Chapter 7
Rice Production in Australia

Ali Ahsan Bajwa and Bhagirath Singh Chauhan

7.1 Summary

The rice production is a profitable agro-based industry in Australia. Although the area under rice cultivation and total production in Australia is very little in proportion to global rice production, its unique agronomy and crop management are notable. Since the inception of rice cultivation in irrigated areas of New South Wales (NSW) and Victoria states of Australia in the early twentieth century, this industry has progressed by leaps and bounds. Rice sowing methods in Australia include wet seeding in cultivated water bays, direct dry seeding in previous crop stubbles, and direct seeding on permanent raised beds. The medium-grain temperate varieties perform best under Australian conditions, and many of these have been developed locally through breeding, keeping in view the local climatic and edaphic conditions. Australian farmers produce the most water-efficient rice in the world. The escape from major pests and diseases and good management practices allow them to obtain the highest yield per hectare as compared to all other rice-producing countries. Several weeds infest rice fields in Australia, but effective management through herbicides is in practice. The overall crop husbandry is well mechanized right from sowing to harvest. An integrated system connects farmers, industry, and the government stakeholders which ensures the excellent crop production followed by excellent

---

A.A. Bajwa (✉)
School of Agriculture and Food Sciences, The University of Queensland,
Gatton, QLD 4343, Australia

The Centre for Plant Science, Queensland Alliance for Agriculture and Food Innovation
(QAAFI), The University of Queensland, Gatton/Toowoomba, QLD 4343/4350, Australia
e-mail: a.bajwa@uq.edu.au

B.S. Chauhan
The Centre for Plant Science, Queensland Alliance for Agriculture and Food Innovation
(QAAFI), The University of Queensland, Gatton/Toowoomba, QLD 4343/4350, Australia

B.S. Chauhan et al. (eds.), *Rice Production Worldwide*,
DOI 10.1007/978-3-319-47516-5_7

processing and marketing within and out of the country. The declining water resources, the terminal cold stress during the reproductive stage of rice crop, and the environmental concerns are major constraints to the Australian rice industry. However, the highest water-use efficiency, rapid adoption of innovative conservation technologies, development of new cultivars suitable for the changing climate, and integrated research with holistic approach are strong features of this enterprise.

7.2 Introduction

The rice production in Australia is quite different from the rest of the world in the perspective of production, processing, and marketing. The rice is produced only in a few regions of the country due to strict regulations about water and land use for rice production. The Riverina region of NSW (latitude 33–36°S) is the main hub of rice production in Australia (Thompson 2002). Almost all the rice is grown in this valley with exception of a small acreage in Queensland and Western Australia. However, the cultivated area and production from those sites are negligible. The Riverina Valley is irrigated by two major rivers, Murrumbidgee and Murray, and the rice crop uses up to 70 % of the available irrigation water. The overall share of rice production from Australia to global production might be only 1 %, but the sustainable production under harsh climates is a success in its own way (Humphreys et al. 2006). With the highest yields per unit area and water-use efficiency, Australian rice has proved its worth internationally (Khan et al. 2010; RGA 2015). The adoptions of technology, immense coordination between growers, policy makers, and marketing authorities, and good management practices have made Australian rice a success. The rice production system in Australia has gone through a series of transformations, and many agricultural scientists quote the Australian rice industry as a fine example of agricultural innovations and technology adoption. One of the leading agricultural development departments in Australia, the Rural Industries Research and Development Corporation (RIRDC), ranked Australian rice industry as the world leader in agricultural innovation, resource conservation, sustainable production, and environmental safety on the eve of launching Rice 2012–2017 Research and Development (R&D) Plan (RIRDC 2015).

The dry climate and shrinking water resources are the main limiting factors to the growth of Australian rice industry (Lewin and Heenan 1985; Humphreys et al. 2006). The rice growers have managed to sustain rice production in spite of immense pressure from the government and community (Lewis 2012). It has emerged as a great enterprise being run by the farmers and government jointly without any added subsidies. Australian rice has not only gained popularity due to high yields and water-use efficiency but is also well known for its high quality (SunRice 2015). Semidwarf temperate varieties developed by Australian scientists have performed very well under local conditions. The rice growers pay special attention to water use, land use, and environmental protection by adopting various efficient production systems suitable under different cropping rotations (McDonald 1994; Thompson 2002; Humphreys et al. 2006). The lower incidence of natural pests and diseases under Australian conditions is an added benefit (Stevens et al. 2006). The future of rice production in Australia is bright, keeping in view the pace of ongoing research and development.

This chapter focuses on the crop husbandry, management practices, and use of innovative technologies for rice production in Australia. The basic principles and practices of rice production in Australia have been discussed. The developments over time and future endeavors have also been highlighted along with the elaboration of constraints and opportunities.

7.3 History

Rice was one of the earliest crops introduced in Australia after British settlement in the continent. Having vast experience of growing rice in America and India, English people also tried rice farming in different regions of Australia. However, due to the climatic differences, varying soil fertility, and other management constraints, it was mostly unsuccessful. Although northern regions of Australia have plenty of water, rice production was never successful there mainly due to iron and manganese toxicity in the soil and pest problems (RGA 2015). Some sources indicate the entry of rice seeds to Australia back in the 1850s when Chinese people came here as a part of famous “Gold rush.” Rice was cultivated first time in 1906 in Murray River basin near Swan Hill by a former Japanese parliamentarian, Isaburo Takasuka, who was given 80 ha for this purpose by the state government of Victoria (RGA 2015). Although it was an unsuccessful experience due to droughts and floods, he continued the effort, and the crop was grown and produced on a commercial scale in 1914. In the 1920s, the opportunity of growing rice as irrigated crop in Murray-Darling basin was availed, and since then, it has become the core area of rice production in Australia (RGA 2015). Almost all the Australian rice production comes from this area. The first commercial rice crop was produced in 1924 by a group of eight farmers in Murrumbidgee Irrigation Area (MIA) (around Leeton and Griffith). The seed was imported from California by the NSW government. In 1928, the NSW government established the Rice Marketing Board to regulate the marketing and export of Australian rice. A company, Ricegrowers Limited (SunRice), was registered to buy and export Australian rice, and it is the sole authorized buyer of rice produced in NSW for domestic and international outlets since then.

