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Biosolids Fertilization for Dryland Pacific Northwest Wheat Production

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Abstract

The fertilizer value of anaerobically-digested, dewatered biosolids in dryland cereal cropping systems was evaluated at six locations in central and eastern Washington (25 to 35 cm annual precipitation zone). Biosolids were applied at rates of 3 to 20 Mg/ha (approximately 150 to 900 kg N/ha). We measured increases in soil nutrient levels [phosphorus (P), sulfur (S), and zinc (Zn)] with biosolids fertilization that will contribute to increased site productivity for one or more cropping cycles. Biosolids fertilization at 300 kg N/ha produced yields equal to inorganic N fertilizers (anhydrous/aqua ammonia or ammonium nitrate) applied at 55 kg N/ha. Biosolids applied at 300 kg N/ha supplied more than enough N for maximum yield as demonstrated by higher grain N, higher grain N uptake, and lower grain test weight compared to inorganic N fertilization. Increasing the biosolids application rate to 600 kg N/ha reduced grain yield due to lodging and grain shrivel, and resulted in high levels of postharvest soil nitrate-N. Biosolids increased grain production by increasing spike number and kernels per spike. These visual responses were offset by reduced grain kernel weight with biosolids fertilization. We conclude that biosolids rates of approximately 300 kg N/ha will provide maximum benefits for wheat growers in the 25 to 35 cm precipitation zone in the Pacific Northwest. Future research is needed to identify wheat varieties which respond best to biosolids fertilization.

Keywords: biosolids application rate, dryland wheat, nitrogen, phosphorus, sulfur, zinc fertilizer value, grain yield, grain N, soil nitrate.

Materials and Methods

Biosolids Sources. We obtained biosolids from three cooperating wastewater treatment plants. A single biosolids source was used at each location (Table 1). All biosolids met EPA Exceptional Quality criteria for the ten regulated trace elements (Table 3 of 40 CFR Part 503) . All biosolids were produced by anaerobic digestion of solids generated by primary + secondary wastewater treatment. Following digestion, all biosolids met EPA Class B pathogen reduction standards. Biosolids from treatment plant A (field locations 1 and 2) were air-dried in outdoor drying beds to 800 to 900 g/kg total solids prior to land application. Biosolids from treatment plants B and C (field locations 3-6) were applied as dewatered cake (180 to 220 g/kg total solids). At application, a minimum of three samples were collected from the field biosolids stockpile for determination of total solids, Total Kjeldahl N and ammonium-N (Table 2).

Field Plot Techniques. Field plots were arranged in a randomized** complete block design with 3 to 5 replications at all locations. Small plots (4 x 8 m) were used at locations 1 and 2. For locations 1 and 2, biosolids were weighed and applied manually, and grain was harvested from a 1.5 x 7 m swath in the center of each plot with a Hegi small plot combine. Field-scale plots were used at locations 3, 4, 5, and 6. Biosolids were applied with a John Deere 455 Hydropush manure spreader to 2.5 ha plots. Grain was harvested from one or two combine header widths in the center of each plot (about 1.2 ha).

Field Location Information (Table 3). Soils at all locations were developed under grasslands (Haploxerolls great group), with a silt loam surface horizon susceptible to wind erosion. All locations were managed using a wheat/fallow production system (one year of crop, one year of fallow in a two year crop production cycle). Biosolids were applied in the fall after crop harvest (Locations 2, 4, and 5) or during the summer fallow (Locations 1, 3, and 6).

Tillage, wheat variety, herbicide and other cultural practices were those routinely used by the cooperating grower. Wheat varieties at Locations 1, 2, 3, and 4 were common soft white wheat varieties, with moderate straw strength, selected primarily because of their resistance to snow mold. Varieties at locations 5 and 6 were soft white club wheats with greater straw strength (less susceptible to lodging). The field locations represent two counties in central Washington (Locations 1-4) and two counties in eastern Washington (locations 5 and 6). Locations 1 and 2 were in the same field (about 75 m apart). Locations 3 and 4 were located in nearby fields (about 1 km apart). Location 1 was harvested in 1992, locations 3 and 6 in 1993, and locations 2, 4, and 5 were harvested in 1994.

Grain testing. Grain yields are reported on an "as is" basis (about 10 % moisture content). Subsamples of the grain harvested from each plot were collected in the field. Grain was cleaned to remove chaff and grain test weight (bulk grain weight per unit volume) was determined with a standard USDA grain grading apparatus. Grain nitrogen was determined via a LECO combustion analyzer. Grain N uptake was calculated by multiplying the grain N content by the corresponding grain yield (minus 10 % moisture).

Soil sampling and analysis.

Preapplication soil samples (0-90 cm) were collected immediately prior to biosolids application. Surface (0-30 cm) samples were analyzed for pH, Olsen (bicarbonate) P, and exchangeable K; nitrate-N was determined for the 0-90 cm depth (Table 3).

Postharvest samples for determination of nitrate-N, ammonium-N and sulfate-S were collected during the late summer or early fall following crop harvest, prior to significant precipitation. Soil samples were collected in 30 cm depth increments to a depth of 90 cm (Locations 1, 2, and 5) or 120 cm (Locations 3, 4, and 6), using a hydraulic auger (Kauffman sampler; Albany, OR) mounted on a small tractor. Approximately 10 to 15 cores (0-30 cm depth) and 3 to 6 cores (30-60, 60-90, and 90-120 cm depths) were collected from each plot. For conversion of soil concentrations to kg per hectare, we assumed a soil bulk density of 1.3 g/cm^3 at all locations. Soil nitrate was determined via a colorimetric method or a cadmium reduction method. Soil reference samples run with each batch of unknown samples showed both nitrate analysis methods to be accurate and precise. Soil sulfate-S was determined via a turbidimetric method. Surface (0-30 cm) samples were analyzed for ammonium-N via a colorimetric method.

