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Plant Parameters for Plant Functional Groups of Western Rangelands to Enable Process-based Simulation Modeling

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Authors' contributions

This work was carried out in collaboration between all authors. Author JRK designed the study, performed the statistical analysis, helped write the protocol, and wrote the first draft of the manuscript. Authors JB and JE helped write the protocol and managed data collection. Author MW helped manage literature searches, authors KJ, DT, MS, AYM, TB, MSK, SW and DG managed field research and field data collection. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To quantify western rangeland plant parameters for a wide range of representative species in the region.

Study Design: Use field measurements to quantify leaf area index (LAI), light extinction coefficient (k), radiation use efficiency (RUE), and nutrient concentrations of representative plant species. Measure fraction of intercepted photosynthetically active radiation, leaf area index, and dry matter during the growing season. Use these plant parameters to simulate five representative ecological sites in the region.

Place and Duration of Study: Beaver, UT, Fillmore, UT, Stone, ID, Logan, UT, Bridger, MT, Aberdeen, ID, Lockeford, CA, and Meeker, CO in 2011 and 2012.

Methodology: Fraction of light intercepted was measured repeatedly above and below the plant canopy. Plant samples were harvested, dried until constant weight, then weighed. Nitrogen and phosphorus concentrations were determined using standard protocols.

LAI and RUE were calculated from the destructive samples, the leaf area estimates, the light interception, and the dry weights.

Results: LAImax of grass generally ranged from 1.0 to 2.1. Values for k generally ranged from -0.50 to -0.85. RUE generally ranged from 0.70 to 1.3g MJ^{-1}. For forbs, values for LAImax of the two leguminous forbs were 0.6 and nearly 3.0. Values for LAImax for the non-leguminous forbs ranged from 0.5 to about 1.1. Correspondingly, among the five genera, k varied from -0.3 to -0.6 and RUE varied from near 1.1 to 4.4g MJ^{-1}.

For shrubs, Prunus and Cleome values of LAImax were 0.2 and 1.5; values for k were -0.5 and -1.65, respectively.

Conclusion: Results demonstrated that assessments with process-based models such as ALMANAC are feasible with realistic estimates of plant parameters for plant functional groups in a region. Our measurements of individual species within these groups provide estimates for the needed parameters for the group for these assessments.

Keywords: Plant Parameters; western rangelands; simulation modeling; functional groups; native plants.

1. INTRODUCTION

Regional assessments with process-based models such as Soil and Water Assessment Tool (SWAT) [1,2]; Agricultural Policy/Environmental eXtender (APEX) [3], or Agricultural Land Management Alternatives with Numerical Assessment Criteria (ALMANAC) [4] require realistic estimates of plant parameters for the primary plant functional groups in the region. Assessments such as Rangeland-CEAP (Conservation Effects Assessment Project) are designed to evaluate impacts of various management strategies such as grazing management, invasive species, and revegetation. Plant cover, soil stabilization by plants, and nutrient cycling by plants represent the major aspects varying within each season and between years in response to these management strategies. As such, realistic simulation of plant development is necessary for effective simulation evaluations. Likewise, to proceed with these evaluations in a timely manner, the primary plant species within a region need to be characterized into plant functional groups. “Functional group” in this context is an operational term, based on similarities in plant type and in plant parameter values. Measurement of a representative species within each group will provide estimates for the needed growth parameters. Errors in applying such plant group parameters can be evaluated by comparing model simulation outputs to those using parameters for individual plant species contained in the group.

Process-based models such as ALMANAC are capable of realistically predicting production potentials of multiple species of exotic perennial warm-season grasses. The ability of ALMANAC to simulate the old world bluestem (OWB) group (*Bothriochloa ischaemum* (L.) Keng) and buffelgrass (*Pennisetum ciliare* [L.] Link) [5] suggest that it may be possible to apply ALMANAC to the simulation of plant functional groups. This possibility is bolstered by previous successes with ALMANAC realistically simulating communities of grasses and forbs in the arid western U.S. with a generic set of community-based parameters [6].

There are a number of contexts in which it might be useful to simulate functional groups or communities rather than individual species. For example, large scale regional assessments, such as those predicting a plant community's response to climate change or to conservation practices, may benefit from a coarser, functional group approach rather than a fine-scale species approach to simulation. Work with ALMANAC continues to explore the potential to identify, parameterize, and simulate trait-based functional groups with this process-based plant growth model. It is intended that this concept be expanded towards development of a workable plant functional group system that could be simulated by ALMANAC. Thereby model output will be applied to assessing ecosystem impacts and services associated with shifts in both species composition and management practices. For example, the ALMANAC model could be implemented to interpret site monitoring and adaptive management approaches as such that it could prove a valuable and critical tool for conservation practice planning.

The concept of plant functional groups has been used for a variety of applications and with a diversity of systems for grouping. They have been used to characterize plant communities and productivity [7-9] Functional groups have been used when assessing plant community responses to disturbance and grazing [10-17]. These groups have been used to assess resistance to plant invasion into communities [18,19]. Functional groups have been used for managing rare plants [20] and for looking at drivers of soil biota [21].

Functional groups have also been used in the context of simulation models or model platforms. Cousins et al. [14] used plant functional groups when applying a landscape modeling platform called LAMOS to simulate plant succession and grazing disturbance. Grigulis et al. [16], also using the LAMOS model, used plant functional groups to simulate changes in fire regimes with invasion by a non-native grass in northern Spain. Boer and Smith [15] used plant functional groups when applying the ARENA model to simulate water and nitrogen competition on some Australian rangelands. Pausas [22] used plant functional types to simulate dynamics of grasslands with a grid-cell raster based stochastic model called MELCHA in fire-prone ecosystems.

In the present study, field data to derive plant parameters relied heavily on ongoing research at Plant Materials Centers (PMC's) of the Natural Resources Conservation Service of USDA. These centers are valuable resources, often overlooked and underutilized for plant evaluations in the different regions of the USA. Their efforts over the last several decades have led to identification of important ecotypes of promising native plants in the different regions [23]. They have relatively large plots of such plants that can readily be measured for parameter derivation for process-based models. Consequently, the objective of this project was to work with PMC's in the western states, along with USDA-ARS researchers at Logan, UT and Temple, TX, to develop plant parameters for representative species from some of the primary plant functional groups in these regions. These were developed for the ALMANAC model for the Rangeland-CEAP project, with the idea that these parameters can also be readily applied in the SWAT, APEX, and similar process-based models.

