**Short-term Effects of Grassland Set-Asides on Soil Properties in the Fraser River Delta of British Columbia**

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Short-term Effects of Grassland Set-Asides on Soil Properties in the Fraser River Delta of British Columbia

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ABSTRACT

Grassland set-asides (GLSA) in the Fraser River delta are fields that are taken out of crop production and seeded with a mixture of grasses and legumes for one to four years. During this time, the farmer is compensated with a cost-share payment to recover a portion of the financial returns that could have been earned from cash crops. The objectives of this study were to (i) evaluate the effects of GLSA on soil properties during the initial two seasons of enrollment, (ii) determine how GLSA effects differ between fields that were considered productive and unproductive, and (iii) identify soil baseline indicators and preliminary soil thresholds for predicting GLSA vegetation responses. Out of eight fields entering the program, two were considered to be unproductive and exchangeable sodium had the strongest negative relationship to GLSA aboveground biomass ($r = -0.61$, $P=0.0002$). During the second season of GLSA establishment, the mean weight diameter of water-stable soil aggregates was consistently higher in productive GLSAs than paired annual crop rotation (ACR) fields, being 21% higher in April, 14% in July, and 19% in September after crop harvest. After two seasons of GLSA enrolment, both aeration porosity and bulk density were improved by GLSA relative to ACR fields with aeration porosity being 24% greater and bulk density 7% lower in GLSA. The results suggest that GLSA rotations in productive agricultural fields within the Fraser River delta provide an alternative to continued ACR that can improve soil structure and reduce compaction after only two seasons of establishment.

**Key words:** perennial grass systems, exchangeable sodium, soil aggregate stability, agriculture
INTRODUCTION

Set-aside programs (or schemes) were introduced in Europe and the United States (US) in the 1980s, in an attempt to reduce agricultural surpluses and help conserve biodiversity and associated ecosystem services (Clarke 1992; Baer et al. 2000). The original definition of a set-aside is arable land taken out of production (Clarke 1992). This definition, however, has been broadened, since set-asides vary in terms of their objectives, duration, and inclusion of associated management practices (e.g., fertilizer application, mowing, seeding of grasses and/or grass-legume mixtures, tillage). Consequently, as Kleijn and Baldi (2005) have pointed out, set-aside programs should be evaluated within the geographical, agronomic, and socioeconomic context of the country or region where they are implemented.

In British Columbia (BC), a local non-government organization, the Delta Farmland and Wildlife Trust (DF&WT), offers farmers several programs to help them undertake soil conservation practices. One of those programs is the Grassland Set-Aside Stewardship Program, which provides cost-share payments to farmers for taking active agricultural land out of production and seeding it with a grassland set-aside (GLSA) mix for a period of one to four years (Delta Farmland and Wildlife Trust 2000). The main goals of the GLSA program, are to provide habitat for wildlife and enhance soil organic matter and structure, but farmers also enroll their fields to transition them to organic production or to include these short-term GLSAs into annual crop rotations (ACR) (Fraser 2004). This model of GLSA program requires a shorter commitment from farmers than more typical, long-term (>10 years) GLSA programs offered in other parts of the world (Clarke 1992; Karlen et al. 1999; Bowman and Anderson 2002), and provides greater flexibility for farmers to integrate GLSA within their ACRs. This flexibility is
particularly important in the Fraser River Delta (FRD) where most farmers are faced with insecure land tenure and/or continuous land value increases (Fraser 2004).

The majority of GLSA studies have focused on the effects of this practice on farmland biodiversity and wildlife habitat (Kleijn and Baldi 2005; Tscharntke et al. 2011), while evaluations of GLSA effects on soils have received less attention. An example of a program focused on the long-term improvements of soils is the Conservation Reserve Program (CRP) in the US through which farmers remove environmentally sensitive land from agricultural production for 10-15 years and seed it with perennial vegetation to improve environmental health (Karlen et al. 1999). It has generally been reported that long-term set-asides tend to improve soil structure, eliminate compaction, and increase soil organic matter (Karlen et al. 1999; Baer et al. 2000; Guo and Gifford 2002).

