PREDICTING WATER USE, CROP GROWTH AND QUALITY OF BERMUDA GRASS UNDER SALINE IRRIGATION

FINAL REPORT TO THE

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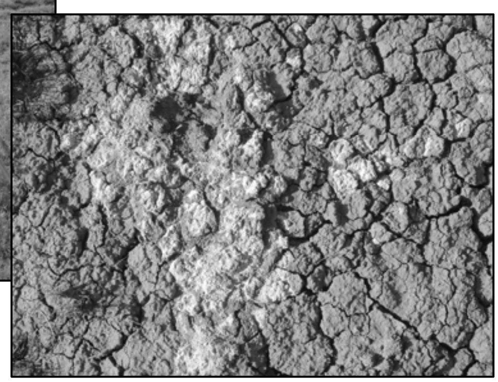

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Summary

Reusing saline drainage and other waste waters to produce forages suitable for ruminant livestock production would help to alleviate the shortage of the forages needed for California's expanding dairy herd and for beef and sheep production. It would also help to manage salinity problems in the western San Joaquin Valley (WSJV) providing an economic alternative to land retirement. In previous studies we have demonstrated that low quality drainage and waste waters can be used to produce forages on a salt-affected site in the WSJV while raising beef cattle without apparent adverse health effects and with acceptable rates of average daily gain. Our objectives for this study were: 1) to quantify the relationships between Bermuda grass growth and quality, soil and irrigation water salinity, and N fertilization level in saline soils; and 2) to create a simple model to predict grass growth and quality as a function of water use, N fertility and soil salinity. Our results indicate that Bermuda grass under an optimal irrigation with saline water (6 dS m^{-1}) and fertilized with the equivalent to 600 kg N $ha*y^{-1}$ can yield up to 20 ton DM $ha*y^{-1}$ in a soil of 7 dS/m ECe. With a fertilization equivalent to 300 kg N $ha*y^{-1}$ yields were close to 16 ton DM $ha*y^{-1}$. Without fertilization yields were around 1 ton DM $ha*y^{-1}$. Under grazing and a suboptimal irrigation Bermuda grass yields were between 5-7 ton DM $ha*y^{-1}$.
The leaf/stem ratio (LSR) was significantly different ($p<0.05$) between unfertilized and fertilized treatments. The difference between fertilized treatments (300 and 600 kg N $ha*y^{-1}$) was not significant ($p>0.05$). The differences in LSR at different soil salinity levels (7, 14 and 22 dS/m) was not significant ($p>0.05$) also. Nitrogen fertilization not only increases yield, but changes the aerial composition of Bermuda grass. Our results indicate that nitrogen fertilization increases the proportion of leaves by 20% and decreases the proportion of inflorescences by the same percentage. The proportion of stems is not affected. Although the differences in the aerial composition between fertilized and unfertilized treatments were significant ($p<0.05$), they were not significant ($p>0.05$) between treatments fertilized with 300 and 600 kg N/ha. Differences in aerial composition between soil salinity levels were not significant ($p>0.05$). Model predictions fit observed values. Results of the model indicate the feasibility of growing Bermudagrass on the saline soils of the western San Joaquin Valley of California when irrigated with drainage water. Using crop-specific and site-specific parameters' values the model could be used by farmers in the WSJV and elsewhere for salinity management and farm planning.

INTRODUCTION

California is short of the forages needed for its expanding dairy herd and for beef and sheep production. Reusing saline drainage and other waste waters to produce forages suitable for ruminant livestock would help alleviate this shortage while finding an economic use for them. Reusing saline drainage also would help manage salinity problems in the western San Joaquin Valley (WSJV), and provide an economic alternative to land retirement. In previous studies we have demonstrated that low quality drainage and waste waters can be used to produce forages on a salt-affected site in the WSJV while raising beef cattle without apparent adverse health effects and with acceptable rates of average daily gain. Soil quality at the research site has improved in the process. Our objectives for this study were: 1) to quantify the relationships between grass growth and quality, soil and irrigation water salinity, and N fertilization level; and 2) to create a simple model to predict grass growth and quality as a function of water use, N fertility and soil salinity. Using crop-specific parameters, available weather data and field scale measurements of soil salinity, the model is intended to be used by farmers in the WSJV and elsewhere for salinity management and farm planning. Since much of the research on crop salt tolerance and crop water use under saline conditions has been carried out in small scale and greenhouse trials, using small plots or other artificial conditions, the research carried out here has the advantage of reflecting the effects of more complex conditions found at the farm scale.

This report summarizes results from a trial funded by the DWR under grant 4600004616 that monitored changes in abandoned crop fields in Kings County at a research site near Stratford on Westlake Farms, for the period 2006 to 2008. These measurements and the methods used to collect and analyze them are described in detail in several published reports (Kaffka et al., 2004; Corwin et al., 2008). As an integrative measure, the results documenting forage growth and soil salinity, forage quality, livestock performance and irrigation water use have been included in a comprehensive simulation model of Bermudagrass growth and quality and livestock grazing performance. To help with model development through the measurement of detailed grass growth and quality parameters, in 2007 and 2008 a container trial was carried out at the University of California, Davis campus (UCD), using soils from the site and Common Bermuda grass. The growth of the grass irrigated with saline water (6 dS m^{-1}) at the equivalent of 0, 300 and 600 kg N $ha*y^{-1}$ was measured. In 2008 additional trace elements (boron, 10 mg/L; selenium, 0.5 mg/L and molybdenum, 0.5 mg/L) were applied with the irrigation water. Details of this trial, funded by a grant (SD-0012) form the UC Salinity Drainage program, can be found in Alonso and Kaffka *(In review).* The model also integrates the results from the pot trial, including observations extending before and after the funded period. An Excel version of the more detailed simulation model is provided for use by farmers and others wishing to estimate the potential for forage production and cattle performance on Bermuda grass pastures at other locations in the San Joaquin Valley and elsewhere.

PROJECT SPECIFIC TASKS

1. Quantification of Bermuda grass growth and quality under varying saline conditions and N fertilizer levels

Bermuda grass Kc

We quantified the relationships between Bermuda grass (*Cynodon dactylon* (L.) Pers.) used for pasture and hydrological, edaphic and climatic factors. To do so, we acquired ETo values from a CIMIS station located approximately 3 miles from the research site in Stratford and collected site-specific ETc values using a Surface Renewal Station (CR1000) located at a high EC_e site (> 14 dS m^{-1}) within the research site. Using these ETo and ETc values and available software (Snyder 2008)[1] we estimated the specific Kc values for Bermuda grass under field conditions (Table 1).

Table 1. Bermuda grass Kc values in WSJV

Month	Kc	Month	Kc
Jan	-	Jul	1.06
Feb	-	Aug	0.96
Mar	0.67	Sep	0.78
Apr	0.84	Oct	0.64
May	0.97	Nov	0.54
Jun	1.06	Dec	-

Bermuda grass yield

Starting in 1999 forage biomass yield has been measured at sites selected to reflect soil salinity variation at the study site (Corwin et al., 2008). Measurements of standing biomass taken at the site during a grazing trial on the period 2001-2003 are shown in Table 2.

Table 2. Pre-grazing DM (kg/ha) of Bermudagrass at the experimental site during a grazing trial 2001-2003. Stocking rates were very low in 2001, and large amounts of biomass accumulated.

Date	Paddock 2	Paddock 3	Paddock 6	Paddock 7
June-01	2,062	3,125	1,734	1,774
July-01	6,654	6,669	5,190	5,567
August-01	4,630	7,800	8,047	6,956
September-01	5,480	5,345	10,266	7,095
October-01	5,855	5,214	9,584	6,906
May-02	1,015	1,527	3,141	2,427
July-02			2,819	
August-02	1,744	2,580		
September-02			2,231	2,777
October-02		956	2,173	907
May-03		1,082		
June-03			2,386	1,821
July-03	930	1,983		
August-03				4,482
September-03	1,314			
October-03				2,968

These DM yield values were also observed in container trials in 2007-08 (Figures 2 & 3). In 2007 dry matter yields of Bermuda grass (expressed on a hectare basis; Table 3) irrigated

[1] Snyder, R. 2008. SR-Excel: An Excel application program to compute surface renewal estimates of sensible heat flux. University of California, Davis.

with saline water (6 dS m^{-1}) growing on soils with an average ECe of 7 dS m^{-1} and fertilized with nitrogen produced more than 12 ton DM ha*year^{-1}, but declined to 5 ton DM ha*year^{-1} without fertilization.

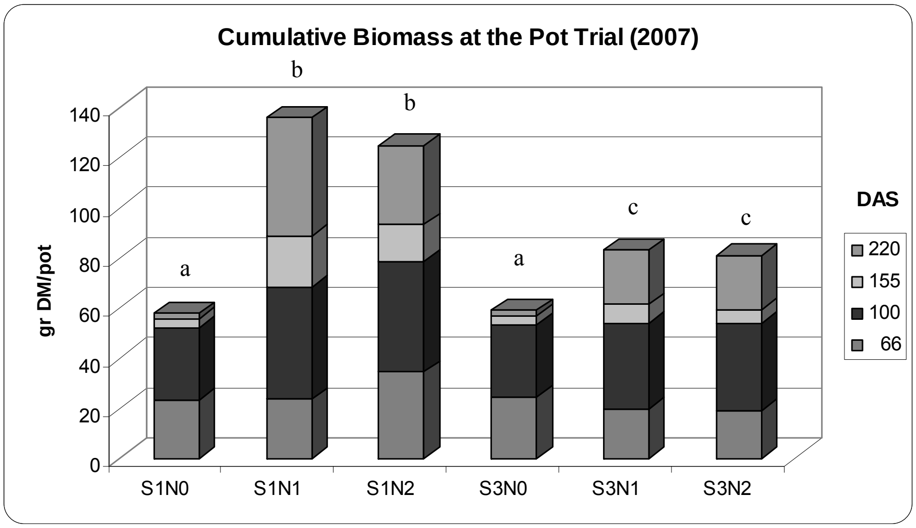


Figure 2. Bermuda grass cumulative biomass in a pot trial under different salinity and nitrogen levels in 2007. S1: 7 dS m^{-1} ECe; S3: 22 dS m^{-1} ECe; N0: 0 kg N ha^{-1}; N1: 300 kg N ha^{-1}; N2: 600 kg N ha^{-}1; DAS: Day after seeding. Columns with the same letter are not significantly different (p>0.05).

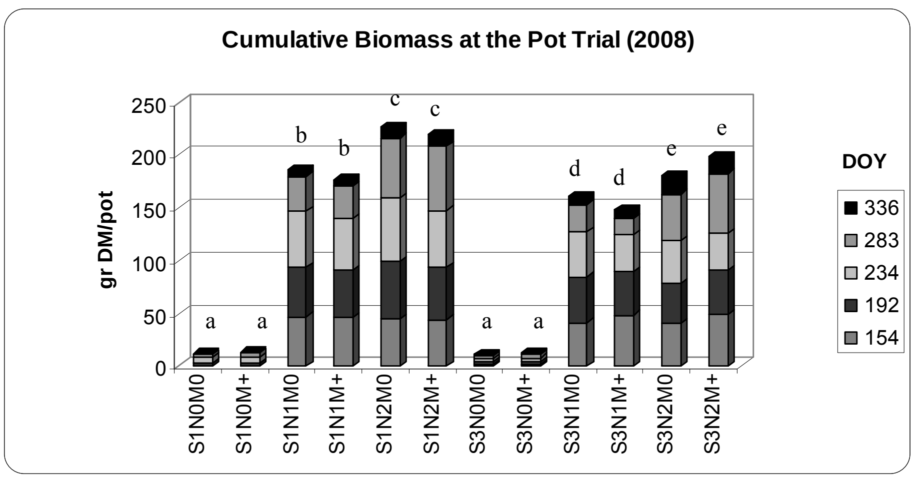


Figure 3. Bermuda grass cumulative biomass in a pot trial under different salinity and nitrogen levels in 2008. S1: 7 dS m^{-1} ECe; S3: 22 dS m^{-1} ECe; N0: 0 kg N ha^{-1}; N1: 300 kg N ha^{-1}; N2: 600 kg N ha^{-}1; M0: No trace minerals; M+: Trace minerals. DOY: Day of the year. Columns with the same letter are not significantly different (p>0.05).