The parameters developed for the ALMANAC model will be useful for the actual species measured and for the plant functional groups they represent. Thus specific objectives of this study were to quantify leaf area index (LAI), light extinction coefficient (k) for Beer's law, radiation use efficiency (RUE), and plant nitrogen and phosphorus concentrations in well-managed stands of representative plant species for some major plant functional groups in the western U.S. Such values, additionally, will be valuable in applying Beer's law with measured fraction of intercepted photosynthetically active radiation (FIPAR) as a nondestructive method of calculating LAI. Values for FIPAR could be measured on the ground with linear photosynthetically active radiation (PAR) sensors (as in this study) or remotely with cameras estimating fraction of plant cover, as a surrogate for FIPAR. In addition, model simulation output using mean values for a group of species was compared to output for some individual species. This was intended to quantify potential simulation errors when using a functional group for plant parameters. Thus the aim of this study was to quantify these plant parameters for a wide range of representative species in this region. Then, once derived, we wanted to investigate how accurately we could simulate plant productivity on some range sites. Thus this study was designed as a test of "proof of concept" for this type of plant parameterization and simulation modeling.

2. MATERIALS AND METHODS

2.1 Site Specific Descriptions and Management

All measurements were taken on well-established plots of each plant type planted well prior to initiation of this project. Measurements were made in 2011 and 2012 at the different sites. Sites varied in soil type, latitude, longitude, and elevation Fig. 1 and Table 1. The study involved on-the-ground measurements of FIPAR (nondestructive), LAI (destructive), and dry matter (destructive). Plant species measured varied among sites and years Table 2.

The Beaver, UT site had an average annual precip. of 300mm. Plots were planted November 2006 as a fall dormant planting at 2.5 seeds per cm of row and spacing between rows was 20cm; plots were 1.25mx5m; each year the forage was removed to a stubble height of 15cm. Plots were not irrigated and no fertilizer was applied.

The Fillmore, UT site had an average annual precip. of 380mm. Plots were planted November 2004 as a fall dormant planting at 2.5 seeds per cm of row and spacing between rows was 20cm. Plots were 1.25mx5m. Each year the forage was removed to a stubble height of 15cm. Plots were not irrigated and no fertilizer was applied.

The Stone, ID (Curlew National Grassland) site had an average annual precip of 250mm and elev. Plots were planted November 2002 as a fall dormant planting at 2.5 seeds per cm of row. Spacing between rows was 20cm and plots were 1.25mx5m. Each year the forage was removed to a stubble height of 15cm. Plots were not irrigated and no fertilizer was applied.

The Logan, UT site had an average annual precip of 450mm. These sites are stock seed fields and are distributed around Cache Valley, all similar in elevation and annual precipitation. They were irrigated twice a year to field capacity near flowering and in August to initiate new growth. They were planted in 91cm row spacings. Within a row they were solid seeded at 3 to 4 seeds per cm of row.

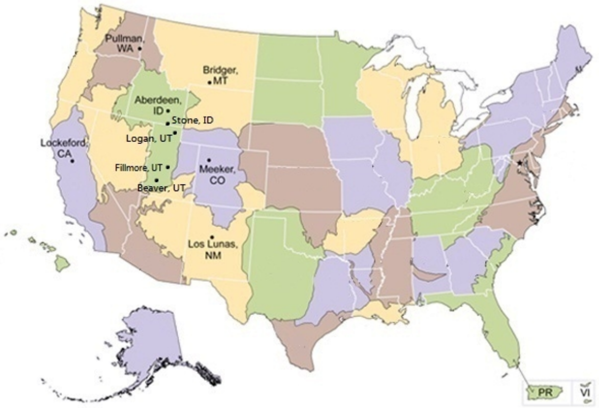

Fig. 1. Locations of field sites where plant parameters were measured

Table 1. Experimental locations

Location	Latitude (N)	Longitude(W)	Elevation(m)	Soil Type
Lockeford, CA	38°10'20”	121°10'3”	20	Oxyaquic Xerofluvents, Columbia fine sandy loam, drained, 0 to 2 percent slopes
Meeker, CO	40°0'17’121"	107°50'17”	1971	Pachic Argiustolls, Zoltay clay loam, 3 to 8 percent slopes
Aberdeen, ID	42°59'6"	112°54'29”	1364	Xeric Haplocalcids, Declo loam, 0 to 2 percent slopes
Pullman, WA	46°43'57”	117°0'1”	786	Argiaquic Xeric Argialbolls, Latahco silt loam, 0 to 3 percent slopes
Bridger, MT	45°16'1”	108°53'3”	1135	Aridic Ustifluvents, Haversonsilty clay loam, 0 to 2 percent slopes
Los Lunas, NM	34°46'20”	106°45'32”	1472	Typic Torripsamments, Bluepoint loamy fine sand, 1 to 3 percent slopes
Beaver, UT	38°20’52’’	112°35’21”	1971	Petrocalcidic Palexerolls, Murdock silt loam, 1 to 3 percent slopes
Logan, UT	41°48’48”	111°49’27”	1382	Aquic Argixerolls, Nibley silty clay loam, 0 to 3 percent slopes
Fillmore, UT	39°12’11”	112°14’14”	1772	Calcic Petrocalcids, Spager gravelly very fine sandy loam, 5 to 15 percent slopes
Stone, ID	42° 02’25”	112°40’18”	1408	Xeric Natrargids and Xeric Haplocalcids, Mellor-Freedom complex, 0 to 2 percent slopes

The Bridger, MT site (Billings, MT Plant Materials Center) had an average annual precip. of 292mm. Establishment date varied among plant species, with indianricegrass being Nov. 2009, western wheatgrass being April 2007, thickspike wheatgrass being April 2005, and basin wildrye being April 1995. Irrigation consisted of 10 cm of flood irrigation in late June or early July. All plots were fertilized with 12kg ha^{-1} N and 58kg ha^{-1} P on 2 Nov 2010 and with 112kg ha^{-1} N and 42kg ha^{-1} P on 1 June 2011.

