Effects of foraging waterfowl in winter flooded rice fields on weed stress and residue decomposition

J.W. van Groenigena,∗, E.G. Burns b, J.M. Eadie b, W.R. Horwath c, C. van Kessel a

a Department of Agronomy and Range Science, University of California at Davis, 1 Shields Avenue, Davis, CA 95616, USA
b Department of Wildlife, Fish and Conservation Biology, University of California at Davis, 1 Shields Avenue, Davis, CA 95616, USA
c Department of Land, Air and Water Resources, University of California at Davis, 1 Shields Avenue, Davis, CA 95616, USA

Received 21 December 2001; received in revised form 23 April 2002; accepted 13 May 2002

Abstract

This study quantifies the agronomic benefits of foraging waterfowl in winter flooded rice fields in the Sacramento Valley of California (US). Fifteen winter flooded rice fields along a 105 km long transect, each with five pairs of waterfowl exclosures and control plots were used to measure residue decomposition in spring, and weed biomass and grain yield at harvest. Experimental exclusion of waterfowl resulted in a significant increase in remaining residue from 1014 to 1233 kg ha⁻¹ across the transect. At seven sites with high waterfowl activity, remaining residue increased from 836 to 1549 kg ha⁻¹ when waterfowl were excluded from the plot. Grassy weed biomass increased from 44 to 91 kg ha⁻¹ over the whole transect in absence of waterfowl. At seven sites with high waterfowl activity the grassy weed biomass more than doubled in the absence of waterfowl from 89 to 204 kg ha⁻¹. No significant yield effect could be detected. Winter flooding rice fields resulted in mutual benefits for waterfowl and agriculture that could be of particular significance in organic farming systems.

© 2002 Elsevier Science B.V. All rights reserved.

Keywords: Waterfowl foraging; Waterfowl habitat; Rice sustainability; Conservation; Weed management

1. Introduction

The total area of natural wetlands has been reduced to 10–15% its original size in Europe, and to 50% in the contiguous 48 states of the United States (Dahl, 1990; Finlayson et al., 1992). Large parts of these wetlands have been converted into rice (Oryza sativa L.) fields. Although rice fields in Europe and the United States comprise only around 2–3% of the 1,500,000 km² of rice grown worldwide, these rice fields are often located in areas that historically provided important waterfowl habitat, such as the Ebro Delta in Spain and the Sacramento Valley in California (Pasola and Ruiz, 1996; Elphick, 2000).

In California, rice is grown on some 250,000 ha, located mainly in the Sacramento Valley. California rice yields are among the highest in the world, because of excellent growing conditions (solar radiation, temperature, water availability). Grain yields surpassing 13t ha⁻¹ are commonly reported by farmers (Eagle et al., 2000). However, the large amounts of rice residue associated with these high yields, often exceeding 10t ha⁻¹, pose a number of problems for farmers. Residue removal or decomposition during winter is essential for seedbed preparation in spring and to ensure that there are no physical barriers or...
allelopathic determinants to successful germination (Anonymous, 1993).

Traditionally, the most common residue removal practice was open-field burning after harvest. However, concerns over air quality have led to a substantial restriction of rice residue burning (California Rice Straw Burning Reduction Act, AB 1378, 1991). California legislation restricts burning to <25% of the total rice acreage but it is foreseen that the allowable burning will decrease further. Winter flooding of rice fields has been proposed to enhance residue decomposition and limit the number of tillage operations in the spring. The mechanisms that enhance residue decomposition under winter flooded conditions are not yet fully understood, and multiple factors are likely involved (Eagle et al., 2000).

The natural wetlands in the Sacramento Valley are an important winter area for large numbers of waterfowl. These wetlands provide wintering habitat for up to 20% of all waterfowl in North America and up to 60% of wintering waterfowl in the Pacific Flyway (Frayer et al., 1989; Reid and Heitmeyer, 1995). Prior to its conversion to a rice growing area, the Valley was comprised mostly of seasonal wetlands, flooded by winter rains (U.S. Fish and Wildlife Service, 1978; Gilmer et al., 1982). Up to 10–20 million waterfowl may have used this area, although numbers now range from 2 to 4 million. Since the 1780s California has lost 90–95% of its wetland acreage (Reid and Heitmeyer, 1995). Although the primary purpose of winter flooding rice fields is for residue management, winter flooded fields potentially serve as an important substitute habitat for many species of wetland-dependent wildlife (Elphick and Oring, 1998; Elphick, 2000).

