

Effects of Biodegradable Mulch on Dryland Rice

Shannon Campbell

shannon.campbell6@student.kpu.ca

Department of Sustainable Agriculture

Kwantlen Polytechnic University

Experimental period: May 2025 - October 2025

December 2, 2025

Advisor: Mike Bomford

Abstract

Rice (*Oryza sativa* L.), a staple food crop, is traditionally grown in flooded fields and is therefore associated with high methane emissions and intensive labour and water inputs. Dryland methods of rice production present an increasingly attractive alternative in many bioregions, but are hindered by increased weed competition and reduced germination and yield. In south coastal British Columbia, dryland cultivation is additionally challenged by low early summer soil temperatures, which further exacerbate weed competition by delaying crop development and canopy establishment. Biodegradable mulches have the potential to impede early weed development.

This research investigated the impact of straw and paper mulches on transplants of rice in Richmond, BC. Results indicated that both mulches suppressed weeds in June and July with no effect in August, while having no significant impact on soil moisture. Rice yields were not affected by mulches, but rice plant density was significantly lower in straw-mulched plots.

Introduction

Rice (*Oryza* spp.) is one of the world's staple food crops, supplying 20% of global caloric value (CSHL 2018). It was the third most produced crop commodity between 1994 and 2023 and yielded 535.2 million metric tonnes in 2023/2024 (FAO Stat; FAO 2025). Almost 75% of global rice yields are grown in irrigated lowland cropping systems, where soil is left in puddled conditions for weeks of the crop's development (Bouman et

al. 2007; Muthayya et al. 2014). These conditions reflect rice's origins as a wetland grass well-adapted to seasonal flooding; puddling—a process which involves flooding rice paddies—is the dominant practice in much of Asia (Fig. 2), where rice (specifically *Oryza sativa* L.) is a key subsistence crop and contributes 50% of caloric intake to households in poverty (Muthayya et al. 2014).

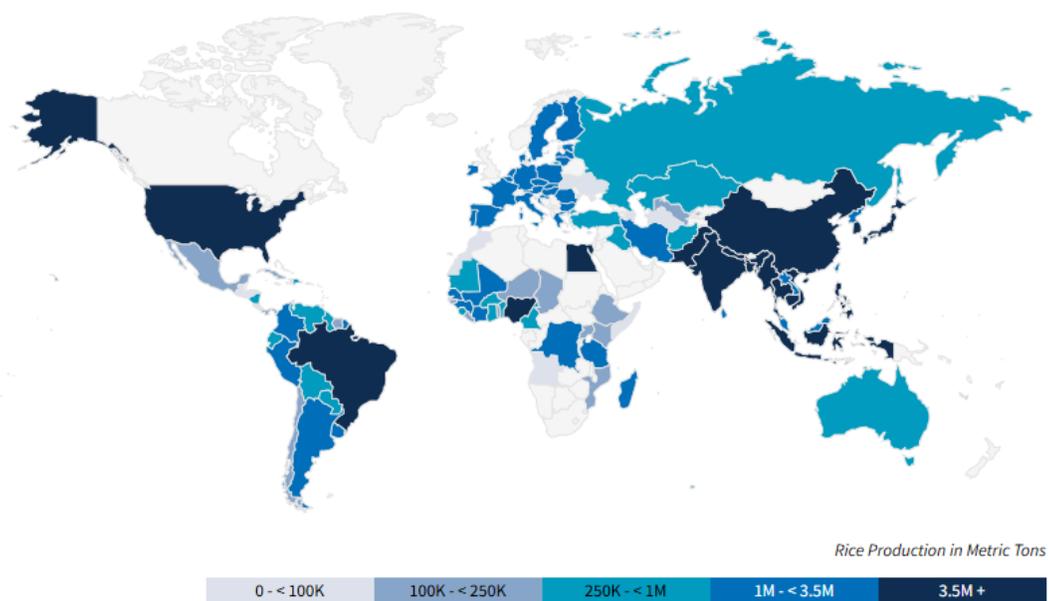


Figure 1. Distribution of global rice production. (Source: USDA Foreign Agricultural Service, [date unknown].)

Flooded lowland rice production is an ancient cultural practice informed by millennia of experience; equipped with oxygen-channeling aerenchyma tissue, rice can endure semi-aquatic conditions that suppress the growth of competitive weeds (Gliessman et al. 2023). When rice is cultivated along river beds or in seasonal flood paths, puddling the paddies can contribute new soil nutrients each year for sustained annual rice production (Fukuoka 1985). In the modern era, this continues to be

demonstrated in studies comparing plant biomass and grain yields in puddled and unirrigated (rainfed) lowland production, where traditionally-flooded paddies produce consistent yields across subsequent seasons while unirrigated production suffers increasingly reduced yields with each year (Peng et al. 2006; Jabran et al. 2014; Sekiya et al. 2025).

