Biosolids Increase Grass Yield, Grass Quality and Soil Fertility in Dryland Pasture

City of Portland
Bureau of Environmental Services
monitoring data

Summarized by
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September 2008

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Contents

Introduction

The purpose of this report is to document changes resulting from long-term application of biosolids to grazed dryland pasture. The report contains two chapters:

- Chapter 1: Biosolids Increase Grass Yield and Quality in Dryland Pasture
- Chapter 2: Biosolids Increase Soil Fertility in Dryland Pasture

Data summarized here was derived from annual reports submitted by the City of Portland Bureau of Environmental Services to the Oregon Department of Environmental Quality (DEQ) from 1996 to 2007.

This report is a collaborative effort by Mark Ronayne, Greg Charr, and Jim Utberg, City of Portland; Don Horneck and Dan Sullivan, Oregon State University; and Kent Madison, Madison Farms.

Mark Ronayne has served as Biosolids Coordinator for the City of Portland from 1995 to present. Mark was the project coordinator. Mark's activities included design of sampling protocols, contracting with third parties for sample collection and laboratory analyses, and preparing annual reports summarizing project data.

Jim Utberg (retired, City of Portland) and Greg Charr (City of Portland) were responsible for record keeping, data checking, and other activities documenting when, where, and how samples were collected, and were responsible for soil and plant database management. Jim and Greg prepared the data tables for the City's annual reports to DEQ.

Don Horneck, Certified Professional Soil Scientist (currently Extension Soil Scientist at the Oregon State University Hermiston Agricultural Experiment Station), collected samples at the field site for determination of grass yield and quality and soil fertility. Don also worked with the City and the landowner (Kent Madison) to determine appropriate sampling locations, sampling timing, and sampling methods.

Dan Sullivan, Extension Soil Scientist, worked with the City in design of data collection protocols. Dan obtained data tables from the City and put together the long-term story presented here. Any biases present in this report are largely the result of Dan's interpretation of the data.

Kent Madison, landowner, farmer, and contractor for the City of Portland, was responsible for land application of biosolids, documentation accompanying land application, and soil sampling on a field-by-field basis (whole-farm monitoring).

Chapter 1

Biosolids Increase Grass Yield and Quality in Dryland Pasture

Researchers and Collaborators

Mark Ronayne, Greg Charr, and Jim Utberg, City of Portland
Don Horneck and Dan Sullivan, Oregon State University
Kent Madison, Madison Farms

Background

Previous research has demonstrated that biosolids provide benefits to soil and plants beyond that provided by inorganic fertilizers. This chapter summarizes biosolids effects on grass forage yield and quality at a semiarid site near Hermiston, Oregon. Soil monitoring data from the same site is presented in Chapter 2.

The City of Portland contracts with a local farmer (Madison Farms) to manage dryland pasture biosolids application sites in the Columbia Basin, near Hermiston, Oregon. Land application of biosolids began in 1990 and has continued to the present. In 2007, approximately 13,500 dry tons of Portland biosolids were applied to 3,700 dryland pasture acres by Madison Farms.

Annual precipitation in the Hermiston area averages 6 to 8 inches per year, with approximately 70% of annual precipitation occurring from October to March. Dryland pasture sites at Madison Farms are dominated by annual grasses, primarily *Bromus tectorum* (cheatgrass). The site is ideally suited to producing early-season forage for beef cattle. The stocking rate of cattle is adjusted to utilize available forage, which varies annually, depending primarily on the amount and distribution of winter precipitation.

Objective

Measure long-term effects of biosolids application on grass forage yield and quality.

Methods

Class B biosolids applied at the site were a mixture of fresh anaerobically digested solids and digested solids that had undergone additional stabilization in a municipal solids storage lagoon. Biosolids were surface applied each year with manure spreaders. At application, the biosolids were a semisolid (cake) with approximately 20% dry matter (80% water). Biosolids were applied annually at a rate of approximately 4 dry tons/acre from 1990 to 2007. After application, biosolids were not incorporated into the soil.

