GROWTH AND PRODUCTION OF RICE

Donn H. Beighley
Southeast Missouri State University, Malden, Missouri, USA

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Summary

Rice is one of the leading food crops in the world; it is reported to feed approximately one half of the world's population. It is known as a semi-aquatic, annual grass plant and is found growing in a wide range of soil types and water regimes: irrigated, rain fed lowland, upland, and flood prone areas depending on where it is produced. Although there are multiple types of rice production the principles of land preparation, planting, management, harvesting, and finally processing are similar throughout the world, apart from the obvious difference between wetland and dry land cultivation.

1. Introduction

Rice (*Oryzae sativa*) belongs to the grass family *Oryzeae*, and is one of the leading food crops in the world. As such, it is a staple of over a half of the world's population, mostly in Asia. Rice is the second most cultivated cereal after wheat. It provides 20% of the per capita energy, and 13% of the protein consumed worldwide (Juliano, 1994). Rice is known as a semi-aquatic, annual grass plant and grows in a wide range of soil and water regimes: irrigated, rain fed lowland, upland, and flood prone. In other words, it is found in a wide range of areas, from deeply flooded to dry flat fields or hilly terraced or non-terraced slopes.

Most cultivated rice is grown in flooded fields and rain fed lowlands. Irrigated rice is defined as rice produced when water is added to supplement that supplied by natural processes such as rainfall. Rain fed wetland rice production occurs in areas of the world where standing water is expected and desired during the growing season. Rain fed rice production is broken into groups depending on the depth of the water layer: rain-fed shallow water is in water 0 to 30 cm deep, rain-fed deep water is in water 30 to 100 cm deep, and floating rice is in water deeper than 100 cm. Dry land rice production is when rice is produced in aerated soil without standing water.

There are various types of rice based on grain length, width, and chemical characteristics, those being a long grain, medium grain and short grain. Rice grows in approximately 115 countries on every continent except Antarctica. Production practices range from very primitive to highly mechanized.

2. World Rice Picture

2.1. Production

Table 1 shows that rice production has increased worldwide over the last 42 years (1965 to 2007). The increases in total production have been steady on each continent except in 2001and 2002. In most continents except the Americas and Oceania, there was a decrease in production in either 2001, 2002 or in both years. After that, most continents saw a major increase in production, although there is a pattern of decrease every five years since 1965.

Of all continents, Asia is the largest producer of rice; it was the most stable and saw the fewest number of years of decreased production as compared to the other continents. South America is the one continent with regular decreases. The breakup of the Soviet Union into individual countries has limited the availability of data about that part of Asia.

Year[a]	World	Asia[b]	South America	N&C America	Africa	Europe[h]	USSR[i]	Ocea-nia
1965	254060	232173	9865	4499	5473	1875	543	174
1970	316346	290101	10443	5263	7287	2977	1190	274
1975	356963	324808	11929	7940	8100	3773	1870	413
1980	396871	360105	14325	8747	8608	4440	2594	646
1985	468165	429945	14324	8803	9619	4575	2400	898
1990	518556	477681	13421	9235	12697	4570	2166	951
1995	547432	499456	19232	9965	14923	2700	...	1156
2000	598894	545482	20482	11153	17477	3181	...	1119
2001	598036	544630	19758	12250	16584	3150	...	1664
2002	569228	515385	19602	12195	17625	3210	...	1211
2003	584822	530412	20453	11664	18576	3258	...	459
2004	607741	547445	24488	12809	18957	3468	...	574
2005	631868	571544	24077	12365	20179	3344	...	360
2006	644116	583873	22605	11203	22014	3428	...	992
2007	650193	590170	21402	11455	23483	3498	...	185

Source: FAOSTAT Database, 2008. FAO, Rome. 22 Sep 2008 (FAO last access).
Note: Year 2004 to 2007 are provisional data.
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Table 1. Paddy rice production (000, t), by country and geographical region, 1965-2007. (Source: www.faostat).

