 10 (i.e. Layer10).							
75	MU0 Plant Parameters	Warm Season Gr	Cool Season	Legumes	Shrubs	Forbs		
76	biomLAconv	30.0	28.0	35.0	18.0	35.0	Ref: Garnier et al 1997 Oecologia 111:490-498; Shipley 1995 Functional Ecology 9(2):312-3	
77	decayCoeff	0.001	0.001	0.001	0.001	0.001		
78	elongateGDD	643	735	812	2800	567		
79	propRootTrans	0.005	0.005	0.005	0.005	0.007	Ref: Hanson et al. 1987. Plant component. In Wight&Skiles (eds.). SPUR.	
80	emergGDD	170	310	105	270	105		
81	fallRate	0.02	0.02	0.02	0.02	0.02		
82	foragePref	0.4	0.9	0.9	0.2	0		
83	forMaxTDN	0.64	0.67	0.7	0.6	0.53		
84	forMinTDN	0.54	0.57	0.57	0.45	0.4		
85	lastGDDSen	2230	3420	2382	3440	2382		
86	matureGDD	2050	2340	1335	3030	1188		
87	maxGrowthRate	0.25	0.25	0.17	0.17	0.17	Ref: Groeneveld 1998. Annals of Botany 82:803-808	
88	maxHeight	20	30	25	120	25		
89	NParm	1.25	1.4	1.75	1.4	1.3		
90	propPop	0.31	0.66	0	0	0.02		
91	ratioSG	0.75	0.75	0.75	0.75	0.75		
92	respRate	0	0	0	0	0		
93	rootBiomass	3000	3000	0	0	135	Ref: Reeder et al. 2001. Root Biomass and microbial processes. In Follett, Kimble, & Lal (e	
94	rootDepth	50	50	152	152	86		
95	rootMortRate	0.004	0.002	0.01	0.01	0.005		
96	RSRatio	20	18	3	3	4		
97	senescent	0	0	0	0	0		
98	senGDD	1840	1650	1858	1877	1685		
99	senRate	0.005	0.005	0.005	0.001	0.002		
100	shootBiomass	0	0	0	0	0		
101	tempBase	5	0	3	4	3		
102	tempMaxG	45	36	35	36	35		

Fig. 7–3. Excel interface focused on the plant parameter input spreadsheet for the Miles City, MT location.

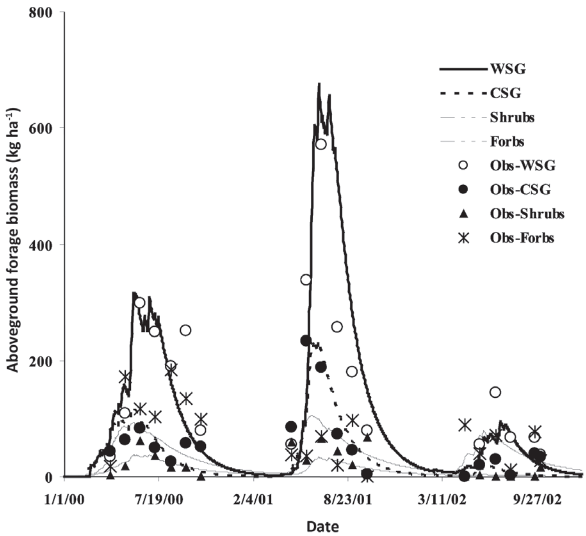


Fig. 7–4. Simulated growth of the various forage functional groups at the Central Plains Experiment Station (CPER), Nunn, CO. (Source: Andales et al., 2005).

monly used are (i) the coefficient of determination (R^2), (ii) the root mean square error (RMSE), and (iii) the Willmott (1981) *d* index of modeling efficiency (EF). The equations for the last two statistics are as follows:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{i=n}(p_i - o_i)^2}{n}} \qquad [1]$$

$$d = 1 - \left[\frac{\sum_{i=1}^{i=n}\left(p_i - o_i\right)^2}{\sum\left(\left|p_i'\right| + \left|o_i'\right|\right)^2}\right] \qquad 0 \le d \le 1 \qquad [2]$$

where p_i and o_i are the predicted and observed forage, $p_i' = p_i - \bar{o}$, $o_i' = o_i - \bar{o}$, with $\bar{o}$ being the observed mean. A perfect agreement between the predicted and the observed is indicated by a *d* index of 1. In general, the RMSE must be as small as possible, and a *d* value approaching unity is desired.