Table 3. Yield (ton DM ha*y^{-1}) for the different treatments in the container trial (2007) irrigated with synthetic saline water solution of 6 dS/m. S1: 7dS/m ECe; S3: 22 dS/m ECe; N0; 0 kg N/ha; N1: 300 kg N/ha; N2: 600 kg N/ha; M0: no trace minerals; M+: trace minerals. DOY: Day of the year

Treatment	DAS 66	DAS 100	DAS 155	DAS 220	TOT
S1N1	2.1	4.0	1.9	4.3	12.3
S1N2	3.1	4.0	1.3	2.9	11.3

S3N1	1.8	3.1	0.7	2.0	7.5
S3N2	1.8	3.2	0.5	2.0	7.3
S1N0	2.1	2.6	0.3	0.2	5.2
S3N0	2.2	2.6	0.3	0.2	5.4

In a second consecutive growing season (2008) in containers, Bermuda grass under frequent irrigation with synthetic saline water (6 dS m^{-1}) and fertilized with the equivalent to 600 kg N ha*y^{-1} yielded 20 ton DM ha*y^{-1} in a soil of 7 dS/m ECe (Table 4). With a fertilization equivalent to 300 kg N ha*y^{-1} yields were close to 16 ton DM ha*y^{-1}. Without fertilization yields were around 1 ton DM ha*y^{-1}. An increment in soil salinity from 7 to 22 dS/m ECe reduced yield by 15% and 7% with and without fertilization respectively. Differences in yield between 2007 and 2008 were due a depletion of nitrogen in the soil of the unfertilized containers and an accumulation of nitrogen in the soil of the fertilized treatments.

Table 4. Yield (ton DM/ha) for the different treatments at the pot trial (2008) irrigated with synthetic saline water solution of 6 dS/m. S1: 7dS/m ECe; S3: 22 dS/m ECe; N0; 0 kg N/ha; N1: 300 kg N/ha; N2: 600 kg N/ha; M0: no trace minerals; M+: trace minerals. DOY: Day of the year

Treatment	DOY 154	DOY 192	DOY 234	DOY 283	DOY 336	TOT
S1N2M0	4.1	5.0	5.4	5.1	1.0	20.6
S1N2M+	4.0	4.6	4.9	5.6	1.0	20.0
S3N2M+	4.5	3.8	3.2	5.1	1.5	18.0
S3N2M0	3.7	3.4	3.7	4.0	1.6	16.4
S1N1M0	4.2	4.3	4.8	3.0	0.6	16.9
S1N1M+	4.2	4.0	4.5	2.8	0.6	16.1
S3N1M0	3.7	3.9	3.9	2.4	0.7	14.6
S3N1M+	4.4	3.7	3.1	1.4	0.7	13.4
S1N0M+	0.0	0.2	0.5	0.4	0.0	1.2
S1N0M0	0.0	0.2	0.5	0.3	0.0	1.1
S3N0M+	0.1	0.3	0.3	0.3	0.1	1.1
S3N0M0	0.1	0.3	0.2	0.3	0.1	1.0

Bermuda grass quality

Forage samples from the research site have been analyzed periodically for quality since 1999. The nutritive value of mature Bermuda grass growing under saline conditions in the period 2000-2003 is shown in Table 5.

Table 5. Bermuda grass forage quality under saline conditions at the research site (2000-2003)

Variable	n	Mean	Median	SD	SE	Max	Min	NRC*
N (%)	414	1.43	1.42	0.36	0.023	2.58	0.67	1.92
P (%)	414	0.18	0.18	0.036	0.002	0.34	0.1	0.2
K (%)	414	1.63	1.6	0.4	0.02	3.41	0.76	1.7
Ca (%)	414	0.41	0.4	0.11	0.005	0.77	0.19	0.32

S (mg kg-1)	236	5430	5470	1093	72.1	9450	2670	---
Na (mg kg-1)	414	5026	4400	3210	158	23920	530	---
Mn (mg kg-1)	414	89.6	84	31	1.52	234	34	---
Fe (mg kg-1)	414	386.5	243.5	466	22.9	4714	78	---
Mg (%)	414	0.193	0.18	0.6	0.003	0.56	0.1	0.16
CP (%)	414	10.7	9.9	3.78	0.186	22.1	4.2	12
ADF (%)	414	29.6	29.4	3.03	0.149	42.3	20.7	38
NDF (%)	414	60.4	60.4	4.01	0.197	71.2	40.8	76
Ash (%)	414	10.4	9.3	3.34	0.165	24.1	5.8	10
Zn (mg kg-1)	414	27.3	26	8.49	0.414	58	12	---
B (mg kg-1)	414	245.4	209	131.7	6.48	1004	73	---
Cu (mg kg-1)	414	7.34	7.1	1.79	0.088	14.4	3.4	---
Mo (mg kg-1)	414	1.44	1.2	0.95	0.047	5.3	0.3	---
Se (?g kg-1)	129	84.9	84	47.3	2.31	328	10	---

* Hay, sun cured (29-42 days growth)

Yellow sweet clover (*Melilotus officinalis*) and five-horn smotherweed (*Bassia hyssopifolia)* are also present in the pasture at the experimental site, representing a valuable source of forage for cattle, especially at the end of the summer. Sweet clover established itself in winter and was available in spring as forage and was consumed by cattle. Bassia is a warm season annual and was consumed by cattle in summer and fall. Bassia grew in the most saline locations in the field. Samples were collected from both species as utilized by cattle and analyzed for quality. The nutritional value of these two species when growing in saline soils is shown in Table 6 and Table 7.

Table 6a. *Bassia hyssopifolia* forage quality under moderately saline conditions at the research site (2000-2003)

Variable	Mean	sd	Variable	Mean	sd
N (%)	2.8	0.51	CP (%)	18.5	8
P (%)	0.3	0.08	ADF (%)	22.7	9.31
K (%)	2.99	1.47	NDF (%)	34	14.4
Ca (%)	0.46	0.08	Ash (%)	20.4	9.02
S (mg kg-1)	0.1	0	Zn (mg kg-1)	32.6	10.8
Na (mg kg-1)	50960	26887	B (mg kg-1)	50960	26887
Mn (mg kg-1)	53.6	9.81	Cu (mg kg-1)	10.14	3.51
Fe (mg kg-1)	188.8	29.9	Mo (mg kg-1)	1.1	0.56
Mg (%)	0.3	0.06	Se (mg kg-1)	<0.1	0

Table 6b. *Bassia hyssopifolia* forage quality under highly saline conditions (ECe > 20 dS M-1) at the research site (2000 - 2003)

Variable	Mean	sd	Variable	Mean	sd
N (%)	2.96	0.51	CP (%)	17.8	3.22
P (%)	0.3	0.04	ADF (%)	18.9	2.57
K (%)	1.6	0.31	NDF (%)	31.1	3.57
Ca (%)	0.3	0.05	Ash (%)	22	6.41
S (mg kg-1)	11927	3428	Zn (mg kg-1)	26.6	6.56
Na (mg kg-1)	68473	22292	B (mg kg-1)	145.3	54.3
Mn (mg kg-1)	66.8	17.35	Cu (mg kg-1)	9.8	1.42
Fe (mg kg-1)	208.2	55.4	Mo (mg kg-1)	1.5	0.72
Mg (%)	0.2	0.03	Se (mg kg-1)	<0.1	0

Table 7. *Melilotus officinalis* forage quality under moderately saline conditions at the research site (2000-2003)

Variable	Mean	sd	Variable	Mean	sd
N (%)	3.99	0.11	CP (%)	25	0.7
P (%)	0.37	0.01	ADF (%)	20	1.7
K (%)	---	---	NDF (%)	26.8	0.3
Ca (%)	0.75	0.08	Ash (%)	11.6	0.1
S (mg kg-1)	4403	161	Zn (mg kg-1)	23.3	0.5
Na (mg kg-1)	9690	1903	B (mg kg-1)	41.3	6.6
Mn (mg kg-1)	35	4	Cu (mg kg-1)	9.8	1.3
Fe (mg kg-1)	120	23.4	Mo (mg kg-1)	20.5	5
Mg (%)	0.3	0.03	Se (mg kg-1)	<0.10	0

Forage quality has been also analyzed dividing the standing biomass by height into different height classes, roughly corresponding to the portions grazed by cattle. Cattle selectively remove the best (upper) portions of the grass canopy. Results are shown in Figures 4a-c.

When comparing the relative value of the top, middle and bottom third of field samples taken in 2001, we observed that the top fraction with the largest amount of leaves had the highest nutritional value, but also the highest concentrations on boron, selenium and molybdenum (Figure 7a). The middle section fraction of the forage had the highest concentration of sulfur, magnesium and chlorine (Figure 7b). The bottom fraction had the highest values of ADF, NDF, sodium and iron (Figure 7c). These results differed from the container trial and may have been influenced by soil contamination under surface irrigated and grazed conditions.

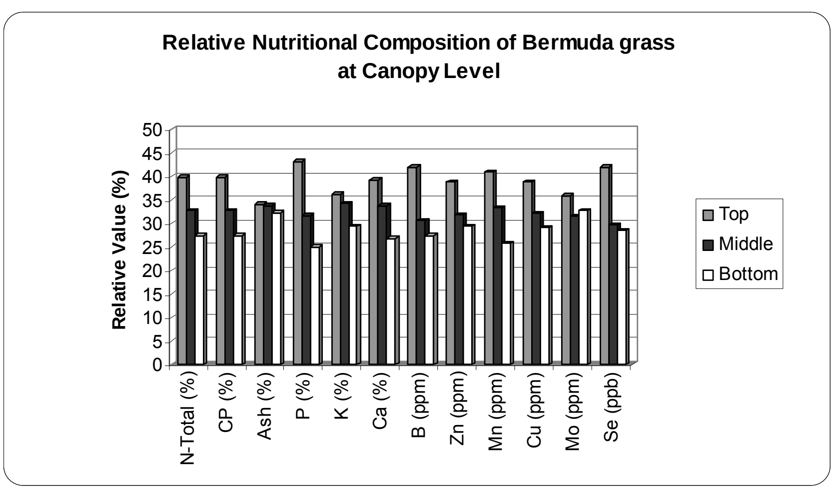


Figure 4a. Relative nutritional composition of Bermuda grass at the research site in 2001. Parameters shown have greater relative value on the top fraction of the forage.

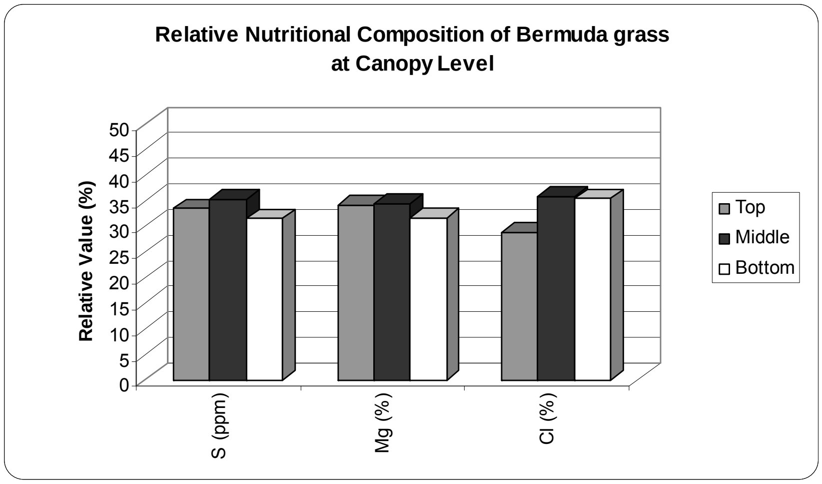


Figure 4b. Relative nutritional composition of Bermuda grass at the research site in 2001. Parameters shown have greater relative value on the middle fraction of the forage.