Only a limited number of studies have been conducted on the DF&WT’s short-term GLSAs and they have reported variable findings when evaluating the effects on soil properties (Hermawan and Bomke 1996; Principe 2001; Yates et al. 2017). For example, a study by Hermawan and Bomke (1996) reported a greater mean weight diameter (MWD) of water stable aggregates after only two years of GLSA in a field that was accompanied by a subsurface drainage installation relative to a paired field under continuous cultivation. A more recent FRD study by Yates et al. (2017), which compared 2-, 3-, 4- and 6-year GLSAs and paired fields managed for potatoes in the previous season, reported varying responses of aggregate stability, bulk density and aeration porosity and no differences in total soil carbon. Although an assessment of baseline soil properties was not done in the study by Yates et al. (2017), the inclusion of fields with a range of soil properties was speculated to have affected soil responses to GLSA.
Typically, farmers in the FRD enroll in the Grassland Set-aside Stewardship Program fields that they consider to be unproductive (or degraded) and also those that are deemed productive. Consequently, evaluations of soil responses to GLSA and decisions on how long a field should be enrolled in the program could be enhanced by including a characterization of baseline soil properties prior to GLSA seeding. Unproductive sites likely require a longer enrollment period for soil improvement to occur (Baer et al. 2000), while productive fields entering the GLSA program in the FRD may undergo soil improvements in a shorter period of time. Understanding how quickly these benefits accrue could minimize the number of years that land is out of production and thus improve the financial impacts of using this practice to maintain soil productivity. The objectives of this study were to (i) evaluate the effects of GLSA on soil properties during the initial two seasons of enrollment, (ii) determine how GLSA effects differ between fields that were considered productive and unproductive, and (iii) identify soil baseline indicators and preliminary soil thresholds for predicting GLSA vegetation responses.

MATERIALS AND METHODS

Study Sites

This study was carried out from April 2015 to September 2016 on eight sites located on operational farms within the Municipality of Delta and Richmond, BC (49°05’N, 123°03’W; elevation 2 m above sea level). This region is characterized by a humid, temperate climate with a mean annual temperature of 11.1°C and a mean annual precipitation of 1189 mm, as reported by Environment Canada (2017) from 1981 to 2010, with 80% of rainfall occurring between October and April. All soils included in this study were developed from surficial fluvial deltaic deposits and were classified as Humic Luvic Gleysol, Orthic Gleysol, and Rego Humic Gleysol with silty loam to silty clay loam texture (Luttmerding 1981).
All eight study sites included both a GLSA field and an adjacent field managed under ACR for either potatoes (*Solanum tuberosum* L.), beans (*Phaseolus vulgaris* L.), peas (*Pisum sativum* L.), barley (*Hordeum vulgare* L.), wheat (*Triticum aestivum* L.), or corn (*Zea mays* L.). The ACR fields were selected based on similar management history and soil type as their paired GLSA counterpart (Fig. 1). The fields included in this study ranged between 2 and 11 ha in size.

The GLSA fields were all part of the Grassland Set-aside Stewardship Program offered by the DF&WT. Fields were taken out of production in September of 2014 and seeded in 2015 between April 15th and May 10th with a standard seed mix composed of 25% (by seed weight) orchard grass (*Dactylis glomerata* L.), 28% tall fescue (*Festuca arundinacea* Schreb.), 30% short fescue (*Festuca rubra* subsp. *commutata* Gaudin and *F. rubra* subsp. *rubra* L.), 15% timothy grass (*Phleum pratense* L.), and 2% red clover (*Trifolium pratense* L.).

