N AND WATER STRESS IMPACT ON HARD RED SPRING WHEAT YIELD AND QUALITY

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ABSTRACT

Water and nitrogen stress impact wheat (*Titicum Aestivum*) yield and quality. To minimize yield losses from N and water stress it is essential to developing corrective treatment options. The objective of this experiment was to determine the influence of N and water stress on hard red spring wheat, crop reflectance, yield, and quality(protein). A randomized split block experiment with each treatment replicated four times was conducted in 2003. Treatments were four N and two soil moisture regimes. Reflectance data was collected using a cropscan radiometer. ^{13}C isotopic discrimination(Δ) was used to asses N and water stress. Reflectance data was then compared to yield and Δ values. Yields were increased by N rate and were not increased by supplemental irrigation. Reflectance measured at the 5-6 leaf growth stage was highly correlated to N stress. These results indicated that remote sensing can be used to assess N stress. At the boot growth stage, protein content and reflectance were highly correlated. Results from these relationships suggest that corrective N treatment based on crop reflectance can be used to improve wheat quality characteristics. This information can be used to allow for corrective treatments and improve marketing decisions.

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INTRODUCTION

Water and Nitrogen stress are the two most limiting factors to crop growth and development. In production fields they interact to cause variability (Clay et al. 2001b). This variability is the direct consequence of different amounts of available water and N in summit, backslopes , toe slopes, and depressional areas. Matching N to available water is critical (Clay et al. 2001a). Bauer et al. (1965) reported that if stored water was <5.1 cm then wheat did not respond to N and if stored water was >15.2 then the grain fertilizer response was 10 kg grain kg-

[1]N. Over applying N can reduce wheat yields as well as advance environmental consequences while under applying N can reduce wheat quality and yields.

Research conducted in corn (*Zea mays*) showed crop reflectance can be used to assess N and water stress (Barnes et al. 2000; Clay et al. 2006). This work showed nitrogen stress had a larger influence on reflectance in the green band than water stress, while in the near infrared band (NIR), water stress influenced reflectance more than N stress. These findings suggest that corrective N treatments to corn (*Zea mays*) based on reflectance in the green, red, and NIR bands can be developed. To improve profitability and water quality a similar approach must be developed in wheat. The objective is to determine the influence of N and water stress on wheat crop reflectance, yield, and quality (protein).

MATERIALS AND METHODS

Quantifying N and water stress

Plant 13C discrimination (Δ) can be used to evaluate water, nutrients, diseases, and soil compaction stresses. Equations for determining nitrogen and water stress interactions with Δ have been developed for wheat (Clay et al., 2001a) and corn (Clay et al. 2005).

The approach is based on solving two equations:

Optimum yield – measured yield =YLWS + YLNS

dΔ = YLWS (δΔ/δyield WS) + YLNS (δΔ/δyield NS)

where, dΔ is the difference between the Δ value of a well fertilized plant under low water stress, δΔ/δyield NS is the partial derivation of the line relating Δ and yield when N limits yield and water stress was constant (Clay et al. 2005; Clay et al. 2001b). The δΔ/δyield WS is the partial derivative relating Δ and yield when N does not limit yield (Webb et al. 1972).

The testing of this method showed that Δ-based YLNS and YLWS values were highly related to measured yield losses to N and water stress (Clay et al. 2005) and plants growing under high water stress had lower Δ than plants growing under low water stress (Clay et al. 2001). Similar results relating Δ to grass, durum wheat, and barley yields have been reported (Araus et al. 1999).

The approach is based on more $^{13}CO_2$ being fixed during photosynthesis under water stressed than non-water stressed conditions (Farquhar and Lloyd 1993).

