Effectiveness of Wildlife-Friendly Farming on Paddy Field Biodiversity: A Case of Sado Island in Central Japan

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Abstract

Paddy fields are known to serve as alternative wetland habitats for a range of aquatic and semi-aquatic wildlife that once inhabited floodplain wetlands. However, modernisation of agriculture led to loss of biodiversity in Japanese paddy fields. Implementation of wildlife-friendly farming is considered effective means to restore paddy field biodiversity and to revitalise depopulated rural communities. Sado Island (Niigata Prefecture) in central Japan was designated a Globally Important Agricultural Heritage System site in 2011. Sado is known for its island-wide wildlife-friendly farming practices using crested ibis (*Nipponia nippon*) as a wildlife icon. Typical wildlife-friendly farming practices include reduction or omission of agrochemicals (chemical pesticides and fertilizers) and creation of wildlife habitats, such as winter flooding practice and diversion ditch implementation. In this presentation, I will introduce a novel method to assess cost-effectiveness of wildlife-friendly farming by integrating ecological and economic analyses. I will subsequently introduce an experimental study evaluating the effects of different water management practices on amphibians, spiders and macroinvertebrates in agrochemical-free (organic) farming. Based on these results, organic farming with diversified flooding practices in the winter–spring period is recommended to enhance aquatic and terrestrial animal diversity, which in turn, may lead to promotion biological control by natural enemies.

Keywords: Globally-Important Agricultural Heritage System (GIAHS), Biodiversity, Organic farming, Water management, Rice farming

Introduction

Paddy fields are known to serve as alternative wetland habitats for a range of aquatic and semi-aquatic wildlife that once inhabited floodplain wetlands (Natuhara 2013, Usio 2015). However, biodiversity in paddy fields are threatened in many parts of Monsoon Asia, due to the overuse of agrochemicals (i.e. chemical synthetic pesticides and fertilizers), land consolidation and changes in farmland management practices. In Japan, considerable attention has been given to wildlife-friendly farming (Usio 2015). Wildlife-friendly farming is typically performed with reduction or omission of agrochemicals or creation of wildlife habitats. Increased attention has been given to effectiveness of wildlife-friendly farming on paddy field biodiversity.

Sado Island (Niigata Prefecture) in central Japan provides an ideal place for evaluating the effectiveness of wildlife-friendly rice faming. In 2008, a reintroduction programme for the crested ibis (*Nipponia nippon*) started on Sado Island. At the same time, the Sado City government introduced Toki Brand Rice Certification Initiative to rice agriculture using the crested ibis as a wildlife icon. Owing to sustainable ecological restoration activities of Satoyama landscapes using crested ibis as a wildlife icon and indigenous culture influenced by Aikawa gold and silver mine, Sado City was designated a Globally Important Agricultural Heritage System (GIAHS) site in 2011. In addition to reduction or omission of agrochemicals during the rice cultivation period, prolonged flooding practices, such as winter flooding, early-spring flooding and unimplementation of midseason drainage have also attracted attention to promote paddy field biodiversity.

Through the island-wide surveys of over 390 paddy fields across heterogeneous landscapes on Sado Island, our research team has previously shown that agrochemical reduction and fallow flooding were major practices influencing macroinvertebrate diversity in summer, while water coverage and diversion ditch implementation were major factors affecting macroinvertebrate diversity in winter (Usio *et al*. 2015).

In this presentation, I will first introduce a novel method to assess cost-effectiveness of wildlife-friendly farming through integration of ecological and economic approaches. Because agrochemical-free farming (hereafter termed organic farming) was most cost-effective in enhancing a rage of biodiversity indicators, I will subsequently introduce an experimental study that tested whether different water management practices differentially affect amphibians, spiders and macroinvertebrates in organic farming.