Step-by-Step Parameterization of the GPFARM-Range Model

More often, users would want to apply the model to their own observations and validate the model for their locations or other locations of interest. The default parameter values currently used in the model were drawn from the published literature and experience with using the model for rangeland experiment stations in the U.S. Great Plains. The Excel interface cites references for parameters taken from literature, and the user may customize the entry and citations when the field is changed (Fig. 7–3). As indicated, the model was originally parameterized and validated for Nunn, CO and Cheyenne, WY, both of which are located in the more central locations of the Great Plains. However, as one moves away toward either the more northern or southern parts of the plains, vegetation types and soils change. Hence, several parameter values may differ from the default values currently in GPFARM-Range model. In such situations, the direct application of the model based on the default parameters could lead to incorrect simulations. Therefore, models need to be "re-parameterized," recalibrated, and validated for different locations. Parameterization, calibration, and validation are often very tedious and time-consuming procedures. There are two ways to parameterize the model. The first is to manually adjust the default values such that the simulation output matches the observed growth data. The second is to directly determine the parameter values empirically (from experimental data) for the specific animal, soil, and forage type in question.

Manual Adjustment of Default Parameter Values

Because the number of model parameters is often large and they span a wide range of scientific disciplines, it is often not practical to determine all the parameters for every location and time. The first step in model parameterization is therefore to indentify the key process determinants and adjust their parameter values in a way that will minimize the deviations from the observed, using Eq. [1] and [2]. It is often practical to begin by setting the soil parameters, followed by plant parameters, and then the animal parameters. For the soil component, information on texture is required, and this is often available from USDA-NRCS database (http://soils.usda.gov/survey/geography/ssurgo/, verified 4 Apr. 2011) or from other Soil Survey manuals. In the absence of detailed soil hydraulic properties, the GPFARM-Range provides pedotransfer algorithms that use only texture and bulk density data for their estimation. The user must specify the use of these algorithms by setting the "soilPropOpt" option in the hydrologic group to 0.

Having specified the parameters for the soil, the next step is to parameterize the plant module. It is recommended to begin with a non-grazing situation so that the potential forage growth can be first evaluated. This is achieved by setting the "useCrit" = 0. For the plant component, the key determinants are the GDDs accumulated for the various development stages, the RGR, forage respiration and senescence rate, and the initial root biomass. The plant parameters for each functional group are adjusted upward or downward and the model executed using the weather data for the location in question. Based on Eq. [1] and [2], a good agreement between the model output and the observed soil water content distribution, evaporation, transpiration, and forage growth indicates that the adjusted parameter values are adequate for the location in question. Several iterations are usually needed to achieve the desirable agreement.

Once acceptable simulation results for soil water balance and potential forage growth are attained, the animal component can be activated. The key animal parameters include the initial weight, forage intake rate, weight gain rate, and feed conversion efficiency. By varying these values and with the grazing event schedule input, the model is executed and validated once more for the animal parameters as well. Table 7–4 shows the adjustments to parameters from original values from cattle grazing at Nunn, CO to sheep grazing at Miles City, MT.

As noted, the manual adjustment of parameter values is often tedious and time-consuming and requires painstaking efforts to ensure reliable parameterization. Automated parameter estimation methods based on concepts such as the generalized likelihood uncertainty estimation, GLUE (Beven and Binley, 1992) are now being adapted and introduced into crop modeling (He et al., 2010). However, these are not yet available for rangeland modeling.

It is worth noting that the manual or automated methods of parameter estimation are indirect or inverse procedures, using an end product value (e.g., biomass) to determine the value of an input variables (e.g., RGR). In doing so, model users need to ensure that the input parameter values derived lie within physiologically accepted ranges.

Empirical Determination of Parameter Values

The direct empirical parameter determination is also often a daunting task; therefore, before resources are spent on any determinations, users are encouraged to first consult the literature for published data availability for their locations. Procedures and protocols for data collection are available in field and laboratory manuals that are available to consult for guidance.