Postharvest soil samples (0-10 cm) were analyzed for Olsen (bicarbonate) P and DTPA Zn. Twenty to 30 cores were composited per plot.

Above-ground biomass and grain yield components were determined at locations 4 and 5 on 2 m of row per plot. At harvest, we counted the number of spikes per m of row and weighed intact plants. Grain yield was determined by running the harvest bundles through a Hegi combine.

Statistical analyses were performed using the SAS system (SAS Institute, Cary, N.C.). We did not have the same number of biosolids treatments at each location, and biosolids analyses varied between locations. To compare similar biosolids N rates across locations we grouped application rates of 200 to 400 kg N/ha and called this treatment "300 kg N/ha" and grouped higher rates of application 500 to 700 kg N/ha and called this treatment "600 kg N/ha". We used these treatment groups, 300 and 600 kg N/ha as biosolids, for orthogonal contrasts across locations. The combined data set (all locations) was analyzed as a split-plot design with locations as main plots and fertilizer treatments as subplots. Statistical analyses within a location were performed using analysis of variance procedures for a randomized complete block design.

Results and Discussion

Comparisons across locations (Table 4).
Statistical analysis using locations as main plots, and fertilizer treatments as subplots showed highly significant ($P < 0.01$) effects of fertilizer application on grain yield, test weight, grain N, grain N uptake and postharvest soil nitrate-N. The fertilizer treatment * location interaction was also highly significant ($P < 0.01$) for all parameters (Table 4), indicating that the magnitude of fertilizer treatment effects varied between locations.

The mean squares generated by the analysis of variance (Table 4) show the relative importance of sources of variation. Location had a larger effect on yield and N uptake than did fertilizer treatment, showing the unpredictable nature of yield where precipitation is the major limiting factor. Fertilizer treatments had a stronger effect than location on grain N, postharvest soil nitrate-N, and grain test weight. The consistency of these measurements across locations shows that biosolids was a dependable nutrient source. The lower test weight across locations was due to increased vegetative growth and increased plant water stress during the grain fill period.

Averaged over locations, biosolids at 300 kg N/ha and inorganic N fertilizer at 55 kg N/ha had the same yield and postharvest nitrate-N. Biosolids at 300 kg N/ha significantly ($P < 0.05$) reduced test weight and increased grain N compared to inorganic N fertilization. Increasing the biosolids application rate from 300 to 600 kg N/ha significantly reduced grain yield, test weight, and increased grain N and postharvest nitrate-N.

Comparisons by location (Fig 1 and 2; Table 5).

Grain yield. Preapplication nitrate-N analyses (90 cm depth) showed that all sites except location 6 should respond to N fertilization (Table 3). Other nutrients tested were present at adequate levels. Soil P (0 - 30 cm) was well above (locations 1 and 5) or slightly above (locations 3, 4, and 6) the recommended minimum soil P level for maximum yield of dryland winter wheat (10 mg/kg Olsen P). Exchangeable K was well above recommended minimum (100 mg/kg). Surface soil pH values ranged from 6.3 to 6.7 (near neutral).

Fertilization significantly increased grain yield at 4 of the 6 locations (Table 5; Fig. 1). Yield responses were largely due to the N supplied by biosolids. The locations that did not respond to fertilization had high preapplication soil nitrate-N analyses (Table 3). The WSU fertilizer guide for dryland wheat correctly predicted non-responsive sites; it recommended application of reduced N rates (location 2; 28 kg N/ha) or no N (location 6). Locations that did respond to fertilization (locations 1, 3, 4, and 5) had estimated fertilizer N requirements of 52 to 73 kg N/ha for a target yield of 4 Mg/ha (60 bushels per acre).

Using the current WSU guidelines for biosolids application, suggested biosolids application rates for the responsive sites were 3.9 to 6.5 Mg/ha (Table 2). This is below the minimum application rate for most manure spreaders currently used to apply biosolids, and below the biosolids application rates used at our sites (except location 1 and 2). Actual yield responses (Fig. 1) show that low (<300 kg N/ha) rates of biosolids were needed for maximum yield at all locations except location 6. The cause of the significant yield increase at the highest rate of biosolids application at location 6 is unknown. Preapplication and postharvest soil tests at location 6 showed high nitrate levels, so the yield response was probably not due to nitrogen.

The yield data demonstrated that higher rates of N application were not needed in years with above average yield potential. Locations 1 and 2 (same field, different harvest years) both produced near-optimum yields with 300 kg N/ha biosolids applied, although maximum yields were 3.0 Mg/ha for Location 1 and 5.0 Mg/ha for Location 2. Locations 3 and 4 (adjacent fields, different harvest year) had similar increases in yield due to fertilization (approximately 1.2 Mg yield increase over the zero N treatment), although maximum yields were 5.8 Mg/ha for Location 3 and 3.8 Mg/ha for Location 4.

The largest yield reductions at high biosolids application rates occurred when wheat plants lodged (fell over). We observed some lodging at the 300 kg N/ha rate and severe lodging at the 600 kg N/ha rate at locations 2 and 3. Some lodging was also observed at Location 4 with the 600 kg N/ha rate. Locations 2, 3, and 4 had the same wheat variety, Eltan, which has only moderate straw strength. Locations 5 and 6 had the potential for lodging (high N supply and above average precipitation), but had wheat varieties with greater straw strength. Location 1 had a variety even more susceptible to lodging than Eltan, but low precipitation during the crop year limited excessive growth.