Methods

Cost-effectiveness of wildlife-friendly farming

Biodiversity surveys were performed using terrestrial plants, aquatic plants, wandering spiders (on levees), web-spinning spiders (on rice plants), zooplankton and aquatic maroinvertebrates as biodiversity indicators in 18 paddy fields in Kuninaka Plain on Sado Island (Fig. 1). Four types of paddy fields were selected with 4–5 replicates each: 1) organic farming with winter flooding practice, 2) herbicide farming with winter flooding practice, 3) agrochemical farming with winter flooding practice, 4) agrochemical farming without winter flooding practice (conventional farming). Taxonomic richness or abundance of dominant taxa were determined in the four types of paddy fields.

To evaluate the difficulty of implementing each wildlife-friendly faming practice, a questionnaire survey was performed. The questionnaire was mailed to all 5,010 farmers on Sado Island. To quantify the relative difficulty of implementing each of representative wildlife-friendly farming practices, the best-worst scaling approach was employed (Finn and Louviere 1992), a simple evaluation technique used in the field of environmental and resource economics.

Cost-effectiveness was calculated based on effectiveness (taxonomic richness or abundance of biodiversity indicators) and cost (difficulty of implementing farming practice).

Effects of water management practice on amphibian, spider and macroinvertebrate diversity

Using 12 experimental paddy fields, a 1.5-year experimental study was performed in 2011–2012 that tested the effectiveness of prolonged flooding practices on paddy field biodiversity (Fig. 2). A 2 × 2 factorial design (with and without midseason drainage and winter-spring flooding practice) was adopted with 3 replicates each in a completely randomised design. Macroinvertebrates, web-spinning spiders and amphibians (egg mass) were used as biodiversity indicators.

Results and discussion

Cost-effectiveness of wildlife-friendly farming

As a result of the questionnaire survey (response rate: 44.5%) and the best-worst scaling, organic farming was considered the most difficult practice while winter

flooding was regarded the least difficult practice. Nevertheless, organic farming turned out to be most cost effective in terms of enhancing a range of biodiversity indicators. On the other hand, winter flooding practice alone was not cost-effective despite its wide-spread implementation across Sado Island.

Effects of water management practice on amphibian, spider and macroinvertebrate diversity

Effectiveness of prolonged flooding practices on aquatic and terrestrial animals were variable depending on taxon. Macroinvertebrate taxonomic richness, total macroinvertebrate abundance and the abundance of five major macroinvertebrate taxa (Odonata, Ephemeroptera Heteroptera, Gastropoda, and Coleoptera) were greater in paddy fields without than with midseason drainage. Although the abundance of Nematoda and Oligochaeta in winter were greater in paddy fields with than without winter-spring flooding practice, the abundance of Odonata larvae was less in paddy fields with than without such practice. For Spiders, the abundance of *Tetragnatha* was greater in paddy fields without than with midseason drainage. The egg masses of montane brown frog (*Rana ornativentris*) and Japanese black salamander (*Hynobius nigrescens*) were more numerous in paddy fields with than without winter-spring flooding practice.

Overall, unimplementation of midseason drainage leads to enhance aquatic macroinvertebrate diversity and *Tetragnatha* abundance in summer. In contrast, the effects of winter-spring flooding practice were variable depending on taxonomic groups and season; amphibians (egg masses) were positively influenced, *Tetragnatha* spiders showed no measurable effect and the responses of macroinvertebrates were variable depending on taxon.

Implications for wildlife-friendly farming

Despite the difficulty of implementation, organic farming turned out to be most cost effective in enhancing a range of biodiversity indicators. When implementing organic practices, flooding practices should be diversified in the winter–spring period to enhance a range of aquatic and terrestrial animals, which in turn, may lead to promotion of biological control by natural enemies. If possible, midseason drainage should be avoided in organic farming. When midseason drainage is inevitable, water should be kept at a minimal depth to avoid complete desiccation of paddy sediments.