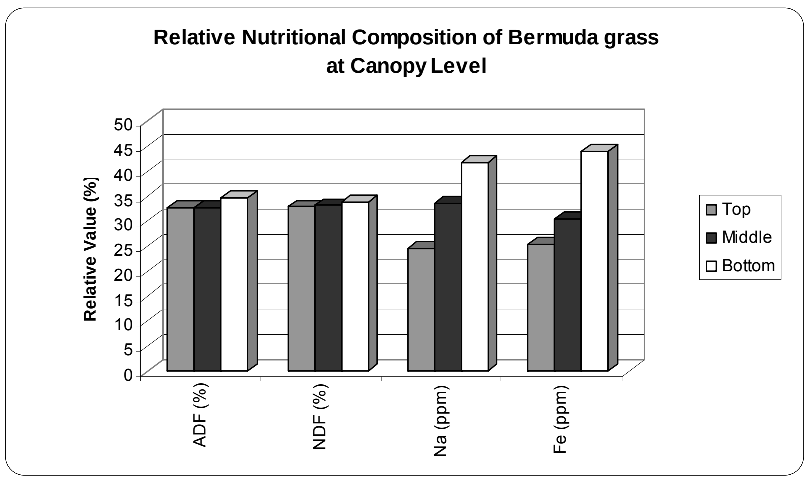


Figure 4c. Relative nutritional composition of Bermuda grass at the research site in 2001. Parameters shown have greater relative value on the bottom fraction of the forage.

The leaf/stem ratio (LSR) is a traditional index of forage quality. We used the container trial to evaluate the proportion of leaves and stems in 2007 and 2008 to help modeling forage quality of different aged stands. Samples were analyzed for nutritional value at the ANR laboratory on the UCD campus. Results were similar in both years. LSR was significantly different ($p<0.05$) between unfertilized and fertilized treatments. The difference between fertilized treatments (300 and 600 kg N/ha) was not significant ($p>0.05$). The differences in LSR at different soil salinity levels (7, 14 and 22 dS/m) was not significant ($p>0.05$) also. LSR in unfertilized and fertilized treatments in pooled samples from 2007 and 2008 are shown in Figures 4 and 5.

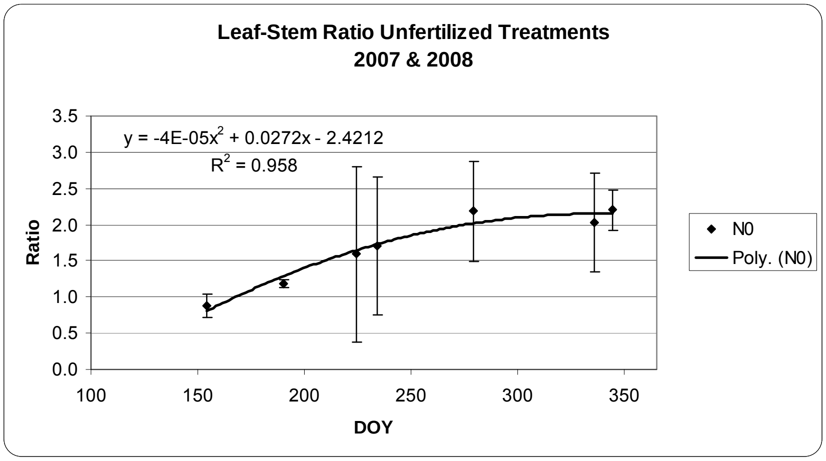


Figure 4. Leaf-stem ratio and polynomial fit of unfertilized treatments (N0) at a pot trial in 2007 and 2008. DOY: Day of the year.

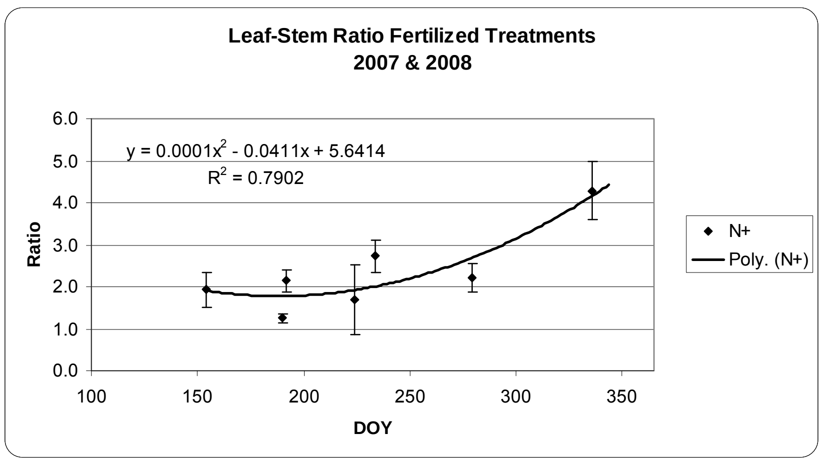


Figure 5. Leaf-stem ratio and polynomial fit of fertilized treatments (N+) at a pot trial in 2007 and 2008. DOY: Day of the year.

Nitrogen fertilization not only increases yield, but changes the aerial composition of Bermuda grass (Figures 6 and 7). Results of the pot trial indicate that nitrogen fertilization increases the proportion of leaves by 20% and decreases the proportion of inflorescences by the same percentage. The proportion of stems is not affected. Although the differences in the aerial composition between fertilized and unfertilized treatments were significant ($p<0.05$), they were not significant ($p>0.05$) between treatments fertilized with 300 and 600 kg N/ha. Differences in aerial composition between soil salinity levels were not significant ($p>0.05$).

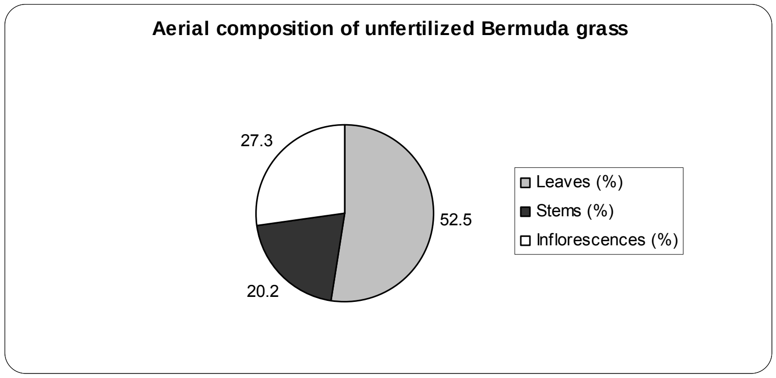


Figure 6. Aerial composition of unfertilized Bermuda grass in a pot trial (2008).

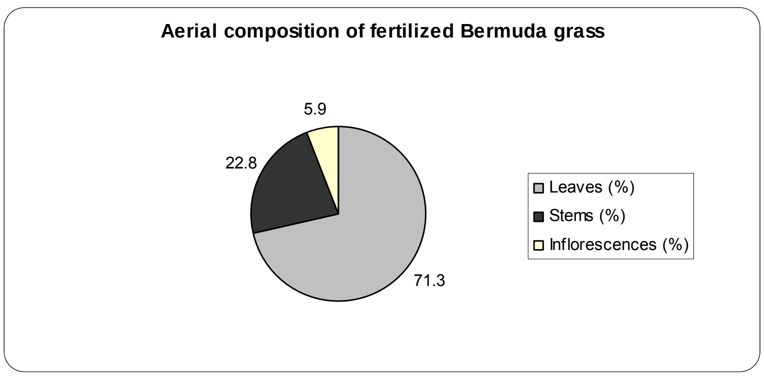


Figure 6. Aerial composition of unfertilized Bermuda grass in a pot trial (2008).

Grazing Trials

Information about the proportion of leaves and stems in a pasture is important for the management of grazing cattle because the nutritional value of different canopy structures also varies. Table 5 shows the differences in the nutritional quality of Bermuda grass leaves and stems under different salinity and fertilization.

Table 5. Nutritional quality of Bermuda grass leaves and stems under different salinity and fertilization levels. S1: 7 dS/m; S3: 22 dS/m; N0: Unfertilized; N+: Average values for rates of 300 and 600 kg N/ha.

		Leaves S1 N0	Leaves S1 N+	Leaves S3 N0	Leaves S3 N+	Stems S1 N0	Stems S1 N+	Stems S3 N0	Stems S3 N+
N (Total)	%	1.07	2.66	1.54	2.81	0.72	1.90	0.93	2.11
Protein	%	6.68	16.65	9.68	17.54	4.45	11.89	5.83	13.21
ADF-Reflux	%	30.75	23.83	27.20	22.36	26.73	21.66	24.43	21.95
NDF-Reflux	%	65.88	56.60	65.08	57.30	59.63	52.30	56.90	52.75
Ash	%	10.89	9.41	8.90	8.80	5.02	6.81	5.81	7.82
P (Total)	%	0.24	0.21	0.23	0.22	0.21	0.18	0.21	0.22
K (Total)	%	0.95	1.93	1.33	1.88	1.02	1.87	1.53	1.97
S (Total)	ppm	5,760	5,998	6,350	6,543	4,268	4,751	4,645	5,279
B (Total)	ppm	123	78	312	236	36	17	55	34
Ca (Total)	%	0.77	0.53	0.54	0.45	0.34	0.22	0.24	0.22

Mg (Total)	%	0.34	0.30	0.24	0.28	0.23	0.23	0.19	0.22
Na (Total)	ppm	6,510	3,868	4,903	4,298	5,968	3,741	4,653	4,385
Zn (Total)	ppm	32	29	26	25	45	41	37	38
Mn (Total)	ppm	58	68	65	75	42	47	47	64
Fe (Total)	ppm	480	197	274	195	138	103	136	113
Cu (Total)	ppm	13.5	13.3	11.6	12.0	13.7	13.0	15.5	13.1
Mo	ppm	1.0	1.2	0.9	1.0	0.5	0.5	0.4	0.4
Se (Total)	ppm	0.06	0.12	0.06	<0.05	<0.05	<0.05	<0.05	<0.05
As (Total)	ppm	0.18	0.13	0.28	0.22	0.11	0.08	0.18	0.15

2. Formulation of a simple model to predict Bermuda grass growth and quality as a function of water use, N fertility and soil salinity

The parameters values obtained from the pot trial were used to formulate a dynamic simulation model in Stella ®. The model was validated with data from the field by comparing model predictions to observed data. These model and data comparisons are reported elsewhere (Alonso et al., *In review*). A simplified version of the Stella® model was formulated in MS Excel for easy use by farmers growing forages in saline soils and others interested in using forages to manage saline water supplies.

The model

The model integrates the different components in 5 subroutines: Soil moisture; soil salinity; soil trace minerals (B, Mo and Se); plant yield and quality; and grazing. Simplified diagrams and brief descriptions of the subroutines indicating flows and stocks are shown below.

Soil moisture

In *Soil Moisture* (Figure 8) the soil has been divided in 4 layers 30cm deep each. There are two inflows, Irrigation (IW) and Precipitation (PP), and three outflows, ETc, Drainage and Leaching. ETc depends on ETo and Kc, and was directly measured at the experimental site by a surface renewal station (CR1000) in the growing season 2007-2008. ETo values integrate air temperature, day length and wind speed measurements, and are download online from the CIMIS station at Stratford. Kc values vary along the growing season and were estimated using ETo and ETc values in a software developed for this purpose at UC Davis (Snyder 2008).

