Simulating grass productivity on diverse range sites in Texas

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ABSTRACT: Simulation models addressing soil erosion and water quality issues on range sites should realistically simulate grass dry matter yields across a wide diversity of soils and climate regimes. This study was designed to evaluate the ability of the ALMANAC (Agricultural Land Management Alternatives with Numerical Assessment Criteria) model to simulate annual range grass biomass production under diverse climatic conditions and soils in Texas. The objective was to compare range grass production at rangeland ecological sites, as reported in the U.S. Department of Agriculture Natural Resources Conservation Service ((USDA NRCS) soil surveys, with production simulated by ALMANAC using the most common grasses for each site. The model was run with 60 years of daily weather data on 20 different soils from a diverse set of sites in Texas. The weather data was from seven sites. Model inputs included parameters for the soil series, grass species characteristics, and locally measured climate data. After allowing 10 years for the model to equilibrate, means for simulated production for the sites for the next 50 years were similar to reported means. Simulated production in high rainfall years and low rainfall years were also similar to reported values. The soils, climate, and grass parameter data sets developed here can be useful starting points for deriving data for additional range sites, giving model users examples of realistic input data. The model shows promise as a tool for realistically simulating grass production on a diverse group of soils and in diverse climatic conditions.

Keywords: Grass biomass, grass modeling, range yields

Complexity in grassland simulation models can easily outpace available validation data. The challenge for developing useful grassland models is to include sufficient detail to quantify differences among plant species, soils, and climate conditions without making the input requirements prohibitively large. Such models must complement the available soils data and the available validation data sets for grasses.

Grassland models such as the Simulation of Production and Utilization on Rangelands (SPUR) model (Wight and Skiles 1987; MacNeil et al. 1985; Stout 1994) and the Ecosystem Level Model (ELM) (Innis 1978) differ in the degree of local calibration required to simulate plant biomass. A robust model not requiring local calibration that is capable of realistically simulating range productivity would be valuable for a variety of applications. Such a model should use the readily available U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS) soils data. It should rely on plant parameters derived for a species under nonlimiting environmental conditions. The model could be used to compare soil erosion for row cropping systems against perennial forages. It could help answer water quality questions downstream from such production systems. Such a model could be used to compare productivity of communities composed of native grass species with productivity of improved pastures. Finally, the model could help evaluate changes in soil erosion and range productivity in response to overgrazing or invasion by woody species.

The ALMANAC (Agricultural Land Management Alternative with Numerical Assessment Criteria) model has potential for such applications. It is a process-oriented simulator of plant communities with several competing species (Kiniry et al. 1992). It simulates growth of one plant species or several competing species in a general way and with sufficient detail so that it can be easily transferred among regions without recalibration. The model simulates water and nutrient balances and the interception of solar radiation by competing plant species. ALMANAC includes subroutines and functions from the Erosion Productivity Impact Calculator (EPIC) model (Williams et al. 1984) and has additional details for plant growth. Required climate and soil inputs are readily available, and parameters for many common grass and crop species are available with the model. Likewise, parameters for other plant species can be easily derived from the literature.

The objective of this study was to demonstrate the capability of ALMANAC to dynamically simulate annual productivity of grasses in five regions of Texas. Fifty-year simulations were compared to published USDA NRCS annual productivity values for the rangeland ecological sites in each region. This sites will hereafter be referred to as range sites.

Methods and Materials

Data sets for model evaluation. Texas, by the nature of its soils, rainfall zones, and grass species distributions, has diverse values for range productivity. Range sites for this study were selected to represent this diversity for rainfall zones in the state (Figures 1 and 2 and Table 1). The selected sites represent some of the most extreme climatic conditions found in the United States, from high humidity, high rainfall, subtropical conditions near Anahuac to low humidity, low rainfall conditions near Pecos. There were also sites on the Southern High Plains near Amarillo, and in central and northeastern Texas.

