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**Comparison of Selected Soil Properties following Grassland Set-Aside and Annual Crop Rotations
in the Fraser River Delta of British Columbia**

Short Title: Soil Properties following Grassland Set-Aside Management

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Abstract

Selected soil properties were compared after two to six years of grassland set-aside (GLSA) management and an annual cropping system (potato). Generally, GLSA and nearby arable cropping fields had similar soil properties, with some improvements of aeration porosity, aggregate stability, bulk density and mechanical resistance following short-term GLSA management.

Key words: perennial grass systems, total soil C, soil aggregate stability, agriculture

For Review Only

A grassland set-aside (GLSA) is a field that a farmer seeds with a mixture of grasses and legumes and takes out of crop production typically for one to four years; the farmer receives a cost-share payment to recover a portion of the value of the crop that otherwise could have been harvested for the duration of the GLSA (DF&WT, 2000). The main goals of the GLSA Program, run by the Delta Farmland (DF) and Wildlife Trust (WT) in the Fraser River delta of British Columbia (BC), are to provide habitat for wildlife and enhance soil organic matter and structure, but farmers often enroll in the Program to transition their fields to organic production or to include these short-term set-asides within annual crop rotations that include potatoes (Fraser, 2004). Prior to GLSA establishment, farmers are encouraged to undertake land laser levelling¹ and surface and sub-surface drainage, especially on fields that have depressions prone to ponding. There is a great deal of variability among set-aside systems around the world, including duration, objective, type of plants used to provide vegetative cover, and accompanying management practices such as mowing and (occasional) grazing (Karlen et al., 1999; Baer et al., 2000). These variations emphasize the need for local studies when evaluating effectiveness of set-aside systems for soil conservation. Yet a limited number of studies have evaluated the effects of GLSA on soil in the Fraser River delta (Hermawan and Bomke, 1996; Principe, 2001; Armstrong, 2013). Since one of the main goals of the GLSA Stewardship Program is to increase soil organic matter and improve soil structure, the objective of this preliminary study was to compare selected soil properties following two to six years of GLSA management to adjacent fields with annual rotations that include potatoes.

¹ Laser levelling is used to improve drainage by using laser emitters, global positioning systems (GPS) and earthmovers to precisely contour the topography of agricultural fields, grading them to facilitate surface water runoff (DF&WT, 2000). Levelling also removes low spots where water tends to pool, reducing the occurrence of standing water (or ponding).

MATERIALS AND METHODS

This study was carried out in the Municipality of Delta, BC (49°05'N, 123°03'W; elevation 2 m above sea level) located in the western part of the Fraser River delta. The region has a humid maritime climate with a mean annual temperature of 9.6°C and mean annual precipitation of 1008 mm. About 75% of precipitation falls between October and April. Study sites were representative of the typical agricultural soils of this region developed from surficial fluvial deltaic deposits. Sites 1, 3 and 4 were on a complex of silt loam Crescent–Westham soil series with moderately poor to poor drainage, while site 2 was on a poorly drained silt loam to silty clay loam complex of Delta-Spetifore–Ladner series.

The four study sites were on operational farms located within 10 km of each other. Each study site included two adjacent fields with an established GLSA and a potato crop grown in 2011 (referred to henceforth as “Cropped”). Both the GLSA and Cropped fields on site 2 were under certified organic management, while the other three sites were under conventional management. All Cropped fields were harvested in fall 2011 and left bare until sampling in spring 2012. The Cropped fields did not have GLSA on them for at least six years prior to establishment of this study. The exact cropping histories of the Cropped fields prior to 2011 are unknown, but likely included potatoes, beans, peas, barley, and/or cole crops. Annual tillage practices on all Cropped fields were representative of those used on potato fields in this region and included: moldboard plowing, disking once or twice, rotovating once or twice, culti-packing² multiple times, and rotovating again prior to seeding. The four GLSAs included in this study were established using the DF&WT seed mix of 98% (by seed weight) of grass mixture and 2%

² Culti-packing is a form of cultivation that breaks down soil clods, contributes to leveling the seedbed, and helps seal the soil surface to contain moisture.

red clover (*Trifolium pratense*). The GLSAs were established in the fall of: 2006 (six years old at sampling – site 1), 2008 (four years old – site 2), 2009 (three years old – site 3), and 2010 (two years old – site 4), and were representative of the typical management practices carried out within the GLSA Program (Fig. 1).