Test weight (Fig.1; Table 5). Test weight is a measure of grain plumpness. Decreases in test weight are usually associated with plant water stress during the grain fill period. Lodging and excessive vegetative growth increase plant water stress. Large reductions in grain test weight were associated with lodging at high biosolids application rates (Locations 2, 3, and 4). Where lodging did not occur (Locations 1, 5 and 6), even high rates of biosolids produced grain with acceptable test weight. Low rates of biosolids increased test weight at locations 1 and 5, probably because of improved root development and extraction of soil water.

Grain N (Fig. 1; Table 5). High grain N is undesirable in soft white winter wheat. High protein grain is less suitable for production of cakes, crackers, cookies and other confectionery items. Some export markets specify soft white wheat less with less than 18 g/kg N. Currently, there are no premiums paid to growers for low protein wheat, so high protein does not negatively affect the grower. Grain N increased with biosolids application rate at all locations except location 6. Excluding location 6, low N grain (<18 g N/kg) was produced only at biosolids application rates of less than 200 kg N/ha (Locations 1 and 2). Grain N levels continued to increase at locations 1, 2, and 5 at biosolids rates above that needed for maximum yield.

Grain N uptake (Fig. 2; Table 5). This measurement shows how much N is removed from the field at grain harvest. Because of lodging, grain N uptake was actually reduced at locations 2 and 3 as the biosolids rate increased from 300 to 600 kg N/ha. Grain N uptake with biosolids at 300 kg N/ha was higher than with inorganic N fertilization at locations 1, 3, and 5 demonstrating that biosolids supplied a greater quantity of N than the inorganic N fertilizer.

Postharvest nitrate-N (Fig. 2; Table 5) was similar for biosolids at 300 kg N/ha and inorganic N fertilizer at all locations except location 5. Postharvest nitrate-N increased significantly when the biosolids rate was increased from 300 to 600 kg N/ha at all locations. This was expected, since yield was maximized at biosolids application rates of 300 kg N/ha.

Biomass and Yield Components (Tables 6 and 7). Locations 4 and 5 showed changes in biomass production and yield components due to biosolids fertilization. The yield response to biosolids at Location 4 was largely due to increased tillering (more spikes per unit area). At Location 5, the biggest factor in the yield response was a greater number of kernels per spike. At both locations, yield increases from more spikes and/or larger spikes were offset by a lower grain kernel weight. Some of the light kernels produced with biosolids may have been blown out the back of the combine when the large plots were harvested. We got this idea by comparing the hand harvest yields with the combine yields. For the biosolids treatments, the grain yield determined by hand harvesting (Tables 5 and 6) was about 1 Mg/ha higher than for combine harvest (Fig. 1). For the zero N treatment, hand harvest and combine harvest gave similar yield estimates.

The differences in yield response pattern between Location 4 and 5 were probably strongly influenced by wheat variety. The Eltan variety used at Location 4 responded to increased biosolids application rates by producing large quantities of tillers and straw. In contrast, the Tres variety at location 5 did not increase tiller production above that produced with inorganic N fertilization, even with 900 kg N/ha applied as biosolids. Increased straw production is desirable in terms of soil conservation and the opportunity for a straw harvest. It is a negative when it reduces grain yield by increasing plant water stress. Choosing the right variety is an important component of a program to beneficially use biosolids in dryland cropping systems.

Extractable soil nutrients (S, Zn, and P; Fig. 3 and Table 8).

Sulfate-S was significantly increased ($P < 0.10$) by biosolids fertilization at all locations. The increase in extractable sulfate-S with biosolids was equal to 3.1, 4.9, and 3.8 g S/kg biosolids at locations 3, 4, and 5, respectively. Based on this estimate of sulfate-S per unit of biosolids, the increase in soil sulfate-S after application of biosolids at 300 kg N/ha should be about 27 kg S/ha. Sulfur uptake by wheat grain is usually less than 10 % of the N uptake. Since grain N uptake at a high yielding dryland site is about 100 kg N/ha (Fig. 2), we would expect S removal to be less than 10 kg/ha. Therefore, the sulfate-S generated by application of biosolids at a rate of 300 kg N/ha should be enough to satisfy crop requirements for 2 or 3 cropping cycles, provided leaching losses are not significant.

Olsen (bicarbonate) P was significantly increased ($P < 0.01$) by biosolids fertilization at all locations. The depth sampled (10 cm) probably does not fully represent the depth of biosolids incorporation; additional P from biosolids application is probably present below 10 cm. Across locations, application of biosolids at a rate of 300 kg N/ha (175 kg P/ha) increased bicarbonate P from 20 mg/kg to 33 mg/kg. The additional P removed with biosolids fertilization at 300 kg N/ha was about 2 kg P/ha at locations 4 and 5 (data not shown). The P supplied by biosolids should be enough to satisfy crop requirements for many (10 + ?) crops.

Zinc (DTPA extraction) was significantly increased ($P < 0.01$) by biosolids fertilization at all locations. Even at high biosolids rates, extractable Zn levels in our study are far below levels toxic to plants. The increase in plant-available Zn probably does not represent a major soil fertility benefit. Wheat is very tolerant of low soil Zn availability, and yield response to applied Zn on wheat has not been demonstrated in our area.