Range site yields from USDA NRCS county soil surveys were compared to simulated annual production. Potential annual production values for each range site for "favorable," "normal," and "unfavorable" growing seasons were reported. Reported annual production values were generally derived from three to five years of sampling

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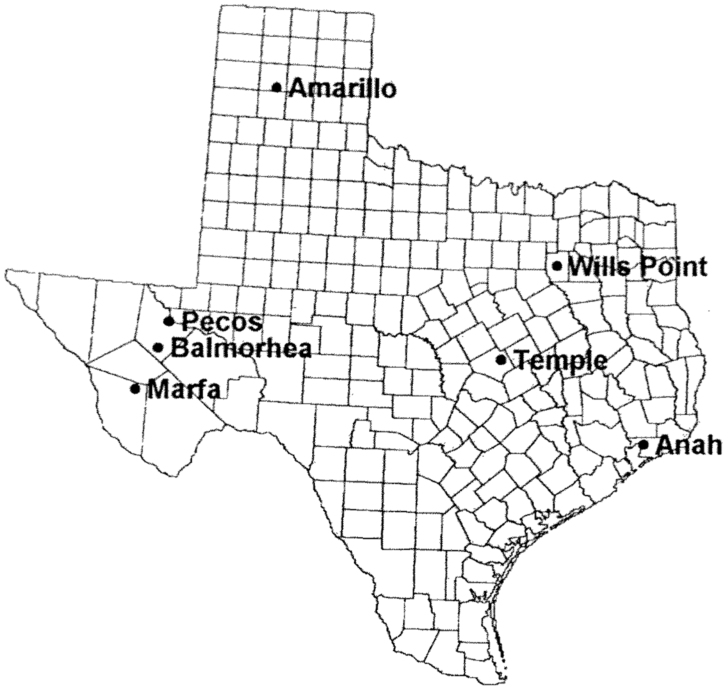
Figure 1

Locations of the weather stations used for the simulations.



on sites closest to pristine climax condition. Sampling was typically done at the end of the growing season; however, this technique can reconstruct annual production for all species taking climatic variations and time of sampling into account. At least 10 randomly selected sample plots were measured at each site. These plots were clipped, and the aboveground biomass was measured. Samples, which were assumed to contain 10% moisture, were air dried (Morrison 1941). The species composition was recorded, and the biomass weight of each species was measured. Annual production was simulated using the most common one or two reported grass species for a range site and 60 years of generated climate data. The first 10 years allowed the model to equilibrate, and we analyzed only the last 50 years of results. This procedure provided realistic soil moisture and soil nutrient levels for the range sites.

In order to standardize the analysis across sites, a consistent system was used to compare simulated production and annual production published in the soil surveys. The published "normal" annual production was compared to the average of the 50 years of simulations. The published "favorable" production was compared to the mean of the 10 years with the greatest simulated production, and the published "unfavorable" production was compared to the 10 years with the lowest simulated production.

Soil water inputs were based on the most prevalent soil series for the range site (Table 2). Simulated annual production values were from a single harvest at the end of the growing season. Climate data came from the nearest available weather station. These data were used to generate the 60 years of climate data. The authors traveled to representative range sites to inspect vegetative composition and percentage cover for nearly all the range types considered.

Model description. The ALMANAC model (Kiniry et al. 1992) simulates water and nutrient balances and interception of solar radiation. This model simulates daily plant growth with leaf area index (LAI), light interception, and a constant for converting intercepted light into biomass (radiation use efficiency, RUE). Stresses such as nutrient deficiency, drought, or temperature extremes reduce LAI and biomass growth.

The ALMANAC model holds promise for applications in range environments. The model realistically simulated Alamo switchgrass production at several locations in Texas (Kiniry et al. 1996). The model can simulate a single plant species or several species competing for light, water, and nutrients. The soil inputs can be derived from the USDA NRCS National Soil Information System (NASIS) database. Required inputs (daily maximum and minimum temperatures, solar irradiance, and precipitation) are readily available from many sources.