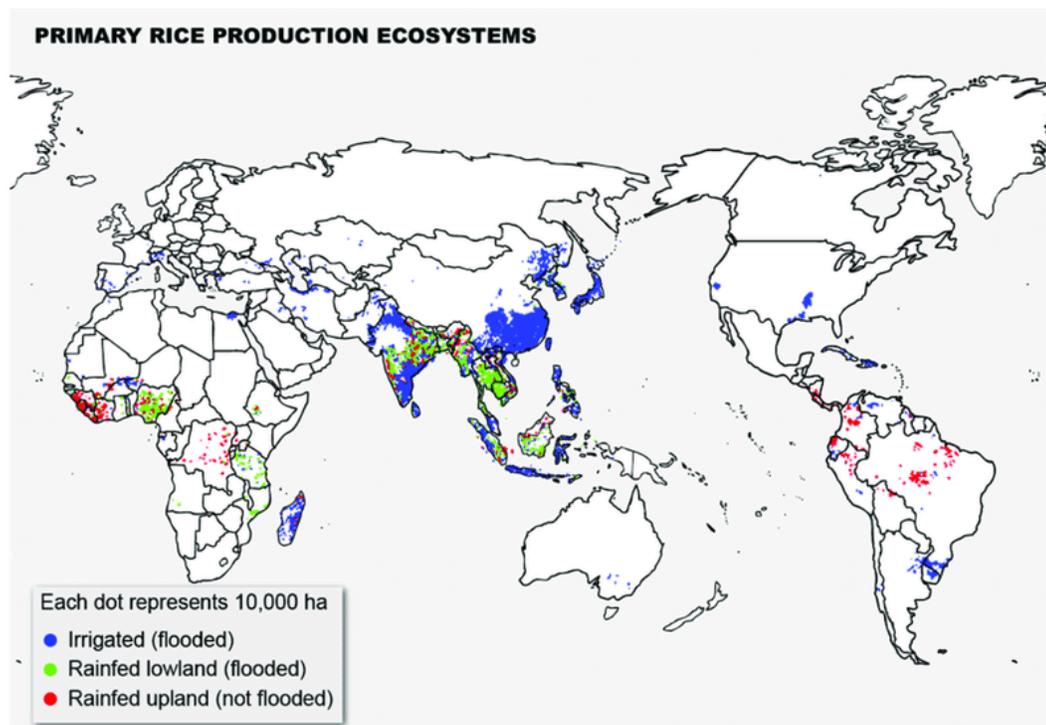


Figure 2. Distribution of global rice production systems. The red dots indicating rainfed upland production can be considered synonymous with “dryland” production. Source: Reproduced from IRRI (2009) in Min (2020).

However these benefits aren't without cost: as the climate crisis unfolds, frequent droughts exacerbated by extreme weather events put stress on agricultural water supplies. In regions where rice production is high, neighbours collaborate to stagger and drain flooding from one paddy into the next and reuse water (Fukuoka 1985); even so, irrigated lowland rice production accounts for up to 30% of the world's freshwater withdrawals (Bouman et al. 2007). Rice paddies are typically waterlogged for weeks at a

time, which stimulates redox processes in the soil leading to anaerobic fermentation, producing methane emissions (Gliessman et al. 2023). As a result, rice production contributes an estimated 48% of cropland methane emissions (Qian et al. 2023); in 2024, this totalled 24.81 Mt (Climate Trace 2025).

Although flooding may impede weed development, it wreaks havoc on soil structure, destroying soil aggregates and reducing macropore volume (Bouman et al. 2007). In parts of the world where water resources are limited, rice production is arrested: one review noted that 30% of rice production land was lost in the Philippines from 1997 to 2012 due to inadequate irrigation (Taer 2025). Furthermore, lowland rice cultivation involves transplanting rice seedlings into the flooded paddies, a labour-intensive process that may impact efficiency and productivity as aging farmers fail to find successors (Liu et al. 2023).

This highlights the need for viable alternative methods of rice production—particularly ones capable of meeting global demands on yield and grain quality without contributing to environmental or climate crises. While some efforts look at periodically draining (and subsequently reflooding) fields to minimize anaerobic fermentation (Toensmeier 2016) or synchronizing rice production with seasonal wetland use for migratory birds (Jackson & Jackson 2002), others turn to practices as old and familiar as rice paddies.

Upland or dryland rice cultivation is a traditional practice in highland regions and an alternative to flooded rice production. While it uses far less water, dryland rice cultivation is uniformly associated with lower yields and reduced grain quality than its lowland counterpart (Fukuoka, 1985; Zhang et al. 2008), in part due to the effects of

increased weed competition (Pambudi et al 2019; Mahajan & Chauhan 2013).

Nevertheless, the potential for a rice production system that meets global demands while mitigating methane emissions and water usage provokes continued study, and formerly flooded rice production can be easily adapted to dryland techniques from one season to the next (Yadav et al. 2013).

As previously mentioned, research has shown that unirrigated lowland production systems suffer reduced crop biomass and grain yield in comparison to traditionally-flooded rice paddies, which compounds over subsequent seasons; however, flooded paddies have an increase in micropores and an established plowpan that impedes root development and limits capillary uptake of water through the soil profile (Bouman et al. 2007). Repeated seasonal flooding may mitigate the negative impact this would have on soils and, subsequently, crops; dryland rice, therefore, may require soil rehabilitation in order to maintain the necessary soil health required for viable production. In many studies, the application of mulches to dryland rice has demonstrated a marked improvement in the parameters associated with good seed development and harvest output (Jabran et al. 2015; Kato et al. 2007; Zhang et al. 2008; Zhao et al. 2024).