Table 2. Plant species measured. nomenclature follows USDA-NRCS (2012) [24]

Plant Species	Common Name 'Variety'	Location
Cleome isomeris Greene	Bladderpod spider flower 'Dorado'	Lockeford, CA
Distichlis spicata (L.) Greene	saltgrass LK517f Germplasm	Lockeford, CA
Elymus elymoides (Raf.) Swezey	Squirreltail	Lockeford, CA
Sporobolus airoides (Torr.) Torr.	alkali sacaton	Lockeford, CA
Festuca arizonica Vasey	Arizona fescue 'Redondo'	Meeker, CO
Hedysarum boreale Nutt.	Utah sweetvetch	Meeker, CO
Pascopyrum smithii (Rydb.) Á. Löve	western wheatgrass 'Arriba'	Meeker, CO
Penstemon strictus Benth.	Rocky Mountain penstemon 'Bandera'	Meeker, CO
Prunus virginiana L.	Chokecherry	Meeker, CO
Elymus elymoides	bottlebrush squirreltail 'Wapiti'	Meeker, CO
Bromus marginatus Nees ex. Steud.	mountain brome "Garnet"	Meeker, CO
Achnatherum hymenoides (Roem. &Schult.) Barkworth	Indian ricegrass '739'	Meeker, CO
Elymus wawawaiensis J. Carlson and Barkworth	Snake River wheatgrass	Aberdeen, ID
Elymus lanceolatus (Scribn. and J.G. Sm.) Gould	thickspike wheatgrass	Aberdeen, ID
Elymus trachyacaulus (Link) Gould ex Shinners	slender wheatgrass	Aberdeen, ID
Pascopyrum smithii	western wheatgrass	Aberdeen, ID
Pseudoroegneria spicata (Pursh) Á. Löve	Bluebunch wheatgrass	Aberdeen, ID
Pseudoroegneria spicata	Blue bunch wheatgrass	Pullman, WA
Achnatherum hymenoides	Indian ricegrass 'Rimrock'	Bridger, MT
Elymus lanceolatus	thickspike wheatgrass 'Critana'	Bridger, MT
Leymus cinereus (Scribn. and Merr.) Á. Löve	basin wildrye 'Trailhead'	Bridger, MT
Pascopyrum smithii	western wheatgrass 'Rosana'	Bridger, MT
Gaillardia aristata Pursh	Blanket flower Meriwether germplasm	Bridger, MT
Ratibida columnifera (Nutt.) Woot. &Standl.	upright prairie coneflower Stillwater Germplasm	Bridger, MT
Dalea candida Michx. Ex Wild.	white prairie clover Antelope germplasm	Bridger, MT
Pleuraphis jamesii Torr.	galleta grass 'Viva'	Los Lunas, NM
Bouteloua curtipendula (Michx.) Torr.	Sideoats grama 'Vaughn'	Los Lunas, NM

Table 2 Continued…………

Agropyron cristatum (L.) Gaertn.	crested wheatgrass 'Hycrest'	Beaver, UT
Thinopyrum intermedium (Host) Barkworth & D.R. Dewey	intermediate wheatgrass 'Oahe'	Beaver, UT
Psathyrostachys juncea (Fisch.) Nevski	Russian wildrye 'Bozoisky'	Beaver, UT
Agropyron fragile (Roth.) P. Candargy	Siberian wheatgrass 'Vavilov II'	Beaver, UT
Bromus inermis Leyss.	smooth brome 'Manchar'	Beaver, UT
Achnatherum hymenoides	Indian ricegrass 'Rimrock'	Beaver, UT
Elymus wawawaiensis	Snake River wheatgrass 'Secar'	Beaver, UT
Elymus elymoides	bottlebrush squirreltail 'Sand Hollow'	Beaver, UT
Elymus lanceolatus	thickspike wheatgrass 'Bannock'	Beaver, UT
Elymus lanceolatus	thickspike wheatgrass 'Critana'	Beaver, UT
Elymus trachycaulus	slender wheatgrass 'Firststrike'	Beaver, UT
Leymus cinereus	basin wildrye 'Trailhead'	Beaver, UT
Pascopyrum smithii	western wheatgrass 'Rosana'	Beaver, UT
Pseudoroegneria spicata	bluebunch wheatgrass 'Goldar'	Beaver, UT
Bromus biebersteinii	meadow brome 'Cache'	Fillmore, UT
Agropyron cristatus	crested wheatgrass 'Hycrest'	Fillmore, UT; Stone, ID
Psathyrostachys juncea	Russian wildrye 'Bozoisky'	Fillmore, UT; Stone, ID
Pascopyrum smithii	western wheatgrass 'Rosana'	Fillmore, UT; Stone, ID
Pseudoroegneria spicata	bluebunch wheatgrass 'Goldar'	Fillmore, UT; Stone, ID
Agropyron fragile	Siberian wheatgrass 'Vavilov II'	Stone, ID
Agropyron cristatum	crested wheatgrass 'Hycrest II'	Logan, UT
Thinopyrum intermedium	intermediate wheatgrass 'experimental'	Logan, UT
Psathyrostachys juncea	Russian wildrye 'Bozoisky II'	Logan, UT
Agropyron fragile	Siberian wheatgrass 'Vavilov II'	Logan, UT
Elymus wawawaiensis	Snake River wheatgrass 'Discovery'	Logan, UT
Elymus trachycaulus	slender wheatgrass 'Firststrike'	Logan, UT
Leymus cinereus	basin wildrye 'Continental'	Logan, UT

The Aberdeen, ID Plant Materials Center site had an average annual precip. of 250mm. Plots were all planted in 2007. Plots received 41cm of total water (rainfall plus irrigation) each growing season. Plots were mowed each summer near anthesis date to prevent seed spread. They were fertilized each year with 264kg ha^{-1} of 16-20-0 and 73kg ha^{-1} of 46-0-0. Bunchgrasses at this location had 20 plants m^{-2}.

The Lockeford, CA Plant Materials Center site had an average annual precip. of 480 mm. Bladderpod plots were mature 18-year-old shrubs planted on about 3m spacing. The saltgrass plot was a 19-year-old solid stand that was mowed once per year and disked every few years to maintain vigor. Neither received fertilizer or irrigation during the previous 5 years. Sacaton was 7 years old with 4 plants m^{-2} and squirreltail was 1 year old with 20 plants m^{-2}. Sacaton plots were fertilized each spring with 112kg ha^{-1} of 16-20-0, surface irrigated 2-3 times per year during seed ripening, and mowed each fall. Squirreltail plot did not receive any supplemental irrigation, fertilizer or mowing.