During the World War II, rice was declared as an essential and precious food commodity, and the Commonwealth pushed the NSW government to reach the target of 100,000 tons during that period (SunRice 2015). The task was nearly impossible due to shortage of water in the Burrinjuck dam; however, keeping in regard the crucial, the NSW government decided to improve cooperation with farmers and to expand the area under rice cultivation (RGA 2015). In cooperation with the Ricegrowers’ Association of Australia (RGA), the NSW government formed the Rice Production Committee (RPC), and rice cultivation was started in Murray Valley in addition to MIA. After the establishment of RGA, the rice production in Australia flourished a lot. A royal commission not only investigated the causes of rice failure in MIA but also focused on the cooperation and marketing. The "SunRice" worked efficiently on storage, milling, processing, packaging, sale, and export of Australian rice. The first rice mill was opened in 1951 in Leeton. Temperate rice varieties from California performed well in Riverina. In the 1950s, the rice production recovered a boost in Australia. The number of rice farmers in MIA increased from 368 in 1950 to 591 in 1955. In addition, 310 growers also started rice cultivation in Murray Valley by 1955. Such a substantial increment improved the economy of that area, and rice production became a profitable industry (SunRice 2015). Nowadays, over 1500 farm businesses are linked with rice production in MIA of NSW and Murray Valley of NSW and Victoria (RGA 2015).

7.4 Area and Production

Rice in Australia has an area of 52,000 ha, a production of 819,000 tons, and an average yield of >10 t ha^{-1}. More than 85 % of Australian rice is exported to over 70 countries across the globe (RGA 2015). During the last decade, Australia has increased rice yield per hectare by 30 % while reducing the water consumption by 60 %, which is a remarkable achievement by any means in modern-day agriculture. Rice production shares 11 % of the total irrigation water available for agriculture. Some of the key facts about Australian rice are given in Table 7.1. In the recent years, the production has decreased due to drought. The highest yield per unit area, excellent quality, 50 % less usage of water for every kilogram of rice produced as compared to the rest of the world, and environmental friendly cultural practices make Australian rice superior and unique.

Table 7.1 Latest facts and figures about rice in Australia (2013–2014)

Cultivated area	52,000 ha
Annual production	819, 000 tons
Per capita consumption	10 kg per annum
Domestic use	15 % of total production
Export	85 % of total production
Average national yield	10.7 t ha^{-1}
Farm gate value of industry	A$ 350 million
Total value including exports	A$ 800 million
Rank in Australian exported grains	Third
Rank in Australian exported agricultural commodities	Ninth

Sources: Australian Bureau of Statistics (2015), National Farmers' Federation (2015), SunRice (2015)

7.5 Production Methods and Cropping Systems

All the rice sown in Australia is irrigated, mostly through river water or sometimes groundwater. The rice is grown in summer season in Riverina, and sowing starts in the month of October. The rice seeds are either dispersed aerially in flooded fields (wet-seeded) or directly drilled in dry soil (dry-seeded) followed by irrigation (Thompson 2002). Pre-germinated seeds and dry seeds are sown for wet seeding and dry seeding, respectively. For dry seeding, 120 kg seed ha^{-1} is drilled in 15 cm apart rows at the depth of 1–3 cm. First irrigation is applied immediately after seeding, but water is drained out after 24 h (Lewin and Heenan 1985). Rice fields are kept flooded for most part of the growing season. A water depth of 15–25 cm is maintained depending upon the crop growth stage. A layer of water protects rice plants from high day temperatures during early growth stages and also provides insulation against very low night temperatures after the month of January. Under certain instances, flooding is started after the three-leaf stage, but this prolongs the crop (Thompson 2002). The soil type for rice production is very important and given special attention in Australia. The heavy soils with high water holding capacity are usually preferred. Moreover, the whole area allocated to one farmer for rice production cannot be cultivated in one season. In this regard, farmers have to get approval from respective irrigation corporation (the Murrumbidgee Irrigation Limited, Murray Irrigation Limited, or Coleambally Irrigation Cooperative Limited) before having a license from the state government (Thompson 2002; RGA 2015). The land suitability is determined before the approval to grow rice mainly on the basis of soil water holding capacity, infiltration rate, and runoff. No farmer can grow rice beyond a set limit on his farm. The subsoil water percolation should also be less than 200 mm (Beecher et al. 2000; Thompson 2002). Sowing is mostly done on a flat surface, but the raised bed system has also gained popularity due to high water-use efficiency and yield improvement. The land is prepared using laser land levelers, and usually the whole farm layout is designed in such a way that large bays are formed with strong soil embankments (bunds) to hold water (RGA 2015).