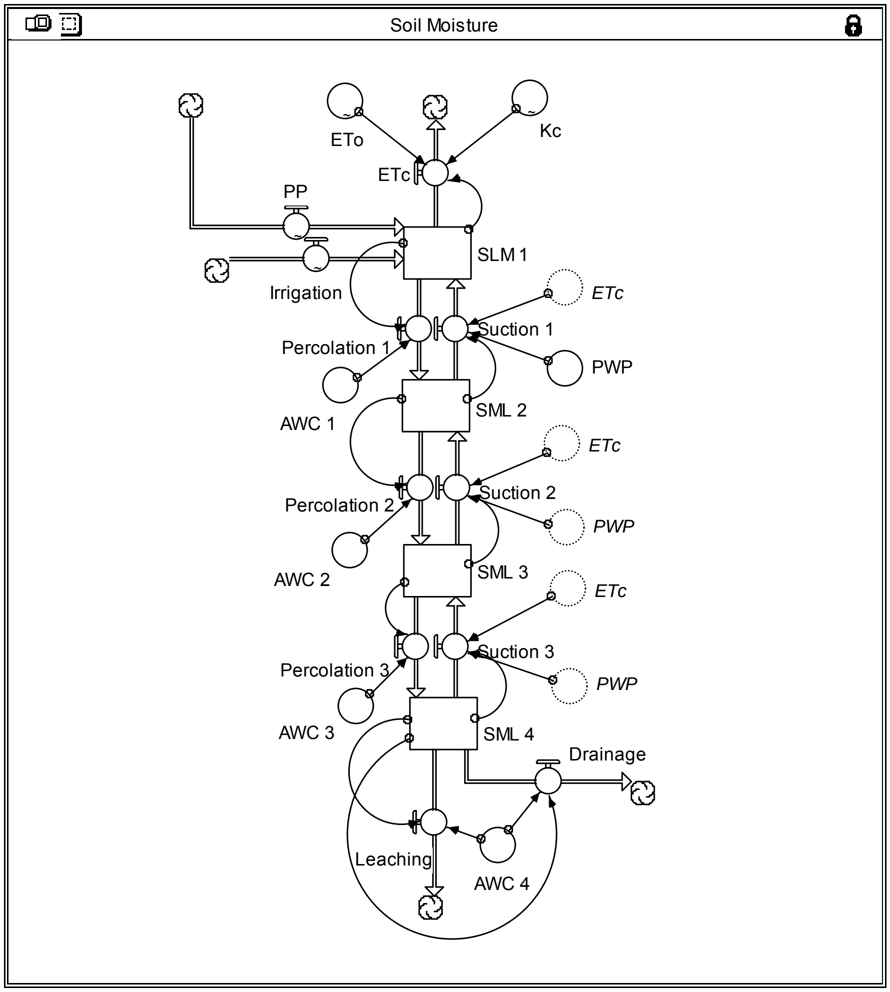


Figure 8. A simplified diagram of the Soil Moisture subroutine. The soil has been divided in 4 layers. Inputs: Precipitation (PP) & Irrigation. Outputs: ETc, Drainage and Leaching. Water moves to the bottom through Percolation and to the top by Suction.

The equations used in this subroutine are:

$$ETc(t) = ETo(t) * Kc(t) \qquad \text{[Eq. 1]}$$

$$SML_1(t) = SML_1(t - dt) + (PP + IW + Suc_1 - ETc - Per_1) * dt \qquad \text{[Eq. 2]}$$

$$SML_2(t) = SML_2(t - dt) + (Suc_2 + Per_1 - Suc_1 - Per_2) * dt \qquad \text{[Eq. 3]}$$

$$SML_3(t) = SML_3(t - dt) + (Suc_3 + Per_2 - Suc_2 - Per_3) * dt \qquad \text{[Eq. 4]}$$

$$SML_4(t) = SML_4(t - dt) + (Per_3 - Suc_3 - DW - LF) * dt \qquad \text{[Eq. 5]}$$

$$Per_i(t) = f(SML_i, AWC_i) * dt \qquad \text{[Eq. 6]}$$

$$Suc_i(t) = f(SML_i, ETc_i, PWP) * dt \qquad \text{[Eq. 7]}$$

$$AWC_i(t)= 3048000 * AWF_i(t) \qquad \text{[Eq. 8]}$$

Where:

(t) = Time t
ETc = Crop evapotranspiration (L/ha*d)
ETo = Potential evapotranspiration (L/ha*d)
Kc = Crop coefficient
SML_i = Soil moisture layer I (L/ha)
PP = Precipitation (L/ha*d)
IW = Irrigation water (L/ha*d)
Suc_i = Suction to upper soil layer i (L/ha*d)
Per_i = Percolation from upper soil layer i (L/ha*d)
DW = Drainage water (L/ha*d)
LF = Leaching fraction (L/ha*d)
AWC_i = Available water capacity soil layer i (L/ha)
PWP = Permanent wilting point (L/ha)
AWF_i = Available water fraction soil layer i (L)
$INIT$ = Initial values at $t=0$

And:

$AWF_1 = 0.12$
$AWF_2 = 0.08$
$AWF_3 = 0.08$
$AWF_4 = 0.06$
$INIT\ SML_1 = 365760/3$
$INIT\ SML_2 = 243840/2$
$INIT\ SML_3 = 243840/2$
$INIT\ SML_4 = 182880/2$
$PWP = 30480$

Drainage and Leaching are functions of the water inputs through Precipitation and Irrigation, and the available water capacity of the soil ($\Sigma\ AWC_i$).

Soil salinity

Salts flow through the soil profile dissolved in water. In the *Soil Salinity* subroutine (Figure 9) ECe values are transformed to total dissolved solids (TDS). TDS in the Soil (TDS Soil) depend on the balance of TDS in the irrigation water (TDS iw), drainage water (TDS drainage), leaching fraction (TDS leaching) and plant uptake (TDS plant uptake). TDS in the irrigation water are estimated through the volume of irrigation and its electrical conductivity (ECiw). TDS move through the soil profile due forces of evapotranspiration and percolation.

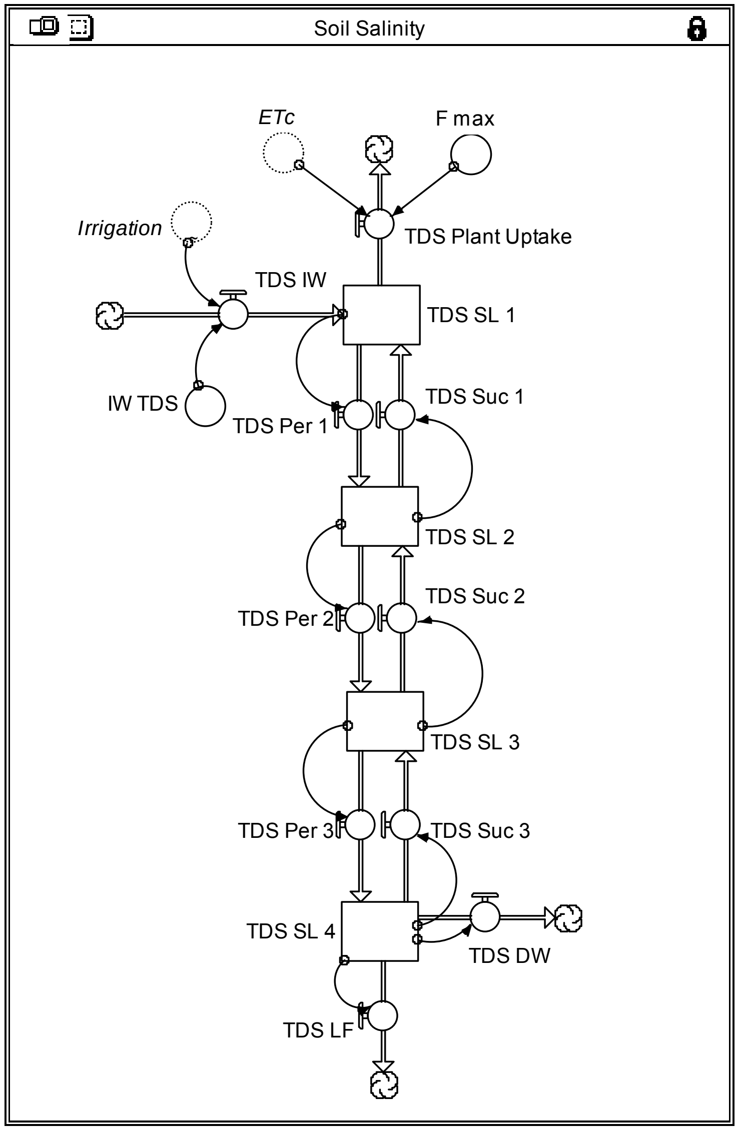


Figure 9. A simplified diagram of the Soil Salinity subroutine. The soil has been divided in 4 layers.

The equations used in this subroutine are:

$$TDS\_SL_1(t) = TDS\_SL_1(t - dt) + (TDS\_IW + TDS\_Suc_1 - TDS\_Per_1 - TDS\_PU) * dt \quad \text{[Eq. 9]}$$

$$TDS\_SL_2(t) = TDS\_SL_2(t - dt) + (TDS\_Per_1 + TDS\_Suc_2 - TDS\_Per_2 - TDS\_Suc_1) * dt \quad \text{[Eq. 10]}$$

$$TDS\_SL_3(t) = TDS\_SL_3(t - dt) + (TDS\_Per_2 + TDS\_Suc_3 - TDS\_Per_3 - TDS\_Suc_2) * dt \quad \text{[Eq. 11]}$$

$$TDS\_SL_4(t) = TDS\_SL_4(t - dt) + (TDS\_Per_3 - TDS\_Suc_3 - TDS\_DW - TDS\_LF) * dt \quad \text{[Eq. 12]}$$

$$TDS\_IW(t) = f(IW,\ IW_{TDS}) * dt \quad \text{[Eq. 13]}$$

$$TDS\_Per_i(t) = f(TDS\_SL_i, Per_i) * dt \quad \text{[Eq. 14]}$$

$$TDS\_Suc_i(t) = f(TDS\_SL_{i+1}, Suc_i) * dt \quad \text{[Eq. 15]}$$

$$TDS\_PU(t) = f(ETc, Fmax) * dt \qquad [Eq. 16]$$

Where:

(t) = Time *t*
TDS_IW(t) = Total dissolved solids in the irrigation water (gr)
IW(t) = Irrigation water (L)
$IW_{TDS}(t)$ = Concentration of TDS in the irrigation water (gr/L)
$TDS\_SL_i(t)$ = TDS in the soil layer *i* (gr)
$TDS\_Per_i(t)$ = TDS in percolation water from the soil layer *i*
$TDS\_Suc_i(t)$ = TDS in suction water from the soil layer *i*
TDS_PU(t) = TDS in plant uptake (gr)
TDS_DW(t) = TDS in drainage water (gr)
TDS_LF(t) = TDS in leaching fraction (gr)
Fmax(t) = Maximum plant uptake rate of TDS (mg/L*d)

And:

$INIT\ TDS\_SL_1 = 10304*SML_1$
$INIT\ TDS\_SL_2 = 15180*SML_2$
$INIT\ TDS\_SL_3 = 19780*SML_3$
$INIT\ TDS\_SL_4 = 20700*SML_4$

TDS_IW = 740*ECiw, IF ECiw<5 dS/m
TDS_IW = 840*ECiw, IF ECiw = 5-10 dS/m
TDS_IW = 920*ECiw, IF ECiw>10 dS/m
Fmax = 29.6 mg/L*d

Soil trace minerals

The flow and accumulation of boron, selenium and molybdenum in the soil and plant tissues are described in the subroutine *Soil Trace Minerals* (Figure 10). The concentration of minerals in the soil depend on the initial content plus the additions through irrigation water (volume of water added multiplied by the concentration of the mineral in the water) minus the losses through drainage, leaching and plant uptake.

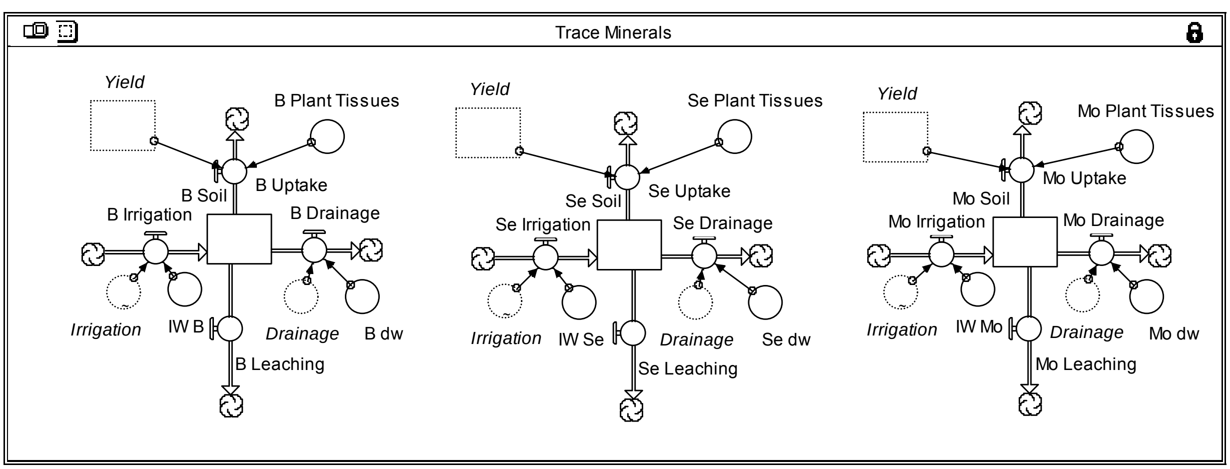


Figure 10. A simplified flow diagram of the subroutine of Trace Minerals (B, Se & Mo) indicating inflows and outflows.

