Post-harvest Field Manipulations to Conserve Waste Rice for Waterfowl

Joshua D. Stafford,[1] *Department of Wildlife and Fisheries, Box 9690, Mississippi State University, Mississippi State, MS 39762*

Richard M. Kaminski, *Department of Wildlife and Fisheries, Box 9690, Mississippi State University, Mississippi State, MS 39762*

Kenneth J. Reinecke, *U.S. Geological Survey, Patuxent Wildlife Research Center, 2524 South Frontage Road, Suite C, Vicksburg, MS 39180*

Mark E. Kurtz, *Delta Research and Extension Center, Mississippi State University, P.O. Box 197, Stoneville, MS 38776*

Scott W. Manley, *Ducks Unlimited, Inc., Tri-State Field Station, 2302 County Park Drive, Cape Girardeau, MO 63701*

Abstract: Rice seeds escaping collection by combines during harvest (hereafter, waste rice) provide quality forage for migrating and wintering waterfowl in the Lower Mississippi Alluvial Valley (MAV) and other rice growing regions in the United States. Recent sample surveys across the MAV have revealed abundance of waste rice in fields declined an average of 71% between harvest and late autumn. Thus, we evaluated the ability of common post-harvest, field-management practices to conserve waste rice for waterfowl until early winter via controlled experiments in Mississippi rice test plots in 2001 and 2003 and analyses of data from MAV-wide surveys of waste rice in rice production fields in 2000–2002. Our experiments indicated test plots with burned rice stubble that were not flooded during autumn contained more waste rice than other treatments in 2001 ($P \leq 0.10$). Waste-rice abundance in test plots did not differ among post-harvest treatments in 2003 ($P = 0.97$). Our analyses of data from the MAV sample surveys did not detect differences in abundance of waste rice among fields burned, rolled, disked, or left in standing stubble post-harvest ($P \geq 0.04$; Bonferroni corrected critical $\alpha = 0.017$). Because results from test-plot experiments were inconclusive, we based our primary inference regarding best post-harvest treatments on patterns of rice abundance identified from the MAV surveys and previously documented environmental and agronomic benefits of managing harvested rice fields for wintering waterfowl. Therefore, we recommend leaving standing stubble in rice fields after harvest as a preliminary beneficial management practice. We suggest future research evaluate potential of post-harvest practices to conserve waste rice for waterfowl and reduce straw in production rice fields managed for wintering waterfowl throughout the MAV.

Key words: agriculture, food resources, habitat management, Mississippi, Mississippi Alluvial Valley, rice, waterfowl.

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1. Present address: Illinois Natural History Survey, Bellrose Waterfowl Research Center, Forbes Biological Station, P.O. Box 590, Havana, IL 62644.

The Lower Mississippi Alluvial Valley (MAV) originally was a 10-million ha bottomland hardwood ecosystem that flooded seasonally and provided extensive habitat for migrating, wintering, and resident waterfowl (Fredrickson and Heitmeyer 1988, Reinecke et al. 1989; Fredrickson et al. 2005). Although many forested lowlands in the MAV have been converted to croplands, including extensive areas for rice production, the MAV remains critically important to North American waterfowl (Canadian Wildlife Service and U.S. Fish and Wildlife Service 1986).

Rice fields are important foraging habitats for wintering waterfowl in the MAV and elsewhere in the United States (Reinecke et al. 1989, Smith et al. 1989). Uihlein (2000:58) estimated 80,830 ha of flooded rice fields existed in the MAV in winters 1993–1995, and recent data from satellite imagery revealed 126,515 ha of flooded rice fields in the MAV on 3–4 January 2003 (T. E. Moorman, Ducks Unlimited, Inc., unpublished data). Because rice fields are designed to be flooded during the growing season to maximize grain production, fields can be easily reflooded after harvest to establish winter habitat for waterbirds (Manley et al. 2004). Moreover, rice seeds resist decomposition more than other agricultural seeds (Neely 1956, Shearer et al. 1969, Nelms and Twedt 1996) and are more nutritious than soybean or corn, based on research with captive waterfowl (Joyner et al. 1987, Loesch and Kaminski 1989).

Previous research documented waste rice was abundant in MAV fields at the time of harvest during mid-September (140–490 kg/ha: Reinecke et al. 1989, Huitink and Siebenmorgen 1996, Manley et al. 2004). However, Stafford et al. (2006) reported waste rice declined 71%, on average, between harvest in mid-September and early December 2000–2002, markedly reducing availability of this food resource for wintering waterfowl in the MAV. Further, abundance of waste rice in early winter may be approaching a 'threshold' of 50 kg/ha below which seed availability may be insufficient for foraging by waterfowl (Reinecke et al. 1989, Rutka 2004). Several factors, including increased harvest efficiency, fall germination, consumption by granivores, and decomposition, likely contributed to the current decline in waste rice (McGinn and Glasgow 1963, Stafford et al. 2006).