Most of the parameters descriptive of the growth of the grass species were derived from an ongoing field experiment at Temple, Texas. The results of the first three years of that study were published by Kiniry et al. (1999). In the following sections, "Temple results" or "Temple study" will refer to that study as well as continuing research on other warm-season

Table 1. Locations of data sets used in range simulations.

Region	Counties	Lat.,Long.	Weather Station	MLRA†	Mean Annual Precipitation† mm
Northeast Texas					
	Kaufman	32° 36' N, 96° 18' W	Wills Point	86A, 87A	1050
Central Texas					
	Coryell, Bell	31° 06' N, 97° 20' W	Temple	85, 86A	794
High Plains					
	Moore, Potter	35° 14' N, 101° 49' W	Amarillo	78A	444
West Texas					
	Reeves	31° 26' N, 103° 30' W	Pecos	42	221
	Presido	30° 19' N, 104° 01' W	Marfa	42	329
	Reeves	31° 00' N, 103° 40' W	Balmorhea	42	466
Coastal Region					
	Chambers	29° 46' N, 94° 41' W	Anahuac	150B	1189

†Major Land Resource Areas.

†Average for the sixty simulated years.

Figure 2
Pictures of some of the range sites simulated.

Table 2. Soils used to simulate range sites in Texas.

Range site	Soil Series	Soil Depth m	PAW m	Runoff Curve Number
Northeast Texas				
Claypan prairie	Crockett	2.03	0.22	80
Central Texas				
Blackland	Houston Black clay	1.89	0.26	80
Clay loam	Topsey	2.03	0.29	80
Adobe	Brackett	0.86	0.12	80
Shallow	Doss	0.46	0.07	80
Stony clay loam	Nuff	2.03	0.32	80
High Plains				
Very shallow	Potter	0.23	0.02	80
Deep hardland	Pullman	2.03	0.26	80
Sand hills	Tivoli	1.52	0.08	39
Sandy loam	Amarillo	1.00	0.12	80
Mixed slope	Mobeetie	1.52	0.14	61
Loamy bottomland	Spur	1.50	0.22	80
Wet bottomland	Sweetwater	1.52	0.16	80
West Texas				
Gravelly (mixed prairie)	Santo Tomas	1.91	0.08	61
Gravelly desert grassland	Delnorte	1.52	0.04	80
Igneous hill and mountain	Brewster	0.20	0.01	61
Loamy desert grassland	Reakor	1.50	0.25	61
Draw desert grassland	Balmorhea	1.52	0.22	74
Gulf Coast				
Blackland	Lake Charles	2.03	0.23	80
Firm brackish marsh	Harris	1.52	0.21	80

PAW is the plant available water, the difference between the drained upper limit and the lower limit for the profile. Runoff curve numbers are based on soil hydrologic groups.

Table 3. Leaf area index (LAI) values based on typical grass stands at each site for wet years.

Range Site	Species	Input potential LAI
Central Texas		
Blackland	Little bluestem	2.9
	Switchgrass	0.9
Clay loam	Little bluestem	1.5
	Switchgrass	0.7
Adobe	Little bluestem	1.5
	Sideoats grama	1.5
Shallow	Buffalograss	0.5
	Sideoats grama	0.8
Stony clay loam	Little bluestem	2.9
High Plains		
Very shallow	Little bluestem	0.4
	Sideoats grama	0.1
Deep hardland	Buffalograss	0.5
	Blue grama	0.4
Sand hills	Little bluestem	0.4
	Big bluestem	0.4
Sandy loam	Little bluestem	1.0
	Sideoats grama	0.9
Mixed slopes	Buffalograss	0.4
	Blue grama	0.5
Loamy bottomland	Indiangrass	1.9
	Switchgrass	1.4
Wet bottomland	Eastern gamagrass	1.4
	Switchgrass	1.4
Northeast Texas		
Claypan prairie	Indiangrass	3.1
	Switchgrass	1.8
West Texas		
Gravelly (mixed prairie)	Sideoats grama	0.4
	Blue grama	0.4
Gravelly desert grassland	Black grama	0.5
Igneous hill and mountain	Black grama	0.5
	Sideoats grama	0.6
Loamy desert grassland	Blue grama	0.4
	Black grama	0.5
Draw desert grassland	Sideoats grama	1.8
Gulf Coast		
Blackland	Little bluestem	1.5
	Switchgrass	1.0
Firm brackish marsh	Marshhay cordgrass	3.1