The equations used in this subroutine are:

$$B\_Soil(t) = B\_Soil(t - dt) + (B\_IW - B\_DW - B\_LF - B\_PU) * dt \quad \text{[Eq. 17]}$$

$$Se\_Soil(t) = Se\_Soil(t - dt) + (Se\_IW - Se\_DW - Se\_LF - Se\_PU) * dt \quad \text{[Eq. 18]}$$

$$Mo\_Soil(t) = Mo\_Soil(t - dt) + (Mo\_IW - Mo\_DW - Mo\_LF - Mo\_PU) * dt \quad \text{[Eq. 19]}$$

$$B\_IW(t) = f(IW, IW_B) * dt \quad \text{[Eq. 20]}$$

$$Se\_IW(t) = f(IW, IW_{Se}) * dt \quad \text{[Eq. 21]}$$

$$Mo\_IW(t) = f(IW, IW_{Mo}) * dt \quad \text{[Eq. 22]}$$

$$B\_PU(t) = f(Yield, B\_PT) * dt \quad \text{[Eq. 23]}$$

$$Se\_PU(t) = f(Yield, Se\_PT) * dt \quad \text{[Eq. 24]}$$

$$Mo\_PU(t) = f(Yield, Mo\_PT) * dt \quad \text{[Eq. 25]}$$

Where:

B_Soil(t) =Boron in the soil (gr)
B_IW(t) = Boron in irrigation water (gr)
B_DW(t) =Boron in drainage water (gr)
B_LF(t) = Boron in leaching fraction (gr)
B_PU(t) = Plant uptake of boron (gr)
B_PT(t) = Boron in plant tissues (ppm)
$IW_B(t)$ = Concentration of boron in irrigation water (ppm)

Se_Soil(t) = Selenium in the soil (gr)
Se_IW(t) = Selenium in irrigation water (gr)
Se_DW(t) = Selenium in drainage water (gr)
Se_LF(t) = Selenium in leaching fraction (gr)
Se_PU(t) = Plant uptake of selenium (gr)
Se_PT(t) = Selenium in plant tissues (ppm)
$IW_{Se}(t)$ = Concentration of selenium in irrigation water (ppm)

Mo_Soil(t) = Molybdenum in the soil (gr)
Mo_IW(t) = Molybdenum in irrigation water (gr)
Mo_DW(t) = Molybdenum in drainage water (gr)
Mo_LF(t) = Molybdenum in leaching fraction (gr)
Mo_PU(t) = Plant uptake of molybdenum (gr)
Mo_PT(t) = Molybdenum in plant tissues (ppm)
$IW_{Mo}(t)$ = Concentration of molybdenum in irrigation water (ppm)

And:

INIT B_Soil = 17.9*460955
INIT Se_Soil = 0.0125*460955
INIT Mo_Soil = 0.8351*460955

Plant yield and quality

In the subroutine *Plant Yield and Quality* (Figure 11), crop yield is function of crop growth. Harvest is the fraction of total yield that is used. In a grazing system, Harvest depends on the grazing efficiency (H) of the pasture. Grazing efficiencies can range from 40% in a continuous grazing system to 80% in a rotational system.

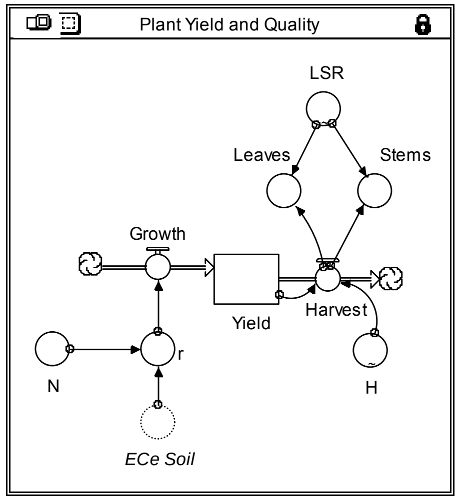


Figure 11. A simplified flow diagram of the subroutine Plant Yield and Quality indicating inflows and outflows.

$$Yield(t) = Yield(t - dt) + (Growth - Harvest) * dt \quad \text{[Eq. 26]}$$

Where:

Yield(t) = Total yield (kg/ha)
Growth(t) = Plant growth (kg/ha*d)
Harvest(t) = Fraction of the total yield harvested (kg/ha)

Growth is described by a logistic curve where the intrinsic growth rate (r) is affected by the level of nitrogen (N) and soil Salinity (ECe Soil). Response functions were obtained from the pot trial and tested against field data. Figure 12 shows the average growth rate of Bermuda grass under different levels of nitrogen fertilization.

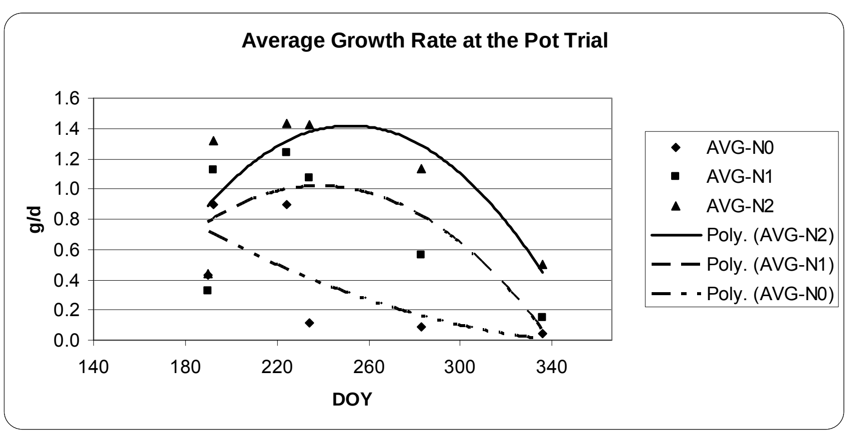


Figure 12. Average growth rate of Bermuda grass at the pot trial under different nitrogen levels based on pooled samples from 2007 and 2008. N0: 0 kg N ha^{-1}; N1: 300 kg N ha^{-1}; N2: 600 kg N $ha^{-}1$; DOY: Day of the year.

$$Growth(t) = f(r) * dt \qquad \text{[Eq. 26]}$$

$$r(t) = f(N, ECe\_Soil) * dt \qquad \text{[Eq. 27]}$$

$$Harvest(t) = Yield(t) * H(t) \qquad \text{[Eq. 28]}$$

$$LSR(t) = f(N) * dt \qquad \text{[Eq. 29]}$$

Where:

- $r(t)$ = Intrinsic growth rate (kg/ha*d)
- $N(t)$ = Nitrogen added in the water or as fertilizer (kg/ha)
- $ECe\_Soil(t)$ = Soil salinity (dS/m)
- $H(t)$ = Harvest efficiency (%)
- $LSR(t)$ = Leaf-stem ratio

And:

$LSR(t) = -4E\text{-}05 * t^2 + 0.0272 * t - 2.4212$	IF N = 0
$LSR(t) = 0.0001 * t^2 - 0.0411 * t + 5.6414$	IF N > 0
$r(t)^{¥} = -0.0039 * t^2 + 0.817 * t + 3.4132$	IF N = 0
$r(t)^{¥} = -0.0046 * t^2 + 1.1487 * t - 1.4509$	IF N >300 kg/ha & soil ECe > 7dS/m
$r(t)^{¥} = -0.0052 * t^2 + 1.3987 * t - 3.8312$	IF N >300 kg/ha & soil ECe < 7dS/m

$(t)^{¥}$ = Days after seeding

Finally, in the subroutine *Grazing* (Figure 13) the model estimates the optimum stocking rate (SR) for the pasture given the forage yield and the average daily weight gain (ADG). It also predicts the maximum average daily weight gain per animal unit given the forage yield and the stocking rate.

Grazing

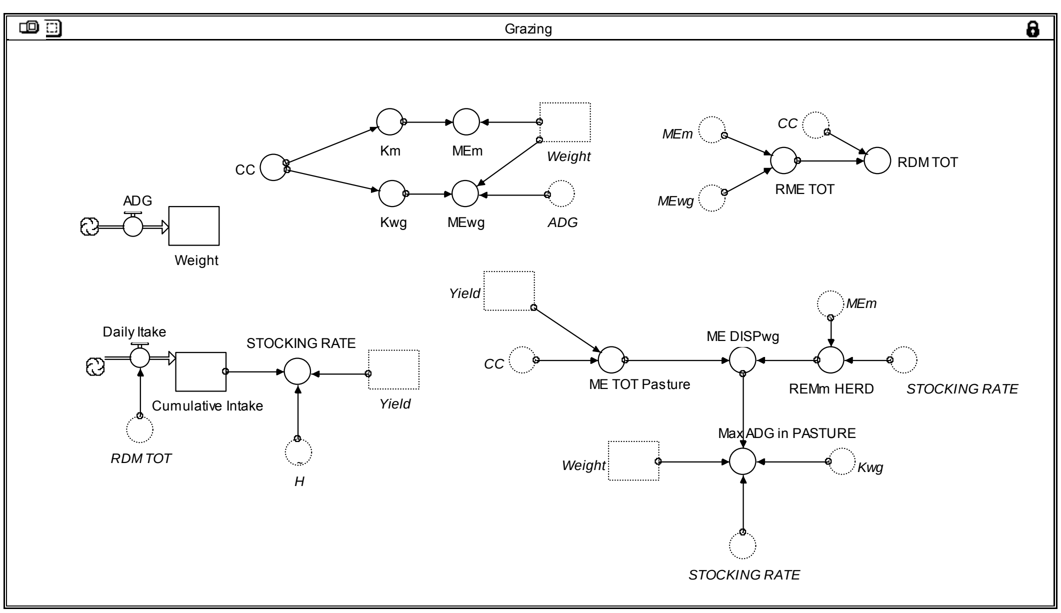


Figure 13. Subroutine Grazing.

In this subroutine the requirements of dry matter and metabolic energy for maintenance and weight gain of grazing animals are matched with the forage dry matter and energy supply on a daily basis, identifying the dates where the animals require supplementation at any given stocking rate. The principal equations are:

$$RME\_TOT(t) = MEm(t) + MEwg(t) \quad \text{[Eq. 30]}$$

$$MEm(t) = (5.67 + 0.061 * Weight(t)) / Km(t) \quad \text{[Eq. 31]}$$

$$MEwg(t) = ((ADG * (6.28+0.0188 * Weight)) / (1-0.3 * ADG)) / Kwg(t) \quad \text{[Eq. 32]}$$

$$RDM\_TOT(t) = RME\_TOT(t) / CC(t) \quad \text{[Eq. 33]}$$

$$Weight(t) = Weight(t - dt) + ADG * dt \quad \text{[Eq. 34]}$$

$$STOCKING\_RATE(t) = (Yield(t) * H(t)) / Cumulative\_Intake(t) \quad \text{[Eq. 35]}$$

$$REMm\_HERD(t) = MEm(t) * STOCKING\_RATE(t) * 1.05 \quad \text{[Eq. 36]}$$

$$ME\_DISPwg(t) = ME\_TOT\_Pasture(t) - REMm\_HERD(t) \quad \text{[Eq. 37]}$$

$$Max\ ADG\ in\ PASTURE\ (t) = ((ME\_DISPwg(t) * Kwg(t)) / (6.28 + 0.0188 * Weight(t) + 0.3 * ME\_DISPwg(t) * Kwg(t)) / STOCKING\_RATE(t) \quad \text{[Eq. 38]}$$

Where:

RME_TOT(t) = Total requirement of metabolic energy (Mj)
MEm(t) = Requirement of metabolic energy for maintenance (Mj)
MEwg(t) = Requirement of metabolic energy for weight gain (Mj)
Weight(t) = Live weight (kg)
Km(t) = Maintenance efficiency (%)
Kwg(t) = Weight gain efficiency (%)
RDM_TOT(t) = Total requirement of dry matter (kg)
ADG(t) = Average daily gain of weight (kg/d)
CC(t) = Caloric concentration of the pasture (Mj)
STOCKING_RATE(t) = Stocking Rate (AU/ha)
Cumulative_Intake(t) = Intake of an AU(kg)
REMm_HERD(t) = Herd requirement of metabolic energy for maintenance (Mj)
ME_DISPwg(t) = Metabolic energy available for weight gain (Mj)
ME_TOT_Pasture(t) = Total metabolic energy of the pasture (Mj)
Max ADG in PASTURE (t) = Max possible ADG per AU in the pasture (kg/d)

And:

$Km(t) = 0.55 + 0.016 * CC$
$Kwg(t) = 0.0435 * CC$

Model validation and testing

Forage yield and quality

The model performance was tested using data collected at the research site in 2001 and 2003. Field data and the corresponding predictions by the model were paired and analyzed. Predictions of crop yield under different soil salinity levels match field data. Table 6 shows the standing biomass pre-grazing at WLF in 2001. Figure 14 shows the fit between the observed and predicted yield values for that year.