In Australia, the rice crop is usually followed by a fallow season of up to 6 months as the intensive cropping systems are not common. Hence, rice is grown as sole crop in most of the rice farming areas (Humphreys et al. 2006). However, some farmers also include winter crops like wheat, barley, and some legumes. As most of the rice fields are kept ponded for most part of the growing season, soil moisture levels are very high for the succeeding crops (Humphreys et al. 2006). The productivity of winter crops grown on rice-based permanent beds was increased by 26 % (Thompson and North 1994). The major benefits in this system were sufficient soil moisture, easy drainage, facilitated interculture and farm operations, and less losses during harvesting (Tisdall and Hodgson 1990; Beecher et al. 2003). Earlier, a single rice crop in 5 years in rotation with legume-based pastures was also common. Still many farmers practice such rotations because they cannot grow rice on more than a specified area (McDonald 1979). The direct drilling of rice in pasture sward is useful to reduce the cost of production (Lewin and Heenan 1985). The seed is drilled at the rate of 140 kg ha^{-1} with a triple disk seeder in a well-grazed dry pasture at 15 cm row-row distance. A knockdown herbicide is applied prior to seeding to avoid pasture regrowth. The permanent water stand is established after three-leaf stage (Lewin and Heenan 1985). This rotation significantly improves rice yield because of improved soil fertility, suppression of diseases and pests, and weed control due to well-established preceding pasture crop (Lewin 1979).

7.6 Varieties

Temperate rice varieties are grown in Australia. More than 80 % of Australian rice is raised from semidwarf medium-grain japonica varieties (Thompson 2002). Similar varieties performed well in the Mediterranean regions and California due to a similar kind of climate (Thompson 2002). Eleven varieties are being successfully grown in Australia. These have high water-use efficiency and yield potential. Australian scientists have developed most of these varieties through breeding by using germplasm from California and other temperate rice-growing regions (RGA 2015). The first semidwarf medium-grain variety, M7, was introduced in 1983 in Australia and proved successful (Humphreys et al. 2006). Several semidwarf varieties were developed and released for commercial use in the following years. Those varieties had multiple quality traits, but major focus was given to the water-use efficiency. Since 2001, almost 97 % rice cultivation in Australia was based on such semidwarf medium-grain varieties (Humphreys et al. 2006). During 4 years field trails in the eastern Murray Valley, the semidwarf medium-grain cultivars, Illabong and Amaroo, produced 9.3 and 10.1 t ha^{-1} rice grains, while a tall variety, Calrose, produced 7.9 t ha^{-1} (Humphreys et al. 2006).

Several semidwarf varieties, including Amaroo, Doongara, Illabong, Jarrah, Kyeema, Langi, Millin, and Opus, were locally developed and released for Australian rice growers during 1987 to 1999. Those varieties covered a large area due to the added benefits of efficient water use and higher yield (Humphreys et al. 2006). The rice industry of NSW not only regulates the development and dissemination of new varieties but also ensures the pure seed availability to all the registered growers. However, growth period reduction to improve the water-use efficiency also caused yield reduction (Reinke et al. 1994; Williams et al. 1999). Developing cold-tolerant (during reproductive stage) varieties in addition to high yield and water-use efficiency is another major task of breeding program (Farrell et al. 2000).

7.7 Irrigation Management

Water shortage is a major concern in Australian rice production. Australia is the driest continent of the planet, and, thus, the freshwater is considered a precious resource (RGA 2015). The rice-producing area of Australia is mainly irrigated by the Murray and Murrumbidgee rivers. The average evapotranspiration during the whole growing season is 1200 mm. Soils having root zone drainage of more than 200 mm ha^{-1} are restricted for rice production (Thompson 2002). Water use for rice production in Australia is almost 50 % less than that for the rest of the world (RGA 2015). Rice growers have improvised the irrigation management in a number of ways to improve the water-use efficiency. The alternate flooding and drying system (intermittent irrigation) is one such conservation method in which water is applied to saturate the root zone every week, but fields are not kept flooded continuously until panicle initiation starts. Rice reproduction being a highly sensitive water limitation, fields are kept flooded onward from panicle initiation (Thompson 2002). In this way, 23–26 % water saving is achieved in comparison with permanent flooding after the three-leaf stage. Heenan and Thompson (1984) concluded that the intermittent irrigation system was water saving, without reducing the yield and quality of rice at Yanco, MIA. The localized irrigation for the rice crop grown on raised beds is another way to enhance irrigation efficiency. Borrell et al. (1997) reported up to 32 % water saving in this system in Queensland. Australian rice water productivity has significantly improved over the years mainly due to higher yields and reduction in water use (Humphreys and Robinson 2002). The improved water-use efficiency of Australian rice is mainly attributed to yield improvement through an innovative approach, rapid technology adoption, varietal improvement, excellent regulations like the Ricecheck approach by the NSW Department of Primary Industries (DPI), improved nitrogen management, and judicious irrigation scheduling (Russell and Dunn 2001; Macadam et al. 2002; Ciavarella et al. 2003; Humphreys et al. 2006). On the other hand, the substantial cuts in water use through setting up a water-use limit, reduction in deep percolation, intermittent irrigation approach, raised bed technique, and good crop husbandry practices have also improved the overall water-use efficiency in rice (Muirhead et al. 1989; Bouman and Tuong 2001; Humphreys et al. 2001, 2003; Beecher et al. 2002; Thompson et al. 2003; Khan et al. 2004; Humphreys et al. 2006).