The animal growth and intake module allows small, medium, and large animal body types. The default body type for cattle studies is large, and mature animal weight can be obtained from the animal breed characteristics. The daily feed requirement is the amount necessary to obtain the daily weight gain rate goal. The amount of available range forage subject to the "UseCrit" utilization efficiency, in addition to any supplemental feed, is used to meet the daily requirement. When demand is not met, the weight gain goal is not attained. Parameterizing the animal

Table 7–4. Adjustment in parameter values from cattle grazing at Nunn, CO to sheep grazing at Miles City, MT.†

	Previous parameter values			New parameter values		
Animal module	**Cow**		**Calf**	**Ewe**		**Lamb**
Mature weight, kg	540			75		25
Daily forage requirement, kg head^{-1}	7.7		3.8	1.5		0.6
Plant module	**Warm season grass**		**Cool season grass**	**Warm season grass**		**Cool season grass**
tempBase, °C	8.0		3.0	5.0		0.0
matureGDD, °C d	1600		2200	2045		2160
maxGrowthRate, kg kg^{-1} d^{-1}	0.26		0.25	0.16		0.10
respRate, kg kg^{-1} d^{-1}	0.04		0.04	0.005		0.005
senRate, kg kg^{-1} d^{-1}	0.018		0.013	0.01		0.01
propPop	0.64		0.23	0.35		0.60
Soil module	**Clay**	**Sand**	**Bulk density**	**Clay**	**Sand**	**Bulk density**
	——— % ———		g cm^{-3}			g cm^{-3}
Layer						
10 cm	15.00	71.05	1.45	22.50	9.50	1.33
40 cm	24.29	54.04	1.43	26.50	9.00	1.31
80 cm	11.50	71.79	1.48	30.00	6.80	1.28
152 cm	11.50	71.79	1.48	30.00	6.80	1.28

† Parameters whose values remain unchanged are not listed.

module entails feeding experiments in relation to the metabolic weight of the animals. Walker (1993) provided details for such experiments. As noted, the minimum determinations must include the animal weight and weight gain rate, forage intake and utilization efficiency, dietary preferential grazing of functional groups, among others. In the absence of detailed feeding trials, breed characteristics from literature can be used to obtain initial parameter estimates.

For the soil module, the determination of texture and bulk density is simple and straight forward, and these are often routinely determined in most laboratories. However, the hydraulic properties (e.g., saturated hydraulic conductivity K_{sat}, pore-size distribution index λ, air-entry value h_e) are not normally available for most locations and must be determined for individual situations following standard procedures. The pressure plate method is commonly used to establish the soil moisture retention or characteristic curve, while the saturated hydraulic conductivity can be determined in the laboratory using the constant-head permeameter setup. For field conditions, simple methods such as the single ring infiltrometer (Wu et al., 1999) may suffice to determine the saturated hydraulic conductivity, although more sophisticated and more accurate methods such as the Guelph permeameter (Elrick and Reynolds, 1992) are also available. Given data on the soil bulk density and water content at field capacity (33 kPa suction), the air-entry value and the pore-size distribution index can be derived using the approaches such as the one-parameter for soil moisture characteristic (Williams and Ahuja 2003) and saturated hydraulic conductivity from effective porosity (Ahuja et al., 1989). Texts such as the *Methods of Soil Analysis* series (Klute, 1986; Dane and Topp, 2002) also provide method descriptions.

For the forage plant growth module, both parameters affecting the plant's phenology and productivity of tissue require data. Several plant ecophysiological and modeling texts, such as Charles-Edwards et al. (1986), provide useful directions for determining plant parameters. Recordings of the calendar dates for green up, anthesis, senescence, and maturity for each functional group and the daily temperature would provide the necessary data to parameterize the phenology aspects of the plant module using the GDD formula:

$$\mathrm{GDD} = \sum_{t=1}^{t=n} \left(T_{\mathrm{av}} - T_{\mathrm{b}} \right) t \qquad [3]$$

where t is time (days), n is the number of days for a given development stage, T_{av} is average daily temperature, and T_{b} is the base temperature, a threshold for development. The model describes daily growth rate of each forage group i by:

$$\frac{\mathrm{d}W_i}{\mathrm{d}t} = W_i \,\mathrm{RGR}\,\mathrm{EVP}_i \qquad [4]$$

where W_i is the biomass of group i, (g m^{-2} or kg ha^{-1}), RGR is the potential relative growth rate (g g^{-1} d^{-1}), t is time (d), and EVP_i is an environmental fitness factor that combines the temperature and water stress effects on growth (0–1) of class i. The RGR is the major plant growth parameter and can be determined from sequential forage biomass clippings. This can be determined as (South, 1995):

$$\mathrm{RGR} = \frac{\mathrm{Ln}(W_2) - \mathrm{Ln}(W_1)}{t_2 - t_1} \qquad [5]$$

where W_1 and W_2 are any two biomass harvests at times t_1 and t_2, and Ln is the natural logarithm. However, to translate measured RGR to the parameter maximum relative growth rate one would need to assume no grazing, water, or temperature stress, which is an unlikely occurrence in rangelands. Therefore, biomass clippings from grazing protected enclosures across years (so as to include wet climate years) at times before peak standing biomass is reached for each functional group would be most ideal.