Table 6. Field values of forage production at WLF

	Pre-Grazing (kg/ha)			
Date	Paddock 2	Paddock 3	Paddock 6	Paddock 7
June-01	2,062	3,125	1,734	1,774
July-01	6,654	6,669	5,190	5,567
August-01	4,630	7,800	8,047	6,956
September-01	5,480	5,345	10,266	7,095
October-01	5,855	5,214	9,584	6,906

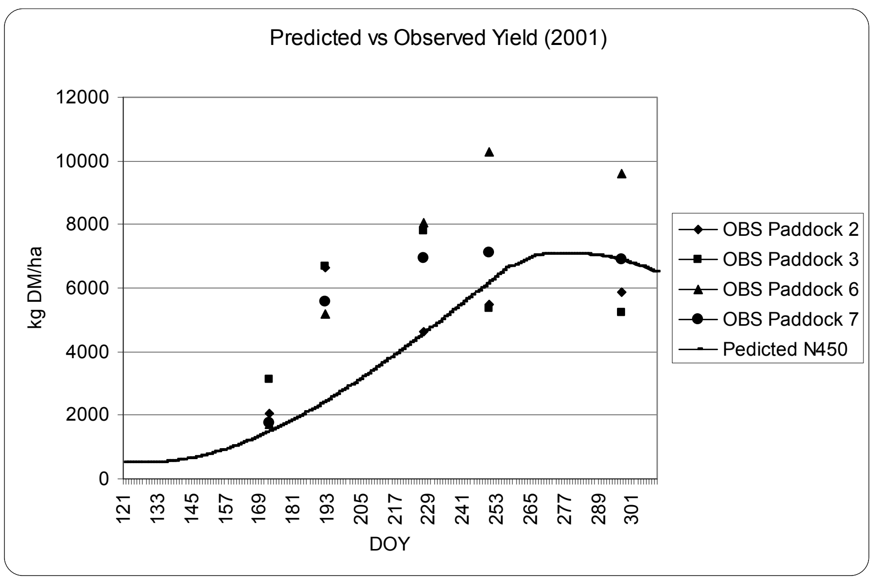
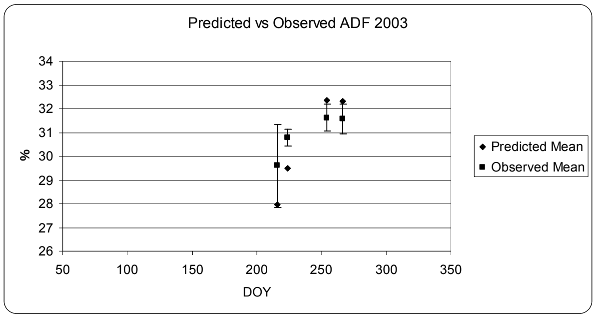


Figure 14: Observed and predicted Bermuda grass yields in 2001.

The fit between model predictions and observed values of forage quality is reasonable good also. Figures 15-18 show the model fit for ADF, NDF, crude protein, ash, B, Se and Mo. 95% confidence intervals for the mean of field data samples on each parameter were built and model predictions were tested against them. Figures shown correspond to the year with higher number of observations.



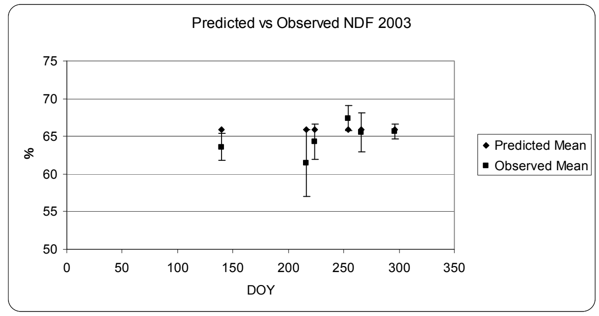
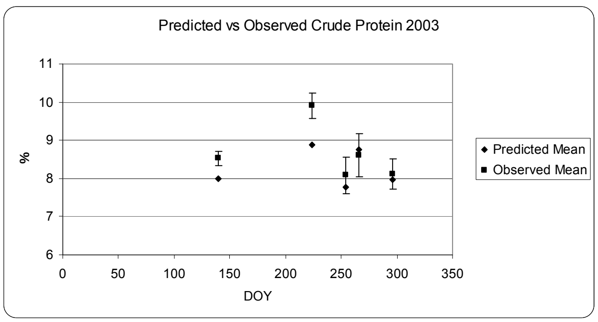


Figure 15. Model fit for ADF and NDF values in Bermuda grass.



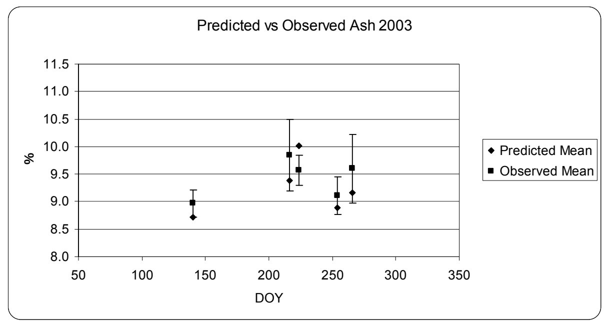
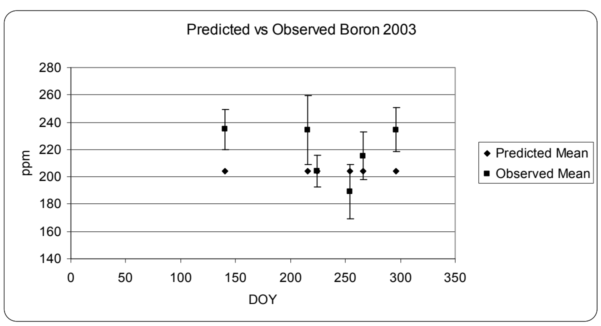


Figure 16. Model fit for crude protein and ash values in Bermuda grass.



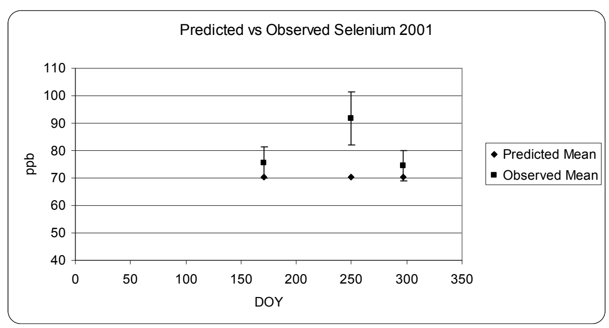


Figure 17. Model fit for crude boron and selenium values in Bermuda grass.

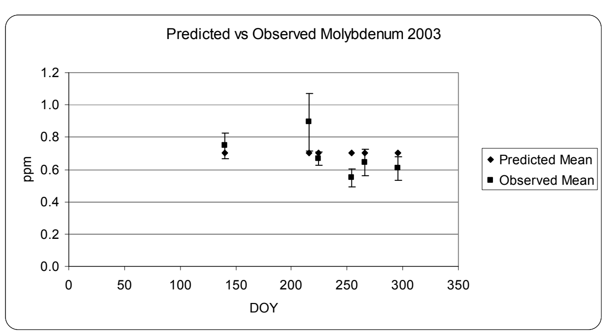


Figure 18. Model fit for molybdenum values in Bermuda grass.

Beef cattle production

Table 7 shows the average daily gain (ADG) of weight of beef cattle grazing at the experimental site during 2001 and 2003.

Table 7. Average daily gain (ADG) of weigh of steers grazing at WLF during the growing seasons 2001 and 2003

Year	Gazing Period Days	Treatment	Steers #	Stocking Rate Heads/ha	ADG kg/ha*d	SD kg/ha*d
2001	143	Control	8	Low	0.56	0.09
	143	Treatment	18	Low	0.46	0.23
2003	150	Control	10	Low	0.55	0.15
	150	Treatment	30	Low	0.72	0.12

There is a good fit between the observed and predicted values of ADG. Figure 19 shows the daily gain predicted for the field conditions in 2001. Predicted values are within the rage of those observed at the field site at WLF.

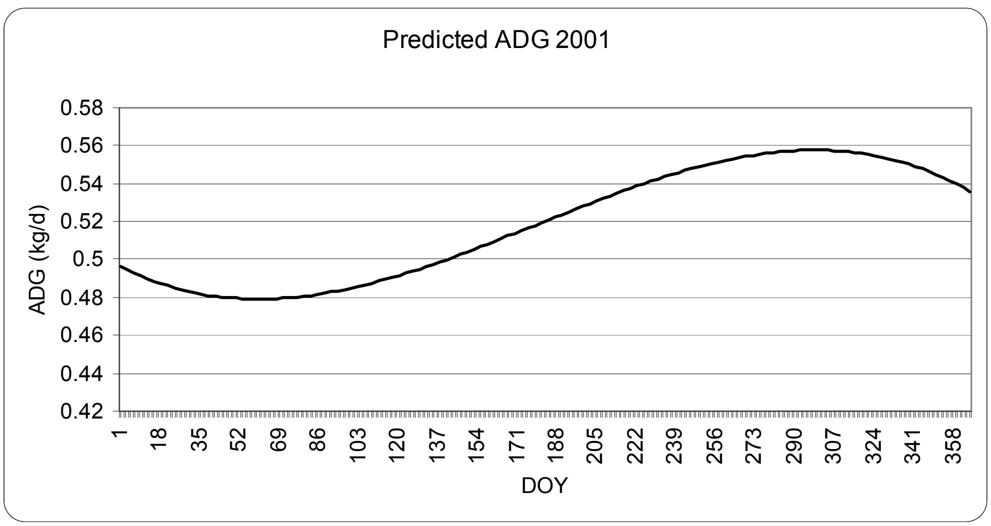


Figure 19. Predicted maximum daily gain (ADG) for steers grazing Bermudagrass at WLF in 2001.

Final Discussion

Results of the model indicate the feasibility of growing Bermudagrass on the saline soils of the western San Joaquin Valley of California when irrigated with drainage water. Although leaf/stem ratio was not influenced by soil salinity, the effect of salinity and nitrogen levels greatly affected the total biomass produced. The model also shows the feasibility of grazing Bermudagrass with average daily gains of 0.7 kg ha*d^{-1} at low stocking rates or at least maintenance at higher stocking rates. Using crop–specific and site-specific (i.e. soil and irrigation) parameters' values the model could be used to predict yield and quality for different pastures and crops cultivated under saline condition on the western San Joaquin Valley and elsewhere.

OTHER OUTPUTS OF THE PROJECT

Recent Presentations

Kaffka, S. and Alonso, M. 2008. Linking drainage water management in the Western San Joaquin Valley to bio-energy production. California Energy Commission's Sustainability Working Group. December 5, Sacramento, California.

Alonso, M., Kaffka, S. and Corwin, D. 2008. Bermuda Grass as an Alternative for Retired Farmland in the Western San Joaquin Valley of California. Farming with Grass Conference. October 20-22, Oklahoma City, Oklahoma.