Biosolids applications at Madison Farms began in 1990. Grass forage yield and quality data reported here was collected annually from 1999 to 2007. Two sites were sampled each year—a biosolids-amended site and a no-biosolids control site. At the start of forage monitoring (1999), the cumulative site application rate was 40 dry tons biosolids/acre. By 2007, the cumulative biosolids application rate (1990 to 2007) was 75 dry tons/acre. The no-biosolids control sites did not receive biosolids from 1990 to 2007.

Forage was harvested from three areas (1.4 square feet each) within each site. A composite forage sample from the biosolids-treated site and the no-biosolids control site was submitted to AgriCheck, Inc. (Umatilla, OR) for forage quality analysis.

Results

Because of annual variations in climate, grass yields and nitrogen (N) uptake with biosolids application varied substantially across years (Figures 1.1 and 1.2). With biosolids, the median annual grass yield was approximately

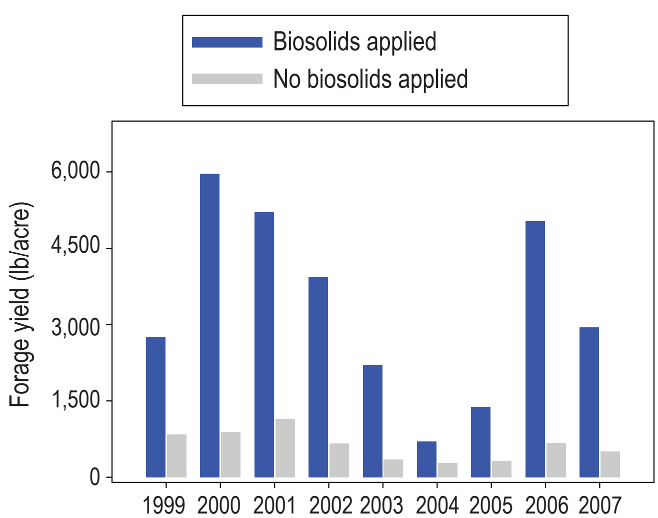

Figure 1.1. Biosolids application increases grass forage yield. Madison Farms, 1999–2007.

3,000 lb/acre, with grass N uptake of 100 lb/acre (625 lb protein/acre). In years with optimal environment (2000 and 2006), grass yields were 5,000 to 6,000 lb/acre, with grass N uptake of 140 lb/acre.

Without biosolids, the grass was not able to take advantage of years with above-average precipitation. Without biosolids, median annual grass yield was approximately 670 lb/acre, with grass N uptake of 7 lb/acre (45 lb protein/acre). Over the 9-year monitoring period (1999 to 2007), biosolids increased grass yield by 530% and protein production by 1,150%.

In addition to producing more grass, forage quality was improved by biosolids application (see Figure 1.3 and Table 1.1, page 4). In large part, the improved quality attributes measured are due to greater leafiness of grass plants with biosolids fertilization. Grass plants receiving higher levels of fertility (with biosolids) responded by producing more shoots with more leaves.

Forage monitoring documented consistent increases in the digestibility of forage with biosolids application (reduced grass fiber and increased protein) and higher concentrations of nutrients. Biosolids are a rich source of nitrogen, phosphorus, sulfur, zinc, copper, and manganese, so increased forage concentrations of these elements were expected. The ratio of N to K in forage was about 1:1, typical for a leafy plant. Biosolids had a small impact on forage magnesium and no effect on forage molybdenum and calcium. Biosolids application increased the forage copper-to-molybdenum ratio, reducing the danger of molybdenosis (a nutritional imbalance sometimes observed in cattle consuming forage with a low copper-to-molybdenum ratio).