Example of Parameterizing the GPFARM-Range for a New Location

As an example of parameterizing the GPRAFRM-Range model for a different location in the Great Plains, we simulated the rangeland studies conducted during sheep grazing at Fort Keogh Livestock and Range Research Laboratory located near Miles City, MT (46°22′ N, 105°5′ W). The site receives an annual rainfall of 340 mm with 60% falling from mid-April to mid-September. The mean daily temperature ranges from −10°C in the winter months to 24°C in the summer months. Soils range from silty clay loam to fine montmorillonitic Ustochrepts. The vegetation is a mixed grass with grama–needlegrass–wheatgrass (*Bouteloua* Lag.–*Stipa* spp.–*Agropyron* Gaertn.) as the dominant species (Küchler, 1964).

Two sets of studies were performed from 1993 to 1996 (Set 1) and from 1998 to 2001 (Set 2). During these studies, forage growth was determined under ambient rainfall (*A*) or imposed short-term drought (*D*) and grazing conditions. Eight dry matter harvests were performed in each year and each treatment. The imposition of drought occurred via the exclusion of rainfall using rainout shelters. In the Set 1 studies, the drought was imposed only in 1994, from late May to mid October. In the Set 2 studies, the drought was imposed in 1998 and 1999, and the periods were from 1 April to 30 June. Grazing, which we described as "flash" due to the high intensity and very short duration of a few hours a day, was implemented by allocating six ewes and their twin lambs to graze paddocks of size 50 m^2, removing more than 75% of the standing biomass. According to Heitschmidt et al. (1999, 2005), the grazing start dates were early June and July each year. For the simulation we set the grazing dates to 2 June and 3 July each year. Control studies in both Set 1 and Set 2 involved no drought and no grazing treatments. Details of this study can be found in Heitschmidt et al. (1999, 2005).

Using this information in addition to the daily weather data for the site during the study years, the GPFARM-Range model was re-parameterized for the Fort Keogh site as follows. First, the soil profile data, which included depth, texture, and bulk density of horizons, were obtained from the USDA-NRCS. The hydraulic parameters required for water balance simulation were estimated from texture and bulk density using the pedotransfer functions provided in the GPFARM-Range model, by setting the "soilPropOpt" = 0. Second, the model was adapted to sheep, which hitherto was not one of the animal types. To do so, the animal parameters were modified by substituting ewes and lambs for cows and calves, and setting the weights of the ewes and lambs to 65 and 25 kg, respectively. Further, the maximum daily dry matter intake by the ewes and lambs were also set to 1.5 and 0.6 kg, respectively (Table 7–4). Third, the forage growth component of the model was re-parameterized by manually adjusting the RGR values for each functional group. The meteorological input variables, except solar radiation, were obtained from the website of the Western Regional Climate Center (Western Regional Climate Center, 2009), for the years 1993 to 1996 and 1998 to 2001. The daily solar radiation was estimated from the daily maximum and minimum temperature and latitude, using algorithms of Hargreaves and Samani (1982).

As shown in Table 7–4, there were major differences between the CPER (the previous site of model parameterization) and Miles City (the new location of interest). First, the soil type at Miles City was more clayey compared with the more sandy loam at the CPER. Second, whereas the WSG dominated at CPER (64%), the reverse was the case at Miles City. Presumably, the species that comprised the WSG and CSG at Miles City were different from those at the much warmer central locations at CPER. Thus, in applying the model to Miles City conditions, the differences between sites must reflect in parameter values.

The results of the studies showed that forage growth under the control conditions (ambient rainfall and non-grazed) followed the rainfall patterns closely (Fig. 7–5). For non-grazed forage growth in the Set 1 studies, the high rainfall in 1993 (Fig. 7–5a) resulted in relatively high forage growth (Fig. 7–5b), whereas declining rainfall in the years 1994 to 1996 resulted in lower growth in those years. In the Set 2 studies when rainfall was comparatively lower than Set 1 (Fig. 7–5c), forage growth was reduced (Fig. 7–5d).