7.8 Nutrient Management

Nitrogen (N) is the only mineral nutrient applied in the form of fertilizer to rice crop in Australia. A rare use of other macro- or micronutrient-based fertilizers also exists. N is mostly applied in the form of urea as a basal dose, but the amount of fertilizer depends on the rotation being followed (Lewin and Heenan 1985). The use of anhydrous ammonia and ammonium sulfate as N fertilizer has also been reported (McDonald 1979). On the lands where rice is grown in a rotation with legume pastures, usually no N fertilizer is applied. N fixed biologically through legume pastures is sufficient for the rice crop in the following season. Chapman and Myers (1987) found that rice grown in rotation with soybean and sesbania crops had no N fertilizer requirements and the yield was also significantly higher as compared with the rice grown in rotation with fallow fields. Up to 260 kg N ha^{-1} was added by these legumes, which was available for the rice crop. However, the soils having low fertility status needed around 200 kg N ha^{-1} for semidwarf short-grain rice varieties (Lewin and Heenan 1985).

In case of wet-seeded aerially sown rice, the whole N fertilizer is mixed in the soil before flooding, whereas the N is applied at the three-leaf stage in dry-seeded rice when farmers start holding water in those fields (Boerema 1970). There might be N top dressing in some cases depending on rice variety, crop rotation, and total N requirement (Heenan and Lewin 1982; Bacon and Heenan 1997). In a broader view, the average N application rate was reported to be 120 kg ha^{-1} (Batten et al. 2001). The decision about the right dose and timing of N application is very important (Humphreys et al. 2006). The overdose at an earlier vegetative stage may lead to lodging and sterility particularly under cooler conditions during the reproductive phase (Williams and Angus 1994). In some soils, the N supply to plant roots may be hindered due to high ambient temperatures, which is another key factor to determine the adequacy of N fertilizer (Angus et al. 1994). Humphreys et al. (2006) suggested that increasing the N-use efficiency will also improve the water-use efficiency and may help to further enhance the productivity of Australian rice. Farmers still do not have reliable standard protocols to measure the actual N requirements for rice in a particular kind of soil. Research in this area may further boost the vertically oriented Australian rice industry.

7.9 Weed Management

Weeds are a major problem in rice fields, depending upon the sowing method and crop rotation (Lewin and Heenan 1985). A variety of weeds infest rice fields in Australia (Table 7.2). Usually the weed diversity and weed density in wet-seeded rice is much lower than dry-seeded rice. The most problematic weed species in Australian rice are *Echinochloa* spp. Earlier, the postemergence herbicides, thiobencarb, molinate, and propanil, were commonly used to control *Echinochloa* spp. with varying degrees of efficacy (Fisher et al. 1966; Penman and Jones 1984). Some farmers also used to apply postemergence herbicides in water during flooding (Fisher et al. 1966). In such a case, the efficacy was improved, but consideration of water depth and herbicide dose remained critical (Lewin and Heenan 1985). Aerial sowing of rice in flooded bays had problems of *Cyperus difformis* L. which was controlled through application of MCPA (Nott et al. 1974). However, the application of MCPA had a negative effect on rice growth, especially when applied before tillering. The application after tillering was ineffective because weed had already caused substantial losses to crop growth due to resource competition (Cox 1980). The use of thiobencarb to control *C. difformis* has also been reported but a risk of damage to small rice seedlings was associated with it (Lewin and Heenan 1985). The existence of *Typha* spp., especially in a rice crop grown in shorter rotations, was also reported (Lewin, 1979). The best management strategy for *Typha* spp. was found to be the manual eradication and herbicide (MCPA) application during the fallow period (Lewin and Heenan 1985).

Table 7.2 Weed flora of Australian rice

Weed species	Family	Reference
Alisma lanceolatum With.	Alismataceae	McIntyre and Barrett (1985)
Ammannia spp.	Lythraceae	Hill et al. (1990)
Azolla filiculoides Lam.	Azollaceae	McIntyre and Barrett (1985)
Cyperus difformis L.	Cyperaceae	Nott et al. (1974), Cox (1980), McIntyre and Barrett (1985), Lewin and Heenan (1985)
Cyperus eragrostis Lam.	Cyperaceae	McIntyre et al. (1991)
Damasonium minus (R. Br.) Buchenau	Alismataceae	McIntyre and Barrett (1985), Lewin and Heenan (1985)
Diplachne fusca (L.) P. Beauv. ex Roem. & Schult.	Poaceae	McIntyre et al. (1991), Lewin and Heenan (1985)
Echinochloa colona (L.) Link	Poaceae	Penman and Jones (1984), McIntyre and Barrett (1985), Lewin and Heenan (1985)
Echinochloa crus-galli (L.) P. Beauv	Poaceae	Fisher et al. (1966), McIntyre and Barrett (1985), Lewin and Heenan (1985)
Echinochloa microstachya (Wiegand) Rydb.	Poaceae	McIntyre and Barrett (1985)
Echinochloa oryzoides (Ard.) Fritsch	Poaceae	McIntyre and Barrett (1985)
Elatine gratioloides A. Cunn.	Elatinaceae	McIntyre and Barrett (1985)
Eragrostis parviflora (R. Br.) Trin.	Poaceae	McIntyre et al. (1991)
Ludwigia peploides (Kunth) P.H. Raven	Onagraceae	McIntyre and Barrett (1985)
Lythrum hyssopifolia L.	Lythraceae	McIntyre and Barrett (1985)
Marsilea drummondii A. Braun	Marsileaceae	McIntyre and Barrett (1985)
Paspalum paspaloides (Michx.) Lams. Scribn.	Poaceae	McIntyre and Barrett (1985), Lewin and Heenan (1985)
Rumex crispus L.	Polygonaceae	McIntyre et al. (1991)
Rumex dentatus L.	Polygonaceae	Lewin and Heenan (1985)
Rumex tenax Rech. f.	Polygonaceae	McIntyre and Barrett (1985)
Sagittaria montevidensis Cham. & Schltdl.	Alismataceae	McIntyre and Barrett (1985)
Scirpus spp.	Cyperaceae	Hill et al. (1990)
Typha domingensis Pers.	Typhaceae	McIntyre and Barrett (1985)
Typha orientalis C. Presl	Typhaceae	McIntyre et al. (1991)