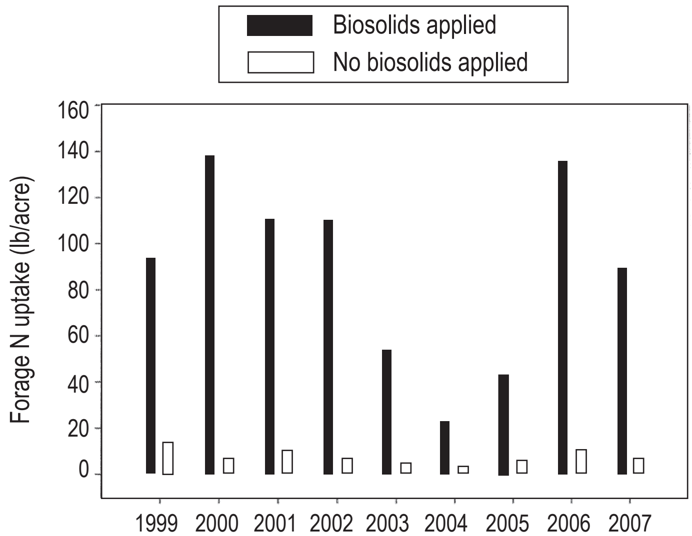

Figure 1.2. Biosolids application increases grass N uptake. Madison Farms, 1999–2007. Forage N uptake x 6.25 = forage protein (lb/acre).

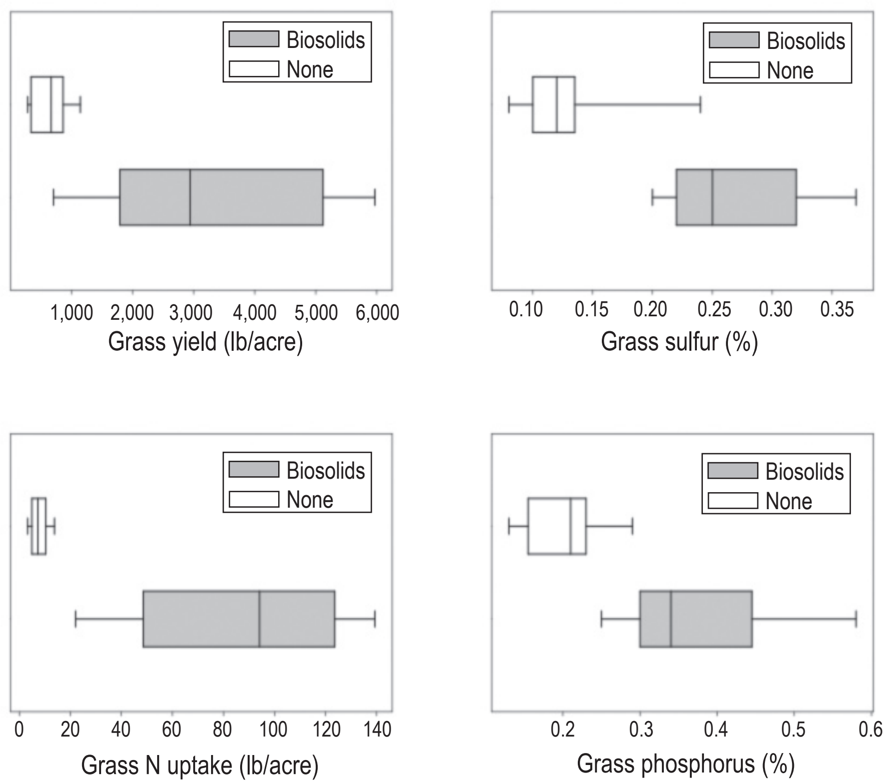

Figure 1.3. Biosolids application increases annual grass yield and nutrient content. Madison Farms, 1999–2007. Box plot shows variation across nine annual grass harvests. The vertical line in the center of each box is the median of nine annual grass harvests. Box edges are 25th and 75th percentile values. Whiskers are 5th and 95th percentile values.

Significance

The monitoring data highlighted here shows dramatic benefits to grass yield and quality from biosolids application, even for dryland pasture with annual precipitation of 6 to 8 inches. The major factors responsible for increased productivity are probably increased nitrogen availability and increased soil water storage.

Increased production of digestible forage has increased beef production. Since biosolids application began at Madison Farms in 1990, cattle stocking rates have increased substantially. Animal unit months (a measure of pasture grazing "capacity") have increased approximately 10-fold since 1990. Cows grazing the higher-protein, more digestible forage grown with biosolids also gain weight faster than cows on unamended pasture.

