POSSIBLE BREAKTHROUGHS
WATER-SAVING RICE SYSTEMS

Rice is the largest single freshwater user, accounting for a quarter to a third of total freshwater withdrawals.[1] More than 90% of total rice is produced and consumed in Asia. Rice feeds billions of people and will continue to play an increasingly relevant role in sustaining food security and livelihoods in various regions of the world. This is especially true in sub-Saharan Africa where rice demand and production is expected to grow most – a 130% increase relative to 2010.[2] Irrigated systems predominate in Asia, rainfed rice in Africa.[3] Increasing water scarcity in rice growing areas, low nitrogen use efficiency, high energy inputs for water pumping, and rising concerns for the huge amounts of methane emissions (8.7-28% of total anthropogenic methane emissions) from paddy fields, call for a shift in practices towards water-saving technologies, a search for new varieties and, possibly, even for more fundamental rethinking of rice systems.

[1]CA, 2007 [2]Seck et al. 2012, [3]Seck et al. 2012

Description

Some 25 million hectares of rainfed rice suffer frequent droughts, and 15-20 million hectares of irrigated rice are projected to suffer some degree of water scarcity over the next 25 years.[4] This, and the high cost of pumping, demands sustainable solutions for the improvement of water productivity. Water consumed by farmers during the growing period is much higher than actual crop water requirements,[5] and continuous submergence is not a prerequisite for high yields.[6] The reasons for inundating paddies include better weed control, easier soil labor, temperature regulation and water storage during monsoons.

In many circumstances, however, water consumption can be reduced. Alternate wet/dry irrigation (AWDI) and direct seeding are among the most promising methods at hand to reduce water consumption in rice systems. Whereas in traditional lowland rice systems fields are kept permanently inundated throughout the growing cycle, in alternate wet/dry irrigation, irrigation water depth and intervals are manipulated to allow the field to dry intermittently.[7] This allows for important water savings without significant yield reductions. Also, better soil aeration stimulates root growth, leading to higher yields and water-use efficiency.[8] Chapagain and Riseman[9] also found a low incidence of pests and diseases under alternate dry and wet irrigation and explained this as a consequence of less favorable environmental conditions and disruption of the pest and disease life cycles.

In many rice systems, land preparation is the practice that consumes the largest amount of water, and particularly so when the establishment of the crop is done by transplanting. Before transplanting the young seedlings, paddy fields are first saturated with water, then plowed and puddled. Farmers often delay plowing and puddling while waiting for the seedlings to be nurtured in the seedbed. This implies large water losses through seepage, percolation and evaporation.

[4]CA 2007, [5]van der Hoek et al. 2001, [6]Guerra et al. 1998, [7]Chapagain and Riseman 2011, [8]Shuichi and Uphoff 2007, [9]Chapagain and Riseman 2011

Description (continued)

Direct seeding, especially dry direct seeding, is a method to minimize land preparation duration and thus irrigation water inputs.[10] In dry seeding, dry seeds are sown onto the dry or wetted soil, often coinciding with the first rains. In this case, by ensuring early crop establishment, and as it does not require pre-saturation irrigation, this method can reduce water inputs consistently.[11] Moreover, direct seeded rice develops deeper roots and needs less frequent irrigation.

Nitrogen-use efficiency is also a major concern, with an average of 65% of nitrogen lost to the environment.[12] Rice production, particularly permanently inundated paddy fields, also contributes to climate change through methane and nitrous oxide emissions.[13] Methane emissions per growing season can range 30-50 kg CH_4/ha in dryland rice and 200-1100 kg CH_4/ha in wetland rice.[14] Constraints to direct-seeded rice are higher weed infestation and weeds that are difficult to control. This requires improved information on chemical and biological (rotations, consociations) weed control methods. More research is needed to improve the productivity of direct-seeded rice through the development of higher yielding varieties suitable for different agro-ecological zones, improved nutrient and water management as well as improved weed control.

Researchers are trying to develop varieties with improved tolerance to water stress without compromising high yields under optimal water supplies (see box 1). Varieties have been developed that are more tolerant to water-limited conditions, such as aerobic rice used in upland systems. However, at present, their yields are not nearly comparable to those of lowland rice. Additional research, especially into root morphology and root biology, and the underlying genetic differences, is needed to understand drought tolerance mechanisms and rice response to water.

[10]Cabangon et al. 2002, [11]Ibid, [12]Pathak et al. 2011, [13]Ibid, [14]Wassmann et al. 2004

Geography

Direct seeding, once a traditional practice in India, is currently back in vogue as a promising water and laborsaving technique.[15] PepsiCo also endorsed the technique through a number of initiatives with farmers in India covering about 10,000 acres. The company also introduced for the first time in India, a special tractor with a direct-seeding machine that is adjustable according to seed variety, planting depth and plant-to-plant spacing. Currently, direct seeding in India is applied to 29 million hectares, approximately 21% of the total rice cultivation area.[16] It is also extensively practiced in the U.S. and Australia.[17]

AWDI is particularly advantageous in areas with sandy soils. Nevertheless, where water supplies are really restricted or more costly, for instance if capital-intensive irrigation systems have been used, it is more economically viable to grow other crops than rice under non-flooded conditions.[18] In China, where almost all rice is irrigated, this is common practice in lowland rice systems.[19]

Globally, there are about 150 million hectares of rice cultivation, 50% of which are in irrigated lowlands. This gives an order of magnitude for the potential spread and impacts of water saving technologies for rice.