The model could mimic the observed trends of the peak standing crop (PSC), despite the overestimation in 1993 and 1998. The statistical comparison between the simulated and the observed gave an $r^2 = 0.72$, RMSE = 194.5, and a d index = 0.87, with a slight negative bias. Judging from the modeling statistics, it could be concluded that the adapted model satisfactorily simulated the forage growth under the range of conditions considered. Hence, the adjusted parameters could be assumed to be adequate for simulating potential forage growth at the Miles City site.

A further evaluation of the re-parameterized model involved applying it to situations involving drought and grazing. As shown in Fig. 7–6, the model generally captured the forage growth trends under varying drought and grazing conditions. For Set 1 studies, forage growth was largely determined by the ambient rainfall when there was no grazing or imposed drought in 1993 (Fig. 7–6a). In 1994, however, the imposed drought not only decreased the peak standing crop, but also there was a sharp decline of the post-grazing forage biomass. In 1995, the peak forage growth was still low despite the removal of the drought treatment. Forage regrowth after the grazing event was considerably low. Forage growth recovered in 1996 when both the drought and grazing effects were removed. The

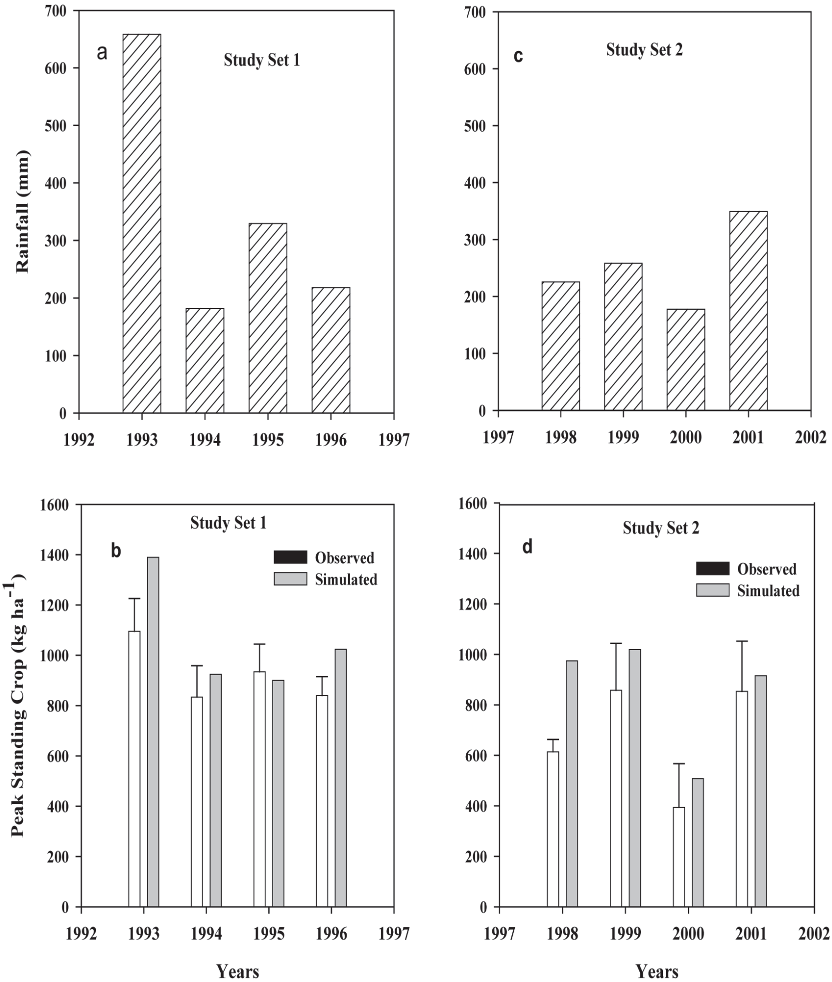


Fig. 7–5. Seasonal (April–September) (a, c) rainfall for the two sets of studies and (b, c) observed and simulated peak standing crop for non-drought and non-grazed conditions at Miles City, MT.

simulated forage growth followed the observed trends satisfactorily except for the overestimated growth under the ambient rainfall and non-grazed conditions in 1993 and 1996.