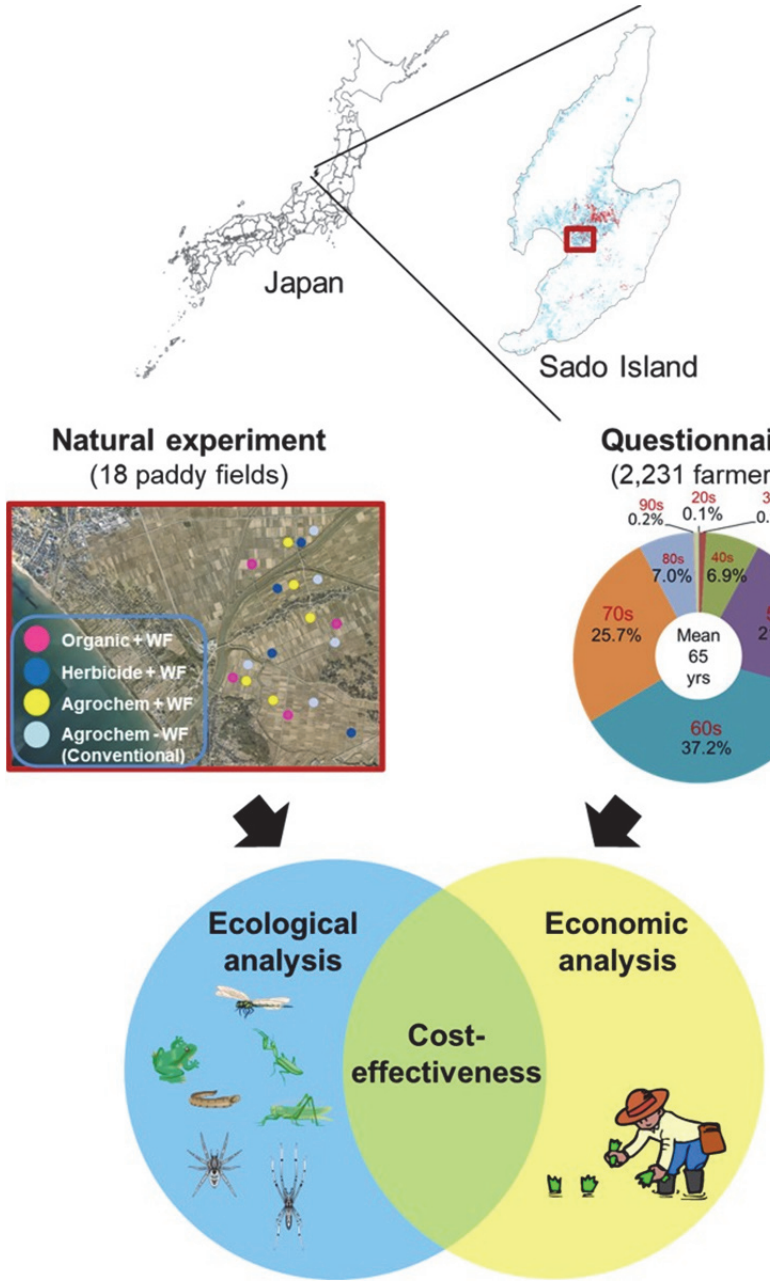

Fig. 1. Diagram of integrated ecological and economic analyses in cost-effectiveness calculation. A natural experiment was conducted with 4 treatments comprising 1) organic farming + winter flooding (WF), 2) herbicide farming + WF, 3) agrochemical farming + WF and 4) agrochemical farming without WF (conventional farming) in a total of 18 paddy fields (4–5 replicates each). Economic analysis was based on a questionnaire survey (2,231 farmers) with the best-worst scaling approach (Tsuge *et al* 2015).