2.2. Rice Types and Products

There are two main types of rice, *Japonica* and *Indica*, differentiated by the area where they are grown and by their traits when cooked. *Japonica* types grow best in temperate environments and have kernels that are either medium or short in length and are sticky (glutinous) when cooked. *Indica* types have long kernels that are mostly not sticky (non-glutinous) when cooked and are produced in southern Asia and the Americas.

There are three grain types based on kernel traits and cooking qualities which include kernel dimensions of length and width after milling and sizing (Table 2). Within each kernel type is a brown-rice and white-rice type, depending on how much it has been milled.

	Length - Width Ratio of		
Rice Form	**Long - Grain**	**Medium - Grain**	**Short - Grain**
Rough	3.4 and more	2.3 - 3.3	2.2 and less
Brown	3.1 and more	2.1 - 3.0	2.0 and less
Milled	3.0 and more	2.0 - 2.9	1.9 and less

Table 2. Kernel dimension (length-width) ratio as a function of grain type (Juliano, 1994).

Cooking quality is of primary importance to millers and processors. These traits depend on the chemical composition of the rice grain. Long-grain rice is usually dry and fluffy (non-sticky) when cooked and is used in parboiled, quick-cooked or processed-rice products. There are also aromatic long-grain types that have a distinct taste and aroma when cooked.

Medium-grain rice is usually moist, sticky and used for dry cereals, soups, baby food and brewing purposes while short grain rice is very sticky. Sake, or rice wine, and beer are made from non-waxy rice. Other non-grain rice products include rice bran, rice straw, rice milk, etc. Low-amylose rice is used for baby food, cereals, and rice bread, while intermediate-amylose rice is used in fermented rice cakes. High-amylose rice is the basis for extruded-rice noodles.

Rice bran is a feed concentrate for livestock and fish. Bran oil is used for human consumption and in pharmaceutical products. The bran itself, though containing protein, has limited use. Traditionally, in many places in Asia, the bran was fed to swine and piggeries, which were often located in the direct neighborhood of the mills.

Rice straw has been used to make coarse paper, as a cellulose source for ruminant livestock, composting and building materials, and as an ultra-pure source of silica. Other uses for rice plants include footwear and headwear, and rice glue from boiling ground rice. One unique use of rice is called rice marble, where rice is placed on book covers during manufacturing for a decorative effect.

2.3. Rice Varieties

Depending on the information source, there are between 40,000 and 80,000 rice varieties made up of old traditional varieties, semi-dwarf varieties, and hybrids. Traditional rice varieties have changed through the years from the land races that were tall, slender in stature with droopy leaves, photoperiod sensitive along with a strong grain dormancy to plants with a semi-dwarf stature, erect leaves, photoperiod insensitive, lodging resistant, a greater harvest index as well as a greater responsiveness to fertilizers – particularly nitrogen fertilizers. Through the years traditional varieties have been collected, catalogued, increased, and distributed by private and public institutions such as the IRRI (International Rice Research Institute, Philippines) and the USDA-ARS (United States Department of Agriculture- Agricultural Research Stations) Small Grains Lab.

Newer conventional varieties from public breeding programs are now adapted to shorter growing seasons, tolerant to a-biotic factors such as saline, acidic or alkaline soils, drought, deep water or flooded soils, variations in ambient temperatures, either high or low, and biotic stress factors due to disease or insects, as well as varieties adapted to specialty-use markets; the latter situation is mainly true for irrigated rice, and less for other rice ecosystems where water control is much more a problem. Hybrid rice varieties from private and public breeding programs have been on the increase as breeders seek to match the best traits of two parents in a short time as well as increase yields to meet the consumer demands. The amazing experience of the Chinese public research institutes is a good example of this.