In the Set 2 studies (Fig. 7–6b), 2 yr of repeated drought phases and flash grazing events in 3 yr resulted in a drastic decline in forage growth during the first 3 yr, with the annual peak growth below 300 kg ha^{-1}. Although growth recovered in 2001 when both drought and grazing treatments were removed, the annual peak growth of 600 kg ha^{-1} was far less than that observed in the same year under ambient rainfall and non-grazed conditions. Thus, full recovery did

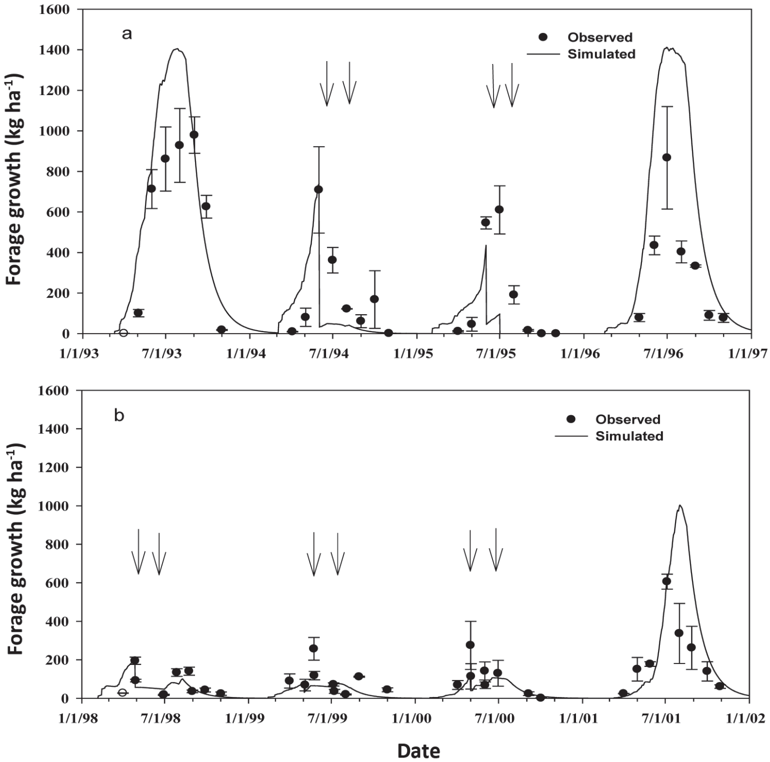


Fig. 7–6. Time course of observed (closed circles) and simulated (lines) forage growth at Miles City, MT. (a) Set 1 includes studies with drought imposed in 1994 and grazing in 1994 and 1995; (b) Set 2 includes studies with drought imposed in 1998 and 1999 with grazing during 1998 through 2000. Arrows indicate approximate grazing times.

not occur after the prolonged drought and grazing effects. The model captured the low growth trends during the first 3 yr (1998–2000) but overestimated the recovery in year 2001.

The comparison of the simulated and observed forage growth for treatments indicated that despite the variability of the observed data, the agreement was satisfactory (R^2 = 0.68, RMSE = 145 kg ha^{-1}, and Willmott's d = 0.91).

The flexibility of model to adapt it from cattle to sheep grazing systems expands the scope of the application of the GPFARM-Range model to many locations within the Great Plains. Further, the parameterization of the GPFARM-Range model resulted in acceptable model output. Herein lies the strength of models as tools for exploring soil–plant–animal–management interactions for a wide range of locations and time.

Further Improvements of the GPFARM-Range Model

The GPFARM-Range model is constantly improved and upgraded to address the many issues that determine rangeland productivity. In a recent paper, Adiku et al. (2010) proposed a framework for simulating the effect of soil compaction due to animal trampling on forage growth. Another effort is to simulate forage composition change due to grazing and other disturbances. In an ongoing work, efforts are being made to include the sensitivity of the model to global climate change by introducing functions that relate the stomatal conductance and RGR to changing atmospheric CO_2. In relation to this is the question of how much carbon rangelands sequester compared to other land use systems. To address this, efforts are under way to include components in the model that simulate soil carbon and nitrogen dynamics.

Conclusions

This chapter sought to briefly present the GPFARM-Range model and explore some of the practical ways of parameterizing the model for application at different locations and management purposes. Two main methods were proposed: (i) manual adjustment of default parameter values and (ii) direct empirical parameter determination from experimental data. It was recommended that in view of the level of information and expertise required for the second method, users could first adjust default values to minimize the difference between the simulated and observed. However, the published literature is a major source of data that could be used in parameterizing models. In the case where parameter values must be determined empirically, we recommend strict adherence to standard protocol for making measurements. A number of texts were suggested to assist in empirical parameter determination. It was also shown that by varying the values of some few key parameters, the GPFARM-Range model could simulate forage growth at new locations.

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