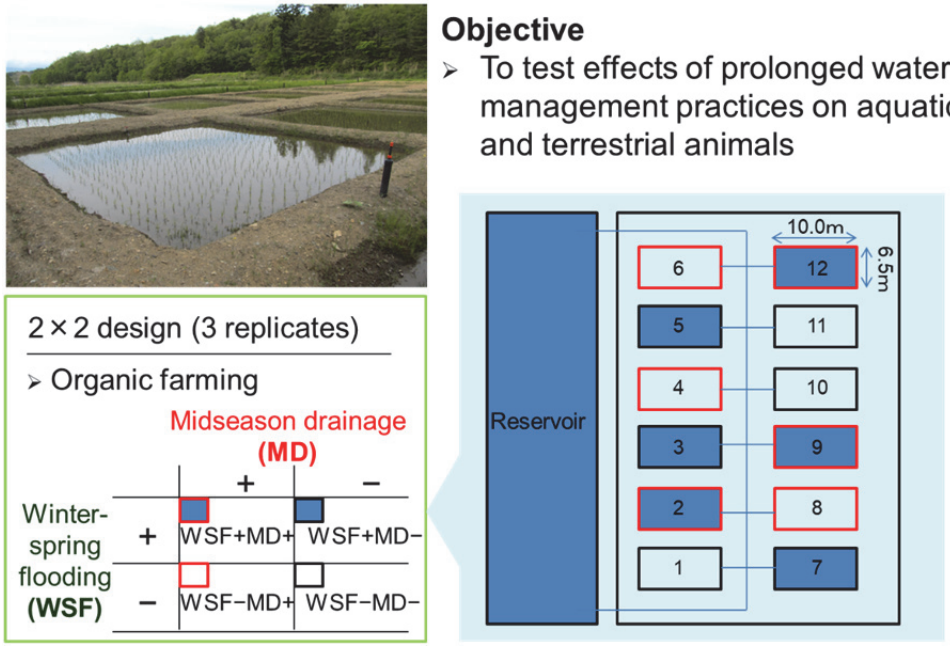

Fig. 2. Plan of 12 experimental paddy fields. A manipulation experiment was performed with or without winter-spring flooding practice and midseason drainage with 3 replicates each in a 2 × 2 factorial design. The experiment was conducted in 2011–2012.

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友善野生動植物農耕對水稻田生物多樣性的效益：以日本中部佐渡島為例

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摘要

對多種曾經居住在洪泛濕地的水生及半水生野生動植物來說，稻田是濕地棲地的替代選擇，然而農業現代化已經導致日本稻田的生物多樣性流失。野生動植物友善耕作被認為是可以有效恢復稻田生物多樣性以及能讓人口流失鄉村社區再生的方法。日本中部新潟縣的佐渡島在 2011 年時獲譽為全球重要農業文化遺產，佐渡最為人所知的就是全島範圍實行的野生動植物友善耕作，及選用朱鷺作為其野生動植物的象徵。典型的野生動植物友善耕作包含使用零或少量的農業化學品（化學除蟲劑及肥料）進行耕作，並提供野生動植物棲息地，譬如冬季灌水作業以及截水溝的使用。在此報告中，我將會整合生態及經濟分析，建立的新穎評估方法，評估野生動植物友善耕作的成本效益，並提出一實驗研究，評估在零農業化學品（有機）耕作中，不同水管理方式對兩棲動物、蜘蛛、大型脊椎動物的影響。根據研究結果，本研究建議使用有機耕作搭配冬春季間的多樣化灌水方式，藉以增進水陸生動物的多樣性，進而透過天敵促進生物控制。

關鍵詞：全球重要農業文化遺產、生物多樣性、有機農業、水管理、稻米耕作

為使多數讀者可清楚瞭解本研究內容，本場特委託專業翻譯團隊將原文譯為中文，為利閱讀流暢，部分語句可能與原文直譯略有差異。

前言

稻田對於多種曾經居住在洪泛濕地的水生及半水生野生動植物來說，是濕地棲息地的替代選擇 (Natuhara 2013, Usio 2015)，然而在許多季風亞洲地區，稻田的生物多樣性正因為農業化學品（化學合成除蟲劑及肥料）的過度使用、土地重劃及農地管理方式的改變而受到威脅。在日本，野生動植物友善耕作已經受到大量關注 (Usio 2015)，野生動植物友善耕作通常不使用或使用較少的農業化學品，抑或是提供棲息地給野生動植物，因此這類耕作方式對稻田生物多樣性的效益已經獲得越來越多的關注。