The study was conducted on operational farms, therefore management practices varied by field (Fig. 1). For example, the ACR fields at Sites 5 and 7 were under organic management and received an annual composted poultry manure rate of 12.4 t ha$^{-1}$ (wet basis) which is typical for the region. The same manure rate was also applied on the ACR field at Site 2 and synthetic fertilizers were applied on all conventional fields. Fertilization of ACR conventional fields was heavily dominated by the management of potatoes in the rotation. General recommendations for potatoes in the regions are 90 to 100 kg ha$^{-1}$ of N, 90 kg ha$^{-1}$ of P$_2$O$_5$, and 170 kg ha$^{-1}$ of K$_2$O$^1$. Other crops in the rotation, peas, barley, bean or corn receive much reduced rates of each nutrient if any. A variety of tillage practices were implemented at each site and included practices such as disking, rotovating, plowing, and pulvi-mulching.

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$^1$ Personal Communication with Dave McKimm, Terrelink, Delta, BC.
Sampling and Laboratory Analysis

The soil and vegetation samples were collected from April 2015 to September 2016 (i.e., during the initial two seasons of GLSA establishment), from four randomly selected sub-plots per field. These sub-plots (with a 3 m radius) were located at least 10 m away from each other and 10 m away from field edges.

In April 2015 (prior to GLSA seeding), samples for baseline soil properties were collected from sub-plots in GLSA fields and analyzed for exchangeable sodium, bulk density, total soil carbon, and MWD of water stable aggregates. Following this baseline assessment, samples for MWD, bulk density, aeration porosity, total soil carbon, and GLSA biomass were collected in GLSA and paired ACR fields at multiple times during the growing season over the study period.

In April 2015, soil samples were collected from the 0-30 cm depth (reflective of a rooting depth of GLSA vegetation) using an Oakfield soil sampling probe to measure exchangeable sodium. Exchangeable sodium was extracted using 1:10 (vol/vol) soil to 0.1 M barium chloride (Hendershot et al. 2008) and analyzed with an Inductively Coupled Plasma Optical Emission Spectrometer (Teledyne Leeman Labs' ProdigyPlus, Hudson, NH).

Total soil carbon was determined on samples collected from the 0-15 cm depth (using Oakfield probe) in April 2015 and September 2016. Samples were air-dried, sieved to <2 mm, and ground to a fine powder before being analyzed using the diffuse Fourier transform mid-infrared spectroscopy method (Reeves et al. 2001; see Thiel et al. [2016] for details) run on a Tensor 37 HTS-XT spectrometer (Bruker Optics, Ettlingen, Germany).

Aggregate stability samples were collected using trowel at the 0-7.5 cm depth on April, July and September in both 2015 and 2016. Analysis was done using a variation of the wet
sieving method by Nimmo and Perkins (2002; see Wallace et al. [2009] for details). The results for aggregate stability were expressed as the MWD, which is the summation of a series of $D_i \times W_i$ products where $D_i$ is the mean diameter of each size fraction and $W_i$ is the proportion of the sample weight occurring in the corresponding size fraction.

Soil samples for aeration porosity and bulk density were collected from the 0-7.5 cm depth using a double-cylinder drop-hammer sampler and 7.5 cm diameter by 7.5 cm-deep cores. Aeration porosity (i.e., soil pores having diameter $> 50 \mu m$ or macropores) was determined in September of 2015 and 2016 using a water tension table (Danielson and Sutherland 1986). After completion of the aeration porosity analysis, the cores were then dried for 24 h at 105°C and soil bulk density was determined as mass of dry soil per unit volume of soil at field moisture (Blake and Hartge 1986). Coarse fragments (diameter $>2$ mm) within the sample were screened out and weighed. Volume of mineral coarse fragments was determined from dry mass, assuming a particle density of 2.65 Mg m$^{-3}$. Soil bulk density was determined in April and September of 2015 and also in September of 2016.