A previous study using experimental enclosures indicated that the presence of foraging waterfowl in winter flooded rice fields may yield important agronomic benefits. Bird et al. (2000) reported a 78% increase in residue decomposition in 5 m × 5 m plots where waterfowl were allowed to forage. Such increased decomposition might lead to better nitrogen availability during the growing season, and to a reduced need for N fertilization (Eagle et al., 2001). Waterfowl may reduce weed biomass at harvest time, and diseases and pest occurrences in subsequent growing seasons (Hill et al., 1999). However, Bird et al.’s (2000) study was conducted in small 5 m × 5 m plots under tightly controlled conditions, and it is not clear whether the effects observed would be replicated at a larger spatial scale under more natural conditions. The objective of the present study was to conduct a series of on-farm experiments throughout the rice growing region of the Sacramento Valley to quantify the effects of foraging waterfowl on straw decomposition, weed pressure and yield under natural waterfowl densities.

2. Materials and methods

A transect of 105 km was established through the main rice growing region in the northern Sacramento Valley (Fig. 1), on which 15 winter flooded rice fields were selected. To avoid confounding effects of various residue treatments (e.g. wet-rolling or disking of residue), the only residue treatment chosen was chopping of residue, without subsequent incorporation of straw in the soil. All fields were located on poorly drained, heavy soils on alluvium from sedimentary rocks, with large amounts of smectite/montmorillonite (Begg, 1968). Three soil orders were distinguished, with more weathered and lighter alfisols in the south, more fertile mollisols in the middle and the east bank of the Sacramento River, and heavy vertisols in the north (Table 1).

Study plots were established on the fields in the fall of 1999, after harvest and residue management was completed. All plots were set up within a week of the initiation of winter flooding. On every field, five paired plots were set up at randomized locations, consisting of two square areas of 3 m × 3 m each. To minimize disturbance to waterfowl, one plot (the control) was only demarked by two stakes, allowing free foraging of the waterfowl within the plot, and the plots were spaced 40 m apart. The other plot (the exclusion) consisted of four 1.5 m tall metal stakes at the corners, and two stakes in the middle, with all sides covered with chicken wire to keep waterfowl out. All plots were located at least 40 m from a levee in order to avoid edge effects or disturbance of the birds. The locations of the plots were geo-referenced using a differentially corrected global positioning system (GPS, model Trimble Pathfinder Pro XRS, Trimble Co., CA), resulting in an accuracy of 0.3 m or better.

After draining the fields in early spring of 2000, the enclosures and the stakes of the controls were...
removed. Subsequent sampling was carried out using the GPS and by sampling the inner 1 m² of the 3 m × 3 m plots, allowing for a maximum sample location error of 1 m in all directions.

During the first half of January 2000, two soil cores of 15.2 cm diameter to a depth of 20 cm were sampled randomly from all plots (controls and exclosures) for residue measurements and seed counts. The cores were
Table 1