Soil sampling was just before the termination of GLSA in spring of 2012. At each study site, four 10-m long transects were randomly established within each of the GLSA and Cropped fields. Soil samples were collected from the 0-7.5 cm depth, at two points along each transect.

Aeration porosity and bulk density samples were determined on the same undisturbed core samples (7.5 cm diameter by 7.5 cm depth). Aeration porosity (soil pores having diameter > 50 μm) was determined using a water tension table technique (Danielson and Sutherland, 1986). The soil cores were dried at 105°C for 24 h and weighed to find the oven-dry mass of soil. A correction was made for coarse fragments by sieving the samples to remove particles >2 mm in diameter.

Soil mechanical resistance (Bradford, 1986) was recorded at 1.5 cm intervals down to a depth of 7.5 cm using a hand-pushed 13-mm-diameter 30° cone penetrometer with an attached data logger (Aggridry Rimik PTY Ltd., Toowoomba, QLD, Australia). Measurements were made at six random locations along each transect. Gravimetric soil water content was also determined alongside mechanical resistance to correct the mechanical resistance readings for variability in water content using a method outlined by Busscher (1990).

Aggregate stability was assessed on two composited samples (comprised of five individual samples) per transect using a variation of the wet sieving method of Nimmo and Perkins (2002), and reported as the mean weight diameter (MWD), which is summation of a series of $D_i \times W_i$ products where D_i is the mean diameter of each size fraction (2-6, 1-2, 0.25-1,

and <0.25 mm) and W_i is the proportion of the sample weight occurring in the corresponding size fraction.

Two samples/transect were also collected for total C and N determination by dry combustion method (Nelson and Sommers, 1982) using an automated elemental analyzer (LECO CNS-2000, Leco Corp., St. Joseph, MI). Given the differences among the four study sites in GLSA durations and management practices (Fig. 1), the comparisons of soil properties between GLSA and Cropped areas ('treatments') were done using unpaired T-tests on a site-to-site basis. The UNIVARIATE procedure (SAS Institute Inc., 2007) was used to check the residuals for normality and for potential outliers (none being found) before performing the T-tests. Results were considered significant at $P < 0.10$.

Principal component analysis (PCA) of the soil properties (total soil C and N, soil bulk density, MWD, and aeration porosity) was used to examine the multivariate relationships between the GLSA and Cropped treatments based on overall correlations among the measured variables. Soil mechanical resistance was not included in the PCA because it was not measured at site 2 since that site was too wet. The PCA was run using PCORD (McCune and Mefford, 2006) based on a matrix of averages of the 5 soil variables in 32 transects (4 sites x 2 treatments x 4 transects per treatment).

RESULTS AND DISCUSSION

Study site 1 had serious degradation issues including high salinity and weed infestation prior to the GLSA establishment in 2006 (Hugh Reynolds personal communication, 2012); hence, it was kept in GLSA longer than two years (the typical duration of a GLSA in this region). This site also had a limited number of management practices that accompanied GLSA establishment (only subsoiling and laser levelling). Greater presence of macropores (as indicated

by the greater aeration porosity), lower mechanical resistance and greater MWD were observed on GLSA, indicating improvements of soil properties (Table 1). Additionally, the GLSA treatment on site 1 also had the longest period (6 years) without tillage relative to its paired Cropped treatment, which received numerous tillage practices as is typical for potato fields in this region. The GLSA on site 1 was the only treatment in this study with aeration porosity above $0.10 \text{ m}^3 \text{ m}^{-3}$, a commonly cited critical value for root growth (Dohnal et al., 2009) also indicative of favorable soil water retention and aeration/drainage. The latter is of particular importance for medium to fine textured soils in the lower Fraser River delta.