The Meeker, CO Plant Materials Center site had an average annual precip. of 410 mm. Annual fertilizer applications consisted of 90kg ha^{-1} N, 11kg ha^{-1} P and 5.6kg ha^{-1}S for all plots except chokecherry and Indian ricegrass. These two species had no fertilizer applied.At this site, overhead sprinklers were used to irrigate sufficiently to avoid drought stress three times each growing season for Utah sweetvetch, Arizona fescue and Bottlebrush squirreltail. Similarly, gated pipe was used to irrigate three times each growing season for Western wheatgrass, Rocky Mountain penstemon, and mountain brome. Indian ricegrass and chokecherry were not irrigated. Weeds were controlled by mechanical weeding, hand weeding, and herbicides. Harvesting and mowing was completed by hand/combine or swather. Prior to measurements, chokecherry had been established 6 years, Utah sweetvetch 2 years, Arizona fescue 8 years, western wheatgrass 5 years, Rocky Mountain penstemon 8 years, mountain brome 19 years, bottlebrush squirreltail 7 years, and Indian ricegrass 7 years.

The Los Lunas, NM Plant Materials Center site had an average annual precip. of 251mm. Foundation seed field of sideoats grama grass "Vaughn" was planted in 2004. Plots were clipped to 10cm. in March. Plots were fertilized with 45kg ha^{-1} N and 45kg ha^{-1} P on 26 March 2012. Pre-emergence herbicide was applied on 6 April 2012. Plots were irrigated on 12 April, 24 May, 15 June, 5 July, and 3 August 2012 in sufficient amounts to prevent any drought stress. Initial green-up occurred on 22 April 2012 and full green-up on 1 May 2012.

At this Los Lunas site, foundation seed field of galleta grass cultivar "Viva" was planted in 2003. Plots were burned 13 March 2012. Plots were fertilized with 45kg ha^{-1} N on 26 March and 9 Sept 2012 and 45kg ha^{-1} phosphorus on 12 April and 9 Sept 2012. Pre-emergence herbicide was applied on 6 April 2012. Plots were irrigated sufficiently to avoid drought stress on 16 April, 22 May, 14 June, and 10 August 2012. Initial green-up occurred on 20 April 2012 and full green-up on 1 May.

2.2 Field Measurements

Values for FIPAR were determined by repeated measurements of PAR below the plant canopy with an AccuPAR LP-80 ceptometer (Decagon Devices, Inc., Pullman, WA), with concurrent measurements above the canopy with a PAR sensor. Plant samples were harvested from a 0.5x0.5m ground area at 0.05m height, weighed fresh, and a subsample weighed fresh. This subsample was measured for leaf area with a LI-3100 Area Meter (LI-COR Biosciences, Lincoln, NE), dried in a forced air oven at 65°C until constant weight was reached, then weighed. The nitrogen concentration was determined using a Leco FP-528 nitrogen/protein analyzer (LECO Corp., St. Joseph, MI) with Dumas combustion [25,26]. Phosphorus concentration was determined using a microwave assisted acid digestion and analyzed through a Thermo IRIS Advantage HX analyzer (Thermo Fisher Scientific Inc., Waltham, MA).

LAI was calculated as:

$$\text{LAI}=\text{Total fresh wt./subsample fresh wt.} * \text{leaf area of subsample (cm}^2\text{)/(50cmx50cm)} \quad [1]$$

Radiation use efficiency (RUE) was calculated as the rate of increase in above-ground dry matter (g per m^2 ground area) per unit of intercepted photosynthetically active radiation (IPAR) (MJ per m^2 ground area). Ideally this was calculated as a slope of the line for dry matter =f(IPAR). However, sometimes only two harvest dates were usable; in those cases RUE was calculated from differences. Only data from dates showing increases in dry matter were included. This constrained RUE values for time periods when plants were growing and not static, as can occur on range sites especially with drought stress. Values for FIPAR were calculated on a daily basis, with values for dates between measurement dates calculated by linear interpolation.

2.3 ALMANAC Simulations

USDA-NRCS Ecological site description (ESD) data were used to demonstrate the validity of the derived plant parameters. The simulation sites were constrained by availability of ESD data. Only two of the states considered had such data available for testing the application of plant parameters to nearby sites. These were in Utah and New Mexico Table 8a. Thus, these serve as examples of applications of a small number of our derived parameters, with the idea that these model demonstrations will be expanded in the future as more extensive ESD data becomes available.

Initially each of these sites was simulated with the parameters for the represented individual plant species. Next, only one or two of these species were simulated, with the potential leaf area index values adjusted to match the total for the site in the previous runs. Finally, simulations were repeated with the mean parameters for each plant functional group represented. Similarly for this last set of simulations, the total potential leaf area index was set to the same value as the sum of all species simulated in their group. This was accomplished in each case by adjusting plant density. The difference in aboveground plant biomass yield were compared to the reported NRCS biomass yields for each of these three approaches for each site.

3. RESULTS

3.1 Field Measurements

Results below are described by plant genera Table 3. Values for individual plant species are in Appendix A.

Maximum LAI (LAImax), light extinction coefficient for Beer's law (k), and RUE are the three main driving parameters defining potential leaf canopy development and potential dry matter production in the absence of environmental stress Table 3. Grass LAImax ranged from 1.0 to 2.1 with a few exceptions. The bromes, Indian ricegrass, and Arizona fescue had LAImax below 1.0, and basin wildrye and galleta grass had LAImax of 2.9 and 3.3, respectively. Values for k ranged from -0.50 to -0.85 with a few exceptions. The mean k value of brome, crested/Siberian wheatgrasses, and intermediate wheatgrass had k values lower than -0.5. High mean k values of -0.90 and -1.06 were measured for Arizona fescue and sideoats grama, respectively.

Radiation use efficiency (RUE) values ranged from 0.70 to 1.3g MJ^{-1} with some exceptions. Saltgrass mean RUE was low, at 0.35, as was Russian wildrye at 0.47g MJ^{-1}. Arizona fescue had a high mean RUE value of 2.07g MJ^{-1}.

For forbs, the three parameters varied widely among the few genera represented. Values for LAImax of the two leguminous forbs were 0.6 and nearly 3.0. Values for LAImax for the non-leguminous forbs ranged from 0.5 to about 1.1. Correspondingly, among the five genera, k varied from -0.3 to -0.6 and RUE varied from near 1.1 to 4.4g MJ^{-1}.

Shrubs had an even more limited set of values, with measurements only on *Prunus* and *Cleome*. Values of LAImax were 0.2 and 1.5; values for k were -0.5 and -1.65, respectively. There were no values for RUE for these due to the slower, more long-term nature of their growth. However due to drastically different values for LAImax and k, it appeared that these two genera will require different parameters to simulate each.