Experimental Design

The field experiment was conducted in 2003 at the Aurora research farm (96° 40' West and 44° 18' North). The soil is a Brandt silty clay loam (fine-silty, mixed, frigid, Calcic Hapludoll.) The experimental design was a randomized split block design. Two water treatments and four N rates were used for the experiment. Each treatment was replicated four times. The plot size was 12 X 12 m. Hard red spring wheat was planted at 90 lbs/acre on April 15th. Herbicides were applied to control weeds at 783mL/ha Puma, 37 mL/ha Harmony GT, and 890 mL /acre MCPA. The four N rates used were 0, 56, 140, and 224 kg N/ha. The two water treatments were natural precipitation and natural precipitation + irrigation. The natural precipitation received 38 cm of rain. The irrigated treatments received 1.9 and 4.4 cm of water on June 19 and July 15. The total natural precipitation and irrigation was 44.3 cm. Crop reflectance was collected on May 20th, June 4th, and June 29th. Growing degree days (base 10°C) was 1171 GDD. The grain was harvested from an area 18.9 m^2. Grain samples were analyzed for yield, protein, moisture, ^{13}C discrimination(Δ), N,$\delta^{15}N$ using a 20-20 Europa Ratio mass spectrometer (PDZ Europa, Chesire, UK; Clay et al. 2005). Reflectance was measured on May 20th, June 4th, and June 29th. Anova was conducted using SAS. Relationships between parameters were determined using correlation analysis.

Reflectance

Crop reflectance in the blue (485 ± 68 nm), green (568 ± 70 nm), red (661 ± 57 nm), NIR (840 ± 151 nm), and MIR (1650 ± 195 nm) bands were measured 2 m above the plants at three dates (Clay et al. 2006). Based on these values the reflectance indices were calculated using the equations: NDVI = (NIR-Red)/(NIR + Red); $GNDVI_S$ = (NIR-Green)/(NIR+Green)/$GNDVI_r$; NDWI=(NIR-MIR)/NIR+MIR); and NRI=(NIR/green)/(NIR_r/Greenr), where $GNDVI_r$, NIR_r, $Green_r$, were taken from well fertilized and water controlled plots (Bausch and Duke, 1996; Shanahan et al. 2001; Jackson et al. 2004). The three other indices were Cgreen [($R_{800\ nm}/R_{700\ nm}$)-1], Cred [($R_{800\ nm}/R_{550\ nm}$)-1], CNIR [($R_{840\text{-}870}/Rr_{ed(720—740)\ nm}$)-1] where R is reflectance (Gitelson et al 2005).

RESULTS AND DISCUSSION

Plant Characteristics

The two inputs in the study were nitrogen and water. The data in table 1 shows the results for each treatment individually and combined. Nitrogen had a significant impact on yield, protein, Yield Loss to N Stress (YLNS), and Yield Loss to Water Stress (YLWS). Increasing the N rate from zero to low increased the yield from 3180 kg/ha to 3680 kg/ha. Associated with this yield increase was reduced YLNS and YLWS. These results suggest that N and water can have additive effects on yields. Increasing the N rate from low to high reduced yields and increased YLWS.

The protein values ranged from 11.8% in the 0 N treatments to 15.0% in the high N treatments. Protein concentrations were higher in the irrigated then the non-irrigated treatment. These results were attributed to supplemental irrigation proving additional N. Supplemental irrigation did not increase yields or reduce YLNS.

Table 1. The influence of 4 N Rates and soil moisture regime on grain yields, yield losses due to N stress, and yield losses due to water stress in 2003.

N RATE	MOISTURE REGIME	YIELD	PROTEIN	YLNS	YLWS
		kg/ha			
0	Natural	3090	11.2	611	493
Low	Natural	3630	12.8	241	318
Medium	Natural	3530	13.8	144	516
High	Natural	3460	15.3	95	631
0	Irrigated	3270	12.4	494	426
Low	Irrigated	3720	13.0	334	136
Medium	Irrigated	3310	14.7	302	578
High	Irrigated	3240	14.6	260	690
p value		**ns**	**<.05**	**ns**	**ns**
—N Rate—					
0		3180	11.8	552	460
low		3680	12.9	288	227
Medium		3420	14.3	223	547
High		3350	15.0	177	660
p value		**<.001**	**<.0001**	**<.0002**	**<.0001**
lsd (0.05)		**208**	**0.67**	**144**	**148**
—Moisture Regime—					
	Natural	3428	13.3	273	490
	Irrigated	3385	13.7	348	457
p value		**ns**	**<.05**	**ns**	**ns**

Wheat eflectance was impacted by N rate and sampling date. On May 20th, N rate and reflectance had mixed results. Increasing the N rate from 0 to the medium level generally decreased reflectance in the blue, green, red, and NIR bands. (Table 2). Further increases in N reversed these relationships. Mixed results were attributed to interactions among N, water, and the amount of bare soil exposed to the sensor. On June 4th (Table 3) and June 29th (Table 4) reflectance in the blue, green, red, and MIR decreased with N rate. Reflectance in the NIR band had opposite results.