<table>
<thead>
<tr>
<th>No.</th>
<th>Soil series</th>
<th>Soil taxonomy classification</th>
<th>Landscape position</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pescadero</td>
<td>Fine, montmorillonitic, thermic type Natraquoll&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Basins</td>
</tr>
<tr>
<td>2</td>
<td>Capay</td>
<td>Fine, montmorillonitic, thermic type Chromoxerert&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Basins</td>
</tr>
<tr>
<td>3</td>
<td>Sacramento</td>
<td>Fine, montmorillonitic, non-calcareous, thermic cumulic Haplaquoll&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Basins</td>
</tr>
<tr>
<td>4</td>
<td>Clear lake</td>
<td>Fine, smectitic, thermic xeric Endoaquert&lt;sup&gt;d&lt;/sup&gt;</td>
<td>Basins</td>
</tr>
<tr>
<td>5</td>
<td>Vina</td>
<td>Fine-loamy, mixed, superactive, thermic pachic Haploxeroll&lt;sup&gt;e&lt;/sup&gt;</td>
<td>Flood plains</td>
</tr>
<tr>
<td>6</td>
<td>Westfan</td>
<td>Fine-loamy, mixed, superactive, thermic pachic Haploxeroll&lt;sup&gt;e&lt;/sup&gt;</td>
<td>Alluvial fans</td>
</tr>
<tr>
<td>7, 8, 10–13</td>
<td>Willows</td>
<td>Fine, smectitic, thermic sodic Endoaquert&lt;sup&gt;d&lt;/sup&gt;</td>
<td>Basins</td>
</tr>
<tr>
<td>9</td>
<td>Moonbend</td>
<td>Fine-silty, mixed, superactive, thermic pachic Haploxeroll&lt;sup&gt;e&lt;/sup&gt;</td>
<td>High flood plains</td>
</tr>
<tr>
<td>14, 15</td>
<td>Willows</td>
<td>Fine, smectitic, thermic sodic Endoaquert&lt;sup&gt;d&lt;/sup&gt;</td>
<td>Basins</td>
</tr>
</tbody>
</table>

<sup>a</sup> Source: Wells, 1972.
<sup>b</sup> Source: Soil Conservation Service, personal communication.
<sup>c</sup> Source: Begg, 1968.

subsequently washed through a 500 μm screen until all soil particles were washed out. The remaining residue was dried at 45°C and weighed.

Hand harvesting of the plots was done as close as possible to the time of machine harvesting of the individual fields. One square meter in the center of each plot was hand-harvested 5 cm above the soil surface using a sickle. This harvest was carried out between mid September to mid October 2000. Subsequently, rice was dried at 45°C for 72h, weeds were sorted out, and the rice was threshed. Grain yield weight and above-ground weed biomass were determined.

Because large landscape-scale studies are prone to large variability both within and between fields, a non-parametric approach to analyze the results was chosen. The statistical significance of difference in measured variables was tested by pairwise comparison between control and exclosure plot, using a Wilcoxon signed rank test in Systat version 9.0 (SPSS Inc., Chicago, IL).

3. Results

Across the entire transect, the effects of foraging waterfowl were tested on two different datasets: (i) the entire dataset, resulting in an integrative value of the effect of ambient waterfowl activity across the entire rice growing region; (ii) a subset of seven fields where there was positive confirmation through visual surveys that there had been significant waterfowl activity during the winter flooded period (Fig. 1). Surveys of waterfowl density on experimental plots and adjacent fields were conducted bi-weekly in January and February. Sites were visited in the hour before sunset when birds arrived in the fields to begin nocturnal feeding. Each survey lasted 15–30 min to provide a total count of the number of birds on each field. Surveys were conducted from a vehicle using a window-mounted spotting scope or binoculars. Densities of birds were averaged over all censuses (3–5) for each site. Average densities ranged from 0 to 77 birds ha<sup>−1</sup> (median: 7.6 birds ha<sup>−1</sup>). A value of 5 birds ha<sup>−1</sup> was used as the cutoff to designate sites where significant waterfowl activity occurred. In addition, two fields were included in this group where observations by farmers indicated that large numbers of birds had frequented the fields regularly but were missed by the surveys.

All plots could not be sampled for all parameters. The presented results report all sampled data, whereas the statistical tests are performed on the complete pairs of exclosures and controls that were present.
Table 2
Effects of foraging waterfowl on residue decomposition and weed pressure at harvest. Descriptive statistics for the whole transect and the sites with highest observed waterfowl activity