Alonso, M. and Kaffka, S. 2007. Modeling Bermuda Grass Yield and Quality in the Western San Joaquin Valley of California. American Society of Agronomy, Crop Science Society of America and Soil Science Society of America International Annual Meetings. November 4-8, New Orleans, Louisiana.

Kaffka, S., Oster, J., Corwin, D., and Maas, J. 2007. Saline Drainage Water and its Effects on Forges and Livestock. American Society of Agronomy, Crop Science Society of America and Soil Science Society of America International Annual Meetings. November 4-8, New Orleans, Louisiana.

Publications

Alonso, M. F. and S. R. Kaffka. Bermuda grass (*Cynodon dactylon* (L.) Pers.) yield and quality under different levels of salinity, nitrogen and trace elements: A greenhouse experiment. *(In review)*.

Alonso, M. F. and S. R. Kaffka. Modeling Bermuda grass (*Cynodon dactylon* (L.) Pers.) production in the saline soils of the western San Joaquin Valley of California. *(In review)*.

Corwin, D.L., S. M. Lesch, J. D. Oster, and S. R. Kaffka. 2008. Short-term sustainability of drainage water reuse: Spatio-temporal impact on soil chemical properties. Journal of Environmental Quality 37, S8-S24.

Kaffka, S. R., J. D. Oster and D. L. Corwin. 2004. Forage production and soil reclamation using saline drainage water. Pg 247-253 *In:* Proceedings, National Alfalfa Symposium, 13-15 December 2004, San Diego, California. UC Cooperative Extension, University of California, Davis.

Acknowledgements

The authors acknowledge the California Department of Water Resources for funding part of the field work, the sample analyses and the modeling effort and the University of California Salinity Drainage Program for funding the pot trial as well as field site preparation. The authors thank Ceil Howe III and Westlake Farms for the use of their land, and their efforts to provide and manage livestock and drainage waters to the site.

APPENDIX

Forage*S*

Simulation Model for

Forage Production in Saline Environments

Operation Guide

Version 1.1

for XLS

Maximo F. Alonso & Stephen R. Kaffka

University of California, Davis

July 2009

Table of Contents

INTRODUCTION

ForageS *version 1.1* for XLS is a dynamic simulation model that runs in Excel™. The original version was developed in Stella™. The model has been formulated to predict forage production and beef cattle performance on saline environments. The present version has been validated for Bermuda grass (*Cynodon dactylon* (L.) Pers.) growing on the western San Joaquin Valley of California, and the examples used in this Operation Guide refer to it. For its operation the model requires the input of crop-specific and site-specific parameter values. This guide describes how to parameterize and operate the model. For more references see Alonso et al., (*In review*), Alonso and Kaffka, (*In review*) and Alonso and Kaffka, (2009).

The model uses daily Kc values to estimate ETc based on daily ETo values. Soil moisture, salinity and trace minerals are modeled as a mass balance among the different components of the system (soil, plant and atmosphere). The soil has been divided in four layers 0.3 m deep each, for a total depth of 1.2 m. Inputs to the system occur through precipitation, irrigation and fertilization. Outputs occur through harvest (plant uptake), drainage (including runoff), and leaching.

Crop response functions (Alonso and Kaffka, 2009) for forage yield and quality under different N and salinity levels obtained from greenhouse trails (Alonso and Kaffka, *In review*) are used to predict crop yield and quality on field conditions. Beef cattle stocking rates and average daily weight gains are estimated based on dry matter (DM) and energy balance between animal requirements and pasture yield.

Model predictions were tested against field data measurements (Alonso et al., *In review*). For this purpose, 95% confidence intervals for the mean of field data samples on each parameter were built and model predictions were tested against them. Model predictions fitted field data measurements.

Using crop and site specific parameters' values the model can be used to simulate different scenarios and predict yield and quality of pastures on saline environments elsewhere.

INITIAL PARAMETER VALUES

INITIAL Soil Values

The soil has been divided in 4 layers. The model requires to define the depth (in) and the water capacity fraction (WCF; in/in) of each soil layer. This information is site-specific and can be obtained at http://soildatamart.nrcs.usda.gov/Default.aspx. Initial values are:

	Value	Unit
Depth Soil Layer 1	12	in
Depth Soil Layer 2	12	in
Depth Soil Layer 3	12	in
Depth Soil Layer 4	12	in

	Value	Unit
Available Water Fraction SL1	0.12	in/in
Available Water Fraction SL2	0.08	in/in
Available Water Fraction SL3	0.08	in/in
Available Water Fraction SL4	0.06	in/in
* SL = Soil Layer		

The model also requires specifying the permanent wilting point (%), ECe (dS/m), and the initial concentration of B (mg/L), Se (µg/L) and Mo (µg/L) in the soil. Initial values at the experimental site in the Western San Joaquin Valley (WSJV) are:

	Value	Unit
Permanent Wilting Point SL1	1	%
Permanent Wilting Point SL2	1	%
Permanent Wilting Point SL3	1	%
Permanent Wilting Point SL4	1	%
Permanent Wilting Point Soil	1	%
* SL = Soil Layer		

	Value	Unit
INIT ECe Soil Layer 1	11.2	dS/m
INIT ECe Soil Layer 2	16.5	dS/m
INIT ECe Soil Layer 3	21.5	dS/m
INIT ECe Soil Layer 4	22.5	dS/m
INIT ECe Soil AVG	17.9	dS/m

	Value	Unit
INIT Soil Boron (B)	17.9	mg/L
INIT Soil Selenium (Se)	12.5	µg/L
INIT Soil Molybdenum (Mo)	835.1	µg/L

INITIAL Crop values

The model uses crop-specific Kc values and daily ETo data to estimate daily ETc for the pasture. Kc values for Bermuda grass are shown below. ETo data from the closest CIMIS station can be acquired at http://wwwcimis.water.ca.gov/cimis/data.jsp.

Bermuda grass Kc values in WSJV

Month	Kc	Month	Kc
Jan	-	Jul	1.06
Feb	-	Aug	0.96
Mar	0.67	Sep	0.78
Apr	0.84	Oct	0.64
May	0.97	Nov	0.54
Jun	1.06	Dec	-

Initial yield (lb DM/ac), N fertilization (lb N/ac) and maximum plant salt uptake rate (dS/m*d) values at the experimental site are:

	Value	Unit
INIT Yield	450	lb DM/ac
Nitrogen Fertilization (N)	360	lb N/ac
Maximum Salt Uptake Rate	0.2	dS/m*day

INITIAL Moisture values

The model requires the input of precipitation (in), and irrigation volume (acre-foot) and quality (dS/m). Precipitation data from the closest CIMIS station can be acquired at http://wwwcimis.water.ca.gov/cimis/data.jsp. Precipitation values at WSJV in 2001 used to validate the model are:

DOY *	Date	Precipitation (in)	DOY	Date	Precipitation (in)
8	8-Jan	0.14	96	6-Apr	0.17
10	10-Jan	0.79	97	7-Apr	0.27
11	11-Jan	0.09	98	8-Apr	0.02
12	12-Jan	0.01	99	9-Apr	0.20
23	23-Jan	0.04	108	18-Apr	0.05
24	24-Jan	0.35	187	6-Jul	0.02
25	25-Jan	0.24	188	7-Jul	0.25
32	1-Feb	0.01	303	30-Oct	0.18
40	9-Feb	0.01	314	10-Nov	0.19
42	11-Feb	0.22	315	11-Nov	0.07
43	12-Feb	0.09	316	12-Nov	0.21
44	13-Feb	0.25	330	26-Nov	0.07
49	18-Feb	0.02	333	29-Nov	0.05
50	19-Feb	0.12	335	1-Dec	0.11
51	20-Feb	0.03	341	7-Dec	0.02
52	21-Feb	0.01	343	9-Dec	0.04
54	23-Feb	0.09	348	14-Dec	0.07
55	24-Feb	0.30	354	20-Dec	0.05
56	25-Feb	0.06	358	24-Dec	0.01
57	26-Feb	0.24	359	25-Dec	0.01
59	28-Feb	0.02	360	26-Dec	0.01
62	3-Mar	0.10	362	28-Dec	0.07
63	4-Mar	0.65	363	29-Dec	0.25
64	5-Mar	0.54	364	30-Dec	0.15
68	9-Mar	0.08	365	31-Dec	0.01

* DOY: Day of the year

Irrigation data at WSJV in 2001 used to validate the model is shown below:

DOY	Date	Irrigation (acre-foot)	ECiw (dS/m)
156	5-Jun	0.481	8.7
199	18-Jul	0.356	14.4
214	2-Aug	0.252	11.5

234	22-Aug	0.358	16.2
257	14-Sep	0.28	12.7
271	28-Sep	0.191	12.7

INITIAL Cattle values

The model requires the initial live weight of the cattle (lb/head) grazing the pasture, grazing efficiency (%), caloric concentration or caloric value of the pasture (MJ/lb DM), and the desired or expected stocking rate (AU/ac) and average daily gain of live weight (lb LW/d). Initial values used in the model are:

	Value	Unit
Initial Weight	227	lb
Grazing Efficiency	60	%
CC Pasture	3.0	MJ/lb DM*
Desired Stocking Rate	2.1	AU/ac
Desired ADG	2.2	lb LW/d

*DM: Dry matter
*LW: Live weight

INITIAL Trace minerals values

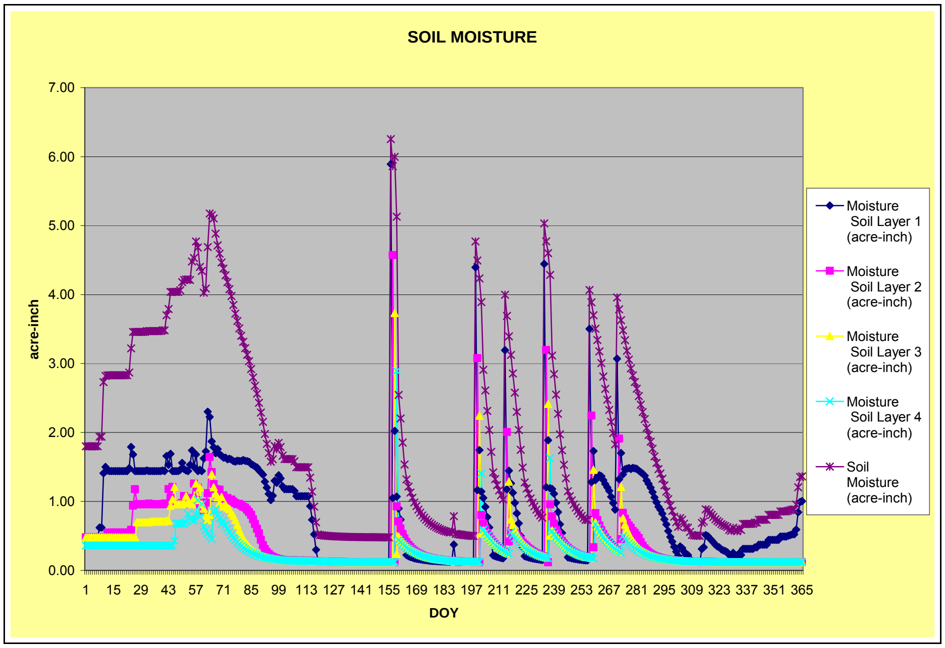
The trace minerals added to the soil through irrigation should be accounted for in this subroutine. Values for B (mg/L), Se (µg/L), and Mo (µg/L) in the irrigation water are:

DOY	Date	Boron IW (mg/L)	Selenium IW (µg/L)	Molybdenum IW (µg/L)
156	5-Jun	15.1	700	400
199	18-Jul	15.1	700	400
214	2-Aug	15.1	700	400
234	22-Aug	15.1	700	400
257	14-Sep	15.1	700	400
271	28-Sep	15.1	700	400