Application of high rates of P fertilizer sometimes result in a crop Zn deficiency. Phosphorus induced Zn deficiency appears highly unlikely with biosolids application, since both nutrients are applied simultaneously

Summary and Conclusions

Anaerobically-digested, dewatered biosolids are a dependable nutrient source for dryland cropping systems. Adequate N for maximum yield was present at all locations with a biosolids application rate of 300 kg total N/ha. A single application of biosolids supplied enough P, S, Zn for two or more crops. In addition to the benefits reported here, growers also observe significant benefits in reducing wind erosion from biosolids application. Long-term research (6 to 10 years after a single application) is needed to measure the residual effects of biosolids on site productivity.

A true "agronomic rate" (exactly matching N supplied with crop N needs) is probably about 5 Mg/ha biosolids (2 dry tons/acre) for our 25 to 35 cm precipitation zone. This would supply about 200 kg total N/ha. This application rate is below the spreading capability of most manure spreaders. A reasonable solution to this problem is to apply a spreadable biosolids rate and eliminate, or reduce N fertilization for succeeding crops, based on soil nitrate tests. After the first crop, we recovered most of the postharvest nitrate-N from the 0-60 cm depth (data not shown). Under our low precipitation conditions, this residual nitrate-N will be available for uptake by the second crop after biosolids application. An application rate of 7 to 10 Mg/ha (3 to 4 dry tons/acre) may provide enough N for 2 or 3 crops.

Grower confidence in biosolids fertilization is essential to continued biosolids utilization in dryland cropping systems. Varieties that do not lodge with high fertility are needed to ensure consistent yield performance with biosolids. In our study, we observed large reductions in grain yield and grain test weight associated with lodging. The high grain N produced by biosolids fertilization is a potential problem for soft white wheat production, but could be an asset for production of hard red winter or hard red spring wheat.

The greatest benefit to the grower from biosolids application comes from the first biosolids application at a site. Biosolids recycling programs designed to maximize beneficial use should concentrate on one-time applications over large acreages, rather than repeated applications on small acreages. Local biosolids permitting agencies can promote beneficial use by streamlining the permit process for dryland sites which have a very low risk of off-site pollution.

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Table 1. Biosolids sources, processing, and selected chemical analyses.

Biosolids Source	Biosolids Digestion Process	Moisture Reduction Process	Field Locations	Biosolids Analysis			
				P mg/kg	Cd mg/kg	Cu mg/kg	Zn mg/kg
A	anaerobic	drying bed	1 and 2	22600	5.3	616	893
B	anaerobic	belt filter press	3, 4, and 5	27000	7.7	840	860
C	anaerobic	belt filter press	6	26200	14.8	405	883

Table 2. Biosolids nitrogen analyses and suggested application rates*.

Field Location	Biosolids Analyses			Fertilizer Guide Fert. N Rqmt. kg/ha	Estimated biosolids plant-available N g/kg	Suggested biosolids appl. rate Mg/ha
	Total Solids g/kg	Total N g/kg	Ammonium-N g/kg			
1	800	40.4	10.4	73	11.2	6.5
2	900	45.0	7.2	28	11.2	2.5
3	200	51.7	14.0	67	14.5	4.6
4	200	43.0	15.4	52	13.2	3.9
5	200	43.0	11.8	63	12.1	5.2
6	200	40.3	9.7	0	11.0	0.0

See Table 3 for calculation of fertilizer N requirement for each location.

* Biosolids appl. rate calculations from WSU Cooperative Extension Bulletin EB 1432, "Sewage Sludge Guidelines for Washington, Part 3":

Estimated biosolids plant available N (g/kg dry biosolids) = 0.2 * biosolids organic N + 0.5 * biosolids ammonium-N

Suggested N application rate (Mg/ha dry biosolids) = Recommended fertilizer N rate (kg/ha)/biosolids plant-available N (g/kg)

Table 3. Field location data and preapplication soil chemical properties

Field Location	Months from application to harvest	Winter wheat variety	Average annual precipitation	Soil chemical analyses						
				Preapplication Soil Nitrate-N		Fertilizer Guide Fert N Rqmt.	Organic Matter	pH	Olsen P	Exch. K
				Avg.	Std. Dev.					
			cm	kg/ha	kg/ha	kg/ha	g/kg		mg/kg	mg/kg
1	14	Sprague	25	46	8	73	22	6.6	19.7	815
2	22	Eltan	25	76	30	28				
3	15	Eltan	27	49	8	67	12	6.7	11.3	344
4	21	Eltan	27	52	3	52	13	6.4	12.0	446
5	21	Tres	29	37	12	63	13	6.5	18.0	488
6	14	Rely	36	227	54	0	28	6.3	12.1	594

Soil sampling depth: NO3-N: 90 cm; organic matter, pH, P, and K: 30 cm

N fertilizer requirement (4.0 Mg grain/ha yield goal) calculated based on Washington State Univ. Fertilizer Guide 34, "Dryland Wheat Nitrogen Needs" using the following factors:

N mineralized from soil organic matter per 12 months (kg/ha) = average annual precipitation (cm) * 0.88

Available soil NH4-N = 35 kg N/ha (average of 3 mg/kg in 90 cm profile)

Nitrogen requirement per unit yield = 0.045 kg N/kg grain

Table 4. Biosolids effects on grain yield, grain quality, and postharvest soil nitrate-N. Averages, significance, and analysis of variance across all locations