<table>
<thead>
<tr>
<th></th>
<th>Whole transect</th>
<th>Highest waterfowl activity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+ Waterfowl</td>
<td>− Waterfowl</td>
</tr>
<tr>
<td>Remaining residue in spring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of observations</td>
<td>56</td>
<td>56</td>
</tr>
<tr>
<td>Range (kg ha(^{-1}))</td>
<td>0–3193</td>
<td>0–6222</td>
</tr>
<tr>
<td>Mean (kg ha(^{-1}))</td>
<td>1220</td>
<td>1617</td>
</tr>
<tr>
<td>Median (kg ha(^{-1}))</td>
<td>1014</td>
<td>1233</td>
</tr>
<tr>
<td>Grassy weed biomass at harvest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of observations</td>
<td>61</td>
<td>62</td>
</tr>
<tr>
<td>Range (kg ha(^{-1}))</td>
<td>0–974</td>
<td>0–1387</td>
</tr>
<tr>
<td>Mean (kg ha(^{-1}))</td>
<td>44</td>
<td>91</td>
</tr>
<tr>
<td>Median (kg ha(^{-1}))</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

site 3. When only sites with high observed waterfowl density were considered, the median value for remaining residue in spring almost doubled within the exclosures (Table 2). This amounted to a significant effect of residue remaining in the enclosed plots (Fig. 2).

At harvest, grassy weeds constituted 97% of the total above-ground weed biomass. Across the whole transect, the grassy weed biomass consisted mostly of rice field bulrush (Scirpus mucronatus L.; 89%), Bearded sprangletop (Leptochloa fascicularis L.; 9%) and Watergrass/Barnyardgrass (Echinochloa spp.; 2%). Average grassy weed biomass increased from 44 to 91 kg ha\(^{-1}\) when waterfowl were excluded \((P = 0.06; \text{Fig. 2})\). For the sites with high levels of observed waterfowl activity, this effect was even stronger \((P = 0.04; \text{Table 2 and Fig. 2})\). There were no significant differences for non-grassy weeds.

Average total above-ground rice biomass was approximately 17,000 kg ha\(^{-1}\), with an average grain yield of 8,000 kg ha\(^{-1}\). No significant differences due to waterfowl activity could be detected.
4. Discussion

The most pronounced result of this study is the reduction of grassy weed pressure in the subsequent growing season due to foraging waterfowl (Table 2). For sites with high waterfowl activity, the decline in weed biomass became more pronounced. The lack of an effect on the non-grassy weed pressure may be due to a generally larger size and corresponding higher nutritional value of grassy weed seeds to waterfowl.

The increase of residue decomposition by foraging waterfowl, although significant, was smaller than the 78% reported earlier by Bird et al. (2000). However, the average waterfowl density of 33 birds ha\(^{-1}\) over the whole growing season in that study may have been higher than in the current transect, resulting in a higher average number of waterfowl over a short period of time. Moreover, in the controlled study by Bird et al. (2000), the water depth was maintained at an optimal 10 cm, whereas water depths in farmers’ fields in the Central Valley tend to fluctuate due to evaporation, drainage and rain (Elphick and Oring, 1998). Therefore, the results obtained by Bird et al. (2000) for residue decomposition by foraging waterfowl may represent a maximum that would not be fully reached under suboptimal field conditions.

It should be pointed out that, while rice fields are winter flooded and used by waterfowl every year, the exclosures were only set up for one winter season. Specific effects of foraging waterfowl may accumulate over several years. In particular, weed pressure could increase when waterfowl are excluded from fields for a number of years, increasing the weed seed bank. The real effect might therefore be larger than observed in this study.

The selection of the subset of seven fields with high waterfowl activity was based on bi-weekly visual surveys at dusk when birds arrive to forage in rice fields. However, a significant portion of waterfowl foraging in rice fields takes place nocturnally, and reliable night surveys still pose technical problems. Furthermore, the movements of birds are often erratic, resulting in extreme day to day variability in waterfowl numbers on specific fields. Accordingly, it is likely that waterfowl densities recorded on the study sites may have been underestimated and fields that were not selected as having a high waterfowl activity may have experienced some level of waterfowl activity.

Sites were selected at regular intervals along a transect across the main rice growing region in the Central Valley, to cover as much of the variability in natural resources as possible. Although accessibility of the fields during the winter, hunting activity, and farm management had to be taken into account, the study fields were quite representative. With a single exception (field 15), the fields were not located close to highways, powerlines or other objects that might have disturbed waterfowl. In addition, farmers typically rotate winter flooding of their fields, and winter flooded fields can therefore be assumed to be representative of much of the rice growing region in the Sacramento Valley.