In a classic study, McIntyre and Barrett (1985) compared the weed flora of flooded rice in NSW and California in order to understand the species composition and diversity under similar cultural and management practices. In NSW, 55 weed species existed, while 60 were present in California. Only 13 species were found to be common at both sites, most of these were well-recognized rice weed species globally. However, large proportions (73 %) of weed species were native in NSW and shifted from aquatic habitats to wetland rice (McIntyre and Barrett 1985). Due to this reason, many native weed species were well adapted to flooded rice and were hard to manage. The effective weed control through herbicides has benefited the rice production in Australia for decades. However, the consistent use of herbicides has caused the evolution of herbicide resistance. The resistance against many commonly used herbicides was reported two decades ago (Hill et al. 1994; McDonald 1994). Taylor (2010) compared the efficacy of four herbicides against weeds in direct-seeded rice in Cobram, Victoria, in order to find a suitable alternative for benzofenap and molinate. Pentoxazone failed to control all the weeds and also had a toxic effect on rice crop when applied at the rate of 100–400 g a.i. ha^{-1}; however, etobenzanid (750 g a.i. ha^{-1}) provided effective control for most of the weeds, including *E. crus-galli* (Taylor 2010). The injury to rice crop was substantial when the rate of etobenzanid was increased to 1000 g a.i. ha^{-1}. Another herbicide, saflufenacil (200–300 g a.i. ha^{-1}), provided complete control of all major weeds with adequate crop tolerance (Taylor 2010). Hence, etobenzanid and saflufenacil might be the alternate herbicides with different modes of action from that of molinate and benzofenap and, thus, could offer a good strategy against herbicide-resistant weeds. Further research is needed in this area with emphasis on integrated weed management options.

7.10 Insect Pests and Diseases

There are only a few insect pests and diseases associated with rice crop in Australia; however, substantial yield losses are caused by them (Lewin and Heenan 1985). The bloodworm (*Chironomus tepperi)* is one of the most important rice insects, as it chews the root tips of rice and also shoots sometimes. To avoid the losses, different chemical insecticides are used, especially in aerially sown rice crop (Jones 1968). Incidence of armyworm (*Pseudaletia convecta*) and leaf miner (*Hydrellia* spp.) as insect pests on Australian rice has also been reported (Lewin and Heenan 1985). However, they can also be effectively controlled through several chemical insecticides. In addition to insects, snails are important pests in rice grown in rotations with winter cereals (Lewin and Heenan 1985). The snails may damage the young rice seedlings and, thus, have the ability to affect the crop stand at early growth stages. Similarly, algal growth in direct-drilled and aerially sown rice also causes a reduction in plant growth (Lewin and Heenan 1985). The use of copper sulfate was found to be effective against both snails and algae (Lewin and Heenan 1985). The nematode, *Paralongidorus australis*, infestation in root zone of rice in Queensland resulted in poor crop growth and yield due to root syndrome (Stirling and McCulloch 1984). Ducks are important bird pests of aerially sown rice and can be controlled through shooting, scare guns, and colored lights (Lewin and Heenan 1985).

Australia is relatively safe from major rice diseases occurring in other rice-growing regions of the world (Cother and Lanoiselet 2003). Only a few diseases have been reported to cause substantial yield losses. The bacterial leaf blight was one of the first reported diseases in Australian rice. The bacteria *Xanthomonas oryzae* was the causal agent of leaf blight and caused severe damage to rice crop in the northern territory (Aldrick et al. 1973). Aggregate sheath blight and sheath spot caused by *Rhizoctonia oryzae-sativae* and *Waitea circinata*, respectively, have also been reported in Australian rice (Lanoiselet et al. 2001, 2002a). According to Lanoiselet et al. (2005), *Rhizoctonia* spp. surviving in the rice fields can cause the disease in the following season. Although rice blast caused by *Magnaporthe grisea* has not been reported in Australia, predictive modeling (CLIMEX and DYMEX) has indicated that many sites in NSW have suitability for a potential outbreak of this devastating disease (Lanoiselet et al. 2002b). Glume blotch and stem necrosis caused by *Pseudomonas syringae* pv. *Syringae* and *Pantoea ananas*, respectively, are also important diseases of rice in Australia (Cother 1974; Cother et al. 2004). Stevens et al. (2006) reported the larvae of chironomid communities (Diptera: Chironomidae) to be causing substantial yield losses in rice crop in NSW. Preventive measures and chemical control have been found to be effective against these pathogens.

7.11 Harvesting, Postharvest Management, and Marketing

Rice fields are drained out after the crop has attained a certain degree of maturity. The timing of draining rice fields in Australia is critical because early drainage can cause lodging and reduction in grain weight (Lewin and Heenan 1985). On the other hand, if drainage of fields is delayed, the crop remains wet at harvest and the grain quality is deteriorated (Lewin and Heenan 1985). Usually, the physical observation serves as a tool for the determination of the right time for drainage (Boerema and McDonald 1965). The late dough stage for lower grains in a panicle is recognized as an ideal stage for field drainage (Hartley et al. 1977). However, in the case of heavy soils, it can be done when lower grains are still in the milky stage. In Australia, the rice crop is harvested at 22 % grain moisture. It improves the grain quality and reduces losses during milling (RGA 2015). Harvesting starts in March and continues up to May, depending upon the crop rotation. All the harvesting is done mechanically through large grain combine harvesters (RGA 2015). These harvesters remove straw and collect paddy (non-milled rice) in large collecting bins from where it is further transferred to containers attached to the operating tractors. In this way, the whole process of harvesting is completed in a single operation.