Fertilizer Source	Total N applied per hectare	Grain Yield	Grain Test Wt.	Grain N	Grain N Uptake	Postharvest Soil Nitrate-N
	kg/ha	Mg/ha	kg/m3	g/kg	kg/ha	kg/ha
None	0	3.56	766	15.8	52.5	38.5
Anhydrous/aqua ammonia	55	3.90	770	17.9	64.2	51.6
Biosolids	300	4.09	761	20.5	77.6	64.9
Biosolids	600	3.53	747	22.9	72.0	143.1
Source of variation	df	P>F				
Locations	4	**	**	**	**	**
Fertilizer Treatments	3	**	**	**	**	**
Fertilizer Trt. * Location	12	**	**	**	**	**
Coefficient of variation (%)		10.78	1.4	8.96	14.08	40.88
LSD (5 %)		0.25	6.70	1.08	5.85	19.63
Source of Variation	df	Analysis of Variance Mean Squares				
Blocks	4	0.5	222	4	98	1628
Locations	4	14.9	1940	59	8510	10510
Main plot error	3	0.4	153	6	108	1489
Fertilizer Treatments	3	1.4	2006	198	2387	44485
Fertilizer Trt. * Location	12	0.8	881	16	545	2954
Subplot Error	47	0.2	114	3	88	936

Note: Location 4 deleted from averages and ANOVA because it lacked a 300 kg N/ha biosolids treatment

** Significant at the 1 % probability level

Table 5. Statistical significance of grain and soil N measurements. Locations 1-6.

Contrast	Field Location					
	1	2	3	4	5	6
	Yield, Mg/ha					
Zero N vs. biosolids (300 kg N/ha)	**	NS	+	**	**	NS
Anhdrous/aqua ammonia vs. biosolids (300 kg N/ha)	NS	NS	NS	NS	NS	NS
Biosolids (300 kg N/ha) vs. biosolids (600 kg N/ha)	NS	**	**	M	NS	*
Coefficient of variation (%)	8.6	8.2	14.5	9.3	7.2	7.9
Standard error of the mean	0.23	0.37	0.73	0.30	0.25	0.27
	Grain test weight, kg/m3					
Zero N vs. biosolids (300 kg N/ha)	+	NS	*	+	**	*
Anhydrous/aqua ammonia vs. biosolids (300 kg N/ha	NS	NS	**	**	NS	NS
Biosolids (300 kg N/ha) vs. biosolids (600 kg N/ha)	NS	*	*	M	**	NS
Coefficient of variation (%)	1.4	1.4	2.3	1.2	0.4	0.6
Standard error of the mean	10.9	10.5	17.3	9.3	2.9	4.9
	Grain N, g/kg					
Zero N vs. biosolids (300 kg N/ha)	**	+	**	**	**	NS
Anhydrous/aqua ammonia vs. biosolids (300 kg N/ha	**	NS	**	**	**	NS
Biosolids (300 kg N/ha) vs. biosolids (600 kg N/ha)	**	**	NS	M	**	NS
Coefficient of variation (%)	7.2	9.5	10.9	7.1	3.9	10.2
Standard error of the mean	1.33	1.89	2.43	1.34	0.69	1.82
	Grain N Uptake, kg/ha					
Zero N vs. biosolids (300 kg N/ha)	**	NS	**	**	**	NS
Anhydrous/aqua ammonia vs. biosolids (300 kg N/ha	**	NS	**	*	**	NS
Biosolids (300 kg N/ha) vs. biosolids (600 kg N/ha)	**	+	**	M	NS	+
Coefficient of variation (%)	10.3	11.6	16.5	13.4	8.2	13.0
Standard error of the mean	4.68	9.45	16.40	7.73	4.57	7.23
	Postharvest soil nitrate-N, kg/ha					
Zero N vs. biosolids (300 kg N/ha)	NS	NS	NS	**	*	NS
Anhydrous/aqua ammonia vs. biosolids (300 kg N/ha	NS	NS	NS	**	*	NS
Biosolids (300 kg N/ha) vs. biosolids (600 kg N/ha)	**	**	*	M	**	**
Coefficient of variation (%)	24.7	30.9	71.4	11.1	38.9	23.7
Standard error of the mean	12.2	20.8	50.1	4.9	33.7	20.9

M = missing data makes this contrast impossible

Note: For Location 4 contrasts, zero N or aqua/anhydrous ammonia treatments compared with biosolids at rate of 600 kg N/ha.

+,*,** Significant at the 10, 5, and 1 % probability levels, respectively

Table 6. Biosolids effects on biomass yields and grain yield components (Location 4).

Fertilizer Source	Total N Applied	Dry Matter Yield			Yield Components		
		Total	Grain	Straw	Kernels per spike	Spikes	Thousand Kernel Weight
	kg/ha	Mg/ha	Mg/ha	Mg/ha		per m2	g
None	0	6.9	2.4	4.5	25.0	288	33.3
Anhydrous/aqua ammonia	56	11.4	3.9	7.5	29.0	394	34.7
Biosolids	486	16.3	5.3	11.0	30.5	565	30.1
Biosolids	971	12.9	3.9	9.0	34.0	423	27.0
				Contrasts:			
Zero N vs. anhydrous/aqua ammonia		NS	+	+	**	NS	NS
Zero N vs. biosolids		*	**	**	**	**	+
Anhydrous/aqua ammonia vs. biosolids		NS	NS	+	NS	NS	*
Coefficient of variation (%)		28.9	22.3	22.0	8.5	18.1	9.8
Standard error of the mean		1.12	2.65	1.76	2.52	75.65	3.07

+,*,** Significant at the 10, 5, and 1 % probability levels, respectively

Table 7. Biosolids effects on biomass yields and grain yield components (Location 5).