Burning, disking, flooding, and rolling rice stubble are common post-harvest field manipulations applied by rice producers in the MAV primarily to prepare fields for spring planting but also to attract wintering waterfowl (Uihlein 2000:59, Manley et al. 2005, Stafford et al. 2006). However, we were unaware of previous research that evaluated the ability of these post-harvest practices to retain waste rice as forage for wintering waterfowl. Therefore, we conducted experimental evaluations of post-harvest field manipulations to conserve waste rice during autumn in test plots at Mississippi State University's Delta Research and Extension Center (DREC) in the MAV of western Mississippi. Additionally, we estimated waste-rice abundance in late autumn in burned, disked, rolled, and standing-stubble rice fields using data from a sample survey of rice fields throughout the MAV (Stafford et al. 2006). Our goal was to gain preliminary knowledge of which post-harvest practices conserved the most waste rice during autumn by examining results at both scales of investigation.

Methods

We conducted experiments in test plots (30 m x 45 m each) at the DREC in Stoneville, Mississippi (33° 25´26˝ N, 90° 54´54˝ W) during autumns 2001 and 2003. Scientists at DREC planted and harvested common rice varieties (e.g., Priscilla, Cocodrie, Clearfield) in plots annually for various agricultural experiments. Collaborators constructed temporary levees around each plot to retain pumped water and precipitation on all plots during the growing season and selected treatment plots during autumn.

In mid-August 2001, we selected 12 plots at the DREC and randomly assigned three replicates each of four post-harvest (mid-September) treatments: (1) standing stubble (control), (2) flooded standing stubble, (3) burned stubble, and (4) burned and flooded stubble. We did not disk or roll stubble in 2001 because personnel and equipment were not available to implement these treatments. We collected five core samples with a depth and diameter of 10 cm (Manley et al. 2004) at random locations within each plot ($N = 120$ samples) on 8 October (i.e., ≤ 18 days after treatment application; initial seed abundance) and 9 December (i.e., late autumn; abundance available to waterfowl), similar to the timing of sampling during the MAV field survey (Stafford et al. 2006).

In early September 2003, we selected 15 plots at DREC and randomly assigned three replicates each of five post-harvest treatments: (1) standing stubble (control), (2) rolled stubble, (3) burned stubble, (4) disked stubble, and (5) mowed stubble. We did not include post-harvest flooding because many rice producers during our MAV sample survey (Stafford et al. 2006) indicated they were not willing to incur costs of pumping water post-harvest to conserve waste rice for waterfowl. We collected 10 core samples from random locations within each plot on 9 October and 1 December ($N = 300$ samples). We increased our sample size per plot in 2003 in an effort to increase precision of rice abundance estimates and to approximate our sampling effort during MAV-wide surveys.

We washed samples through sieves (i.e., mesh sizes 4 [4.75 mm], 10 [2.0 mm], and 18 [1.0 mm]) and removed rice seeds containing whole or partial endosperms (i.e., ≥ 50% of seed remained). We deemed these seeds potential food for waterfowl. We dried seed samples to a constant mass (± 0.5 mg) at 87 C before weighing to estimate mean abundance (kg/ha, dry mass; Stafford et al. 2006). We used one-way analysis of variance (ANOVA) in SAS (SAS 1999) to test for differences in initial seed abundance among treatment plots at DREC (8 October 2001 and 9 October 2003). We also used analysis of covariance (ANCOVA; PROC GLM) in SAS to examine abundance of waste rice in late autumn among experimental treatments (9 December 2001 and 1 December 2003) with the covariate of initial waste rice abundance. Because the covariate was not significant in either year ($F_{1,7} = 0.18$, $P = 0.69$ [2001]; $F_{1,8} = 3.05$, $P = 0.12$ [2003]), we used ANOVA to model 2001 and 2003 data relative to post-harvest treatments. We analyzed each year separately because not all treatments were implemented each year. We made pairwise comparisons of differences among means using Tukey's Honestly Significant Difference (HSD) test when significant treatment effects were detected (SAS 1999). We selected a significance level of $\alpha = 0.10$ for all statistical tests, because our experiments had limited replication and were pilot studies for future large-scale experiments (Zar 1999:82).