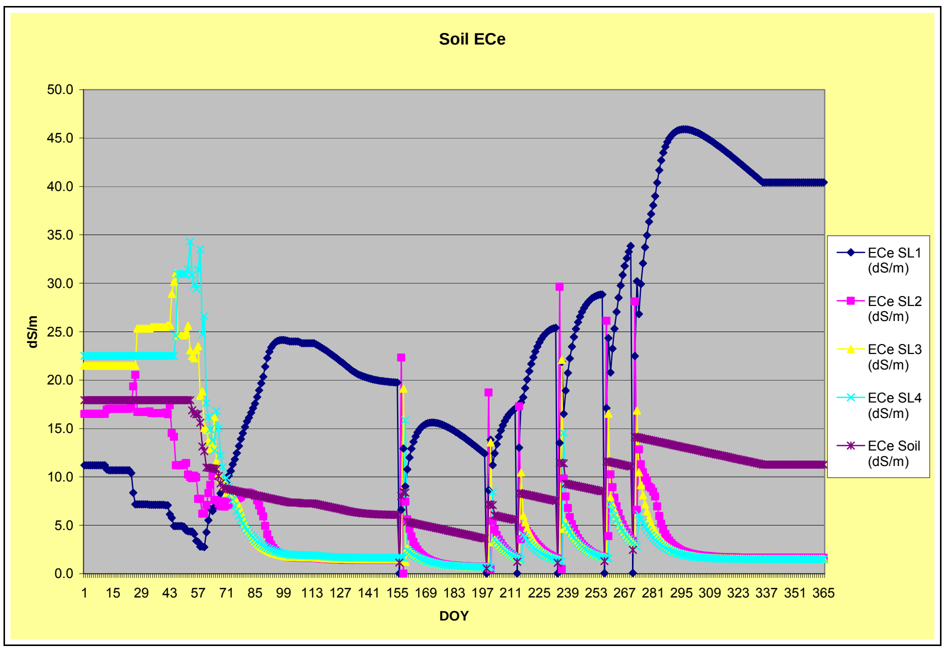
MODEL RESULTS

Results are shown in the worksheets: Soil Moisture, Soil TDS & Soil ECe, Crop Yield, Beef Cattle and Trace Elements. Simulation results are also shown in charts to facilitate their interpretation. The charts include: Soil Moisture, Percolation, Suction, DW & LF, Water Deficit, Soil ECe, Crop Yield, Cattle Maintenance, Cattle ADG, and Boron, Selenium and Molybdenum Uptake by plants.

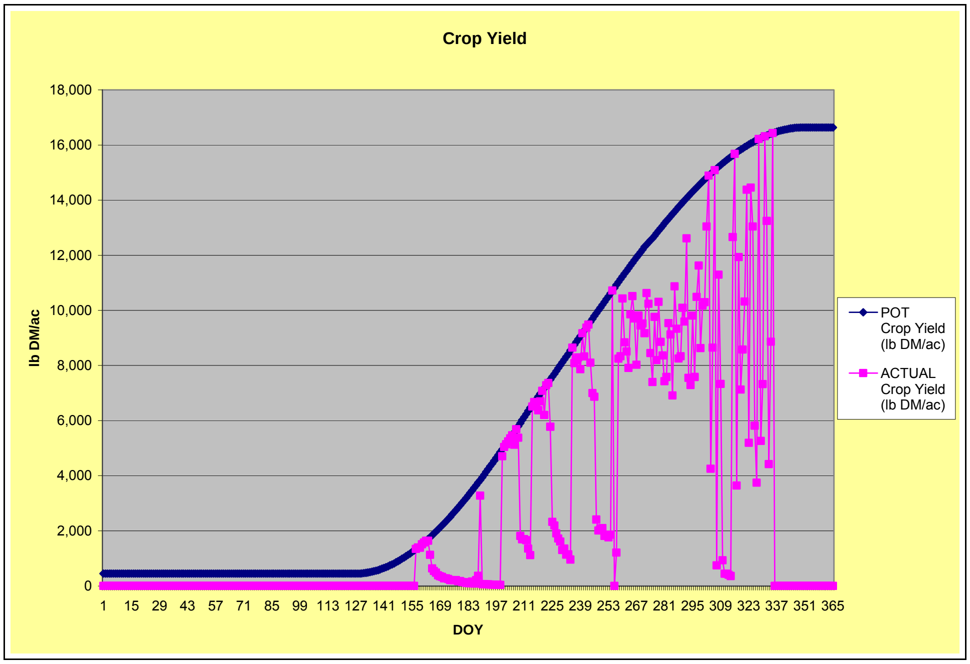
The chart below shows the variation in soil moisture during the growing season in 2001.



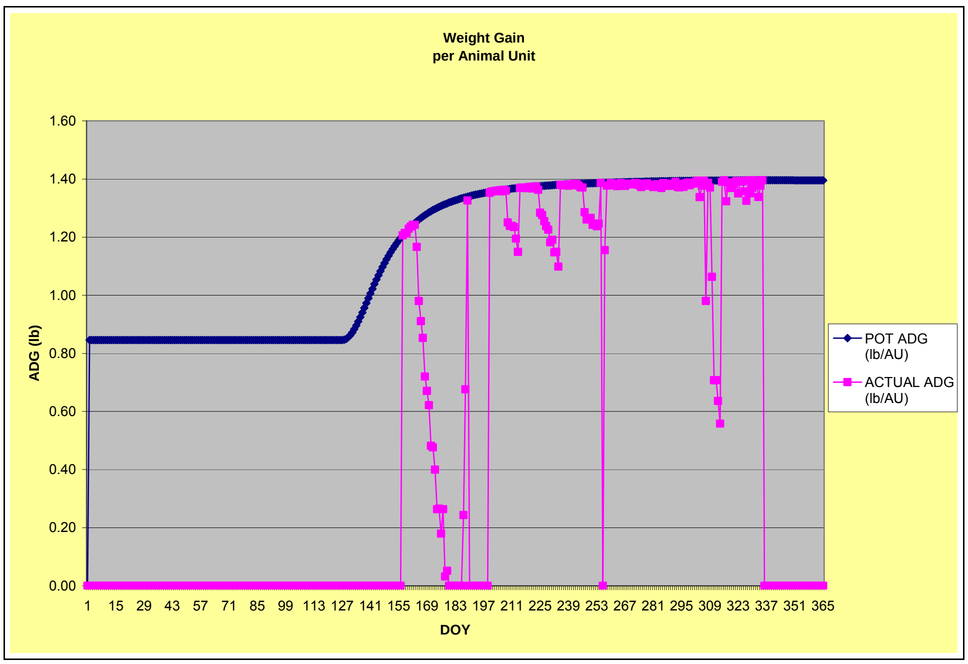
The chart below shows the variation in soil ECe during the growing season in 2001.



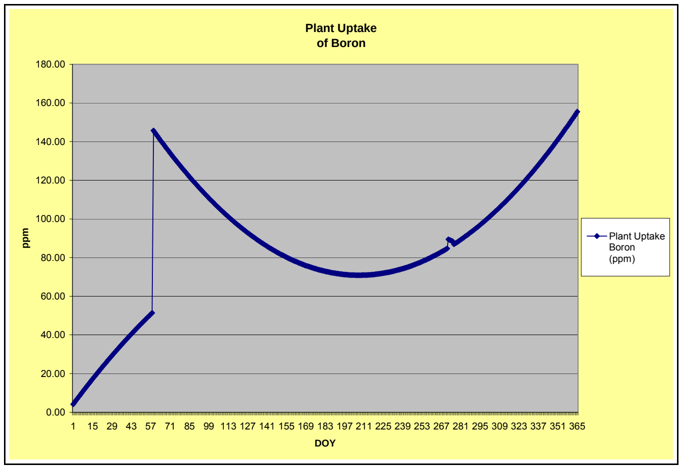
The potential yield is function of the soil and irrigation water salinity, and nitrogen fertilization level. When under-irrigation does not allow the crop to express its potential, the actual yield is lower than the potential yield. The chart below shows the difference between the actual and the potential yield at WSJV in 2001.



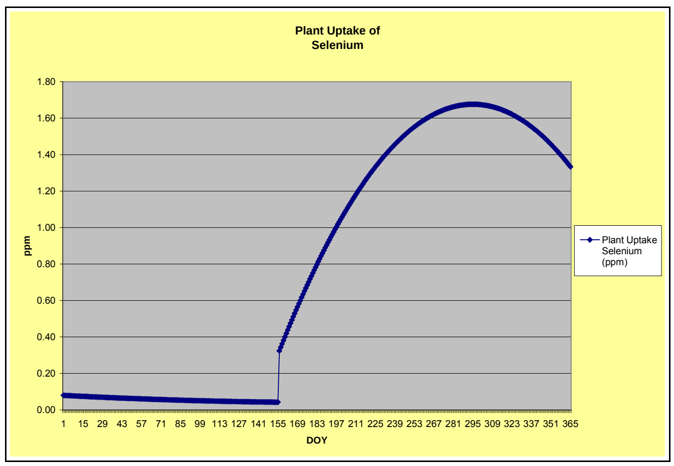
The difference between the potential and actual forage yield originates a difference between the potential and actual average daily gain of live weight for the beef cattle grazing the pasture. The follow chart shows the predictions for grazing animals at WSJV in 2001.



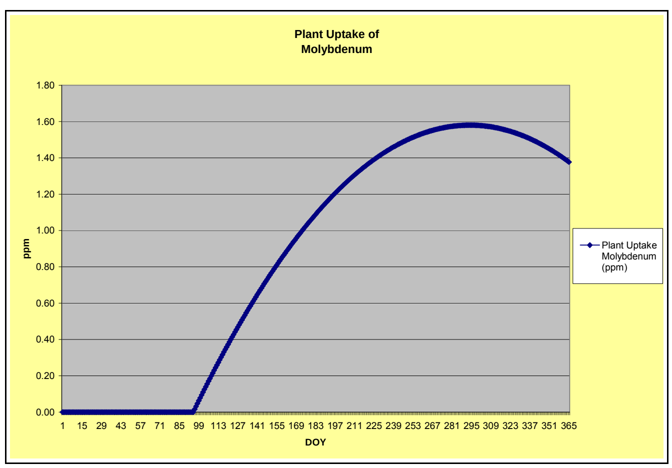
The accumulation of trace minerals in plant tissues is a function of the plant uptake of those minerals. The plant uptake of B, Se and Mo for the experimental conditions at WSJV in 2001 is shown below:



Plant Uptake
of Boron
ppm
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1 15 29 43 57 71 85 99 113 127 141 155 169 183 197 211 225 239 253 267 281 295 309 323 337 351 365
DOY
Plant Uptake Boron (ppm)



Plant Uptake of
Selenium
ppm
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1 15 29 43 57 71 85 99 113 127 141 155 169 183 197 211 225 239 253 267 281 295 309 323 337 351 365
DOY
Plant Uptake Selenium (ppm)



Plant Uptake of
Molybdenum
ppm
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1 15 29 43 57 71 85 99 113 127 141 155 169 183 197 211 225 239 253 267 281 295 309 323 337 351 365
DOY
Plant Uptake Molybdenum (ppm)

REFERENCES

Alonso, M. F., Corwin, D., Oster, J., Maas, J. and Kaffka, S.R. Modeling Bermuda grass (*Cynodon dactylon* (L.) Pers.) production in the saline soils of the western San Joaquin Valley of California. *(In review)*.

Alonso, M. F. and S.R. Kaffka. (*In review*). Bermuda grass (*Cynodon dactylon* (L.) *Pers*.) yield and quality under different levels of salinity, nitrogen and trace elements: A greenhouse evaluation

Alonso, M. F. and S.R. Kaffka. 2009. Predicting water use, crop growth and quality of Bermuda grass under saline irrigation. Final Report for the California Department of Water Resources. Contract

Appendix A: Abbreviations

ADG	Average daily gain (lb)
AU	Animal unit
AWC	Available water capacity (in/in)
B	Boron (mg)
CIMIS	California Irrigation Management Information System
DM	Dry matter (lb)
DOY	Day of the year
ECdw	Electrical conductivity drainage water (dS/m)
ECe	Electrical conductivity paste extract (dS/m)
ECiw	Electrical conductivity irrigation water (dS/m)
ETa	Actual evapo-transpiration (in)
ETc	Crop evapo-transpiration (in)
ETo	Potential evapotranspiration (in)
Kc	Crop coefficient
LW	Live weight (lb)
Mo	Molybdenum (μg)
N	Nitrogen (lb)
Se	Selenium (μg)
TDS	Total dissolved solids (mg)
WCF	Water capacity fraction (in/in)
WSJV	Western San Joaquin Valley