Samples for aboveground biomass of GLSA vegetation were collected from two locations at each sub-plot on GLSA fields using a 50 cm by 50 cm quadrant. All biomass was cut about 2 cm from the ground and collected in paper bags; oven dried at 60°C for one week, and weighed. Aboveground biomass samples were collected at the end of the first season of GLSA establishment in September 2015 and then again at the end of the second season in September 2016. Biomass from samples taken in September 2016 was sorted into the following three broad groups: clover, grasses, and weeds (i.e., all plant species that were not included in the GLSA mix).
Statistical Analysis

All statistical analyses were performed using R software version 3.4.0 (R Core Team, 2017). The comparison of MWD, bulk density, and aeration porosity between GLSA and ACR fields over the study period was done across all sites (n=8) and also on a subset of sites that were considered to have productive GLSAs (n=6). The treatments at the replicated study sites were compared using the \textit{lme} function in the \textit{nlme} package (Pinheiro et al. 2017) and a restricted maximum likelihood (REML) method was used. The treatment with sampling time and its interaction was added as a fixed effect, while sub-plots (nested within treatments and sites) and sites (or blocks) were included as random effects. The mixed model was $y = X\beta + ZY + \epsilon$; where $y$ represents the response variable vector, $\beta$ is an unknown vector of fixed-effects parameters with known design matrix $X$, $Y$ is an unknown vector of random-effects parameters with known design matrix $Z$ and $\epsilon$ is an unknown random error vector. Data were compared separately for each depth of sampling. The Shapiro Wilks test was done on both marginal and conditional means and heteroscedasticity was assessed using residual plots. The \textit{emmeans} function was then used to identify significant differences between treatments at the various sampling times and differences were determined to be significant for $P$-values < 0.05 and < 0.10.

A principal component analysis (PCA) of baseline soil properties collected in April 2015 prior to fields entering the GLSA program (i.e., bulk density, aeration porosity, MWD of water stable aggregates, total soil carbon, and exchangeable sodium) was done on sub-plots using the \textit{prcomp} function in the \textit{stats} package. The PCA was plotted using the \textit{ggbiplot} function and the data was grouped by samples collected from fields considered to be productive or unproductive.

GLSA aboveground vegetation biomass collected at each sub-plot was averaged by site and the standard error of the mean was calculated (n=4). A one-way ANOVA was done using the
lm function and a post-hoc test was conducted using the `HSD.test` function in the `Agricolae` package to determine significant differences between fields (alpha = 0.05).

To determine the relationship between baseline soil properties (obtained in April 2015 before GLSA seeding) and GLSA aboveground biomass, a Pearson correlation analysis was done using the `cor` function. A non-parametric class of regression trees, which embeds tree-structure regression models into a well-defined theory of conditional inference procedures (Hothorn et al. 2006), was used to determine critical thresholds of exchangeable sodium. The function is named `CTree` and is found in the `partykit` package (Hothorn et al. 2017). Significance was set at an alpha of 0.05; The minibucket and minisplit parameters are used to determine the minimum number of observation in a node and terminal node and these were set at 2 and 1, respectively.

**RESULTS AND DISCUSSION**

**Effects of GLSA on Soil Properties during the Initial Two Seasons of Enrollment**

During the first and second season of GLSA establishment on eight sites in the FRD, GLSA and adjacent ACR fields had similar MWD, bulk density, and aeration porosity (Table 1), indicating no soil improvements due to GLSA. The only exception was aeration porosity in September 2016 at 0-7.5 cm depth that was significantly greater in GLSA than ACR.

Since farmers in the FRD enroll their fields in the GLSA program for different reasons (i.e., to improve degraded soils, transition to organic production, and as part of crop rotations), fields entering GLSA are often characterized by a range of differing soil properties. Common constraints to soil productivity in the FRD include high salinity, compaction, poor structure, and low soil organic matter (Paul and de Vries 1979; Coote et al. 1981; Hermawan and Bomke 1996;
Krzic et al. 2000; Principe 2001; Liu et al. 2005; Yates et al. 2017). Using these properties to better understand how GLSA impacts are likely to vary by site conditions, we found that indeed baseline soil properties varied substantially across the eight fields sampled in the spring of 2015 (data not shown). Exchangeable sodium ranged from 0.07 to 2.59 cmol$_c$ kg$^{-1}$, total soil carbon from 1.63 to 3.07%, MWD from 0.4 to 1.7 mm, and bulk density from 1.12 to 1.32 Mg m$^{-3}$ prior to GLSA establishment.