3.1.1 Groupings into functional groups by plant type and maximum LAI

The grasses were grouped into four groups Table 4 and the forbs into two groups Tables 3 and 5. The cool season bunchgrasses were split into those with LAImax values less than 1.0 and those between 1.0 and 2.0. The two higher LAI, warm season grasses, saltgrass and sacaton, were pooled together. The last group consisted of two warm season grasses: galleta grass and sideoats grama. Consistency in each of these four groups makes their simulations with one set of plant parameters very feasible. The one exception may be with the saltgrass/sacaton group where LAImax values differed two-fold. The forbs similarly had a mean LAImax near 1.0 and a mean RUE value greater than for most of the grasses. The two shrubs Tables 3 and 5 differed greatly in LAImax values and will likely need to be simulated with separate parameters for many applications.

3.1.2 Groupings by five broad functional groups based solely on plant type

Finally, as shown in Table 5, the rhizomatous grasses were pooled into one group and the bunchgrasses into another group. The forbs are in two groups as discussed in the previous section, depending on whether they are leguminous or not. The shrubs are in one group, as discussed above. These groupings give estimates for simulations where users simply want to look at the overall water use or soil erosion of a generic set of plants, with no interest in grazing management or other ecosystem services. The LAImax values averaged about 0.8 to 1.4. Values for k showed remarkable similarity among the groups, mostly near -0.5 to -0.7. The non-leguminous forbs had a lower mean k, near -0.4, while shrubs had a higher k, near -1.1. The RUE values likewise ranged from about 0.8 to 1.7g per MJ intercepted PAR, with the one exception being the higher value for non-legume forbs.

3.1.3 Nitrogen and phosphorus concentrations

For this portion of the study, the grasses were split into rhizomatous vs. bunchgrass and the forbs into leguminous vs. non-leguminous, and looked at each by the U.S. state where measurements were taken Tables 6a and 6b. Concentrations of both N and P generally started high early in the season and gradually decreased, as expected. As values were pooled over states, the means became more stable between the two grass groups. These means, either for each of the two grass groups or for all the grasses pooled, provide a reasonable guide for simulating these important plant nutrients.

Trends for N and P concentrations for the various plant types differed between the two years. In 2011 Table 6a, the rhizomatous grasses tended to have higher N concentrations than the bunchgrasses early in development, with the opposite true for mid-season and near maturity. For P, rhizomatous grasses as a group had higher concentrations early, while the two groups had nearly the same values mid-season and near maturity. Different trends occurred in 2012 Table 6b. The bunchgrass group had a higher mean N concentration early and nearly the same mid-season and near maturity. For P in 2012, the bunchgrass group had a higher mean early and mid-season, and lower near maturity. The leguminous forb in 2011 had the highest N and P concentrations for all three stages. However in 2012, the leguminous forb had N and P values similar to the two grass groups. The non-leguminous forb in 2011 had higher initial N and P concentrations than the grass groups early. Values for N decreased to near those of the grass groups thereafter. Values for P remained relatively high after the initial values. In 2012, the non-leguminous forb had N and P values at or below those of the grass groups.

Table 3. Functional group summary split by genera. WR stands for wildrye, WG stands for wheatgrass, and SQT stands for squirreltail. "k" is the extinction coefficient for Beer's law. Max LAI is the mean across data sets for maximum LAI during each season. RUE (radiation use efficiency) is the above ground biomass (g) per MJ intercepted photosynthetically active radiation

	Genus	Max LAI	Avg k	RUE	Number of Site Years
Grasses					
Bromes	*Bromus*	0.76	-0.48	1.15	5
Indian ricegrass	*Achnatherum*	0.64	-0.85	1.32	6
Russian WR	*Psathyrostachys*	1.44	-0.66	0.72	6
Basin WR	*Leymus*	2.88	-0.73	0.47	6
Bluebunch WG	*Pseudoroegneia*	1.34	-0.82	1.31	8
Crested/Siberian WG	*Agropyon*	1.44	-0.46	0.84	11
Intermediate WG	*Thinopyrum*	2.07	-0.39	1.47	4
WG/SQT	*Elymus*	1.26	-0.71	0.78	25
Western WG	*Pascopyrum*	1.84	-0.74	1.10	10
Saltgrass	*Distichlis*	3.30	-0.52	0.35	2
Galleta grass	*Pleuraphis*	1.14	-0.52	1.00	2
Sideoats grama	*Bouteloua*	1.22	-1.06	1.22	1
Arizona fescue	*Festuca*	0.63	-0.90	2.07	2
Alkali sacaton	*Sporobolus*	1.57	-0.77	0.40	1
Leguminous Forbs					
White prairie clover	*Dalea*	2.93	-0.31	2.99	1
Utah sweetvetch	*Hedysarum*	0.61	-0.63	1.13	2
Non-leguminous Forbs					
Rocky Mt. penstemon	*Penstemon*	0.99	-0.43	1.34	2
Blanketflower	*Gaillardia*	1.07	-0.30	4.42	1
Upright prairie coneflower	*Ratibida*	0.47	-0.57	2.16	1
Shrubs					
Chokecherry	*Prunus*	0.21	-0.52		1
Bladderpod spiderflower	*Cleome*	1.47	-1.65		1

3.2 ALMANAC Simulations

As discussed above, simulation sites were chosen based on proximity to measurement sites and availability of ecological site description (ESD) data Table 7a. Simulated plant species were chosen based on their dominance in the ESD database for each site. Plant densities in each community were adjusted to simulate reasonable potential LAI for each site.

As such, simulated annual biomass values using all the species listed were close to reported values in all cases Table 7b. The three ESD's in New Mexico had large differences among reported annual biomass yields. These were closely mirrored by the simulated yields for these sites. These yield differences among sites were due to differences in plant species composition, the potential LAI of each, and the soils. The same rainfall data was used for all three sites due to their proximity.

Similar results are shown using all the species listed for the two ecological sites in Utah. The higher elevation site (Beaver, near Fillmore, elev. 1772m) had much lower potential LAI and only about 0.57 Mg ha^{-1} simulated and published dry matter yields. Thus both sites were simulated with the same three plant species parameters, only changing the potential LAI. Simulations with mean functional group simulations often had similar mean yields as with the more specific parameters, with the possible exception of the Logan UT site Table 7b.