Table 2. The influence of soil moisture regime and 4 N rates on spectral indices and reflectance for May 20, 2003.

		SPECTRAL INDICES								*REFLECTANCE*				
N Rate	**Moisture Regime**	**NDVI**	**GNDVI**	**GNDVIs**	**NDWI**	**NRI**	**Cgreen**	**Cred**	**CNIR**	**Blue**	**Green**	**Red**	**NIR**	**MIR**
							kg/ha							
0	Natural	0.28	0.38	0.99	-0.24	0.99	2.06	1.36	1.49	6.6	9.0	11.6	20.1	32.7
Low	Natural	0.30	0.40	1.04	-0.23	1.04	2.17	1.41	1.54	6.3	8.7	10.9	20.2	32.6
Medium	Natural	0.32	0.41	1.07	-0.21	1.07	2.23	1.45	1.58	6.1	8.5	10.5	20.4	31.5
High	Natural	0.28	0.39	1.01	-0.23	1.01	2.09	1.38	1.51	6.7	9.1	11.6	20.7	32.9
0	Irrigated	0.28	0.38	0.99	-0.22	0.99	2.06	1.36	1.49	6.8	9.3	11.8	20.8	32.7
Low	Irrigated	0.30	0.40	1.03	-0.21	1.03	2.14	1.41	1.53	6.6	9.2	11.4	21.1	32.2
Medium	Irrigated	0.28	0.38	1.00	-0.23	1.00	2.08	1.37	1.50	6.7	9.1	11.5	20.4	32.4
High	Irrigated	0.28	0.39	1.00	-0.22	1.00	2.08	1.38	1.50	6.7	9.2	11.6	20.6	32.1
p value		**ns**	**ns**	**ns**	**<.1**	**ns**	**<.0001**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**
—N Rate—														
0		0.28	0.38	0.99	-0.23	0.99	2.06	1.36	1.49	6.7	9.2	11.6	20.4	32.7
low		0.30	0.40	1.03	-0.22	1.03	2.15	1.41	1.54	6.5	8.9	11.2	20.7	32.4
Medium		0.30	0.40	1.03	-0.22	1.03	2.15	1.41	1.54	6.4	8.8	11.0	20.4	31.9
High		0.28	0.39	1.00	-0.22	1.00	2.09	1.38	1.50	6.7	9.2	11.6	20.7	32.5
p value		**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0002**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0005**	**<.0001**
lsd (0.05)		**0.01**	**0.01**	**0.03**	**0.01**	**0.01**	**0.05**	**0.03**	**0.03**	**0.4**	**0.5**	**0.7**	**0.9**	**1.1**
—Moisture Regime—														
	Natural	0.30	0.40	1.03	-0.23	1.03	2.14	1.40	1.53	6.4	8.8	11.1	20.3	32.4
	Irrigated	0.28	0.39	1.00	-0.22	1.00	2.09	1.38	1.50	6.7	9.2	11.6	20.7	32.4
p value		**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**<.1**	**ns**	**<.1**	**ns**	**ns**

Table 3. The influence of soil moisture regime and 4 N rates on spectral indices and reflectance for June 4, 2003.