In Japan, agronomist Masanobu Fukuoka championed the use of winter grains as a mulch in direct-seeding to improve soil moisture and nutrient levels for improved germination in rice cultivation. In various experiments with both straw mulches and a green manure cover crop of white clover, Fukuoka observed a reduction in seed predation with this practice, as well (Fukuoka 1978; Fukuoka 1985). Zhang et al. (2008) looked at flooded rice production in contrast to dry production using combinations of

plastic film mulch, wheat straw, or no mulch at all. Straw mulch was found to increase photosynthesis, root oxidation, and grain-filling against the flooded control, with a 307-321% improvement in water use efficiency. Significantly, straw mulching was found to match flooded field grain yield (whereas both the plastic mulch and no-mulch treatments suffered a decrease in yield) while also improving milling, appearance, and cooking qualities of the harvested grain.

A similar study analyzing the effects of straw mulch and deep tilling practices on direct dry-seeded rice (DDSR) found that, provided rain levels were ideal, straw mulch improved grain yields and surface soil moisture, concluding this may be the result of improved organic nutrients and microbial activity thanks to the inclusion of biodegradable mulching amendments (Kato et al. 2007). Zhao et al. (2024) investigated the impact of plastic and biodegradable plastic film mulches on DDSR and found the application of mulching improved soil moisture, leaf area, rice yield, and water use efficiency, measuring a 1.1% increase of soil temperatures in the top 5 cm below biodegradable mulches.

Paper mulch is a treatment using sheets of biodegradable paper, often made from closed-loop and recycled materials, which are rolled across the soil surface and perforated for transplanting of seedlings or direct sowing (Shiroki 2025). Ideally this treatment is intended to minimize weed competition and seed predation, but studies have been less conclusive. Jeon et al. (2011) investigated the benefits of paper mulch in combination with plastic against a control of herbicides in a two-year study, and found paper mulch had decreased efficacy against weeds than the control. Previously, Kwantlen Polytechnic University student Wendel Vistan conducted a study comparing

the effect of paper mulch on grain weight and yield in both dry and flooded field rice production. The study concluded that the flooded fields outperformed dryland production in both yield and grain weight while paper mulch had no observable effect on either production system. However, observations noted that although the paper mulch was expected to remain intact for up to 50 days, the mulch decomposed before rice canopy cover could be established (Vistan 2023).

A review by Gwawaly et al. (2021) identified that wheat straw mulch reduced weed emergence in DDSR by 44-77% (Singh et al. 2007 as cited in Gwawaly et al., 2021) and emphasized the importance of timing for mulch applications in studying weed suppression in DDSR, identifying the Critical Period of Weed Competition (CPWC) for rice as occurring in two windows between 15-30 days and 45-60 days after seeding.

Recently a review of rice cultivation practices across three regions in Bangladesh demonstrated that although DDSR rice was associated with 2-8% lower yields than puddled production, it was ultimately more profitable due to lower production costs, including a 15-47% reduction in labour inputs, 15-50% lower energy consumption, and a 58-66% reduction in emissions and global warming potential (Ahmed et al. 2025). This study concluded that the biggest limitation to DDSR yields was weed competition followed by seed predation and poor germination.

In the BC lower mainland, high precipitation in the early summer may cause paper mulch to biodegrade too quickly or prove too fragile on its own, therefore minimizing or negating any potential benefit to weed suppression. Given the success in previous studies with straw as a biodegradable mulching system, this study proposes to

study the effect of using biodegradable mulches (i.e. paper and oat straw) in a dryland rice crop and its impact on rice yield, weed suppression, and soil moisture levels.

Methodology

1. Site

The study was conducted in the east field of the Kwantlen Polytechnic University Farms at the Garden City Lands in Richmond, British Columbia. In previous seasons this site has experienced significant weed pressure. Because of this site's unique history and mixed imported top soil (Bomford 2023), a heterogenous study environment was expected.

2. Design

This study was initially designed with a split plot factorial randomized complete block design, with two factors (straw mulch and paper mulch) at two levels (Fig. 3). Each plot was split in half with a randomized allotment of direct-seeded rice and transplanted rice. Initial direct seeding took place on May 5, 2025, however by May 30 there was determined to be no germination, and the split-plot design was discarded; subsequently all rice was transplanted. The randomized mulching scheme was retained from the original design. Each block measured 4 by 4 metres (16 m²); each plot was 2 by 2 metres (4 m²).

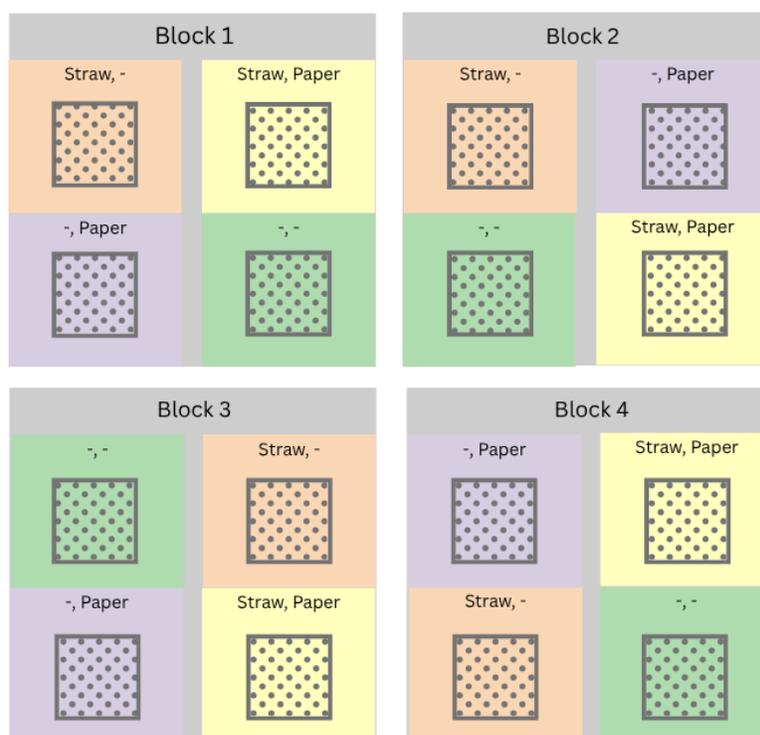


Figure 3. The randomized block and plot scheme used in the study, generated with jamovi RCBD randomizer (seed 8279).