grasses at Temple (Kiniry, unpub.)

Leaf area index (LAI) development requires an input potential LAI for a species at high plant density, and representative values at two lower plant densities. Accurate prediction of light interception depends on realistic values of LAI for a given plant density. Values of LAI for some representative warm-season species were obtained from measurements on plots in the Temple study. Input plant stands were used to provide each range site's values for potential LAI of the plant species (Table 3).

Values for the critical species-specific parameters were derived in the field at Temple (Table 4). The model simulates light interception by the leaf canopy with Beer's law (Monsi and Saeki 1953) and the LAI. The greater the value of the extinction coefficient k, the more light will be intercepted at a given LAI. The fraction of incoming solar radiation intercepted by the leaf canopy is

$$\text{Fraction} = 1.0 - \exp(-k * \text{LAI}) \qquad (1)$$

The value of k was determined for several common warm season grasses in the Temple study.

Simulation of light interception also requires accurate description of leaf area production and decline. The model simulates LAI development through the season with an s-curve through the origin. This curve describes how LAI can increase, under non-stress conditions, as a function of heat units. Likewise, leaf area is lost late in the season and is simulated with a rate of LAI decline factor (RLAD). The value of RLAD determines the shape of this leaf area decline function. When the RLAD value is 1.0, the leaf area declines linearly after flowering as heat units accumulate. Values less than 1.0 cause slower, nonlinear decreases, while values greater than 1.0 cause faster, nonlinear decreases.

Biomass growth is simulated with a radiation use efficiency (RUE) approach. Values for RUE have been derived for honey mesquite (*Prosopis glandulosa* Torr. var *glandulosa*) and eastern red cedar (*Juniperus virginia* L.) (Kiniry 1998) and johnsongrass [*Sorghum halepense* (L.) Pers.] (Kiniry 1994). RUE values varied widely among the grass species. Values ranged from 1.8 g of biomass per MJ (0.063 oz per MJ) of intercepted photosynthetically active radiation (IPAR) for sideoats grama [*Bouteloua curtipendula* (Michaux) Torrey] and blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.] to 4.7 g of biomass

Table 4. Input parameters to simulate the grass species.

Grass	k	RUE g MJ^{-1}	RLAD	RBMD	RDMX — m —
Eastern					
Gamagrass	0.31	5.0	0.2	10.	2.0
Switchgrass	0.33	4.7	1.0	1.0	2.2
Big bluestem	0.36	3.4	0.5	10.	2.0
Little bluestem	0.36	3.4	0.5	10.	2.0
Indiangrass	0.33	3.4	0.5	10.	2.0
Marshhay cordgrass	0.33	3.0	1.0	1.0	2.2
Buffalograss	1.2	2.0	0.2	10.	1.4
Sideoats grama	1.12	1.8	0.1	10.	1.4
Blue grama	1.4	1.8	0.1	10.	1.4
Black grama	1.4	1.8	0.1	10.	1.4

k is the light extinction coefficient for Beer's law. RUE is the radiation use efficiency in g of dry biomass per MJ of intercepted photosynthetically active radiation. RLAD defines the rate of LAI decline after anthesis (see text). RBMD defines the rate of decline in biomass accumulation after anthesis. RDMX is the potential maximum rooting depth.

per MJ (0.17 oz per MJ) for switchgrass (*Panicum virgatum* L.) and 5.0 g of biomass per MJ (0.18 oz per MJ) for eastern gamagrass [*Tripsacum dactyloides* (L.) L.]. Using identical functions as for RLAD, the rate of biomass accumulation decline (RBMD) for decreasing RUE after anthesis was described for each species.