日本中部新潟縣的佐渡島提供了一個可以評估野生動植物友善稻米耕作效益的理想場域。2008 年時，朱鷺 (*Nipponia nippon*) 野放計畫開始在佐渡島上執行，同時佐渡市政府以朱鷺為野生動植物的象徵，對稻米業者發起了朱鷺牌稻米認證倡議 (Toki Brand Rice Certification Initiative)。因為佐渡市針對里山景觀所執行的以朱鷺為野生生物象徵的永續生態復育活動，以及受愛川町金銀礦場所影響的本土文化，佐渡市在 2011 年被列為全球重要農業文化遺產。除了零用量或少量農業化學品的稻米栽培過程外，野生動植物友善耕作中長期灌水的做法，如冬季灌水、早春灌水和不執行季中排水，也已經成為了備受關注的稻田生物多樣性促進方法。

本研究團隊先前透過調查佐渡島上擁有異質景觀的 390 個稻田，發現在夏天時，大型脊椎動物多樣性主要受農業化學品減量及休耕灌水影響，而冬天時，多樣性主要受水覆蓋範圍及截水溝的使用所影響 (Usio *et al.* 2015)。

在本報告中，我首先會提出一個整合生態及經濟的新穎方法，評估野生動植物友善耕作成本效益，而因為零農業化學品耕作（以下簡稱有機耕作）在增進生物多樣性指標上能達到最高的成本效益，以下將會提出一項實驗性研究，測試有機耕作中不同水管理方式是否對兩棲動物、蜘蛛、大型脊椎動物有不同的影響。

研究方法

野生動植物友善耕作的成本效益

本研究以陸生植物、水生植物、（田埂上的）櫛足蜘蛛、（稻米株上的）結網蜘蛛、浮游動物以及大型水生脊椎動物為生物多樣性指標，針對佐渡島國仲平原的 18 處稻田進行生物多樣性調查（圖 1）。我們調查了四種類的平原，每個種類的平原做 4 到 5 次重複：(1)有機耕作搭配冬季灌水、(2)除草劑耕作搭配冬季灌水、(3)農藥化學品耕作搭配冬季灌水、(4)農藥化學品耕作無冬季灌水（傳統耕作方式），以確認各類稻田分類群數或優勢種群的豐富度。

為評估各種野生動植物友善耕作的執行難度，本研究進行問卷調查，將問卷以郵寄方式寄給 5,010 位佐渡島的農夫，並使用常運用在環境及資源經濟領域的簡單評估技巧，最佳最差尺度 (best－worst scaling；Finn and Louviere 1992)，來量化各個野生動植物友善耕作方式的相對執行難易度。

野生動植物友善耕作的成本效益以其效益（分類群數或優勢種群豐富度）及成本（耕作執行難度）來計算。

結果與討論

野生動植物友善耕作的成本效益

問卷調查（回收率：44.5 %）以及最佳最差尺度的結果顯示，有機耕作是最難執行的耕作方式，冬季灌水則是最容易的方式。然而結果指出，有機耕作在增進生物多樣性上是最具有成本效益的，而雖然單獨使用冬季灌水的方式在佐渡島上廣泛地使用，但是此耕作方式並不具成本效益。