Our study area for the MAV sample survey encompassed a 7.57 million-ha area that included most of the MAV and the Grand Prairie in Arkansas adjacent and west of the MAV (Reinecke et al. 1989). Stafford et al. (2006) detailed our study area sampling and statistical methods to estimate waste-rice abundance from sample surveys in the MAV. We determined post-harvest treatments by inspecting fields and conversing with landowners during initial sampling and used data from the MAV surveys to compute separate estimates of waste-rice abundance for burned, disked, rolled, and standing stubble rice fields across all years (2000–2002). We treated each of the four treatments as subpopulations or "domains" (Cochran 1977:34–35, Stafford et al. 2006) by specifying the DOMAIN option in PROC SURVEYMEANS (SAS v8.2; SAS 1999). This procedure ensured inclusion of appropriate selection probabilities at each stage in the sampling design (i.e., landowners, fields within landowners, core samples within fields; Cochran 1977, Stafford 2004). We compared mean abundance of waste rice among post-harvest treatments using z-tests (Sauer and Williams 1989), set a significance level of $\alpha = 0.10$ a priori (Zar 1999:82), and accounted for the number of pairwise comparisons ($N = 6$) among the four treatments using the Bonferroni method ($\alpha_{corrected} = 0.017$; Sauer and Williams 1989).

Results

We did not detect a difference in mean initial waste-rice abundance among treatments after harvest at DREC in October 2001 ($F_{3, 8} = 0.49$, $P = 0.70$). However, mean rice abundance in December 2001 differed among post-harvest treatments ($F_{3, 8} = 3.48$, $P = 0.070$). Burned plots not flooded during fall contained about seven times more waste rice than plots with standing stubble (HSD < 3.8, $P < 0.10$; Table 1). We did not detect a difference in initial waste-rice abundance among treatments after harvest at DREC in 2003 ($F_{4, 9} = 0.69$, $P = 0.72$), nor an effect of post-harvest stubble treatments on late-autumn waste-rice abundance ($F_{4, 9} = 0.14$, $P = 0.97$; Table 1).

Estimates pooled over years (2000–2002) from the MAV sample surveys indicated mean rice abundance in late autumn was variable (20.7% ≤ CV ≤ 29.9%; Table 2) among post-harvest treatments. Thus, we did not detect differences in late autumn rice abundance among field treatments ($-0.27 \le z \le 2.05$; $0.04 \le P \le 0.79$; critical $\alpha = 0.017$; Table 2).

Discussion

Differences in late autumn waste-rice abundance resulting from post-harvest field treatments at DREC and field sample surveys in the MAV were limited and inconsistent. Nonetheless, we attempt to identify potential factors influencing variation in rice abundance among treatments as bases for preliminary management recom-

Table 1. Mean rice abundance (kg/ha; dry mass) by post-harvest field treatment ($N = 3$ plots per treatment) and corresponding standard errors (SE) in test plots at the Delta Research and Extension Center, Stoneville, Mississippi, 9 December 2001 and 1 December 2003.

Year	Treatment	$\bar{x}^{a}$	SE
2001	Burned stubble	416.1A	163.9
	Flooded stubble	103.1B	53.4
	Burned and flooded stubble	101.1B	34.7
	Stubble only	57.1B	25.9
2003	Stubble only	266.9A	151.4
	Rolled stubble	234.7A	96.7
	Mowed stubble	223.7A	165.1
	Disked stubble	172.4A	68.2
	Burned stubble	162.6A	80.0

a. Year and treatment-specific means followed by unlike letters differ ($P < 0.10$) by Tukey's Honestly Significant Difference test.

Table 2. Mean rice abundance (kg/ha; dry mass) by post-harvest field treatment, sample size (*N* fields), and corresponding standard errors (SE) for data collected from a field sample survey conducted throughout the Mississippi Alluvial Valley, 27 November–7 December 2000–2002.

Treatment	N	$\bar{x}^{a, b}$	SE
Stubble only	40	123.4A	25.5
Disked stubble	41	78.5A	16.4
Rolled stubble	55	71.9A	18.3
Burned stubble	23	59.6A	17.8

a. Means followed by the same letters do not differ ($P \geq 0.10$) based on Bonferroni corrected z-tests ($N = 6$ comparisons).

b. Estimates of rice abundance from MAV analysis were corrected for incomplete recovery of seeds (10.5%) during sample processing (Stafford et al. 2006).

mendations and stimulus for future research into the mechanisms for this variation. We also note rice abundance in late autumn in test plots at DREC generally exceeded levels in production fields in the MAV (Stafford et al. 2006). Plots at DREC were subject to various agricultural experiments and not harvested as typical production fields. Hence, reported abundances of waste rice in DREC plots should not be considered representative of production fields in the MAV.