Soil water and nutrients commonly limit grass growth in Texas. ALMANAC's water balance consists of transpiration calculations predicting potential plant water use if sufficient water is present in the current rooting zone. ALMANAC's nutrient balance (N and P) also allows plants to acquire sufficient nutrients to meet the demands if adequate quantities are available in the current rooting zone. Nutrient values for the grasses were derived in the Temple study with adequate fertilizer on a very deep Houston Black clay (data not shown). The grass growth was reduced below potential at the sites as nutrients became limiting.

The maximum rooting depth (RDMX) defines the potential depth of a plant species in the absence of a root-restricting soil layer. On sands in Illinois, little bluestem [*Schizachyrium scoparium* (Michaux) Nash] rooted to 1.1 m (3.6 ft) depth and big bluestem (*Andropogon gerardii* Vitman) to 1.8 m (5.9 ft) (Sperry 1935). Little bluestem in Colorado rooted to 1.5 m (4.9 ft) (Shantz 1911). Weaver (1954) measured rooting depth of several grasses in Nebraska. Switchgrass had the deepest roots, ranging from 2.4 to 3.3 m (7.9 to 10.8 ft) depending on the soil. Canada wildrye (*Elymus canadensis* L. var *canadensis*) had the shallowest rooting at 0.6 m (2.0 ft). Other maximum rooting depths in Nebraska were 1.2 m (3.9 ft) for sideoats grama, 1.2-1.4 m (3.9-4.6 ft) for little bluestem, 1.5-1.7 m (4.9-5.6 ft) for indiangrass [*Sorghastrum nutans* (L.) Nash], 1.5-2.1 m (4.9-6.9 ft) for big bluestem, 1.8 m (5.9 ft) for blue grama and buffalograss [*Buchloë dactyloides* (Nutt.) Engelm.], and 1.8-2.4 m (5.9-6.9 ft) for western wheatgrass (*Agropyron smithii* Rydb.). Soil cores from the plots in the Temple study in 1994 indicated that switchgrass roots extended to at least 2 m (6.6 ft), while sideoats grama was more shallow-rooted. For this study, deep values of 2.2 m (7.2 ft)were used for switchgrass and marshhay cordgrass (*Spartina patens* var juncea), and the most shallow depths were 1.4 m (4.6 ft) for buffalograss, sideoats grama, and blue grama. Eastern gamagrass, big bluestem, little bluestem, and indiangrass were all simulated with a value of 2.0 m (6.6 ft).

Base temperature in ALMANAC is the same for all growth stages for a plant species. Base temperature constrains the initiation of leaf area growth and, thus, dry matter accumulation. Higher optimum temperature can allow increased plant development rate later in the season when temperatures are greater. The sum of heat units from sowing to maturity controls how long forages grow. Base temperature for the warm season grasses in this study was assumed to be 12°C (54°F) and optimum temperature was 25°C (77°F). The input heat units to reach maturity each year were 1800 in all cases.

Results and Discussion

For average years, ALMANAC simulations were realistic at nearly all of the range sites (Table 5). The six highest yielding sites (the Blackland and Clay loam sites in central Texas, the Wet bottomland site in the High Plains, the Claypan prairie site in northeast Texas, and the two sites on the Gulf Coast) on average differed from the expected means by 0.1 Mg ha^{-1} (0.045 t acre^{-1}). For the nine sites with USDA NRCS averages of less than 2.0 Mg ha^{-1}(0.89 t acre^{-1}), the average simulated production for the 50 years differed from the expected mean by an average of 0.1 Mg ha^{-1} (0.045 t acre^{-1}). Of these, the Draw desert grassland site had the greatest difference. The remaining five sites had a mean difference of 0.05 Mg ha^{-1} (0.22 t acre^{-1}).