Because biosolids application promotes annual grass growth, heavy grazing in early spring is needed to make use of the increased forage production. Increased annual grass growth is not desirable on most "native" rangeland sites, so biosolids managers need to choose dryland application sites carefully.

Table 1.1. Biosolids application increases protein, reduces fiber, and increases grass concentration of most nutrients. Madison Farms, 1999–2007.

Forage analysis	**Biosolids**	**None**
	Feed quality (%)	
Crude protein (% N x 6.25)	17	8
Neutral detergent fiber	49	54
Acid detergent fiber	26	35
	Macronutrients (%)	
Sulfur	0.27	0.12
Calcium	0.62	0.57
Phosphorus	0.36	0.21
Magnesium	0.22	0.15
Potassium	2.6	1.2
Sodium	0.014	0.008
	Micronutrients (mg/kg)	
Zinc	40	15
Copper	12	5
Molybdenum	0.91	1.12
Manganese	108	52

Values are the median of nine annual grass harvests.

Chapter 2

Biosolids Increase Soil Fertility in Dryland Pasture

Researchers and Collaborators

Mark Ronayne, Greg Charr, and Jim Utberg, City of Portland
Don Horneck and Dan Sullivan, Oregon State University
Kent Madison, Madison Farms

Background

This chapter summarizes the impact of annual biosolids applications on soil fertility at Madison Farms near Hermiston, Oregon. Chapter 1 gives additional background information on the site and highlights grass yield and quality response to biosolids at this farm.

Biosolids application rates are designed to supply adequate plant-available nitrogen (N) for the crop. However, biosolids supply many other nutrients that increase soil fertility. Agronomic soil tests measure a fraction of the total nutrient content of the soil that is related to plant growth response.

The soil test data reported here is unique in several ways. First, this is one of the few data sets available for biosolids application to dryland pasture in a semiarid environment. Annual precipitation in the Hermiston area averages 6 to 8 inches per year, limiting the opportunity for leaching of soluble nutrients. Second, the data reported here was collected over an 11-year period, allowing an assessment of long-term impact of biosolids applications.

Objective

Measure long-term effects of biosolids application on soil fertility.

Methods

Class B biosolids applied at the site were a mixture of fresh anaerobically digested solids and digested solids that had undergone additional stabilization in a municipal solids storage lagoon. Biosolids were surface applied each year with manure spreaders. At application, the biosolids were a semisolid (cake) with approximately 20% dry matter (80% water). Biosolids were applied annually at a rate of approximately 4 dry tons/acre from 1990 to 2007. After application, biosolids were not incorporated into the soil. Soil samples were collected approximately 6 to 12 months following a biosolids application (minimum of one growing season after application).

Biosolids applications at Madison Farms began in 1990. The monitoring data reported here was collected from 1996 to 2007. Two sampling protocols were used: index site monitoring and whole-farm monitoring.

Index site monitoring

Objective: Determine change in soil fertility due to biosolids application. Compare fertility with annual biosolids application to fertility with no biosolids application.

Sites: 2+ fields sampled each year (same fields as those used for measurement of annual forage yields).

Sampling years and depth: 1996 to 1999: sampled 0- to 6-inch depth. 1999 to 2005: sampled 0- to 3-inch depth.

Sampling intensity: 30 cores per sample, representing 40 acres.

Sampling and testing: 1996 sample by Cascade Analytical. All other years sampled by Don Horneck (certified professional soil scientist). Laboratory analysis by AgriCheck, Inc., Umatilla, OR.

Sample dates: Samples collected in April or May of each year.

Whole-farm monitoring

Objective: Determine whole-farm response to biosolids application.

Sites: 20+ fields each year: 3,500 acres in 2001; sampling acreage increased from 2002 to 2007, to a total of 4,400 acres by 2007.

Sampling years and depth: 2001 to 2007. Sampled 0- to 6-inch depth for all nutrients. Sampled at 0 to 6, 6 to 24, and 24 to 36 inches for nitrate-nitrogen only.