Site 2 was the only study site under the organic management. In the Fraser River delta, farmers often include these short-term GLSAs during the required 3-year transition period to organic production systems (Fraser, 2004). To help site 2 transition to organic production, in addition to GLSA seeding, the site was also laser levelled, subsurface drainage tiles were installed and poultry manure compost was applied annually for at least eight years before GLSA establishment (Fig. 1). Even though this site did not show as many improvements in soil properties due to GLSA as site 1, bulk density and total soil N were significantly lower on GLSA than Cropped (Table 1). It is also noteworthy that due to annual composted poultry manure additions, total soil C and N contents on site 2 were almost two times higher than on all other sites. Additional contributing factors to the much higher soil C and N observed on site 2 could have been its naturally high total C (10-15%) and N (0.5-1%), its finer texture with about 30% clay, and resulting poorer natural drainage relative to the other study sites.

Study sites 3 and 4 had GLSAs for three and two years, respectively, and a similar set of management practices accompanying the GLSAs; hence, it is not surprising that their soil properties responded in a similar way (Table 1). The only soil property that was significantly

lower on GLSA relative to Cropped was mechanical resistance, while all other soil properties were similar on the two treatments. It is also notable that mechanical resistance values on the Cropped treatment of sites 3 and 4 were considerably lower than on Cropped treatment of site 1, which had degradation issues and fewer management interventions. While significant improvements to aggregate stability under GLSA management were not observed on sites where GLSAs were in place for two and three years (i.e., sites 3 and 4), another study carried out in the Fraser River delta found aggregate stability improvements after two years (Hermawan and Bomke, 1996).

The PCA graph displayed the main trends in soil variation among study sites for the GLSA and Cropped treatments and accounted for 71% of the variability in the data (Fig.2). Site 2, with GLSA established in 2008, organic management system and also with inherent soil differences, stands apart from the other three sites due to the higher total soil C and N (Table 1). Treatment differences at site 2 also were apparent and were related to the higher bulk density and N levels for the Cropped treatment. Site 1 (oldest, subsoiled, conventionally managed site) had the most pronounced differences in soil properties between the GLSA and Cropped treatments (polygons farthest apart); the difference was clearly due to the higher aeration porosity and MWD for the GLSA treatment. The two other conventionally managed sites (i.e., site 3 and 4) were similar to each other (polygons mostly overlapping), with no obvious differences between GLSA and Cropped treatments. In addition, Cropped-site 1 was similar to both sites 3 and 4, which provides further evidence that the observed change in site 1 was due to the GLSA system and less likely due to inherent differences in soil.

In the Fraser River delta, set-asides are often established on fields that exhibit some level of soil degradation (Fraser, 2004) and GLSAs are used to improve the soil through perennial

plant growth and a reprieve from cultivation disturbance. The effects of GLSA on soil can be obscured by varying site characteristics, management histories, and even combination of management practices that accompany GLSA establishment, which makes evaluation of GLSA effects challenging. A study carried out by Karlen et al. (1999) on six sites, in the Conservation Reserve Program (CRP), with 2.5 to 6.5 years old set-asides and neighboring cropped fields located on differing soil types and climatic conditions in Iowa, North Dakota, Minnesota, and Washington found varying responses in soil quality indicators. Only one of those sites had greater soil organic C and total N on the set-aside compared to the adjacent cropped field, while two sites had greater MWD on set-asides relative to cropped field. Overall, set-aside CRP management appeared to have some effect on soil quality indicators (mainly on the soil biological indicators), but the variability among site locations in that study made it difficult to reach a general conclusion about the effects of set-aside CRP management on soil, emphasizing the need for site-specific studies.