		SPECTRAL INDICES								*REFLECTANCE*				
N Rate	**Moisture Regime**	**NDVI**	**GNDVI**	**GNDVIs**	**NDWI**	**NRI**	**Cgreen**	**Cred**	**CNIR**	**Blue**	**Green**	**Red**	**NIR**	**MIR**
							kg/ha							
0	Natural	0.63	0.61	0.92	0.05	0.83	3.83	2.38	2.53	3.9	6.5	6.1	27.0	24.3
Low	Natural	0.72	0.67	1.01	0.15	1.02	4.66	2.85	3.02	3.4	5.9	2.0	30.0	22.0
Medium	Natural	0.75	0.70	1.04	0.21	1.23	5.16	3.12	3.28	3.1	5.7	4.5	31.6	20.5
High	Natural	0.71	0.67	1.00	0.16	1.00	4.63	2.84	3.01	3.4	5.9	5.1	29.9	21.8
0	Irrigated	0.62	0.60	0.90	0.06	0.80	3.71	2.32	2.47	4.1	6.8	6.4	27.3	24.4
Low	Irrigated	0.71	0.67	1.01	0.17	1.03	4.74	2.90	3.06	3.5	6.1	5.1	31.0	22.1
Medium	Irrigated	0.69	0.66	0.98	0.13	0.96	4.45	2.72	2.88	3.5	6.1	5.4	29.3	22.6
High	Irrigated	0.70	0.67	1.00	0.17	1.00	4.65	2.86	3.02	3.5	6.1	5.3	30.4	21.7
p value		**ns**	**ns**	**ns**	**<.1**	**ns**	**<.0001**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**
—N Rate—														
0		0.62	0.61	0.91	0.05	0.82	3.77	2.35	2.50	4.0	6.6	6.3	27.1	24.3
low		0.71	0.67	1.01	0.16	1.02	4.70	2.88	3.04	3.4	6.0	5.1	30.5	22.0
Medium		0.72	0.68	1.01	0.17	1.04	4.81	2.925	3.08	3.3	5.9	4.9	30.4	21.5
High		0.71	0.67	1.00	0.16	1.00	4.64	2.85	3.01	3.5	6.0	5.2	30.1	21.7
p value		**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0002**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0005**	**<.0001**
lsd (0.05)		**0.03**	**0.02**	**0.03**	**0.04**	**0.09**	**0.13**	**0.23**	**0.23**	**0.3**	**0.3**	**0.5**	**1.6**	**1.1**
—Moisture Regime—														
	Natural	0.70	0.66	0.99	0.14	0.99	4.57	2.80	2.96	3.4	6.0	5.2	29.6	22.1
	Irrigated	0.68	0.65	0.97	0.13	0.95	4.39	2.70	2.86	3.7	6.3	5.6	29.5	22.7
p value		**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**<.1**	**ns**	**<.1**	**ns**	**ns**

Table 4. The influence of soil moisture regime and 4 N rates on spectral indices and reflectance for June 29, 2003.

N Rate	Moisture Regime	*SPECTRAL INDICES*								*REFLECTANCE*				
		NDVI	GNDVI	GNDVIs	NDWI	NRI	Cgreen	Cred	CNIR	Blue	Green	Red	NIR	MIR
							kg/ha							
0	Natural	0.88	0.81	0.94	0.52	0.72	9.13	5.16	5.33	1.7	3.9	2.4	38.3	12.2
Low	Natural	0.91	0.85	0.98	0.57	0.89	11.42	6.42	6.62	1.7	3.6	2.0	43.6	11.8
Medium	Natural	0.91	0.85	0.98	0.58	0.89	11.40	6.47	6.68	1.7	3.6	2.0	43.5	11.6
High	Natural	0.92	0.85	0.99	0.58	0.89	11.40	6.47	6.68	1.7	3.6	2.0	43.5	11.6
0	Irrigated	0.89	0.83	0.96	0.55	0.78	10.07	5.65	5.82	1.7	3.8	2.2	40.0	11.6
Low	Irrigated	0.91	0.84	0.97	0.57	0.85	10.71	6.08	6.26	1.7	3.6	2.0	41.8	11.3
Medium	Irrigated	0.92	0.86	1.00	0.60	0.98	12.53	7.01	7.22	1.6	3.4	1.9	45.6	11.5
High	Irrigated	0.92	0.86	1.00	0.61	1.00	12.82	7.24	7.46	1.6	3.4	1.8	46.9	11.5
p value		**ns**	**0.08**	**0.09**	**ns**	**0.03**	**0.06**	**ns**	**0.09**	**ns**	**ns**	**ns**	**ns**	**ns**
—N Rate—														
0		0.89	0.82	0.95	0.53	0.75	9.60	5.41	5.58	1.7	3.9	2.3	39.2	11.9
low		0.91	0.84	0.98	0.57	0.87	11.06	6.25	6.44	1.7	3.6	2.0	42.7	11.6
Medium		0.92	0.85	0.99	0.59	0.93	11.97	6.74	6.95	1.7	3.5	2.0	44.5	11.6
High		0.92	0.86	0.99	0.59	0.97	12.37	7.00	7.20	1.6	3.5	1.9	45.9	11.7
p value		**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.005**	**<.0001**	**<.0001**	**<.0001**	**<.1**
lsd (0.05)														
—Moisture Regime—														
	Natural	0.91	0.84	0.97	0.56	0.86	10.97	6.20	6.39	1.7	3.7	2.1	42.5	11.8
	Irrigated	0.91	0.85	0.98	0.58	0.90	11.53	6.49	6.69	1.6	3.6	2.0	43.6	11.5
p value		**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**