Sampling intensity: 10 cores per sample, representing 160 acres.

Sampling and testing: Sampled by Madison Farms. Laboratory analysis by Kuo Testing Labs, Inc., Umatilla, OR.

Sample dates: Samples collected throughout the year. Samples collected at least one growing season following an annual biosolids application.

Results

Index site monitoring

Because the index site monitoring data was collected from consistent field locations and sampled to a shallow depth, it was a reliable indicator of most soil fertility changes over time. Without tillage, most of the biosolids nutrients remain concentrated near the soil surface after application.

Surface soil pH for the biosolids index site was approximately 1 pH unit lower (more acid) than for the no-biosolids control (Table 2.1). The decreased pH (greater acidity) is not an immediate concern for site productivity, but merits future monitoring. Soil pH values less than 5.5 would be a concern. (Present values are near 6.5.)

An important finding in all monitoring data was that soil salinity (as indicated by EC, electrical conductivity measurement) remained low at all sampling dates, indicating that biosolids application did not pose a long-term risk for salt accumulation, even in a nonirrigated semiarid pasture.

Biosolids application increased soil test nutrient levels from 1 to 20 times above those on the control (no-application) site. The ratio of each nutrient (biosolids site:no-biosolids control site) is shown in increasing numerical order in Table 2.1. A ratio of 1 indicates no change.

Ratios for exchangeable cations (calcium, magnesium, and potassium) and hot-water extractable boron showed no change or a slight increase (ratios of 1.1 to 1.6). Greater ratios were observed for soil organic matter and sulfate-sulfur (ratio = 2). Because soil carbon:nitrogen ratios are relatively constant in soil organic matter, total soil nitrogen also likely doubled with biosolids application. Ratios for phosphorus (sodium bicarbonate extraction) increased (ratio = 5 to 6). Micronutrients extracted by the DTPA method (manganese, copper, and zinc) increased strongly (ratios = 3 to 20). The increase in extractable micronutrients was partially the result of decreased soil pH (greater soil acidity), which increases the solubility of these nutrients in soil.

The change in surface soil test values due to biosolids application was not strongly affected by soil sampling depth (0 to 3 inches vs. 0 to 6 inches) or by the cumulative biosolids application rate at the time of sampling. (See Table 2.1 and Figure 2.1, page 7). From 1996 to 1999, the index site had received 30 to 40 dry tons/acre vs. a cumulative total of 40 to 65 dry tons/acre from 1999 to 2005. This finding (equilibrium of soil test values over time) suggests that the soil/plant system is transforming plant-available nutrients to nonavailable forms at approximately the same rate as "new" plant-available nutrients are being added via biosolids.

Nutrient losses from the site also contribute to equilibrium. Nutrient loss pathways include loss of ammonia to atmosphere immediately after biosolids application and nutrient removal by grazing cattle.

This observation of "nutrient equilibrium" suggests that at cumulative biosolids application rates above 40 dry

Table 2.1. Soil test values (index site monitoring). Madison Farms, 1996–2005. Biosolids application resulted in similar increases in soil nutrient levels at two sampling depths: 0–3 inches and 0–6 inches. Soil test values (0–6 inches) are the average of three annual sample collection events over a 4-year period (1996–1999). Soil test values (0–3 inches) are the average of seven annual collection events (1999–2005). 1996 sample by Cascade Analytical. All other years sampled by Don Horneck. Laboratory analysis by AgriCheck, Inc., Umatilla, OR.