3. Mulches

16 irrigation lines were laid down at 24 cm spacing and 11-0-0 feathermeal fertilizer (BioFert) was scattered and loosely raked in (0.3 kg/m^2) to the topsoil. Recycled paper mulch (Kamimulch, Sanyo Paper Co., Ltd. Forestry Department, Tottori City, JPN) was cut to appropriate dimensions and buried in a thin layer of soil at the edges to keep it secure. Oat straw mulch was applied to a depth of approximately 8 cm; on double-mulched treatments (straw, paper) the straw mulch was layered overtop of the paper mulch.



Figure 4. The treatment plots after mulches were applied, pre-transplanting.

4. Rice seedlings

Transplanting took place on May 31 with seedlings provided by Osake Craft Distillery from their rice farm in Abbotsford; the seedlings were approximately four weeks old at the 4-5 leaf stage. Seedlings were planted in the interior 1.69 m² of each plot at a shallow depth (5 cm) with 15 cm x 24 cm spacing. Transplants were covered with floating row cover to prevent birds from dislodging them, and the row cover was removed once roots were firmly established (approximately two weeks later).

The rice used was *O. sativa* cultivar 'Nanatsuboshi', a japonica short grain rice developed for cold, shorter growing periods in Hokkaido, though it's most adapted to lowland (puddled) rice cultivation (The Japanese Food Lab [date unknown]).

5. Sampling & Data Collection

a. Weed Suppression

Plots were hand-weeded in three rounds (May, July, and August). The May weeding took place immediately prior to transplanting. In July and August, weeding was divided across four days with one block being completed in a single day. Canopy photos were taken before and after weeding (Fig. 5) and compared in the CANOPEO app (Oklahoma State University, Android version 1.1.8b) at 0.96 sensitivity to estimate weed canopy coverage.



Figure 5. Comparison shots of plot D4 taken before (left) and after (right) weeding in July.

b. Soil Moisture

A volumetric soil moisture meter (Fieldscout TDR 300, Spectrum Technologies Ltd., Aurora, IL, USA) set to a depth of 20 cm was used for measurements. Soil moisture readings were taken on multiple dates throughout July, August, and

September, with multiple readings taken in each plot on each date and averaged by plot for comparison.

c. Rice Yield & Plant Density

Rice was harvested on October 3 and hung to dry for two weeks (Fig. 6); the seed heads were then hand-threshed and mature grains were filtered using manual hand-sieves (CSS-4000 series, Ø2.40 mm, Seed Processing Holland, Enkhuizen, NLD) before being fed into an air-separator (CAM-4200, Seed Processing Holland, Enkhuizen, NLD) to filter for filled grain, which was then weighed.

Plant density was determined from the canopy photos taken after weeding in August (Fig. 12).



Figure 6. Comparison plant harvests taken from plots A1 (left) and A2 (right).

6. Statistical Analysis

Rice plant density and yield were analyzed using ANOVA in jamovi version 2.7.12. A Linear Mixed Model was applied to repeated measures of weed suppression and soil moisture; treatment-round and paper-straw interactions were included as fixed effects, while intercepts for block and plot were labeled as random effects to account for spatial variation.

Results and Discussion

1) Weed Suppression

Mulch treatments significantly suppressed weed growth compared to the unmulched control (Paper: $p = 0.003$; Straw: $p = 0.002$; Both: $p < 0.001$), although this effect was only significant during the early part of the season (June and July weeding rounds). Given that rice canopies are typically well-established by August, the lack of significant weed suppression may not be a concern to commercial growers.

There was no significant difference in suppression among the individual mulch treatments (Paper, Straw, or Combined). A significant interaction was observed between the paper and straw treatments ($p = 0.039$) (Fig. 8), indicating that layering the mulches together provided no added benefit over applying them individually.