In 2001, plots at DREC that were burned but not flooded following harvest had 5 times more rice seed in late autumn than the mean abundance of waste rice among other treatments. However, data from DREC experiments in 2003 were not consistent with 2001 results. The objective of the MAV field sample survey was to estimate mean waste-rice abundance in fields flooded by early winter and thus managed for waterfowl (Stafford et al. 2006). Consequently, the proportion of fields with different post-harvest treatments selected for our sample could be considered random, and our treatment means were estimated using domain analysis. Although our analysis did not reveal any significant differences among field treatments, we believe it noteworthy that fields with standing stubble averaged nearly twice the amount of waste rice in December compared to disked, rolled, or burned fields.

We are uncertain of the mechanism(s) responsible for the great abundance of rice in burned plots at DREC in 2001. However, post-harvest germination of rice seeds may reduce the amount of waste-grain for waterfowl in late autumn, and we speculate burning rice stubble may have heated seeds sufficiently to kill embryos, possibly leaving grains intact but incapable of germination. Experiments have shown rice seeds stored at ≥55 C exhibited reduced germination (Loewer et al. 2003). Results of post-harvest burning of rice stubble on December waste-rice abundance may be difficult to predict because temperatures at ground level during burning may vary depending on amount of straw, wind, soil and straw moisture contents, relative humidity, and temperature. Thus, variable environmental conditions within rice fields may differentially affect ability of burning rice stubble to kill rice embryos.

Burning plots post-harvest possibly hindered decomposition of rice seeds by impacting microbial communities or their food supply (i.e., straw and other organic detritus) compared to unburned and flooded plots (McGinn and Glasgow 1963:73). Stafford (2004:49) estimated losses of known numbers of rice seeds in the MAV were 58% to decomposition, 14% to predation, and 8% to germination. Kuehn et al. (2000) reported fungi were important decomposers of plant material in wetlands, but fungal and bacterial biomasses decreased following flooding. Nakamura et al. (2003) reported bacteria and fungi were important decomposers of rice straw in flooded and upland plots, and Loewer et al. (2003) noted bacteria and fungi actively decomposed stored rice when relative humidity was 95%–100% and grain moisture 22%. We did not measure effects of decomposition and other agents of loss of waste rice during our study.

Although our results were inconclusive, we suspect leaving rice fields covered with standing stubble may inhibit seed germination by decreasing soil temperatures and light transmission as ambient temperatures and day length decrease in autumn (e.g., planted rice seeds germinate poorly at ≤10 C; Yoshida 1981, Miller and Street 2000). Additionally, presence of stubble and chaff may have hidden waste rice from granivores. We suggest our preliminarily results indicate leaving rice stubble intact may retain most rice seed for wintering waterfowl. However, losses of waste rice associated with rolling, disking, or mowing were equivocal, and burning fields may result in abundant seed under circumstances not yet understood.

Management Implications

Our experiments and analyses were not conclusive, but we believe the combined weight of evidence from this and other studies indicated leaving rice stubble standing after harvest was a beneficial strategy to conserve waste seed for waterfowl and concurrently achieve other desirable ecological, environmental, and agronomic benefits. Rice fields throughout the MAV with standing stubble retained nearly twice as much rice seed as treated fields; moreover, standing stubble flooded during winter also provided water quality and soil conservation benefits. Manley (1999:62) reported export of suspended solids from fields disked and allowed to drain during winter was 10 times greater than from fields left in stubble and flooded. Standing rice stubble flooded during winter also provided economic benefits to producers by suppressing winter vegetation and "red rice" (i.e., naturalized rice variety with no economic value) and accruing financial savings from reduced or eliminated herbicide applications at spring planting (Manley 1999:89). Moreover, mean biomass of aquatic invertebrates, an important source of protein for waterfowl (Krapu and Reinecke 1992), was greater in flooded fields with standing stubble than in disked fields (Manley et al. 2004). Finally, flooded fields with standing stubble provides habitat for crawfish (*Procambarus* spp.), which may be harvested for human consumption or left as food for waterbirds (Huner et al. 2002). If managers believe burning, rolling, mowing or light disking all or portions of harvested fields is necessary to create open water areas to attract waterfowl or facilitate spring planting, we suggest leaving 20%–25% of the stubble untreated at the low end of the field may function to filter suspended solids. Although Manley et al. (2005) reported winter flooding of rice stubble alone reduced residual straw by >50%, we encourage researchers to determine whether leaving and flooding standing stubble decreases subsequent rice production and profits for producers.

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