A PCA was conducted using the baseline soil properties on the eight GLSA fields to distinguish the fields deemed productive or unproductive by farmers enrolled in the program. The PCA graph (Fig. 2) displayed the main trends in soil variation among eight GLSA fields and accounted for 71.2% of the variability in the data. There was a clear separation between the fields that farmers considered productive (GLSA 1, 2, 5, 6, 7 and 8) and unproductive (GLSA 3 and 4) along the first PCA axis (i.e., horizontal spacing among transects) of soil properties. The fields grouped as productive included those that were enrolled as part of a 3-year transition period for organic certification and as part of crop rotations. The unproductive GLSA fields 3 and 4 were characterized by soil properties commonly associated with low crop productivity in the FRD (Paul and de Vries 1979; Coote et al. 1981; Hermawan 1995; Krzic et al. 2000; Principe 2001; Lui et al. 2005; Yates et al. 2017), and perhaps the most distinct feature of these fields was a high exchangeable sodium. These fields also had a MWD well below the 1.0 mm average observed in all other fields entering the GLSA program in this study. High levels of sodium may disperse clay particles (Agassi et al. 1981), and likely contributed to the low MWD at these sites. Furthermore, the GLSA fields 3 and 4 had a total soil carbon well below the 3% threshold suggested by Hermawan (1995) to be necessary for stabilizing aggregates in the FRD.
While soil improvements were minimal when GLSA effects were compared across all the sites, when soil properties on GLSA and adjacent ACR fields were compared for only the six sites classified by our preliminary PCA as productive, improvements due to GLSA started to emerge during the second season of GLSA enrollment (Table 2). At the beginning of the second season (i.e., in April 2016), MWD on GLSA was 21% higher than on paired ACR fields and it remained 14% higher in July and 19% in September 2016 (Table 2). These improvements of aggregate stability after two GLSA seasons were in agreement with a study by Riley et al. (2008), which evaluated 4-year crop rotations with varying GLSA establishment periods over 14-years on a silty loam soil in a region with 600 mm mean annual precipitation in Norway. They found the rotation of 2-year GLSA with two seasons of cash crops to be sufficient to maintain good soil aggregation and pore size distribution. We also found 7% lower soil bulk density in GLSA fields and 24% higher aeration porosity than in ACR fields after two seasons of GLSA establishment (Table 2). The observed differences in bulk density and aeration porosity on GLSA relative to ACR after just two seasons were somewhat unexpected as several GLSA studies have found significant soil changes to take longer to occur (Staben et al. 1997; Karlen et al. 1999; Baer et al. 2000). In contrast to our findings, a FRD study by Yates et al. (2017) that compared 2-, 3-, 4-, and 6-year GLSA fields and paired ACR fields recently managed for potatoes, did not find any difference in aggregate stability, aeration porosity, and bulk density in a 2- and 3-year GLSA relative to ACR. In their study, greater aggregate stability and aeration porosity were only noted in a 6-year GLSA relative to ACR, while differences in bulk density were only found in a 4-year GLSA.

An additional assessment for total soil carbon was done after two seasons of GLSA enrollment at the 0-15 cm depth (data not shown), but there were no significant differences in
total soil carbon between productive GLSA and paired ACR fields, a finding consistent with Yates et al. (2017) as well as CRP studies by Staben et al. (1997) and Baer et al. (2000). As Carter (2002) pointed out, total soil carbon may not be sensitive enough to detect short-term changes caused by management practices; hence, future GLSA studies in FRD and elsewhere should evaluate changes in active carbon pools (Culman et al. 2012).

While no difference in total soil carbon were observed, the changes in aggregate stability, bulk density, and aeration porosity in GLSA indicate that productive fields placed in the GLSA Stewardship Program for two seasons had more stable soil structure and less compaction than fields under ACR management. The findings support the use of GLSA on productive fields in the FRD for a duration of two seasons as a crop rotation practice or as transition to organic production systems.