Paddy after harvesting is transferred to storage facilities through trucks. In the storage facilities, rice is sorted according to varieties and then kept in large bins where moisture contents, humidity, and temperature are regulated through computer-based sensors (RGA 2015). Hot conditions during storage facilitate the drying process. However, further processing is done in milling units. The rice is transported from storage facilities to mills. In mills, the dehusking (removal of husk from paddy) is done to obtain brown rice. Very few people prefer to consume brown rice. Hence, large portion of brown rice is further milled to remove bran, and white rice is obtained after polishing. White rice is further graded and packaged before marketing (RGA 2015). Almost all the rice produced in Australia is sold to Ricegrowers

Limited, which markets it by the brand name of SunRice. SunRice is one of the world biggest rice food companies which markets a large number of rice products across Australia and many other parts of world. A huge proportion of Australian rice (85 %) is exported to over 60 countries in Asia, North America, and the Middle East. Australian rice industry operates without any subsidies in contrast to rice industries of many other countries (RGA 2015). It competes with rice products from many countries in international markets. Every year, rice exports contribute significantly to Australian economy.

7.12 Challenges and Opportunities

Rice production in Australia is on a very limited scale. There are several constraints due to which the area under rice cultivation is limited. The major factor hampering the rice production is limited availability of irrigation water (Lewin and Heenan 1985; Thompson 2002; Humphreys et al. 2006). The climate is mostly arid and water flow in the rivers is less. The rice crop requires a large amount of water and consumes the lion's share out of available water resources. Although the government has imposed many different restrictions to limit the rice-growing area, the changing climate and ever-depleting water resources demand further reductions in rice cultivation (Lewis 2012). In NSW, the rice crop uses the highest amount of irrigation water, and many environmentalists are concerned about the decreased water flow in rivers (Thompson 2002). Not only the limited water availability but certain environmental factors also caused uneven water distribution. According to some ecologists, the reduced water flow in rivers is dangerous for aquatic life and biodiversity sustained through it. However, the Ricegrowers' Association of Australia claims that Australian rice production is purely based on resource conservation especially water saving, and keeping in view the stats, that claim is also realistic (RGA 2015). As climatic conditions are not favorable throughout Australia, a limited area in NSW and Victoria is capable of growing rice (RGA 2015). The major limiting factor is temperature during the growing season (Humphreys et al. 2006). As temperate varieties of rice are successful in Australia, the low temperatures toward their maturity cause substantial yield reductions (Horie et al. 1997). The terminal low temperatures affect the process of grain filling and spike sterility. In contrast to other rice-growing regions, the high temperatures during anthesis are not much harmful (Matsui et al. 2007). The poor stand establishment in dry-seeded rice is another emerging problem. Weed flora has also changed due to changing production systems. For instance, weed infestations have increased in intermittent-irrigated rice systems (Hill et al. 1990). These challenges have posed difficulties to sustainable rice production in Australia.

High-yielding and stress-tolerant varieties, the adoption of short-term rotations, water-saving sowing methods, and irrigation scheduling provide the basis for sustainable rice production in Australia under limited natural resources (Humphreys et al. 2006; Khan et al. 2010; Lewis 2012). Fortunately, very few of the harmful rice insect pests and diseases do exist in Australia, which is really helpful to obtain superior quality production (Thompson 2002). The integrated production regime is another feature of the Australian rice industry which allows sustainable production without subsidies (Lewin and Heenan 1985; Thompson 2002). It also enables the farming community to easily market their product across the country and in the international markets.

7.13 Conclusions and Future Directions

Rice production in Australia may be regarded as a success story in terms of remarkable yield achievement, water and energy savings, innovative adoption of technologies, excellent marketing and export system, and economic benefits. The integrated crop management and optimized postharvest processing enable Australian growers to obtain high-quality produce on a sustainable basis. Although the shrinking water resources and changing climate are haunting Australian rice production which is already restricted to a small area and under observation all the time, the conservation management practices adopted by farmers may help to sustain this production.

References

Aldrick S, Buddenhagen IW, Reddy APK (1973) The occurrence of bacterial leaf blight in wild and cultivated rice in Northern Australia. Crop Past Sci 24(2):219–227

Angus JF, Ohnishi M, Horie T, Williams RL (1994) A preliminary study to predict net nitrogen mineralisation in a flooded rice soil using anaerobic incubation. Aust J Exp Agric 34:995–999

Australian Bureau of Statistics (ABS) (2015) http://www.abs.gov.au/. Accessed online: 26 Sep 2015

Bacon PE, Heenan DP (1997) Response of Inga rice to application of nitrogen fertilizer at varying growth stages. Aust J Exp Agric Anim Husb 24:259–264

Batten GD, Reuter DJ, Unkovich M, Kirkby CA (2001) A nutrient audit for the Australian rice industry. In: Nutrient balance in regional farming systems, soil nutrient, status, national land, water resources audit, final report. Land and water Australia, Canberra. pp 85–87

Beecher HG, Beale P, Clampett WS (2000) Land for rice growing. In: Kealey LM, Clampett WS (eds) Production of quality rice in south eastern Australia. Rural Industries Research & Development Corporation, Canberra, pp. 43–65