Correlation Coefficients

On May 20, 2003 reflectance was generally not correlated to N rate, yield, protein, Δ, YLNS, and YLWS (Table 5). The lack of correlation was attributed to small plants and that bare soil confounded the signal (Chang et al. 2004). Different results were observed on June 4th, where reflectance was correlated to N rate, yield, protein, Δ, and YLNS were correlated. YLWS was not correlated to reflectance (Table 6). YLNS had a higher correlation to reflectance then yield, protein, and Δ. Yield was correlated at the 0.01 probability levels for all values except, blue, green, red, and MIR which were correlated at the 0.05 level. Protein showed correlated values at the 0.05 level for GNDVI, $GNDVI_s$, NDWI, Cred, CNIR, and MIR. Δ showed correlation at the 0.05 level for NDVI, GNDVI, $GNDVI_s$, NDWI, Cred, CNIR, blue, green, red, and MIR.

Similar results were observed on 29 June (Table 7). All of the reflectance values correlated to the N rate at the 0.01 probability level except for MIR which was not correlated to N rate. Protein generally had stronger correlations to reflectance than yield, Δ, and YLNS except for blue and MIR. Protein was correlated at the 0.01 probability level to all of the reflectance values. Blue was correlated to protein at the 0.05 probability level and MIR was not correlated. ^{13}C discrimination was correlated to NDVI, GNDVI, $GNDVI_s$, NRI, Cgreen, Cred, and NIR at the 0.05 probability level. YLNS was correlated at the 0.01 probability level for all values except for Cgreen, blue, NIR, and MIR which showed correlation at the 0.05 level. Yield and YLNS values had higher correlation to reflectance

Table 5. Correlation coefficients on May 20th, 2003. 3-4 Leaf Stage. Values indicated with * and ** were significant at the .05 and .01 level.

	N Rate	Yield	Protein	C13Dis	YLNS	YLWS
NDVI	0.06	0.06	-0.09	-0.20	-0.18	0.12
GNDVI	0.09	0.04	-0.04	-0.22	-0.17	0.12
$GNDVI_S$	0.09	0.04	-0.04	-0.22	-0.17	0.12
NDWI	0.22	.484*	0.22	-0.08	-0.33	-0.24
NRI	0.09	0.03	-0.05	-0.22	-0.16	0.12
Cgreen	0.09	0.08	-0.03	-0.22	-0.19	0.10
Cred	0.12	0.08	-0.03	-0.23	-0.22	0.13
CNIR	0.11	0.05	-0.05	-0.23	-0.20	0.14
Blue	-0.01	0.11	0.14	0.24	0.08	-0.21
Green	-0.03	0.14	0.12	0.26	0.07	-0.24
Red	-0.02	0.09	0.14	0.24	0.10	-0.22
NIR	0.07	0.29	0.16	0.18	-0.09	-0.26
MIR	-0.14	-0.14	-0.03	0.28	0.22	-0.07

Table 6. Correlation coefficients on June 4th, 2003. 5-6 Leaf Stage. Values indicated with * and ** were significant at the .05 and .01 level.