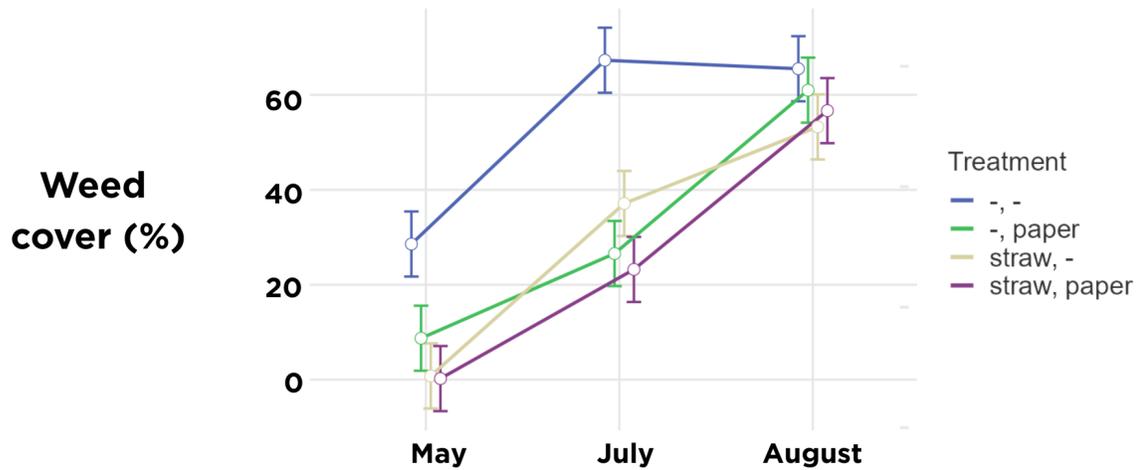


Figure 7. Mean weed canopy coverage (%) (\pm standard error) is shown for four mulch treatments across three sampling dates. Treatments include no mulch (-, -), paper mulch only (-, paper), straw mulch only (straw, -), and straw plus paper mulch (straw, paper). Bars represent standard error.

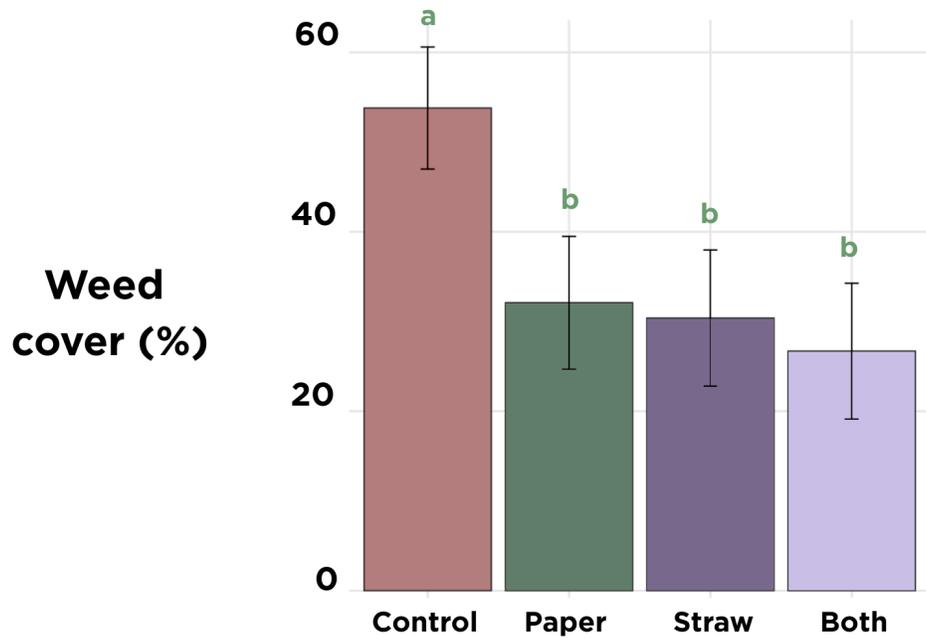


Figure 8. Mean weed canopy coverage (%) (\pm standard error) by mulch treatment. Treatments sharing the same letter above the bar are not significantly different from each other.

As per the manufacturer, the paper mulch was expected to last approximately 45 days in the field before degrading (Sanyo Paper Corporation [date unknown]). Previous studies incorporating paper mulch into rice cultivation on the KPU farm observed that the paper degraded more quickly as a result of wind and precipitation (Vistan 2023). In this study, the paper mulch was heavily deteriorated or even completely absent from all plots in under 20 days. This was due to damage caused by coyotes regularly digging up buried irrigation lines, which resulted in the oversaturation and further scattering of the paper.



Figure 9. *By June, the paper mulch was heavily deteriorated and windswept into other plots. Coyote damage to irrigation lines caused saturated soils and required frequent repairs.*

As such, paper mulch proved to be an effective weed suppressant even weeks after its physical degradation, indicating that the benefits of early application extended well into the growing season. The practice of securing the paper mulch with straw in the double-mulched plots yielded no statistically significant added benefit to suppression.

2) Soil Moisture

Mulching had no significant effect on the soil moisture content versus control, and soil moisture readings remained high (>20%) across all plots even in the hottest and driest part of the season (Fig. 10). This was likely a consequence of frequent animal interference puncturing the irrigation lines and the clay-heavy soils of the study site.