Fertilizer Source	Total N Applied	Dry Matter Yield			Yield Components		
		Total	Grain	Straw	Kernels per spike	Spikes	Thousand Kernel Weight
	kg/ha	Mg/ha	Mg/ha	Mg/ha		per m2	g
None	0	7.3	3.2	4.2	41.8	218	35.0
Anhydrous/aqua ammonia	56	9.1	3.9	5.2	43.6	258	34.7
Biosolids	289	10.2	4.3	6.0	53.3	268	30.2
Biosolids	578	10.0	4.4	5.6	57.1	257	30.1
Biosolids	867	10.6	4.5	6.1	54.7	288	28.8
				Contrasts:			
Zero N vs. anhydrous/aqua ammonia		NS	NS	NS	NS	+	NS
Zero N vs. biosolids		**	**	**	**	**	**
Anhydrous/aqua ammonia vs. biosolids		NS	NS	NS	**	NS	**
Coefficient of variation (%)		13.6	14.8	16.0	7.4	10.4	4.2
Standard error of the mean		0.55	1.40	0.87	3.72	26.80	1.33

+,*,** Significant at the 10, 5, and 1 % probability levels, respectively

Table 8. Statistical significance of extractable soil nutrient measurements. Locations 1-6.

Contrast	Field Location			
	3	4	5	6
	Sulfate-S, kg/ha			
No biosolids vs. biosolids	+	+	*	M
Biosolids (300 kg N/ha) vs. biosolids (600 kg N/ha)	NS	M	M	M
Coefficient of variation (%)	20.4	13.7	14.5	M
Standard error of the mean	37.3	20.5	15.8	M
	Bicarbonate P, mg/kg			
No biosolids vs. biosolids	**	**	**	**
Biosolids (300 kg N/ha) vs. biosolids (600 kg N/ha)	+	M	**	*
Coefficient of variation (%)	27.2	35.0	12.3	19.6
Standard error of the mean	7.9	10.1	5.3	4.9
	DTPA Zn, mg/kg			
No biosolids vs. biosolids	**	**	**	**
Biosolids (300 kg N/ha) vs. biosolids (600 kg N/ha)	NS	M	**	**
Coefficient of variation (%)	54.3	45.4	22.6	18.8
Standard error of the mean	1.1	0.8	0.7	0.5

M = missing data makes this contrast impossible

+,*,** Significant at the 10, 5, and 1 % probability levels, respectively

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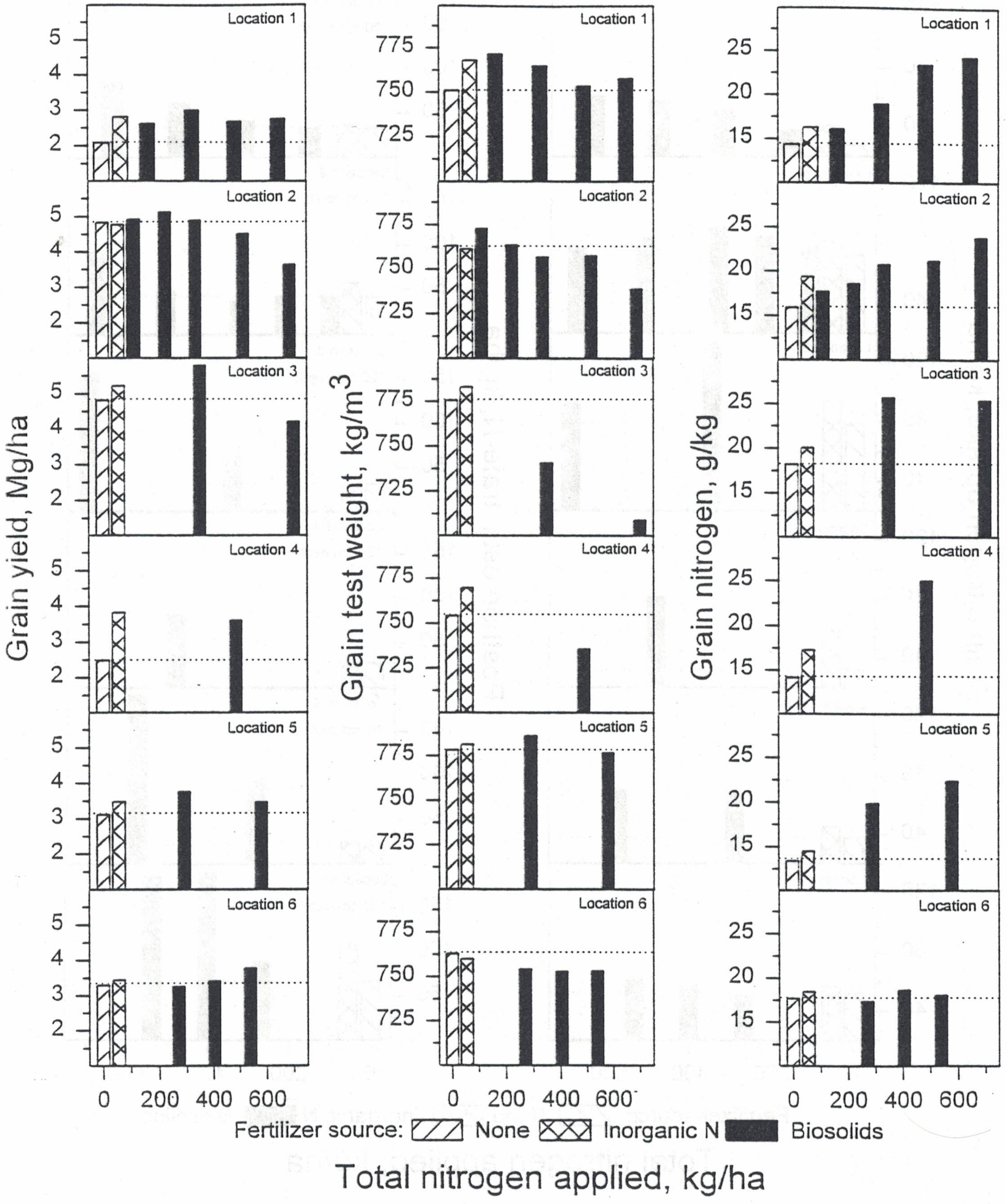