Likewise, in favorable rainfall years, the simulated yields were similar to the reported USDA NRCS yields for good years. The six high-yielding sites had a mean error for good years of 0.4 Mg ha^{-1} (0.18 t acre^{-1}). The nine low yielding sites had a mean error of 0.2 Mg ha^{-1} (0.09 t acre^{-1}). The remaining five sites had a mean error in good years of 0.3 Mg ha^{-1} (0.13 t acre^{-1}).

Finally, for low rainfall, poor years, mean difference between simulated and reported values for the high yielding sites was 0.8 Mg ha^{-1} (0.36 t acre^{-1}). For the low yielding sites, the mean difference was 0.3 Mg ha^{-1} (0.13 t acre^{-1}). For the remaining sites, the mean difference was 0.5 Mg ha^{-1} (0.22 t acre^{-1}).

The use of 10 preliminary years allowed simulations to stabilize at some locations (Table 6). The standard deviations of the first 10 years were 52-196% greater than the standard deviations of the last 50 years for the Blackland site of the Gulf Coast and for the Deep hardland, Sandy loam, and Loamy bottomland sites of the High Plains. The mean simulated yields were 51-78% greater for the first 10 yrs than for the last 50 for the Deep hardland, the Sandy loam, and the Loamy bottomland sites of the High Plains.

Summary and Conclusion

In conclusion, with the soils data provided by the county soil surveys, and with plant parameters derived for several grasses grown at Temple, the ALMANAC model realistically simulated range site yields in a wide diversity

Table 5. Annual range productivity with good, average, or poor rainfall conditions.

Range Site		Yields[1] Mg ha^{-1}		
Central Texas		Good	Avg.	Poor
Blackland	NRCS	7.0	6.0	3.5
	Simulated	6.9	5.9	4.5
Clay loam	NRCS	6.5	5.0	3.0
	Simulated	5.7	4.9	4.2
Adobe	NRCS	4.0	3.2	1.8
	Simulated	3.7	3.2	2.7
Shallow	NRCS	4.0	3.0	1.8
	Simulated	3.1	2.7	2.4
Stony clay loam	NRCS	5.5	4.5	2.5
	Simulated	5.5	4.4	3.1
High Plains				
Very shallow	NRCS	0.8	0.7	0.4
	Simulated	0.8	0.5	0.3
Deep hardland	NRCS	2.1	1.5	0.9
	Simulated	2.0	1.5	1.0
Sand hills	NRCS	2.2	1.6	1.4
	Simulated	2.0	1.6	1.2
Sandy loam	NRCS	2.3	1.6	1.2
	Simulated	2.0	1.6	1.0
Mixed slopes	NRCS	2.7	2.0	1.4
	Simulated	2.6	2.0	1.5
Loamy bottomland	NRCS	3.9	2.6	1.8
	Simulated	3.6	2.5	1.7
Wet bottomland	NRCS	5.6	4.3	3.0
	Simulated	6.4	4.0	1.9
Northeast Texas				
Claypan prairie	NRCS	6.0	5.0	3.0
	Simulated	5.9	5.0	4.3
West Texas				
Gravelly (mixed prairie)	NRCS	1.3	1.1	0.9
	Simulated	1.3	1.1	0.9
Gravelly desert grassland	NRCS	0.8	0.4	0.3
	Simulated	0.8	0.4	0.2
Igneous hill and mountain	NRCS	1.4	1.1	0.8
	Simulated	1.4	1.0	0.5
Loamy desert grassland	NRCS	1.0	0.8	0.6
	Simulated	1.7	0.8	0.2
Draw desert grassland	NRCS	2.2	1.8	1.2
	Simulated	1.8	0.9	0.3
Gulf Coast				
Blackland	NRCS	9.0	7.5	6.0
	Simulated	9.0	7.5	5.9
Firm brackish marsh	NRCS	11.0	8.3	5.5
	Simulated	11.6	8.4	5.8

[1] Mg ha^{-1} multiplied by 1.009 equals thousand of pound acre^{-1}.

of conditions. The model can be expected to accurately simulate grasses in sites differing greatly in soil type, soil depth, temperatures, rainfall amounts, and type of grass cover.