Table 4. Grass functional group summary

	Max LAI	Avg k	RUE	Number of Site Years
Low LAI cool-season bunchgrasses	0.65	-0.75	1.66	
Squirreltail	0.55	-0.78	2.09	5
Brome	0.76	-0.48	1.15	5
Indian ricegrass	0.64	-0.85	1.32	6
Arizona fescue	0.63	-0.90	2.07	2
Cool-season wildryes & wheatgrasses	1.37	-0.75	0.74	
Wildrye*	1.52	-0.78	0.60	12
Wheatgrass**	1.22	-0.71	0.87	53
Warm-season saltgrass & sacaton	2.44	-0.65	0.38	
Saltgrass	3.30	-0.52	0.35	2
Sacaton	1.57	-0.77	0.40	1
Warm-season galleta grass & sideoats grama	1.23	-0.71	0.96	
Galleta grass	1.14	-0.52	1.00	2
Sideoats grama	1.22	-1.06	1.22	1

**Two divergent sets based on LAI, one group with 2 datasets and LAI= 4.89, k= -0.40, and RUE= 0.72, and another group with 10 datasets with LAI= 0.93, k= -0.85, and RUE= 0.47.*

***Two divergent sets based on LAI, one group with 6 datasets and LAI= 3.42, k= -0.27, and RUE= 1.15, and another group with 44 datasets with LAI= 0.59, k= -0.79, and RUE= 0.90.*

Table 5. Functional group summary by plant growth type. Due to the slow growth of shrubs, RUE measurements were not reported for this relatively short-term project

	Max LAI	Avg k	RUE	Number of Site Years
Shrubs	0.84	-1.09		2
Leguminous forbs	1.38	-0.52	1.68	3
Non-leguminous forbs	0.91	-0.43	2.31	4
Rhizomatous grasses	1.26	-0.69	0.80	42
Bunchgrasses	1.14	-0.74	1.24	47

When only one or two plant species were used shown in bold in Table 7b, simulated yields were generally reasonably close in the three New Mexico sites, but were too high in the two

Utah sites. For the three sites in New Mexico, simulated yields were 68%, 90%, and 106% of published values. For the two New Mexico sites, simulated yields were 184% and 176% of published values.

When the mean functional group parameters were used also Table 7b, simulated yields were reasonably close to published values in most cases. In three of the five sites, simulated yields for the functional group of the site were within 5% of published values. Exceptions were in the second site and the last site listed. Simulated yields were 119% and 130% of published values, respectively.

Table 6a. For 2011, representative values for 14 plant functional groups in 6 states. No. msrd. is the number of plant varieties measured. BN values (%) are plant nitrogen concentrations for early in the season, mid-season, and late-season. BP values (%) are for plant phosphorus concentrations for early, mid- and late-season. Rhiz. Grass is for rhizomatous grasses and Bunchgrass is for bunchgrasses

Func. Group	State (No. msrd.)	BN1	BN2	BN3	BP1	BP2	BP3
Rhiz. Grass	ID (2)	2.36	---	1.12	0.228	---	0.154
Bunchgrass	ID (4)	2.64	---	1.21	0.261	---	0.180
Rhiz. Grass	CA (1)	3.35	1.34	0.87	0.378	0.165	0.204
Bunchgrass	CA (1)	2.32	1.74	1.28	0.188	0.183	0.135
Rhiz. Grass	CO (1)	3.46	1.70	1.61	0.285	0.214	0.178
Bunchgrass	CO (1)	2.67	1.85	1.88	0.244	0.203	0.228
Rhiz. Grass	MT (2)	1.92	1.75	1.32	0.235	0.191	0.166
Bunchgrass	MT (2)	2.06	1.56	1.06	0.240	0.203	0.123
Pooled Values							
Rhiz. Grass		2.77	1.60	1.23	0.282	0.19	0.176
Bunchgrass		2.42	1.72	1.36	0.233	0.196	0.167
All Grasses		2.59	1.66	1.29	0.258	0.193	0.171
Leguminous Forb	CO (1) MT(1)	4.63	4.61	2.99	0.385	0.346	0.199
Non-Leg. Forb	CO (1) MT(2)	3.60	1.43	1.66	0.469	0.252	0.262

Table 6b. For 2012, representative values for 14 plant functional groups in 6 states. No. msrd. is the number of plant varieties measured. BN values (%) are plant nitrogen concentrations for early in the season, mid-season, and late-season. BP values (%) are for plant phosphorus concentrations for early, mid- and late-season. Rhiz. is for rhizomatous grasses and Bunchgrass is for bunchgrasses

Func. Group	State (No. msrd.)	BN1	BN2	BN3	BP1	BP2	BP3
Rhiz. Grass	NM (1)	---	---	0.93	---	---	0.195
Bunchgrass	NM (1)	---	---	0.82	---	---	0.158
Rhiz. Grass	ID (1)	2.78	---	---	0.273	---	---
Bunchgrass	CA (1)	3.82	---	---	0.297	---	---
Bunchgrass	CO (2)	3.38	2.03	1.47	0.280	0.230	0.193
Rhiz. Grass	MT (2)	1.92	1.75	1.32	0.235	0.191	0.166
Bunchgrass	MT (2)	2.06	1.56	1.06	0.240	0.203	0.123
Pooled Values							
Rhiz. Grass		2.35	1.75	1.13	0.254	0.191	0.181
Bunchgrass		3.09	1.80	1.12	0.272	0.217	0.158
All Grasses		2.79	1.78	1.12	0.265	0.208	0.167
Leguminous Forb	MT (1)	3.02	1.28	---	0.255	0.115	---
Non-Leg. Forb	ID (1) MT(2)	2.26	1.20	0.88	0.285	0.205	0.173

Table 7a. Simulation locations

Location	Latitude (N)	Longitude (W)	Soil	Mean annual rainfall (mm)	Weather Station
Los Lunas, NM	34°39'40.680"	106°50'6.000"	Caliza-Bluepoint complex, 1 to 2% slopes	242	Quemado
Los Lunas, NM	34°39'40.680"	106°50'6.000"	Wink-Madurez association, gently sloping	242	Quemado
Los Lunas, NM	34°39'40.680"	106°50'6.000"	Gila Loam	242	Quemado
Beaver, UT	38°20'52.440"	112°35'21.840"	Murdock Silt Loam 1-3% slopes	331	Blanding
Logan, UT	41°47'9.240"	111°49'3.720"	Millville Silt Loam 0-2% slopes	411	Bear River Refuge