Soil test*	Average (0–6 inches)		Average (0–3 inches)		Ratio (0–6 inches)	Ratio (0–3 inches)
	Biosolids (BS)		Biosolids (BS)			
	none	+	none	+	+ BS/none	+ BS/none
Calcium (meq/100g)	8.7	9.5	7.4	7.9	1.1	1.1
Potassium (mg/kg)	332	442	322	454	1.3	1.4
Magnesium (meq/100g)	1.8	3.1	1.8	2.4	1.8	1.4
Boron (mg/kg)	0.3	0.4	0.2	0.3	1.5	1.3
Organic matter (%)	1.2	2.2	1.5	3.1	1.8	2.0
Sulfate-S (mg/kg)	3.7	8.2	5.5	12.6	2.2	2.3
Iron (mg/kg)	10.1	27.2	12.0	40.0	2.7	3.3
Manganese (mg/kg)	4.0	16.6	4.7	27.9	4.1	5.9
Phosphorus (mg/kg)	14	71	18	116	5.2	6.4
Copper (mg/kg)	0.8	7.4	0.7	8.1	9.7	12.1
Zinc (mg/kg)	0.5	9.6	0.6	11.1	20.5	18.1
Total bases (meq/100g)	11.4	13.8	10.0	11.4	1.2	1.1
pH	7.5	6.7	7.2	6.2	0.9	0.9
EC (mmho/cm)	0.2	0.3	0.1	0.2	2.0	2.0

*Soil testing methods described in: Gavlak, R., D.A. Horneck, R.O. Miller, and J. Kotuby-Amacher. 2003. *Soil, Plant and Water Reference Methods for the Western Region*, 2nd edition. http://cropandsoil.oregonstate.edu/wera103/Soil_Methods.htm tons/acre, biosolids chemistry controls soil test values. Stated another way: after application of more than 40 tons biosolids/acre, the inherent low soil fertility at this site is obscured by the high fertility provided by biosolids.

Whole-farm monitoring

The whole-farm data includes greater variation than index site monitoring, but it is a more robust reflection of biosolids effects across a large acreage. The whole farm average includes all fields sampled within a 12-month period. Overall, approximately 70% of farm fields were sampled every year and included in the whole-farm average. Some fields were not sampled every year or were first used for biosolids application between 2001 and 2007 ("new" fields). Therefore, the whole-farm average should be regarded as a useful indicator of trends, not as a replicated research study.

For soil nitrate-N, the lack of any trend in increasing or decreasing soil test values from 2001 to 2007 is shown in Figure 2.2. Annual means for whole-farm soil nitrate-N (0 to 36 inches) ranged from 70 to 150 lb/acre, with a 7-year mean of 111 lb/acre. Whole-farm soil nitrate-N is approximately equivalent to the amount of N present in above-ground grass biomass in the spring of a typical year (105 lb N/acre; see Chapter 1: "Biosolids Increase Grass Yield and Quality in Dryland Pasture").

The amount of nitrate-N present at the greatest soil depth (24 to 36 inches) did not increase from 2001 to 2007, indicating that root activity above 24 inches was effective in utilizing nitrate-N. At this site, leaching below the 36-inch depth is typically not observed because of low precipitation amounts and the rapid uptake of soil water by grass roots. In addition, many of the soils at this farm have a cemented soil (caliche) layer near the 36-inch depth that prevents deep leaching from the soil profile.

Whole-farm soil test values for other nutrients (0 to 6 inches, Table 2.2 on page 8) showed trends similar to those demonstrated by soil nitrate-N (Figure 2.2). Soil test values did not show a strong pattern of increasing or decreasing values during the 2001–2007 monitoring period, likely because of residual effects from previous biosolids applications from 1990 to 2000. Seven-year whole-farm mean test values (2001 to 2007) showed that soluble salts (EC), pH, and boron remained at acceptable levels for crop production and were not much different from baseline soil test values from "no-biosolids" fields (Table 2.1). Whole-farm soil test values for micronutrients (copper, zinc, manganese) and phosphorus were "high" in relation to crop need.