	N Rate	Yield	Protein	C13Dis	YLNS	YLWS
NDVI	0.55**	0.60**	0.42	-0.43*	-0.77**	0.07
GNDVI	0.58**	0.61**	0.45*	-.44*	-0.77**	0.06
$GNDVI_S$	0.58**	0.61**	0.45*	-.44*	-0.77**	0.06
NDWI	0.59**	0.61**	0.46*	-.43*	-0.78**	0.06
NRI	0.53*	0.61**	0.41	-0.42	-0.76**	0.05
Cgreen	0.54**	0.60**	0.42	-0.42	-0.76**	0.06
Cred	0.54**	0.60**	0.42*	-0.42*	-0.77**	0.07
CNIR	0.55**	0.61**	0.43*	-0.43*	-0.77**	0.06
Blue	-0.51*	0.47*	-0.35	0.48*	0.67**	-0.14
Green	-0.53*	-0.45*	-0.37	0.49*	0.66**	-0.14
Red	-0.52*	-0.53*	-0.36	0.45*	0.72**	-0.11
NIR	0.50*	0.68**	0.41	-0.28	-0.75**	-0.05
MIR	-0.60**	-0.47*	-0.44*	.52*	0.71**	-0.16

Table 7. Correlation coefficients on June 29th, 2003. Boot Stage. Values indicated with * and ** were significant at the .05 and .01 level.

	N Rate	Yield	Protein	C13Dis	ylns	ylws
NDVI	0.70**	0.359	0.70**	-0.42*	-0.54**	0.12
GNDVI	0.72**	0.316	0.76**	-0.46*	-0.55**	0.18
$GNDVI_S$	0.72**	0.316	0.76**	-0.46*	-0.55**	0.18
NDWI	0.62**	0.404	0.65**	-0.30	-0.57**	0.10
NRI	0.72**	0.265	0.76**	-0.46*	-0.54**	0.23
Cgreen	0.70**	0.263	.73**	-0.44*	-0.53*	0.23
Cred	0.71**	0.267	0.74**	-0.47*	-0.56**	0.25
CNIR	0.72**	0.268	0.75**	-0.48*	-0.56**	0.25
Blue	-0.44*	-0.127	-0.50*	0.12	0.51*	-0.37
Green	-0.67**	-0.219	-0.78**	0.37	0.58**	-0.34
Red	-0.70**	-0.340	-0.71**	0.38	0.56**	-0.17
NIR	.68**	0.309	0.67**	-0.47*	-0.45*	0.09
MIR	-0.17	-0.357	-0.29	-0.20	0.52*	-0.10

at the V4 to V5 (Feekes 3-5) growth stage than reflectance measured at the late boot stage (Feekes 10.5). This reduction in correlation from V4-5 to late boot was attributed to reflectance at the late boot being influenced by two vegetation types (leaves and head), whereas at the V4-V5 reflectance was only influenced by leaves. Similar findings are observed as corn goes from vegetation to reproductive growth stages.

YLWS was not correlated to reflectance at any date. These results are in agreement with the Anova analyis. The lack of correlation between YLWS and reflectance was expected because supplemental irrigation did not increase yields. Results from the reflectance data suggests that reflectance can be used to assess N stress in wheat.

SUMMARY

Nitrogen and water regularly interact and influence grain yields. The ability to quantify YLNS and YLWS by Δ provides a method to asses yield variability. Yields were increased by N fertilizer and were not increased with supplemental irrigation. Protein content was increased by both N fertilizer and supplemental irrigation.

Early in the growing season (May 20) reflectance and the plant parameters were not correlated. As the season progressed to June 4 data showed that reflectance could be used as a tool to identify N stress. At late boot, (Feekes 10.5) reflectance data could be used to assess wheat quality. Reflectance data collected at V4-V5 could be used for developing corrective N rates while data collected at late boot could be used for marketing purposes. In many situation premiums are paid for wheat with high protein content. Utilizing protein information, farmers will be better able to manage their resources.

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