Figure 1. Biosolids and inorganic N fertilizer effects on grain yield, grain test weight and grain nitrogen. Horizontal dotted lines equal values for zero fertilizer treatment.

repa2.spw

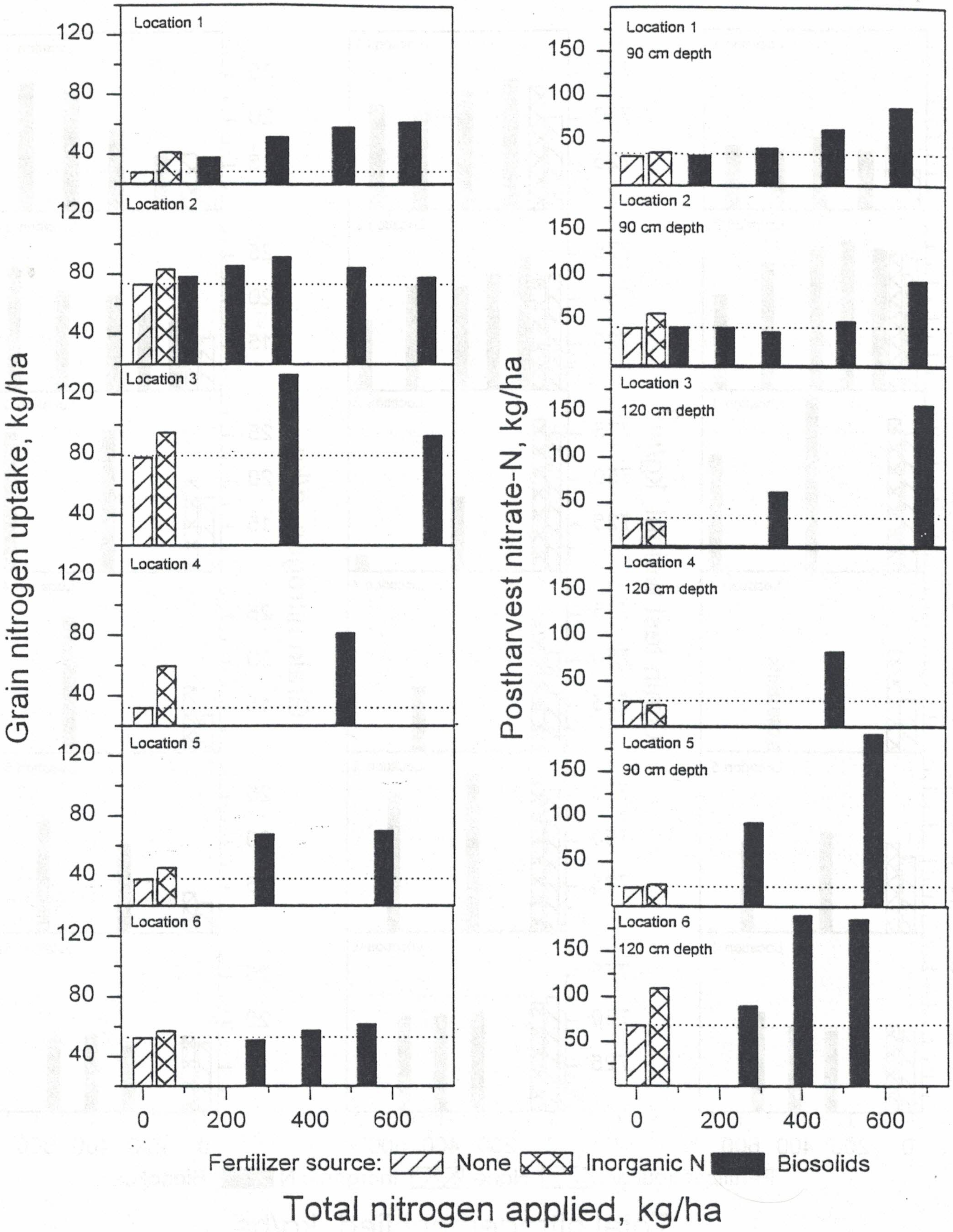

Figure 2. Biosolids and inorganic N fertilizer effects on grain nitrogen uptake and post harvest soil nitrate-N. Horizontal dotted lines equal values for zero fertilizer treatment.