CONCLUSIONS

Findings of this preliminary study showed that GLSA management system can benefit the soil in the Fraser River delta, mainly through reduction of mechanical resistance and bulk density. Since establishment of set-asides within the GLSA Program is always accompanied with a variety of other management practices, evaluation of GLSA effects on soil needs to take into account all the management practices on a particular site. To be able to track soil changes due to GLSA over time and inform farmers of additional practices that might be needed, it is also necessary to characterize the baseline soil conditions before GLSA establishment.

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Figure Captions

Fig. 1. Management practices on grassland set-aside (GLSA) fields of the four study sites located in the Fraser River delta, British Columbia

Fig. 2. Principal component analysis (PCA) of soil data (from 0-7.5 cm depth) at four study sites with grassland set-aside (GLSA, closed polygons) and Cropped (open polygons) treatments in the Fraser River delta of British Columbia. Small symbols at corners of polygons denote the four transects for each treatment. GLSAs were established in 2006 (site 1), 2008 (site 2), 2009 (site 3), and 2010 (site 4). Same colors denote corresponding GLSA and Cropped treatments at same study site; arrows denote relative strengths (length of arrows) and directions of Pearson correlations of the five soil variables with Axes 1 and 2.

Table 1. Soil chemical and physical properties (at 0-7.5 cm depth) on four study sites with grassland set-aside (GLSA-age) and Cropped treatments

Site 1		Site 2		Site 3		Site 4	
GLSA-6 yr	Cropped	GLSA-4 yr	Cropped	GLSA-3 yr	Cropped	GLSA-2 yr	Cropped
0.11 (0.01)**	0.08 (0.01)**	0.09 (0.01)	0.09 (0.01)	0.08 (0.01)	0.06 (0.01)	0.08 (0.01)	0.10 (0.01) ^a
<i>Aeration porosity (m³ m⁻³)</i>							
1.20 (0.04)	1.26 (0.04)	1.13 (0.04)**	1.34 (0.04)**	1.34 (0.04)	1.37 (0.04)	1.30 (0.04)	1.32 (0.04)
<i>Bulk density (Mg m⁻³)</i>							
221 (61.0)**	1319 (61.0)**	n/a ^b	n/a	203 (61.0)**	648 (61.0)**	89 (61.0)**	689 (61.0)**
<i>Mechanical resistance (kPa)</i>							
1.6 (0.11)**	0.8 (0.11)**	1.2 (0.11)	1.0 (0.11)	1.0 (0.11)	0.9 (0.11)	1.1 (0.11)	0.9 (0.11)
<i>Mean weight diameter - MWD (mm)</i>							
1.52 (0.13)	1.79 (0.13)	2.72 (0.13)	2.70 (0.13)	1.60 (0.13)	1.33 (0.13)	1.36 (0.13)	1.38 (0.13)
<i>Total soil C (kg m⁻²)</i>							
<i>Total soil N (kg m⁻²)</i>							
0.13 (0.01)+	0.17 (0.01)+	0.22 (0.01)**	0.27 (0.01)**	0.15 (0.01)	0.13 (0.01)	0.13 (0.01)	0.13 (0.01)

Note: +, *, and ** significant at $P<0.10$, $P<0.05$ and $P<0.01$, respectively between GLSA and Cropped.

^aValues in parentheses are the standard errors of the mean (n= 4).

^bn/a = measurements were not obtained since the site was too wet.

Fig. 2. Principal component analysis (PCA) of soil data (from 0-7.5 cm depth) at four study sites with grassland set-aside (GLSA, closed polygons) and Cropped (open polygons) treatments in the Fraser River delta of British Columbia. Small symbols at corners of polygons denote the four transects for each treatment. GLSAs were established in 2006 (site 1), 2008 (site 2), 2009 (site 3), and 2010 (site 4). Same colors denote corresponding GLSA and Cropped treatments at same study site; arrows denote relative strengths (length of arrows) and directions of Pearson correlations of the five soil variables with Axes 1 and 2.

254x338mm (72 x 72 DPI)