[15]Gupta et al. 2006, [16]Pandey and Velasco 2002, [17]Pathak et al. 2011, [18]van der Hoek et al. 2001, [19]Li and Barker 2004

Box 1

Growing rice like wheat

In 2012, Plant Research International at Wageningen UR, the International Rice Research Institute (IRRI), Bangalore University (India), and Yangzhou University (China) launched a joint program with the objective of fundamentally transforming rice into a crop with water requirements similar to those of wheat. Prem Bindraban, of Plant Research International, believes that as most arguments for growing rice in inundated conditions are agronomic rather than physiological, there should be a way to identify the mechanisms that prevent rice from being grown like wheat. The benefits are manifold and encompass socioeconomic and environmental aspects: less labor requirements, less methane emissions, lower costs, adaptability to water scarce conditions, increased crop diversification and improved profitability.

The program consists of two basic approaches. The first involves making a morphological and physiological comparison of wheat and three types of rice with varying water requirements (the sawah type, "dry" rice and a new hybrid type known as "aerobic" rice) with a number of closely related types of rice. Desired features are then related back to specific genes. A second approach will analyze the genetic characteristics of a wide population of rice species and selections. Genetic differences are then related to certain phonological and physiological features. Rice is very sensitive to spells of drought, and crops will fail as soon as the muddy soil starts to crack. This could be attributed, among others, to root morphology and the capacity of roots to take up water under limited conditions. Sub-Saharan Africa, with scarcer water and lighter soils, could benefit most from the results of this research, as it is precisely here where most of the expansion in rice demand and production is expected to happen.

The water "saved" if rice were to be grown like wheat could be used for other, more valuable crops or uses. Altogether these transformations create opportunities for new business and investments.

Energy

- Alternate wet/dry irrigation can achieve 26% higher nitrogen-use efficiency,[20] which ultimately means a reduction in fertilizer use.
- Up to 60% energy (diesel) savings with direct seeding, as it does not require nursery raising and puddling of fields and requires less water application.[21]

Water

Varietal improvement

- Aerobic rice systems, pioneered in Brazil and China, are higher yielding than traditional upland varieties. But the development of higher-yielding aerobic varieties is still in its infancy.[22]
- Experiments with aerobic rice in China showed 30-50% less water use and 20-30% lower yields with maximum yields of 5.5 t/ha.[23]
- At Wageningen University, efforts are directed at transforming rice into a crop like wheat, consuming 1,000 l/kg compared to actual 2-5,000 l/kg (see box 1).

Water-saving technologies

- Alternate wet/dry irrigation can save up to 15-20% water without reducing yields.[24]
- Water savings of 29% with alternate wet/dry irrigation over conventional irrigation were found in Japan without significant yield reductions (7.2 vs 7.8 t/ha).[25]
- Direct seeding is making advances relative to transplanting[26] and has proven effective in reducing water consumption by making better use of rainfall and reducing irrigation needs.[27]
- Direct seeding can achieve 19-60% water savings.[28]
- An initiative launched by PepsiCo on direct seeding of rice in India demonstrated 30% water savings compared to traditional puddling.
- Direct seeding in lowland rice presents multiple advantages, such as better drought tolerance, better use of early rainfall and improved nitrogen use efficiency.
- Resource-use efficiency increases the possibility of growing a second or even a third crop.[29]

[20]Jothimani and Thiagrajan 2005, [21]Pathak et al. 2011, [22]CA 2007, [23]Wang et al. 2000, [24]Tabbal et al. 2002, Belder et al. 2004, [25]van der Hoek et al. 2001, [26]CA 2007, [27]Cabangon et al. 2002, [28]Pathak et al. 2011, [29]CA 2007

Productivity

- With alternate wet/dry irrigation, 5-15% higher yields could be achieved.[30]
- Inadequate weed control in direct-seeded rice can lead to yield decreases. For instance, 20% yield decreases were found in India compared to transplanted rice, often because of inadequate weed control.[31]
- Yet when are weeds appropriately controlled, yields are comparable to those of transplanted rice.[32]
- Dryland rice currently comprises approximately 12% of the world's rice area, but yields account for only 4% of global rice production.[33] Improved aerobic varieties in upland rice systems in Brazil have shown 6 t/ha.[34]
- In environments prone to droughts, salinity and floods, the combined effect of improved varieties and better management practices increases yields by 50-100%.[35]

Climate change

Reducing methane (CH_4) emissions

- Growing "aerobic rice" under upland conditions and adding aluminum sulfate.
  - Reduces CH_4 emissions, reduction of nitrates (NO_3) remains unsure.[36]
- Using distinct drainage periods in mid-season or alternate wetting and drying of the soil in wetland cultivation.
  - Reductions of 7-80% have been measured, however, nitrous oxide (N_2O) emissions increase.[37]
  - Reductions of 30-50%.[38]
- Direct-seeded rice.
  - Reduction of 18% compared to transplanted rice.[39]
  - Up to 50% reduction when combined with mid-season drainage.[40]

Impacts of climate change on rice

- Increased yields and water productivity due to higher CO_2 concentrations might be offset by higher temperature-induced sterility.
- To optimize potential contributions of increased CO_2 on yields, there is a need to tap into genotypic variation in sensitivity to increased temperatures, breeding for varieties that are less sensitive.

[30]Jothimani and Thiagrajan 2005, [31]Johnson et al. 2003, [32]Tabbal et al. 2002, [33]Wassman et al. 2004, [34]Pinheiro et al. 2006, [35]CA 2007, [36]Wassmann et al. 2004, [37]Wassmann et al. 2004, [38]Lu et al., 2000; Wang et al. 2000, [39]Corton et al. 2000, [40]Wassman et al. 2004

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