Beecher HG, Hume IH, Dunn BW (2002) Improved method for assessing rice soil suitability to restrict recharge. Aust J Exp Agric 42:297–307

Beecher HG, Thompson J, Dunn B, Humphreys E, Christen E, Timsina J, Smith D, Singh RI, Mathews S (2003) Alternative irrigation methods for rice based cropping systems: permanent beds and sub-surface drip. In: Proceedings of third international temperate rice conference, 10–13 March 2003. Punta del Este

Boerema EB, McDonald DJ (1965) Draining rice for a high moisture harvest. Agric Gaz 75:1031–1035

Boerema EB (1970) Nitrogen for rice in New South Wales. Agric Gaz 81:72–76

Borrell A, Garside A, Fukai S (1997) Improving efficiency of water use for irrigated rice in a semi-arid tropical environment. Field Crop Res 52:231–248

Bouman BAM, Tuong TP (2001) Field water management to save water and increase its productivity in irrigated lowland rice. Agric Water Manag 49:11–30

Chapman AL, Myers RJK (1987) Nitrogen contributed by grain legumes to rice grown in rotation on the Cununurra soils of the Ord Irrigation Area, Western Australia. Anim Prod Sci 27(1):155–163

Ciavarella S, Batten G, Blakeney S, Oliver J, Williams R (2003) Reliable nitrogen recommendations depend on good sampling technique. Farm Newsl 162:36–37

Cother E, Lanoiselet L (2003) Maintaining disease-free crops. In: Production of quality rice in South Eastern Australia. Rural Industries Research & Development Corporation, Canberra, pp. 49–58

Cother EJ, Reinke R, McKenzie C, Lanoiselet VM, Noble DH (2004) An unusual stem necrosis of rice caused by *Pantoea ananas* and the first record of this pathogen on rice in Australia. Aust Plant Pathol 33(4):495–503

Cother EJ (1974) Bacterial glume blotch of rice. Plant Dis Rep 58:1126–1129

Cox WB (1980) MCPA dilemma: the effect of MCPA on secondary root development in rice. Farm Newsl 115:18–19

Farrell TC, Fox KM, Williams RL, Fukai S, Reinke RF, Lewin LG (2000) Temperature constraints to rice production Australia and Laos: a shared problem. In: Fukai S, Basnayake J (eds) Proceedings of international workshop on increased lowland rice production in the Mekong Region, Vientiane, Laos, 30 Oct–02 Nov 2000, Canberra

Fisher BB, Swain DJ, Boerema EB (1966) Evaluation of three herbicides for the control of grasses in rice. Aust J Exp Agric Anim Husb 6:219–223

Hartley RA, Lewin LG, Blakeney AB (1977) The rice pure seed scheme. Agric Gaz 88:42–43

Heenan DP, Lewin LG (1982) Response of Inga rice to nitrogen fertilizer rate and timing in New South Wales. Aust J Exp Agric Anim Husb 22:62–66

Heenan DP, Thompson JA (1984) Growth, grain yield, and water use of rice grown under restricted water supply in New South Wales. Aust J Exp Agric 24:104–109

Hill JE, Bayer DE, Bocchi S, Clampett WS (1990) Direct seeded rice in the temperate climates of Australia, Italy, and the United States. In: International rice research conference on direct seeded flooded rice in the tropics, Seoul, Korea, 27–31 Aug 1990. International Rice Research Institute, Los Baños. pp 91–102

Hill JE, Smith RJ, Bayer DE (1994) Rice weed control: current technology and emerging issues in temperate rice. Anim Prod Sci 34(7):1021–1029

Horie T, Ohnishi M, Angus JF, Lewin LG, Tsukaguchi T, Matano T (1997) Physiological characteristics of high-yielding rice inferred from cross-location experiments. Field Crop Res 52(1):55–67

Humphreys E, Bhuiyan AM, Fattore A, Fawcett B, Smith D (2001) The benefits of winter crops after rice harvest. Farm Newsl 157:36–42

Humphreys E, Edraki E, Bethune M (2003) Deep drainage and crop water use for irrigated annual crops and pastures in Australia-a review of determinations in fields and lysimeters. CSIRO land and water technical report. Report No. 14/03

Humphreys E, Lewin LG, Khan S, Beecher HG, Lacy JM, Thompson JA, Batten GD, Brown A, Russell CA, Christen EW, Dunn BW (2006) Integration of approaches to increasing water use efficiency in rice-based systems in southeast Australia. Field Crop Res 97(1):19–33

Humphreys E, Robinson D (2002) Improving water productivity in rice cropping systems in Australia: institutions and policy. In: Proceedings of the 16th International Rice Congress. Beijing, 16–20 Sep 2002. International Rice Research Institute, Los Banos, pp 885–900

Jones EL (1968) Bloodworms, pests of rice. Agric Gaz 79:477–478

Khan S, Khan MA, Latif N (2010) Energy requirements and economic analysis of wheat, rice and barley production in Australia. Soil Environ 29(1):61–68

Khan S, Rana T, Carroll J, Wang B, Best L (2004) Managing climate, irrigation and groundwater interactions using a numerical model: a case study of the Murrumbidgee Irrigation Area. CSIRO land and water technical report. Report No 13/04

Lanoiselet VM, Ash GJ, Cother EJ, Priest MJ, Watson A (2001) First report of *Waitea circinata* causing sheath spot and *Rhizoctonia oryzae-sativae* causing aggregate sheath spot on rice in south-eastern Australia. Aust Plant Pathol 30:369–370