The results demonstrate that foraging waterfowl have increased residue decomposition and reduced weed pressure over large parts of the rice growing region of northern California. Although the experimental setup covered a wide variety of locations and management practices, only residue chopping was selected as a residue management practice. Other residue management practices include wet- and dry-rolling of residue in order to increase contact between residue and microflora, and disking of residue (Eagle et al., 2000). More research is needed to determine the impact of foraging waterfowl on residue decomposition under these alternative residue management practices. For example, disk in the fall could have adverse effects on waterfowl densities as most of the food for foraging birds will be buried. In contrast, wet- and dry-rolling of rice straw should result in positive effects on residue decomposition and weed reduction similar to those observed in this current study, since the food is still available to waterfowl.

Another management factor that might influence waterfowl activity is the type of rice harvester used. Both conventional combines (i.e. cutter bars) and stripperhead harvesters are commonly used in the Sacramento Valley (Miller et al., 1989; Bennett et al., 1993). Stripperhead harvesters are considerably faster, at 3.2–12.8 km h\(^{-1}\), compared with 1.6 km h\(^{-1}\) for conventional harvesters. However, the higher harvesting efficiency of the stripperhead harvester may not shed sufficient grain to attract and sustain waterfowl foraging activity (Miller and Wylie, 1996). Day and Colwell (1996) reported higher species richness in conventionally harvested rice fields than in stripperhead harvested fields. An interesting, albeit
counter-intuitive, way of combining the speed of a stripperhead harvester with the higher resulting habitat value of a conventional harvester might be to purposely operate the stripperhead in a slightly less than optimal way, thereby leaving enough grain in the field to attract and sustain foraging waterfowl activity. However, a careful cost/benefit model for this type of management practice needs to be made before it can be recommended. Furthermore, these practices could be at odds with baiting laws when fields are hunted (Elphick and Oring, 1998).

All participating farmers in this study follow conventional farm management practices. Pesticides were applied at all fields, typically twice during the beginning of the growing season. The observed positive effect of foraging waterfowl on weed pressure might therefore be even greater in organic farming systems, where pesticide application is typically low or zero. No clear relation could be found between soil properties and waterfowl activity. The seven sites with the highest observed activity contain all three soil orders that were encountered during the study. The three sites with the highest observed effects of residue decomposition and weed pressure were sites 1, 9, and 13, again representing all three soil orders (Table 1; Fig. 1).

Farmers integrating wildlife habitat with rice production may realize revenues of eco-tourism by attracting wildlife enthusiasts to the area. This rapidly growing industry can greatly enhance the economic viability of small, especially rural, communities (Lingle, 1991; Kerlinger, 1993). Moreover, a market for rice produced in a manner that benefits wildlife could lend itself to higher prices for the farmer.

The results of this study demonstrate that the presence of foraging waterfowl contribute to increased residue decomposition and reduced weed pressure over large areas of the rice growing region of northern California. These findings may be important for other rice growing regions in the US and elsewhere (Rave and Cordes, 1993). Other non-tropical rice growing regions where waterfowl might make a significant difference include the Mediterranean areas of Europe and the adjoining region (Faosa and Ruiz, 1996; Sanchez Guzman et al., 1999). Introduction of winter flooding, which is not a common practice in the Mediterranean (González-Solís et al., 1996), could lead to a considerable improvement in wildlife habitat quality. Similar opportunities may exist in Japan (Maeda, 2001). However, as in California and elsewhere, water costs will need to be offset against environmental benefits of increased wildlife habitat and its associated agronomic benefits.

Acknowledgements

We thank Ducks Unlimited for providing contacts with cooperating farmers along the transect. J.P. Fleskes, J.K. Daugherty, and W.M. Perry, Western Ecological Research Center, U.S.G.S., provided mapping support. Finally, we are grateful to Robb Evans, Katie Wennig, Sean Kennady, Jake Messerli, Michael Atamian, and Gabriel Valenzuela for assistance during fieldwork and laboratory analysis. Financial support was provided by the Rice Foundation.

References