Table 7b. Simulation location results

Location	Ecological site name	Grasses simulated	Corresponding potential LAI values	Ecol. Site pub. Yields (Mg/ha)	Sim. Yields[1] (Mg/ha)	Sim. Yields[2] (Mg/ha)	Sim. Yields[3] (Mg/ha)
Los Lunas, NM	Gravelly Sand	Bush muhly	0.1	0.34	0.33	0.23	0.33
		Blue grama	0.1				
		Galleta grass	0.2(0.4)				
Los Lunas, NM	Loamy	*Galleta grass* Bottlebrush squirreltail	0.2(0.5)	0.48	0.50	0.43	0.57
		Bush muhly	0.05				
		Indian ricegrass					
		Black grama	0.1				
			0.1(0.15)				
			0.2				
Los Lunas, NM	Bottomland	Galleta grass	0.2	2.11	2.12	2.15	2.10
		Sacaton	7.3(7.3)				
		Blue grama	0.2				
		Vine mesquite	3.6(4.0)				
Beaver, UT	Upland loam	*Squirreltail*	0.1(0.2)	0.58	0.57	1.07	0.61
		Indian ricegrass	0.1				
		Bluebunch wheatgrass	0.1(0.1)				
Logan, UT	Upland loam	*Squirreltail*	0.2(0.3)	0.71	0.69	1.25	0.92
		Indian ricegrass	0.1				
		Bluebunch Wheatgrass	0.2(0.2)				

[1] Simulated yields using derived parameters for each species. [2] Simulated yields using one or two represented species, with potential LAI adjusted to match total potential LAI of the separate species. Italicized grass names are the ones simulated in the second set of simulations and the values in parentheses are the adjusted potential LAI. [3] Simulated yields using mean derived parameters for the relevant plant functional group.

4. DISCUSSION

Previously published values for grasses and shrubs Table 8 demonstrate of the values presented above compare with those published with similar techniques. These values for LAImax, k, and RUE showed ranges similar to those in the present study. Grass LAImax values were generally between 1.5 and 4.0 with notable exceptions. Blue grama was much lower and big bluestem and eastern gamagrass had LAImax values of 5.0 or more. This application of the plant functional group approach offers promise for this type of whole-system, process based simulation model.

Table 8. Previously published values for comparison

Our published values	Max LAI	Mean k	RUE
blue grama[1]	0.26	-1.62	0.57
sideoats grama[2]	1.50	-1.05	1.1
buffalograss[1]	2.13	-1.20	1.38
bahiagrass[1]	2.21	-1.00	1.25
coastal bermudagrass[1]	2.19	-1.10	1.50
big bluestem[2]	8.00	-0.36	1.4
Johnsongrass[3]			2.26
buffelgrass[4]	4.04	-0.52	2.26
old world bluestem[4]	3.57	-0.46	1.18
eastern gamagrass[2]	5.00	-0.31	2.1
eastern red cedar[5]			1.60
mesquite[5]			1.61

[1] Kiniry et al., 2007 [27].[2] Kiniry et al., 1999 [28].[3] Kiniry, 1994 [29].[4] Kiniry et al., 2013 [30].
[5] Kiniry, 1998 [31].

Mean k values from these previous studies fell into two groups, those with k absolute values of 0.31 to 0.52 and those with k absolute values of 1.0 to 1.62. It is interesting to note that the one species found in both tables, sideoats grama, had similar LAI and k values: LAImax values of 1.22 vs. 1.50 for the presnt study and Kiniry et al. [12], respectively and k values of -1.06 vs.-1.05. Likewise RUE values for this species were similar between the two studies: 1.22g MJ^{-1} in the present study and 1.10 in Kiniry et al. [10].

The results of this project demonstrated that assessments with process-based models such as ALMANAC are feasible with realistic estimates of plant parameters for plant functional groups in a region. Realistic simulation of plant development makes such simulation evaluations effective and scientifically defensible. These evaluations should be possible to achieve in a timely manner with these plant functional group parameters. Measurements of individual species within these groups provide estimates for the needed parameters for the group for these assessments.

The numerous contexts in which it is useful to simulate functional groups or communities rather than individual species will be greatly improved by the results of this study. Large scale regional assessments, such as those used to predict plant response to climate change or to conservation practices, will benefit from this coarser, functional group approach. This work demonstrates the potential to identify, parameterize, and simulate trait-based functional groups with this type of process-based plant growth model. This work should be expanded towards a workable plant functional group system that can be simulated by ALMANAC. Thus, model output will be applied to assessing ecosystem impacts and services associated with shifts in both species composition and management practices. The ALMANAC model can be readily implemented to interpret site monitoring and guide adaptive management approaches. The model should prove a valuable and critical tool for Conservation Practice Planning.

Finally, the use of plant functional groups in this study shares some common features with the modeling studies discussed above that used functional groups. Boer and Smith [17] simulated Australian rangeland vegetation with three plant functional groups: annual herbaceous, perennial herbaceous, and woody. Grigulis et al. [16] simulated an introduced grass and shrubs as different plant functional groups. Cousins et al. [14] simulated grassland in Sweden with five plant functional groups based on responses to grazing. Pausas [22] simulated two functional types of woody species in Mediterranean ecosystems, based on whether they resprout or not. The functional groups described herein are based on general plant type and morphology. Thus the final five groups are complementary to some of the approaches in the published simulation studies.

5. CONCLUSION

The parameters described in this project will be useful for the actual species measured and for the plant functional groups they represent. Such values, additionally, will be valuable in applying Beer's law with measured FIPAR as a nondestructive method of calculating LAI. FIPAR could be measured on the ground with linear PAR sensors (as in this study) or remotely with cameras estimating fraction of plant cover, as a surrogate for FIPAR.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX A