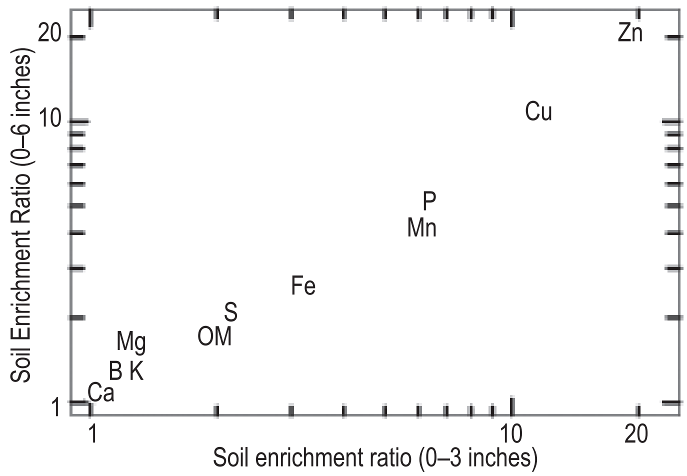

Figure 2.1. Soil Enrichment Ratio (index site monitoring). Madison Farms, 1996–2005. Biosolids increase soil test nutrient values, as indicated by the Soil Enrichment Ratio at two sampling depths: 0–3 inches (x axis) and 0–6 inches (y axis). Soil Enrichment Ratio is the ratio of nutrients measured on an index site (with biosolids application) to a no-biosolids control site. Higher enrichment ratios indicate greater impact of biosolids application on soil test values. Above, the enrichment ratio is plotted on a log scale. Nutrient symbols (left to right): calcium (Ca), boron (B), potassium (K), magnesium (Mg), sulfate-sulfur (S), iron (Fe), manganese (Mn), phosphorus (P), copper (Cu), and zinc (Zn). Samples from the 0- to 3-inch depth were collected annually from 1999 to 2005. Samples from the 0- to 6-inch depth were collected annually from 1996 to 1999. Sampled by Don Horneck. Laboratory analysis by AgriCheck, Inc., Umatilla, OR.

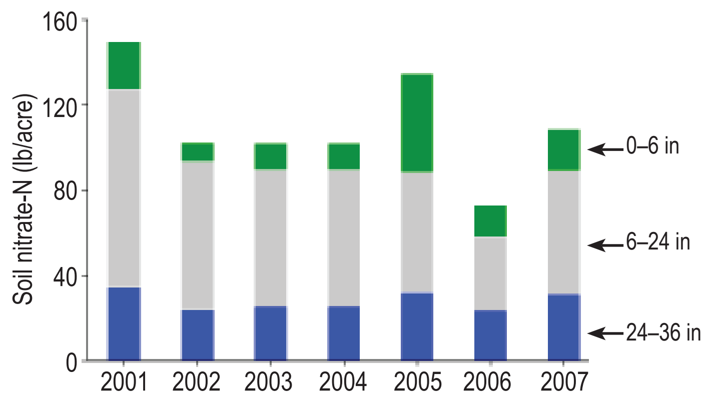

Figure 2.2. Annual soil nitrate-N mean values (whole-farm monitoring). Madison Farms, 2001–2007. Samples represent 20+ fields sampled each year. Soil sampled in depth increments of 0–6 inches, 6–24 inches, and 24–36 inches. Laboratory analysis (mg/kg or ppm) converted to lb/acre, assuming that an acre-ft of soil weighs 4 million lb. Sampled by Madison Farms. Laboratory analysis by Kuo Testing Labs, Inc.

One example is shown (Figure 2.3) to demonstrate the within-farm variability present for samples taken in a single year for one parameter (phosphorus). Soil test P values for 34 fields sampled in 2007 were normally distributed, with a median value of 45 ppm and a mean value of 46 ppm. This distribution reflects site-specific differences in soil sorption capacity for added biosolids P, sampling error, and variation in the quantity of biosolids P applied to different fields.

In 2007, approximately 70% of the fields had soil test P values above the typical "baseline" soil test P measured on no-application acreage (10 to 15 ppm). The high values present for soil test P in many farm fields does not constitute an environmental risk (there is no danger of runoff to surface water). However, the accumulation of P beyond crop need usually represents a waste of a valuable crop nutrient.