**Preliminary Soil Thresholds for Predicting GLSA Vegetation Responses**

Following the first season of GLSA establishment (i.e., September 2015), the average dry aboveground biomass across all eight sites was 3.1 t ha\(^{-1}\) (data not shown). A substantial increase in biomass was observed in the second season of GLSA establishment with an average dry aboveground biomass of 8.2 t ha\(^{-1}\). Total dry aboveground biomass on the eight fields at the end of the second GLSA season (Fig. 3a) ranged from 14.1 t ha\(^{-1}\) on GLSA field 7 to 1.6 t ha\(^{-1}\) on GLSA field 4. The unproductive fields (i.e., GLSA fields 3 and 4) not only had significantly lower aboveground biomass than most other fields, but were also characterized by a higher proportion of weeds (Fig. 3b).

The establishment and growth of GLSA vegetation is essential for meeting the DF&WT program goals of wildlife habitat provision and soil organic matter and structure enhancement.
Therefore, a preliminary evaluation of potential soil thresholds for predicting GLSA vegetation responses was conducted. Of all baseline soil properties, only the exchangeable sodium was significantly correlated ($r = -0.61$, $P=0.0002$) to total aboveground GLSA biomass (data not shown). Hence, the regression tree analysis identified exchangeable sodium values of 0.64 and 2.08 cmol$_c$ kg$^{-1}$ to represent thresholds associated with a significant reduction of aboveground biomass in the second GLSA season (Fig. 4). Plots with an exchangeable sodium below 0.64 cmol$_c$ kg$^{-1}$ had an average aboveground biomass of 10.4 t ha$^{-1}$. On the other hand, average aboveground biomass (5.5 t ha$^{-1}$) was lower ($P \leq 0.0001$) on plots with exchangeable sodium between 0.64 and 2.08 cmol$_c$ kg$^{-1}$, while plots with an exchangeable sodium above 2.08 cmol$_c$ kg$^{-1}$ had a significantly lower average aboveground biomass of 0.9 t ha$^{-1}$ ($P=0.005$). High levels of sodium may have a direct negative impact on plant growth (Fontenele et al. 2014) and/or may restrict plant growth indirectly through prevention of aggregate formation and subsequent dominance of micropores and poor aeration (Tisdall and Oades 1982). Soils with poor drainage in the FRD may be prone to sodium accumulation, making this soil property an indicator of co-founding drainage issues which may further hinder vegetation growth. Future studies are needed to refine these preliminary exchangeable sodium thresholds and to determine the causes of GLSA growth reduction issues.

These preliminary thresholds; however, suggest that fields with a baseline exchangeable sodium >2.08 cmol$_c$ kg$^{-1}$ may require additional management practices such as the installation of sub-surface tile drains to prevent prolonged surface ponding, reduce salts, and/or improve soil structure prior to GLSA seeding. Alternatively, the seeding of a GLSA mix that is more salt or water tolerant than what is currently being used in the FRD may also allow for better GLSA...
vegetation growth and coverage during the first two seasons of enrollment on sites with high exchangeable sodium.

CONCLUSIONS

During the first and second season of the GLSA establishment on eight sites, GLSA and adjacent ACR fields had similar MWD, bulk density, and aeration porosity. According to a PCA of soil baseline properties, two of the eight fields were determined to be unproductive due to the combination of high exchangeable sodium, low MWD, high bulk density, and low total soil carbon. A subsequent analysis comparing only six productive GLSA fields relative to paired ACR, found the MWD of water stable aggregates to be consistently higher in GLSA than ACR fields. The only significant difference in aeration porosity between GLSA and ACR fields was observed after two seasons of GLSA enrolment (i.e., in September 2016), when aeration porosity was 24% greater in GLSA. Similarly, soil bulk density was also significantly different only after two seasons, when it was 7% lower in GLSA relative to ACR. Our study indicates that two-season GLSA rotations may be an alternative to continuous ACR for improving soil structure and relieving compaction in productive agricultural fields and also highlights the importance of including soil baseline information to effectively evaluate soil response to GLSA management.