水管理方式對兩棲動物、蜘蛛、大型脊椎動物多樣性的影響

長期灌水對水陸生動物的效益隨分類群變動，在沒有季中排水時，大型脊椎動物的分類群數、總豐富度以及五類優勢種群（蜻蜓目、浮游目、異翅亞目、腹足綱、鞘翅目）的豐富度較有季中排水時高。相較於沒有冬春季灌水的情況，雖然在有冬春季灌水的情況下，稻田裡的線蟲動物門及貧毛綱在冬天有更高的豐富度，但蜻蜓幼蟲的豐富度卻較低。對蜘蛛來說，稻田內長腳蛛屬的豐富度在沒有季中排水時較有季中排水時來得高。相較於沒有冬春季灌水時，山棕蛙以及黑山椒魚在有冬春季灌水時有較多的卵團數量。

整體來說，不使用季中排水可以增進夏天時大型水生脊椎動物的多樣性以及長腳蛛屬的豐富度。相反地，冬春季灌水的影響隨著分類群以及季節的不同而有所變化，對兩棲類（卵團）有正面影響，但對長腳蛛屬則沒有可測量到的影響，而對大型脊椎動物來說，影響隨分類群變動。

野生動植物友善耕作的啟示

儘管有機耕作有一定的困難度，但結果顯示有機耕作在增進生物多樣性上是最具有成本效益的耕作方式。在執行面上，應在冬春季期間使用多樣化灌水方式，增加多種水陸生動物的多樣性，進而透過自然天敵來促進生態控制。在狀況允許下，採用有機耕作時應避免季中排水，若必須執行季中排水，應確保水位最少有一定的量，以避免稻田底泥完全乾涸。