Lanoiselet VM, Cother EJ, Ash GJ, Harper JDI (2002a) First report of *Sclerotium hydrophilum* on leaf sheath of rice (*Oryza sativa*) in south-eastern Australia. Plant Pathol 51(6):813–813

Lanoiselet VM, Cother EJ, Ash GJ (2002b) CLIMEX and DYMEX simulations of the potential occurrence of rice blast disease in south-eastern Australia. AustPlant Pathol 31(1):1–7

Lanoiselet VM, Cottier EJ, Ash GJ, Hind-Lanoiselef TL, Murray GM, Harper JDI (2005) Prevalence and survival, with emphasis on stubble burning, of *Rhizoctonia* spp., causal agents of sheath diseases of rice in Australia. Aust Plant Pathol 34(2):135–142

Lewin LG, Heenan DP (1985) The agronomy of rice production in the Riverina Region of Southeastern Australia. In: Proceedings of the meeting of the international network on soil fertility and fertilizer evaluation for rice. Griffith, 10–16 Apr 1985. International Rice Research Institute, Los Baños, pp 69–80

Lewin LG (1979) Agronomic aspects of continuous cultivation of rice. In: Proceedings Australian rice workshop. Australian Agricultural Research Centre, Yanco, pp 22–23

Lewis G (2012) The growers' paddy land, water and co-operation in the Australian rice industry to the 1990s. University of Sydney Co-operatives Research Group, Sydney

Macadam R, Drinan J, Inall N (2002) Building capacity for change in the rice industry, Publication no. 02/009. Rural Industries Research and Development Corporation, Canberra

Matsui T, Kobayasi K, Yoshimoto M, Hasegawa T (2007) Stability of rice pollination in the field under hot and dry conditions in the Riverina region of New South Wales. Australia Plant Prod Sci 10(1):57–63

McDonald DJ (1979) Rice. In: Lovett JV, Lazenby A (eds) Australian field crops, vol 2. Angus and Robertson, Sydney, pp. 70–94

McDonald DJ (1994) Temperate rice technology for the 21st century: an Australian example. Anim Prod Sci 34(7):877–888

McIntyre S, Barrett SCH (1985) A comparison of weed communities of rice in Australia and California. In: Proceedings of the ecological society of Australia. Vol 14, pp 237–250

McIntyre S, Finlayson CM, Ladiges PY, Mitchell DS (1991) Weed community composition and rice husbandry practices in New South Wales, Australia. Agric Ecosyst Environ 35(1): 27–45

National Farmers' Federation (NFF) (2015) http://www.nff.org.au/commodities-rice.html. Accessed online: 28 Sep 2015

Nott MJ, Trounce RB, Swain DJ (1974) Dirty dora plunders unsuspecting pockets. Ricemill News No 5:10–55

Penman PF, Jones RE (1984) Farm budget handbook: irrigation cropping and livestock. Murrumbidgee Valley. Department of Agriculture, NSW. Marketing and economics publication. p 70

Reinke RF, Lewin LG, Williams RL (1994) Effect of sowing time and nitrogen on rice cultivars of differing growth duration in New South Wales. I. Yield and yield components. Aust J Exp Agric 34:933–938

Ricegrowers' Association of Australia (RGA) (2015) http://www.rga.org.au/the-rice-industry.aspx. Accessed online: 15 Sep 2015

Rural Industries Research and Development Corporation (RIRDC) (2015) http://www.rirdc.gov.au/research-programs/plant-industries/rice. Accessed online: 06 Oct 2015

Russell C, Dunn B (2001) The Rice CRC's soil nitrogen test-an update and invitation to participate. Farm Newsl 158:4–5

Stevens MM, Helliwell S, Cranston PS (2006) Larval chironomid communities (Diptera: Chironomidae) associated with establishing rice crops in southern New South Wales. Australia Hydrobiologia 556(1):317–325

Stirling GR, McCulloch JS (1984) *Paralongidor Ustralis N*. Sp. (Nematoda: Longidoridae), causing poor growth of rice in Australia. Nematologica 30(4):387–394

SunRice (2015) Fact sheet history of Australian rice industry. https://www.sunrice.com.au/media/6663/history_of_australian_rice.pdf. Accessed online: 26 Sep 2015

Taylor M (2010) Weed management in Australian rice production. Rural Industries Research and Development Corporation (RIRDC). Publication no 10/017

Thompson JA, Griffin D, North S (2003) Improving the water use efficiency of rice, Final report project 1204. Cooperative Research Centre for Sustainable Rice Production, Yanco

Thompson JA, North S (1994) Raised beds reduce wither waterlogging. Farm Newsl 143:38–38

Thompson JA (2002) Water management of rice in southern New South Wales, Australia. In: Bouman BAM, Hengsdijk H, Hardy B, Bindraban PS, Tuong TP, Ladha JK (eds) Proceedings of the international workshop on waterwise rice production, 8–11 Apr 2002. International Rice Research Institute, Los Baños, pp. 62–67

Tisdall JM, Hodgson AS (1990) Ridge tillage in Australia: a review. Soil Tillage Res 18:127–144

Williams RL, Angus JF (1994) Deep floodwater protects high nitrogen rice crops from low temperature damage. Aust J Exp Agric 34:927–932

Williams RL, Farrell T, Hope MA, Reinke R, Snell P (1999) Short duration rice: implications for water use efficiency in the New South Wales Rice Industry. In: Humphreys E (ed) Proceedings of a workshop on rice water use efficiency, 12 Mar 1999. Cooperative Research Centre for Sustainable Rice Production, Yanco, pp. 41–44