Plant parameters for each species at each site

CEAP Total Summary by Functional Groups												
	2010			**2011**			**2012**			**Average across yrs**		
Shrub	**Max LAI**	**Avg K**	**RUE**	**Max LAI**	**Avg K**	**RUE**	**Max LAI**	**Avg K**	**RUE**	**Max LAI**	**Avg K**	**RUE**
Bladderpod spiderflower CA	1.47	-1.65								1.47	-1.65	
chokecherry CO	0.21	-0.52								0.21	-0.52	
Average by Year	0.84	-1.09								0.84	-1.09	
Legume Forb												
Utah sweet vetch CO	0.55	-0.54	0.93	0.66	-0.72	1.13				0.61	-0.63	1.03
Antelope white prairieclover MT							2.93	-0.31	2.99	2.93	-0.31	2.99
Average by Year	0.55	-0.54	0.93	0.66	-0.72	1.13	2.93	-0.31	2.99	1.38	-0.52	1.68
Non-Legume Forb												
Bandera Rocky Mt. Penstemon CO	1.04	-0.55	1.34	0.93	-0.30					0.99	-0.43	1.34
Meriwether Blanketflower MT							1.07	-0.30	4.42	1.07	-0.30	4.42
Stillwater Prairie Coneflower MT							0.47	-0.57	2.16	0.47	-0.57	2.16
Average by Year	1.04	-0.55	1.34	0.93	-0.30		0.77	-0.43	3.29	0.91	-0.43	2.31
Rhizomatous grass												
saltgrass CA	2.53	-0.52	0.29	4.06	-0.51	0.41				3.30	-0.52	0.35
Viva galleta grass NM				1.43	-0.74	0.61	0.84	-0.30	1.39	1.14	-0.52	1.00
Manchar smooth brome B.UT	0.89	-0.20		0.72	-0.58		0.18	-0.65		0.60	-0.48	
Hycrest crested wheatgrass B.UT	0.31	-0.43		0.28	-0.80		0.18	-0.44		0.26	-0.55	
Hycrest crested wheatgrass F.UT	0.21	-0.59								0.21	-0.59	
Hycrest crested wheatgrass S.ID	0.90									0.90		
Hycrest II crested wheatgrass L.UT							3.91	-0.21	1.11	3.91	-0.21	1.11
Oahe Intermediate wheatgrass B.UT	0.56	-0.60		0.48	-0.74		0.13	-0.52		0.39	-0.62	
intermediate wheatgrass "experimental" L.UT							3.76	-0.17	1.47	3.76	-0.17	1.47
slender wheatgrass ID				2.07	-0.74	0.41	1.98	-0.85	0.76	2.02	-0.79	0.59
First Strike slender wheatgrass B.UT	0.54	-0.42		0.14	-1.14		0.07	-2.55		0.25	-1.37	

Table appendix A continued

First Strike slender wheatgrass L.UT							2.77	-0.18	1.29	2.77	-0.18	1.29
thickspike wheatgrass ID	4.74	-0.29	0.10	1.10	-1.58	0.49				2.92	-0.94	0.30
Bannock thickspike wheatgrass B.UT	0.39	-0.47		0.31	-1.02		0.13	-0.62	0.19	0.28	-0.70	0.19
'Critana' thickspike wheatgrass MT	1.29	-0.86	0.29	1.12	-0.48	0.89				1.21	-0.67	0.59
'Critana' thickspike wheatgrass B.UT				0.30	-1.18		0.10	-0.71	0.40	0.20	-0.94	0.40
Arriba western wheatgrass CO	1.31	-1.18	2.38	1.80	-0.36	2.21				1.56	-0.77	2.30
western wheatgrass ID	5.82	-0.45	0.53							5.82	-0.45	0.53
Rosana western wheatgrass MT	3.99	-0.56	0.55	0.61	-0.90	0.40				2.30	-0.73	0.48
Rosana western wheatgrass B.UT	0.29	-0.56		0.38	-0.97		0.14	-0.52		0.27	-0.68	
Rosana western wheatgrass F.UT	0.37	-1.06								0.37	-1.06	
Rosana western wheatgrass S.ID	0.75									0.75		
Average by Year	1.56	-0.59	0.69	1.06	-0.84	0.77	1.18	-0.64	0.94	1.26	-0.69	0.80
Bunchgrass												
Bottlebrush squirreltail CA	0.27	-0.61								0.27	-0.61	
Wapiti squirreltail CO							2.16	-0.14	2.09	2.16	-0.14	2.09
Sand Hollow bottlebrush squirreltail B.UT	0.49	-0.39		0.15	-1.42		0.07	-0.68		0.24	-0.83	
alkali sacaton CA				1.57	-0.77	0.40				1.57	-0.77	0.40
Redondo Arizona fescue CO	0.57	-1.02	3.62	0.69	-0.77	0.51				0.63	-0.90	2.07
Garnet mt. brome CO							1.44	-0.20	1.15	1.44	-0.20	1.15
Cache meadow brome F.UT	0.61	-0.65								0.61	-0.65	
"739" Indian ricegrass CO							1.51	-0.17	3.07	1.51	-0.17	3.07
Rimrock Indian ricegrass MT	0.79	-0.94	0.30	1.00	-1.09	0.60				0.90	-1.02	0.45
Rimrock Indian ricegrass B.UT	0.28	-0.74		0.19	-1.39		0.08	-0.80		0.18	-0.98	
Snake River wheatgrass ID				1.61	-0.97					1.61	-0.97	
Secar Snake River wheatgrass B.Ut	0.31	-0.44		0.22	-1.44		0.14	-0.59		0.22	-0.82	
Discovery Snake River wheatgrass L.UT							2.20	-0.23		2.20	-0.23	
bluebunch wheatgrass ID	6.75	-0.20	0.73	1.96	-0.97	1.00				4.36	-0.59	0.87
bluebunch wheatgrass M.ID				0.86	-1.05	1.76				0.86	-1.05	1.76
Goldar bluebunch wheatgrass S.ID	0.56									0.56		
Goldar bluebunch wheatgrass	0.58	-0.35		0.78	-0.99		0.47	-0.32		0.61	-0.55	

Table appendix A continued

B.UT												
Goldar bluebunch wheatgrass F.UT	0.33	-1.08								0.33	-1.08	
Continental basin wildrye L.UT							6.02	-0.42		6.02	-0.42	
Trailhead basin wildrye MT	2.37	-0.53		1.90	-1.45	0.47				2.14	-0.99	0.47
Trailhead basin wildrye B.UT	0.57	-0.57		0.75	-0.65		0.18	-1.12		0.50	-0.78	
Vaughn sideoats grama NM							1.22	-1.06	1.22	1.22	-1.06	1.22
Bozoisky Russian wildrye F. UT	0.49	-0.74								0.49	-0.74	
Bozoisky Russian wildrye S.ID	1.23									1.23		
Bozoisky Russian wildrye B.UT	0.44	-0.45		0.41	-0.46		0.07	-1.70		0.31	-0.87	
Bozoisky II Russian wildrye L.UT							3.75	-0.38	0.72	3.75	-0.38	0.72
Vavilov II Siberian wheatgrass B.UT	0.45	-0.34		0.24	-1.15		0.14	-0.51	0.07	0.28	-0.67	0.07
Vavilov II Siberian wheatgrass S.ID	0.66									0.66		
Vavilov II Siberian wheatgrass L.UT							3.90	-0.26	1.35	3.90	-0.26	1.35
Average by Year	0.99	-0.60	1.55	0.88	-1.04	0.79	1.56	-0.57	1.38	1.14	-0.74	1.24

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