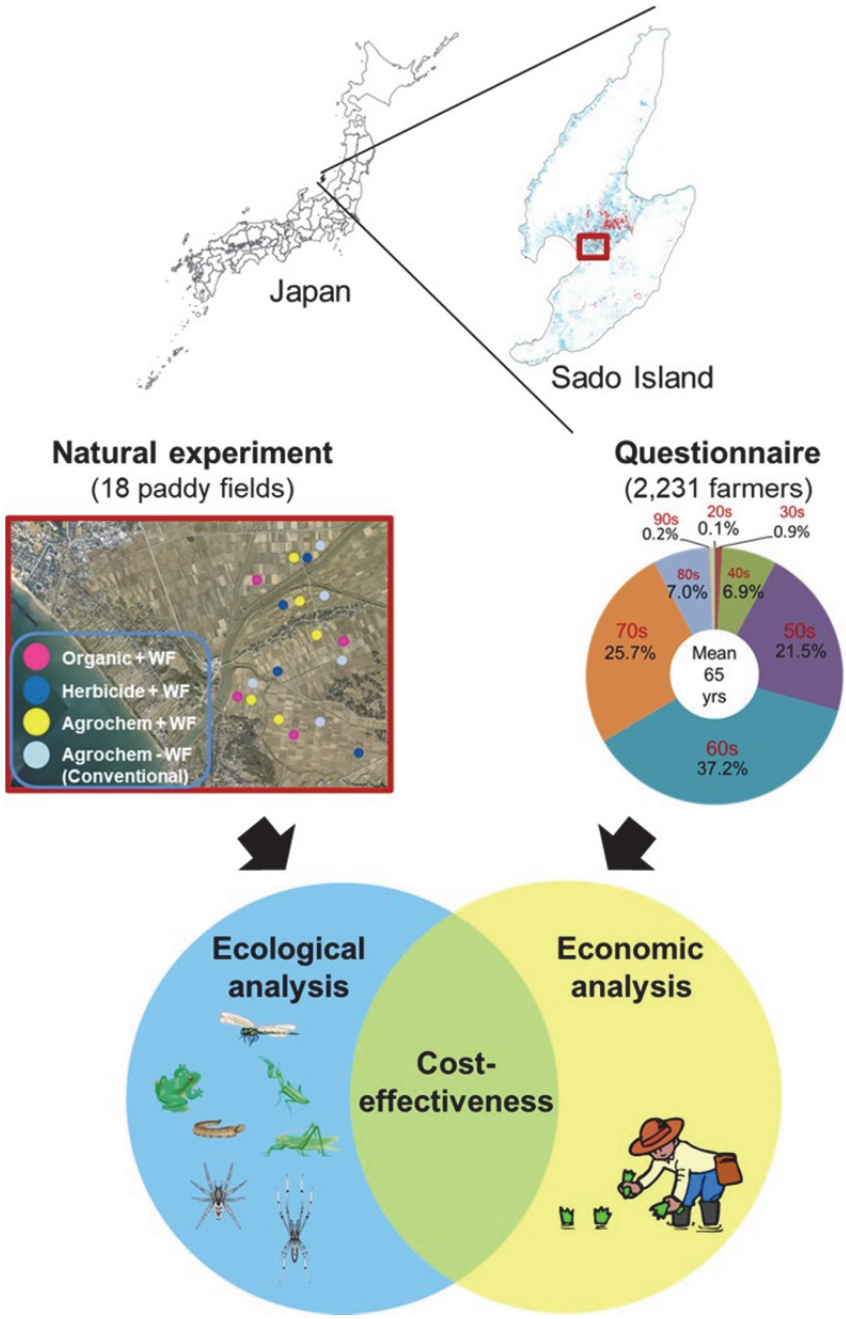

圖 1、整合生態及經濟分析的成本效益計算示意圖：使用以下四種處理在 18 處稻田裡執行自然實驗：(1)有機耕作搭配冬季灌水、(2)除草劑搭配冬季灌水、(3)農業化學品耕作搭配冬季灌水、(4)農業化學品耕作無冬季灌水（傳統耕作方式；每個處理做 4 到 5 次重複）。經濟分析以問卷調查（2,231 位農民）及最佳最差尺度方法執行 (Tsuge *et al* 2015)

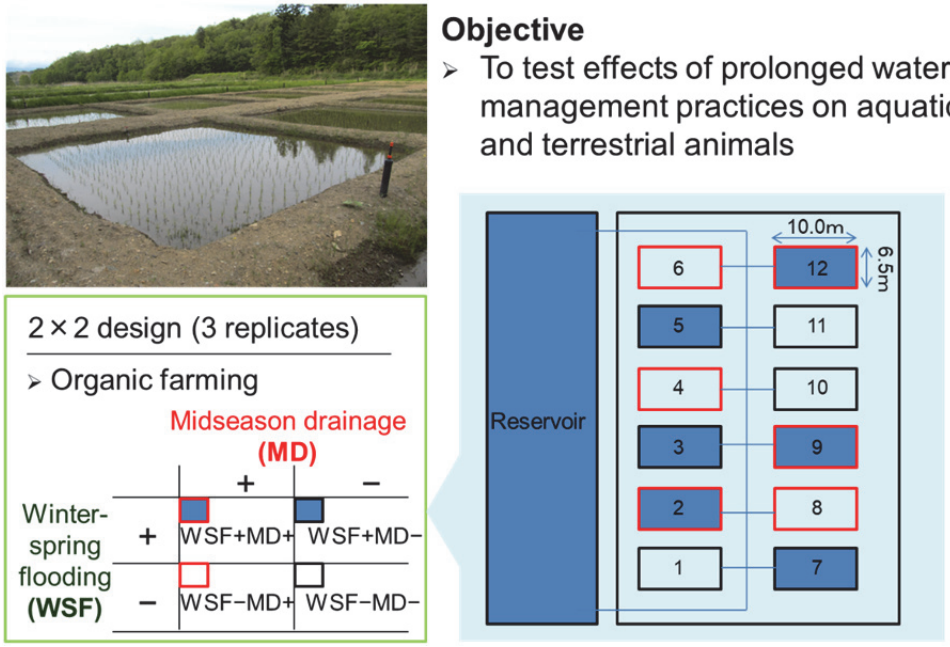

圖 2、12 處實驗稻田的平面圖：以是否使用冬春季灌水以及季中排水來執行操控實驗，每個稻田做 3 次重複，採用 2 × 2 因子設計，此實驗於 2011 至 2012 年間執行。