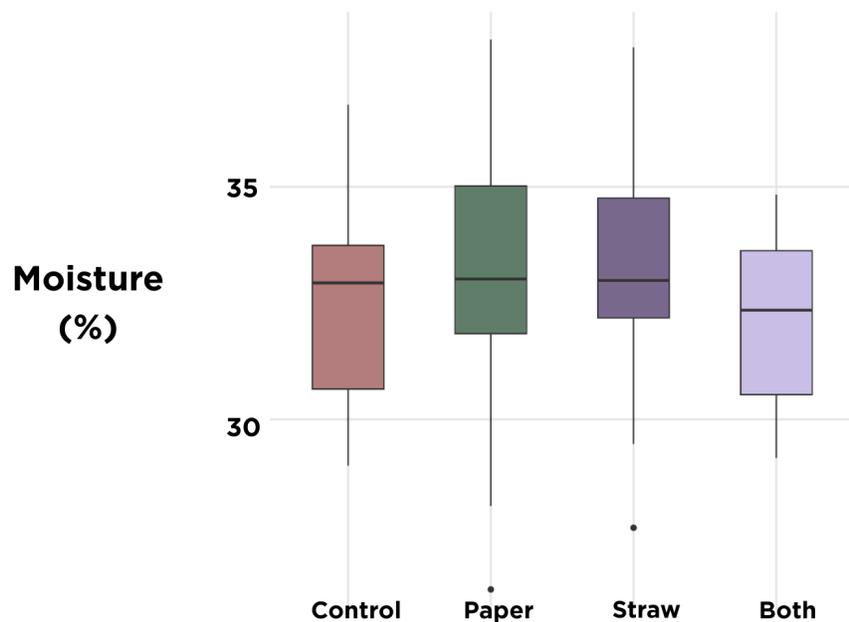


Figure 10. Mean soil moisture (%) from measurements taken throughout July, August, and September. Treatments were not statistically different.

3) Yield

Despite suppressing weeds, mulching had no significant effect on yield (Fig. 11). This seems counterintuitive: as weeds compete for nutrients, the mulched plots should translate into more nutrients available for rice plant uptake and a subsequent increase in harvest. However, this expected increase was likely masked or negated by the study's weeding protocol. Since weeds were completely removed after each round, any competitive advantage may have been neutralized, and nutrients sequestered within the weed biomass were actively removed from the plots.

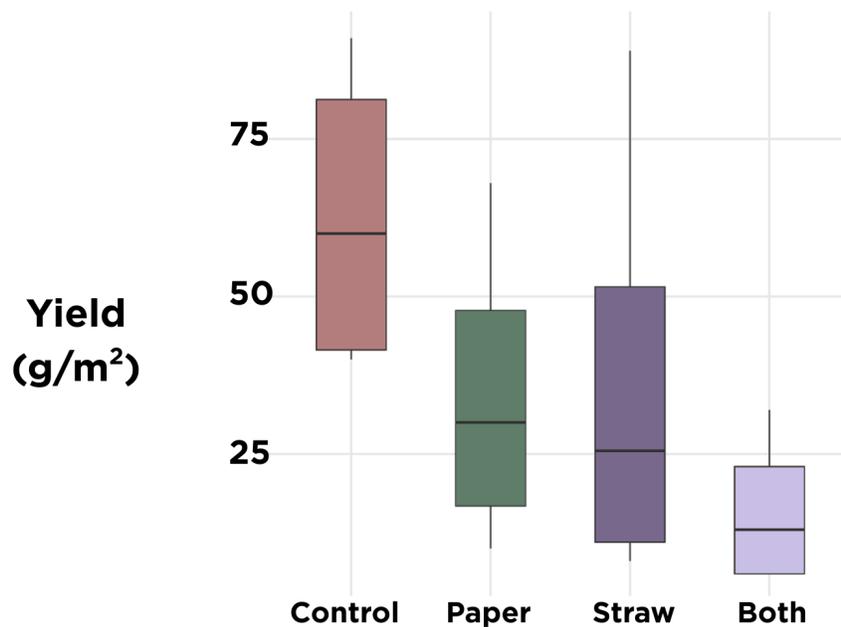


Figure 11. Mean yield (g/m^2) from the rice harvest after separating out unfilled grain. Although the difference between harvests was not statistically significant, the numerical means of the yields under double-mulched (straw and paper) treatments was less than half the mean yields of the control treatments.

While not significantly affected, double-mulched treatments had only half the yield in numerical means. Combined with field observations during harvest, this prompted a measurement of plant densities; an analysis revealed that straw-mulched plots had significantly fewer plants than other treatments (Figs. 12, 13), despite having the same number of transplants at the start of the study.



Figure 12. Canopy photos taken post-weeding in August of a straw-only treatment (left) and a paper-only treatment (right) within the same block.

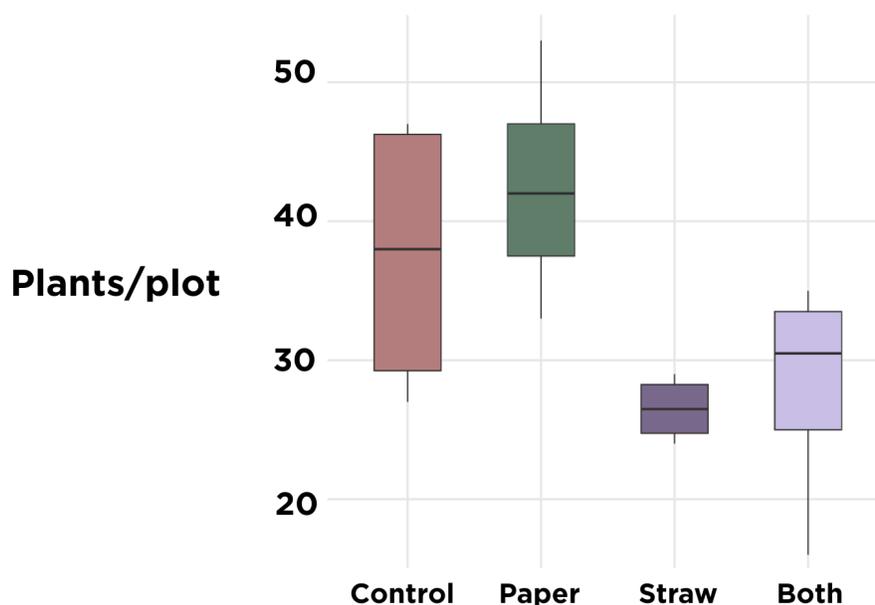


Figure 13. Rice plant density (plants/4m² plot) counted from post-weeding canopy photos taken in August.