Results of this test demonstrate that the model holds promise as a valuable tool for range management, environmental impact assessment, nutrient management, and soil erosion simulation. The model can be used to compare productivity of different grass species, both native and improved species, on different soils and with different rainfall. It can simulate effects of overgrazing of one grass species on the production of competing species. Similarly, it can simulate effects of overgrazing on wind and water erosion, through the removal of grass leaf cover. The model can simulate responses of grass growth to added nutrients, and estimate any resulting nutrients in runoff. Finally, the model can simulate long-term effects of various grazing management practices on soil productivity and runoff water quality.

The results reported herein are a good first step in demonstrating the robustness of the ALMANAC model for range productivity at diverse sites. Failure to accurately simulate productivity at the Draw desert grassland site could have been caused by the unusual nature of the soil water there. The apparent underestimation of soil moisture was likely due to moisture coming from runoff or to subsurface lateral flow from adjacent areas.

Future research deriving accurate growth parameters for additional warm-season grasses and for cool-season species will aid in the application of ALMANAC in other regions. The LAI and RUE approach provide a robust, verifiable system of simulating annual production of range communities for a wide diversity of soils and climates. The model's ability to simulate soil erosion can allow comparison of soil loss from annual crops with that of permanent vegetation. The model's use of USDA NRCS soil data and commonly available daily climate data make it easy to apply.

Endnote

Models and data sets described herein are available to users at no charge. Users wanting these models and data should send three 1.44 MB diskettes to the senior author at USDA-ARS, 808 E. Blackland Rd., Temple, TX 76502.

Table 6. Simulated annual range productivity (Mean ± SD) for the first 10 years, for the last 50 years, and for all 60 years of simulation.

Range Site	Yields[1] Mg ha^{-1}		
Central Texas	**10 yrs**	**50 yrs**	**60 yrs**
Blackland	6.06±1.14	5.85±0.89	5.89±0.93
Clay loam	5.52±0.61	4.86±0.57	4.98±0.63
Adobe	2.98±0.37	3.19±0.36	3.17±0.37
Shallow	2.64±0.19	2.72±0.26	2.71±0.25
Stony clay loam	4.28±0.84	4.42±0.84	4.40±0.84
High Plains			
Very shallow	0.66±0.15	0.53±0.16	0.55±0.17
Deep hardland	2.61±0.72	1.47±0.35	1.68±0.61
Sand hills	1.97±0.36	1.62±0.25	1.68±0.30
Sandy loam	2.49±0.74	1.65±0.25	1.79±0.49
Mixed slopes	2.00±0.33	2.04±0.43	2.03±0.41
Loamy bottomland	3.99±1.25	2.50±0.67	2.77±0.98
Wet bottomland	4.31±1.27	3.99±1.59	4.05±1.54
Northeast Texas			
Claypan prairie	5.18±0.69	5.03±0.56	5.08±0.60
West Texas			
Gravelly (mixed prairie)	1.12±0.17	1.14±0.15	1.14±0.15
Gravelly desert grassland	0.43±0.22	0.41±0.24	0.46±0.24
Igneous hill and mountain	1.09±0.41	1.02±0.48	1.03±0.47
Loamy desert grassland	0.86±0.51	0.83±0.54	0.83±0.54
Draw desert grassland	0.87±0.55	0.90±0.56	0.89±0.56
Gulf Coast			
Blackland	6.64±1.81	7.47±1.19	7.33±1.34
Firm brackish marsh	8.30±1.69	8.44±2.11	8.42±2.05

[1] Mg ha^{-1} multiplied by 1.009 equals thousand of pound acre^{-1}.

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