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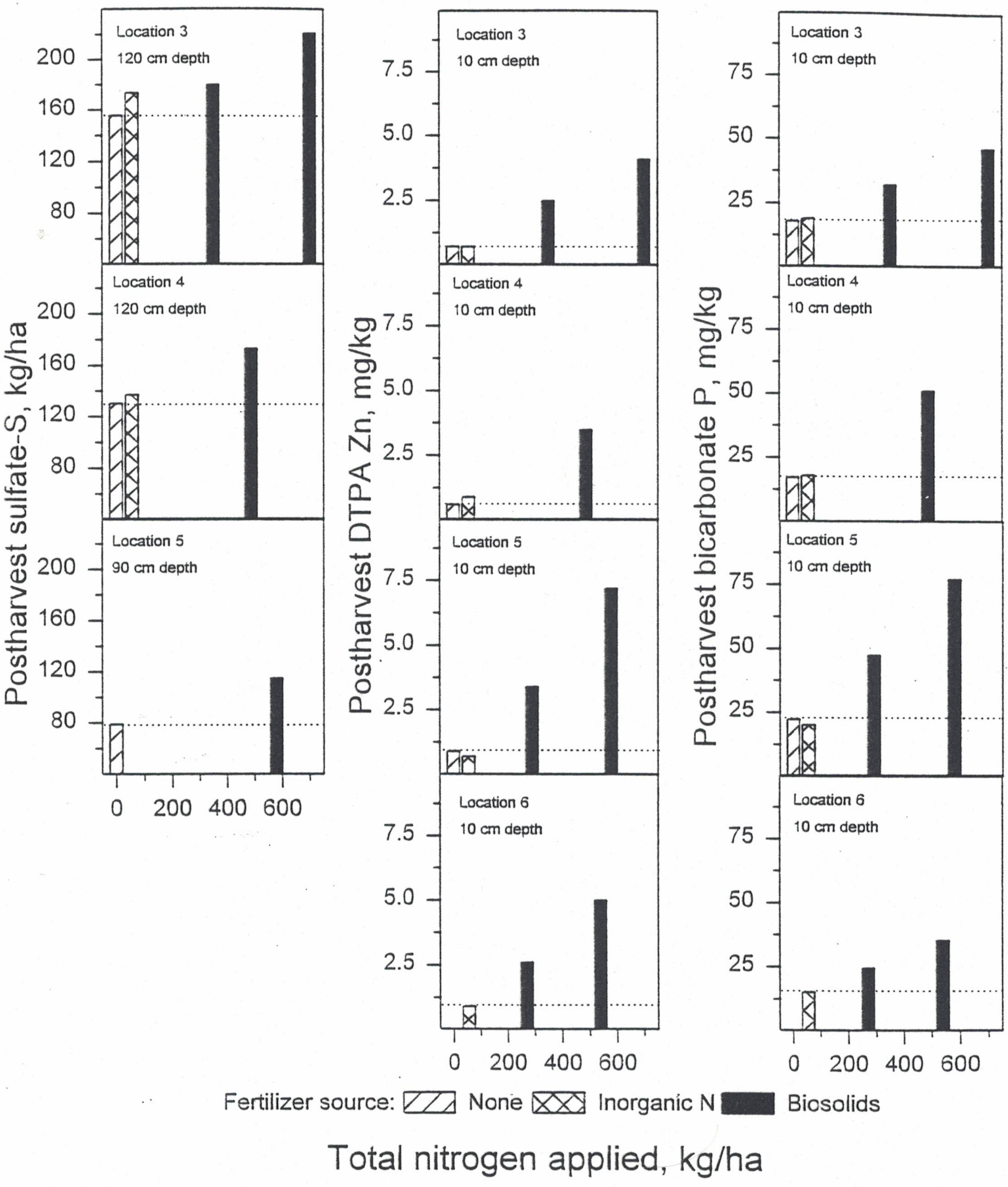

Figure 3. Biosolids and inorganic N fertilizer effects on postharvest soil sulfate-S, DTPA Zn and bicarbonate P. Horizontal dotted lines equal values for zero fertilizer treatment.

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EFFECTS OF LAND APPLICATION OF BIOSOLIDS IN ARID AND SEMI-ARID ENVIRONMENTS

MAY 16 - 19
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PROGRAM

Effects of Land Application of Biosolids in the Arid and Semi-Arid West

Fort Collins, Colorado
May 16-19, 1995

Tuesday May 16, 1995

8:00 - 8:15	Registration
8:15 - 8:30	*Welcome* by Bob Brobst

Session I - Vegetative Response

8:30 - 9:15	Rangeland Restoration with Surface-applied Biosolids: Effects on Soils and Vegetation of the Rio Puerco Watershed, Northcentral New Mexico *S.R. Loftin, R. Aguilar, R.R. Fresquez, and Francis*
915 -10:00	Tobosagrass and Alkali Sacaton Growth Responses to Topically Applied Biosolids in a Chihuahuan Desert Grassland *D.B. Wester, M.W. Benton, P. Jurado, R.G. Gatewood, and R.E. Sosebee*
10:00 - 10:15	Coffee Break
10:15 - 11:00	Evaluation of Sewage Sludge Products for use in Extensive Sheep Production Systems in Australia *D.L. Michalk, presented by G. King*
11:00 - 11:45	Sawmill Waste Utilization for Reclaiming Bentonite Mine Lands *G.E. Schuman, and E.M. Taylor, Jr.*
11:45 - 1:00	Lunch Break

Session II - Crop Benefits

1:00 - 1:45	11 Years of Biosolids Application to Dryland Winter Wheat *K.A. Barbarick, J.A. Ippolito, D.G. Westfall*, and R. Jepson
1:45 - 2:30	Biosolids Fertilization For Dryland Pacific Northwest Wheat Production *D.M. Sullivan, A.I. Bary, J.A. Kropf, and D.M. Granatstein*
2:30 - 3:15	Biosolids from an Agricultural Perspective *G. Wegner*
3:15 - 3:30	Coffee Break
3:30 - 4:15	N-viro Soil as a Gypsum Replacement in Cotton Production on a Sodic/Alkali Soil *B. McCullough-Sanden, H. McCuchin, R. Bailey, T. Logan, and B. Harrison*
4:15 - 5:00	A Comparison of Production of Dryland Wheat Between Use of Anhydrous Ammonia and Biosolids in Southeastern Colorado *R.B. Brobst and P. Hegeman*

Wednesday May 17, 1995

8:00 - 1:00	Attendees will take a field trip to the Fort Collins' ***Meadow Springs Ranch***. A Box lunch will be provided.