Unfortunately, it's difficult to know when these plants were lost, as in photos taken during earlier weeding rounds the rice is too immature to accurately count. Therefore the mechanism driving the significantly lower plant density in the straw-mulched plots remains unknown. Observationally, volunteer oat seeds germinated within these plots, acting as weeds. This could have resulted in more rice being confused for oat grass and mistakenly removed during manual weeding, but it seems unlikely given the two plants were easily distinguishable upon close examination. Another possibility is in more animal interference: rice transplanted through the straw may not have been hilled as securely, and therefore may have been easier for birds to pull out even after the floating row cover was removed.

Despite plant densities being significantly reduced in the straw-only plots, this did not translate into significantly reduced yields. In their study, Zhang et al. (2008) observed that straw-mulched rice demonstrated improved grain filling and speculated straw may support rice yields by enhancing key enzymatic activity and promoting photosynthesis.

Overall, study yields were much lower than industry standards, though the study rice was also planted at a much lower density than it would be in commercial operations.

Table 1. Adjusted yield estimates to kg/acre from experimental treatments (first four columns) to commercial growers in Abbotsford (Masataka Shiroki, email to author, 27 November 2025) and the USA (Thomet 2017) (both grown in puddled conditions).

| | Yields (kg/ha) |
|-----------------------------|----------------|
| Straw | 370 |
| Paper | 345 |
| Both | 160 |
| Control | 628 |
| Abbotsford (Puddled) | 1483 |
| US (Puddled) | 8967 |

Conclusion

Both straw and paper biodegradable mulches significantly suppressed weeds compared to the control; although paper mulches deteriorate quickly, the benefits last throughout much of the growing season and using straw mulch to secure the paper

mulch had no additional benefit. This demonstrates that biodegradable mulches offer a viable strategy for early-season weed suppression in dryland transplanted rice.

Mulches had no significant effect on rice yield or soil moisture, though double-mulched treatments had numerically reduced yields compared to the control. There was no significant difference between yields under paper-only or straw-only mulches, despite the fact that there were significantly fewer mature rice plants later in the season under straw-only mulches than there were under paper-only mulches.

Additional studies investigating potential trade-offs between mulches and yields would greatly benefit future explorations into sustainable rice harvests. Furthermore, the discrepancy between low rice density in straw mulch, while not significantly reducing yields, is ripe for further exploration.

Acknowledgments

Thank you to Mike Bomford, Rebecca Harbut, and Sahar Zandieh for their guidance and support. Special thanks to Masa Shiroki and Akio Nakamura of Osake Craft Distillery for their generous contributions and mentorship.

References

- Ahmed S, Kumar V, Zaman AU, Dewan MR, Khatun A, Hossain K, Singh S, Timsina J, Krupnik TJ. 2025. Dry direct-seeded and broadcast rice: a profitable and climate-smart alternative to puddled transplanted aus rice in Bangladesh. *Field Crops Res.* 322:109739. doi:10.1016/j.fcr.2025.109739
- Bomford M. 2023. The KPU Farm: An Organic Teaching Farm at the Margin of an Ancient Peat Bog. Kwantlen (BC): Kwantlen Polytechnic University. https://www.kpu.ca/agriculture/farming_peat
- Bouman BAM, Lampayan RM, Tuong TP. 2007. Water management in irrigated rice: coping with water scarcity. Los Baños (Philippines): International Rice Research Institute.
- Climate TRACE. 2024. Climate TRACE Emissions Inventory v4. [accessed 2025 Nov 11]. <https://climatetrace.org>
- Food and Agriculture Organization of the United Nations (FAO). 2025. Food outlook – biannual report on global food markets. Rome: Food and Agriculture Organization of the United Nations (FAO). <https://doi.org/10.4060/cd5655en>
- Food and Agriculture Organization of the United Nations (FAO). [date unknown]. Crops and Livestock Products: Most Produced Commodities, 1994-2023. [Internet]. [place unknown]: Food and Agriculture Organization of the United Nations (FAO). [cited 2025 Mar 24]. Available from: <https://www.fao.org/faostat>
- Fukuoka M. 1978. The one-straw revolution. Korn L, Pearce C, Kurosawa T, translators. New York (NY): New York Review.
- Fukuoka M. 1985. The natural way of farming: the theory and practice of green philosophy. Metreud FP, translator. Tokyo (Japan): Japan Publications, Inc.
- Gliessman SR, Méndez VE, Izzo VM, Engles EW, Gerlicz A. 2023. Agroecology: leading the transformation to a just and sustainable food system. 4th ed. Boca Raton (FL): CRC Press.
- Gyawaly P, Sah S, Bhattarai R, Chaulagain B, Pantha P. 2021. Managing weeds in dry direct seeded rice: a profound challenge. *Agronomy Journal of Nepal.* 5:124–135. doi:10.3126/aj.n.v5i01.44826.
- Jabran K, Ullah E, Hussain M, Farooq M, Zaman U, Yaseen M, Chauhan BS. 2015. Mulching improves water productivity, yield and quality of fine rice under water-saving rice production systems. *J Agro Crop Sci.* 201:389–400. doi:10.1111/jac.12099.
- Jackson DL, Jackson LL. 2002. The farm as natural habitat: reconnecting food systems with ecosystems. Washington (DC): Island Press.
- Jeon W-T, Choi B, El-Azeem SAMA, Ok YS. 2011. Effects of green manure crops and mulching technology on reduction in herbicide and fertilizer use during rice cultivation in Korea. *African Journal of Biotechnology.* 10(1). doi:10.5897/AJB10.1657.