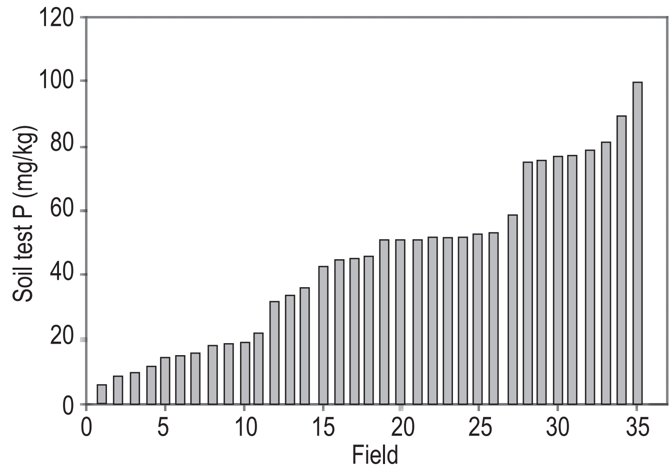

Figure 2.3. Distribution of phosphorus soil test values (whole-farm monitoring). Madison Farms, 2007. Thirty-four fields sampled (0–6 inches). Field size was approximately 160 acres. Sampling by Madison Farms. Laboratory analysis by AgriCheck, Inc., Umatilla, OR.

Significance

Biosolids increased plant-available nutrients in soil as demonstrated by agronomic soil testing. Nutrient soil test values increased from 1.5 to 20 times when compared to nearby sites that had not been fertilized with biosolids or other fertilizers. Soil samples collected repeatedly from "index sites" and soil samples collected from across the whole farm (approximately 4,000 acres) showed similar increases in soil nutrient availability over time.

Table 2.2. Annual soil test values (whole-farm monitoring). Madison Farms, 2001–2007. Sampled to 0- to 6-inch depth over a 7-year period. Each annual whole-farm soil test mean was computed by averaging soil test values from 20+ fields. Total acreage included in each annual mean was approximately 3,500 acres in 2001, increasing over time to 4,400 acres in 2007. (An additional 900 acres was added for biosolids application between 2001 and 2007). Sampled by Madison Farms. Laboratory analysis by Kuo Testing Labs, Inc.

Soil test	Seven-year mean	Lowest annual mean	Highest annual mean
Calcium (meq/100g)	8.4	7.4	9.2
Potassium (mg/kg)	469	415	525
Magnesium (meq/100g)	2.3	2.0	2.6
Boron (mg/kg)	0.6	0.4	1.0
Organic matter (%)	1.5	1.1	1.7
Sulfate-S (mg/kg)	18	11	25
Iron (mg/kg)	21.4	12.0	36.0
Manganese (mg/kg)	15.9	8.0	26.0
Phosphorus (mg/kg)	55	40	72
Copper (mg/kg)	2.7	1.1	4.4
Zinc (mg/kg)	2.6	1.1	4.9
Total bases (meq/100g)	12.0	10.8	12.8
pH	7.0	6.7	7.3
EC (mmho/cm)	0.4	0.2	0.6

Soil test values have remained stable since the monitoring reported here began (1996). Apparently, soil test values increased substantially with the first applications of biosolids at these sites (1990 to 1995), then came into equilibrium with a regime of annual biosolids applications. Apparently, the soil/plant system is removing or converting nutrients to nonavailable forms at approximately the same rate as "new" soluble nutrients are being added by annual biosolids applications. The only major routes for nutrient removal at the site are grazing and ammonia (N) gas to the atmosphere.

The monitoring data from these sites suggests that at cumulative biosolids application rates above 30 to 40 dry tons/acre, biosolids chemistry controls soil test values. The inherent soil fertility at these sites is very low, so it is easily obscured by nutrient-rich biosolids.

Long-term biosolids application resulted in a doubling of surface soil organic matter from approximately 1% to 2% (0- to 6-inch depth). Like nutrients, organic matter content in biosolids-fertilized soil apparently increased rapidly during the first years of biosolids application and has now reached a new "equilibrium value" in balance with a regime of annual biosolids applications. This data suggests that carbon sequestration (fixation of carbon within soil organic matter) is more likely to occur on new biosolids application sites than on long-established application sites.

Accumulation of excessive levels of soil nitrate-N does not seem to be an issue at these dryland pasture sites. Approximately a 1-year supply of plant-available N was present in the soil profile throughout the 2001–2007 monitoring period.