Soil baseline properties were also found to be important for evaluating GLSA vegetation responses. The establishment of vegetation is an important contributor to both wildlife habitat and soil benefits of GLSAs and the unproductive fields included in this study had very limited GLSA vegetation growth in the first and second year of establishment. Of the baseline soil properties evaluated in this study, only exchangeable sodium was significantly correlated ($r= - 0.61; P=0.0002$) to aboveground GLSA biomass and appears to be an important indicator to
assess the suitability of fields for GLSA management and/or the need to incorporate accompanying management practices (e.g., sub-surface drain installation) or use of more salt- and water-tolerant vegetation mix for short-term soil improvements to occur. In order to better support GLSA management decision-making, preliminary exchangeable sodium thresholds were determined and future work should be done to further develop these thresholds.

Even though the findings of our study are specific to the FRD, our work has highlighted the importance of including region-specific baseline soil property assessments in order to effectively evaluate both soil and vegetation responses under this management practice. Future short-term GLSA studies should also consider potential differences among sites that enter GLSA programs, since those differences will most likely lead to varying responses.

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http://doi.org/10.2136/sssaj2011.0286


Table 1. Mean weight diameter (MWD) of water stable aggregates, bulk density, and aeration porosity at 0-7.5 cm depth in eight (productive and unproductive) sites with grassland set-aside (GLSA) and paired annual crop rotation (ACR) fields during the first (2015) and second (2016) season of GLSA establishment.

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<th>2016</th>
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<td>July</td>
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<tr>
<td></td>
<td>GLSA</td>
<td>ACR</td>
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<td>MWD (mm)</td>
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<td>Bulk density</td>
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<td>1.20 (0.04)</td>
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<td>Aeration porosity</td>
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*a Standard error of the mean is shown in brackets

*b Significant differences are indicated in bold and by * for P-value <0.05.
Table 2. Mean weight diameter (MWD) of water stable aggregates, bulk density, and aeration porosity at 0-7.5 cm depth on six productive grassland set-aside (GLSA) and paired annual crop rotation (ACR) fields during the first (2015) and second (2016) season of GLSA establishment.

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<th>Soil property</th>
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<td>MWD (mm)</td>
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<td>1.19 (0.02)</td>
<td>1.17 (0.05)</td>
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<td>–</td>
<td>1.08 (0.03)</td>
<td>1.09 (0.04)</td>
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</table>

a Standard error of the mean is shown in brackets

b Significant differences are indicated in bold and by * for P-value <0.05 and + for P-value <0.10.
Figure captions

**Fig. 1.** Overview of past management practices and inherent soil characteristics on the eight study sites.

**Fig. 2.** A principal component analysis of exchangeable sodium (Exchangeable Na), total soil carbon (TC), mean weight diameter (MWD) of water stable aggregates, and bulk density taken from sub-plots across eight fields prior to being seeded with the grassland set-aside (GLSA) seed mix illustrating clear separation between sets of fields deemed unproductive or productive by the farmers entering the GLSA program.

**Fig. 3.** Total dry aboveground biomass (a) and percentage of biomass by vegetation group (Clover, Grass, and Weeds) (b) in productive and unproductive fields after two seasons of grassland set-aside (GLSA) establishment. Error bars are standard error of the mean of the four subplots within each field and significant differences are indicated by different letters.

**Fig. 4.** Non-parametric regression tree with exchangeable sodium (cmol$_c$ kg$^{-1}$) included as the only independent variable and dry aboveground biomass in grassland set-aside (GLSA) fields as the response variable. Nodes are considered significant at $P<0.05$. 


Figure 1

338x190mm (300 x 300 DPI)
Figure 2

279x215mm (300 x 300 DPI)
Figure 3

199x260mm (300 x 300 DPI)
Figure 4

279x215mm (300 x 300 DPI)