- Kato Y, Kamoshita A, Abe J, Yamagishi J. 2007. Improvement of rice (*Oryza sativa* L.) growth in upland conditions with deep tillage and mulch. *Soil and Tillage Research*. 92(1–2):30–44. doi:10.1016/j.still.2005.12.013.
- Liu J, Fang Y, Wang G, Liu B, Wang R. 2023. The aging of farmers and its challenges for labor-intensive agriculture in China: A perspective on farmland transfer plans for farmers' retirement. *Journal of Rural Studies*. 100. doi:10.1016/j.jrurstud.2023.103013.
- Mahajan G, Chauhan BS. 2013. Dry-seeded rice culture in Punjab State of India: lessons learned from farmers. *Field Crops Res*. 144:89–99. <https://doi:10.1016/j.fcr.2013.01.011>
- Michalowski J. 2018 February 1. More rice, please: 13 rice genomes reveal ways to keep up with ever-growing population. Cold Spring Harbor (NY): Cold Spring Harbor Laboratory. <https://www.cshl.edu/rice-please-13-rice-genomes-reveal-ways-keep-ever-growing-population/>
- Min S. 2020. Effects of different agricultural management systems on CO₂ fluxes from irrigated rice cultivation [PhD thesis]. Olomouc (Czech Republic): Palacký Univ.
- Muthayya S, Sugimoto JD, Montgomery S, Maberly GF. 2014. An overview of global rice production, supply, trade, and consumption. *Ann N Y Acad Sci*. 1324:7–14. doi:10.1111/nyas.12540.
- Oklahoma State University. 2015. *CANOPEO* (Version 1.1.8b) [Android app]. Retrieved 2 April 2025 from <https://canoapeoapp.com/>
- Pambudi PA, Utomo SW, Waryono T, Hartono DM. 2019. Weed management in dryland paddy farming for environmental conservation. *IOP Conf Ser: Earth Environ Sci*. 239:012013. doi:10.1088/1755-1315/239/1/012013.
- Peng S, Bouman B, Visperas RM, Castañeda A, Nie L, Park H-K. 2006. Comparison between aerobic and flooded rice in the tropics: Agronomic performance in an eight-season experiment. *Field Crops Res*. 96(2–3):252–259. doi:10.1016/j.fcr.2005.07.007.
- Qian H, Zhu X, Huang S, et al. 2023. Greenhouse gas emissions and mitigation in rice agriculture. *Nat Rev Earth Environ*. 4:716–732. doi:10.1038/s43017-023-00482-1.
- Sanyo Paper Corporation. Rice Paddy Kami-Mulch [水稲用カミマルチ]. Tottori (Japan). [accessed 2025 Dec 1]. <https://www.sanyopaper.co.jp/business/paper/maruchi/suitou/index.html>
- Taer A. 2025. Shrinking rice bowls: tracing the decline of Philippine rice lands. *J Int Soc Southeast Asian Agric Sci*. 41(1). <https://doi:10.1007/s12571-025-01604-x>
- The Japanese Food Lab. What is Nanatsuboshi Rice? [accessed 2025 Nov 30]. <https://thejapanesefoodlab.com/nanatsuboshi/>
- Thomet H. Exploring dryland rice production in the mid-Atlantic. 2017 Jan 26. Newburg (MD): Next Step Produce; Northeast SARE. Final Report for FNE15-832. <https://projects.sare.org/project-reports/fne15-832/>

- Toensmeier E. 2016. The carbon farming solution: a global toolkit of perennial crops and regenerative agriculture practices for climate change mitigation and food security. White River Junction (VT): Chelsea Green Publishing.
- USDA Foreign Agricultural Service. Production - Rice. [accessed 2025 Nov 30].
<https://www.fas.usda.gov/data/production/commodity/0422110>
- Vistan W. 2023 December 8. Effects of flooding and paper mulch on Fraser Valley rice. Kwantlen (BC): KPU Department of Sustainable Agriculture and Food Systems.
<https://www.kpu.ca/agriculture/student-research/Vistan>
- Yadav S, Malik RK, Humphreys E, Kumar V, Singh SS, Chauhan BS, Kamboj BR, Gathala M, Jat ML, McDonald AJ, Laik R. 2013. Guidelines for dry seeded rice (DSR) in the Eastern Gangetic Plains of India. Los Baños (Philippines): International Rice Research Institute.
https://csisa.org/wp-content/uploads/sites/2/2013/10/DSR-EGP_English.pdf
- Zhang Z, Zhang S, Yang J, Zhang J. 2008. Yield, grain quality and water use efficiency of rice under non-flooded mulching cultivation. *Field Crops Res.* 108(1):71–81. doi:10.1016/j.fcr.2008.03.004.
- Zhao Z, He W, Chen G, Yan C, Gao H, Liu Q. 2024. Dry direct-seeded rice yield and water use efficiency as affected by biodegradable film mulching in the northeastern region of China. *Agriculture.* 14(2):170. doi:10.3390/agriculture14020170.