In recent years transgenic / biotech rice varieties have been developed to meet world food needs as a result of increasing food demand of a growing world population, and to incorporate specialty traits Examples of these are: improved nutritional content of rice by adding genes to increase nutrients such as pro-vitamin A (such as in the GMO Golden Rice program), increased iron content, and phytic acid. The incorporation of other traits such as soil acidity tolerance, disease and pest resistance like Bt rice from China, early maturity, heavier grains, longer grain filling period, and sturdier stems, or even a new plant type, all allow for increased production in areas previously limited in their potential.

The primary goal of plant breeding in past years has been to increase yield, improve milling quality, and to introduce good agronomic traits and some level of pest tolerance, primarily against rice diseases. Morphological traits such as semi-dwarf varieties have been added while trying to hold the grain quality constant. Other agronomic traits of importance to breeders include lodging, days to heading, maturity date and straw strength.

These improvements in rice varieties have been achieved by individual groups as well as through collaborative efforts between such groups as CIAT (International Center for Tropical Agriculture), IRRI, CGIAR (Consultative Group on International Agricultural Research), CIRAD (French Agricultural Research Center for International Development), EMBRAPA (Brazilian Agricultural Research Corporation), WARDA (Africa Rice Center) and US breeders. These improvements have been made using diverse germplasm from around the world to include wild *Oryza* species.

Plant breeding techniques being used in some breeding programs include the pedigree method, recurrent selection, another culture and molecular marker-assisted selection. These techniques reduce varietal development time as well as reduce the volume of experimental lines necessary to find those lines with the proper mix of desired traits.

The yields of old varieties average 2.5 tonnes per hectare while the new varieties average 10.3 tonnes per hectare, depending on the environment and the cultural practices used (Nguyen, 2004). Table 3 gives some indication of how yields have increased worldwide over the last 46 years.

Rice yields (t/ha)						
Year	1961	1971	1981	1991	2001	2007
World	1.87	2.36	2.83	3.54	3.94	4.15

Table 3. Paddy rice yield (t/ha), 1961-2007. (www.faostat)

Improvements to grain quality have been limited due to the numerous factors that make up grain quality. Quality traits of importance to the processors include milling quality with respect to the hull and bran, clear translucent grains, eating quality related to amylose content and aroma; attempts are also made to increase protein content. High milling quality is measured in percent of whole grain remaining after removing the hull / bran and sizing the rice grains.

3. Plant Growth and Development

Rice is an annual grass with a life cycle of 80 to more than 200 days from germination to maturity (Figure 1). Very early-maturing cultivars, such as Vendana, grown in dry areas in India, have a very short growth cycle; very late-maturing and photoperiod-sensitive traditional types growing in the rain fed lowlands of South-East Asia have a growth cycle of more than 200 days. A distinction can also be made based either on the number of days from emergence to 50% heading (USA) or on the rainfall pattern and water depth. The sensitivity to photoperiod during vegetative growth is an important factor in rice differentiation.

The three main growth stages are: the vegetative phase, reproductive phase, and the ripening phase. The three factors that influence yield are: the number of panicles per unit land area, the average number of grains per panicle, and the average weight of individual grains. The number of panicles per land unit depends on the average number of tillers per plant. The number of grains per panicle is influenced throughout the season from panicle initiation through head emergence by environmental, nutritional, and plant conditions. The average weight of individual grains is also affected by environmental and plant conditions.

Figure 1. Rice growth under traditional management. (Photo Verheye).

3.1. Vegetative Development

Rice stand establishment is important, and a uniform stand is necessary to produce a profitable rice crop. Factors of stand establishment that impact the final stand and yield include: crop variety, seedling vigor, seeding method and date, soil properties, seeding rate, seed treatments and growing environment. The most common rice seeding methods involve: dry / drill seeding, water-seeding, and transplanting, each of them with their advantages and disadvantages. The sowing method determines how much seed is needed for an adequate plant population. Currently, the most common technique for crop establishment in irrigated rice in Asia is direct wet seeding.

In dry / drill-seeded or water-seeded rice, 9 to 15 seedlings per square meter is the goal. Transplanted rice is spaced at 15 to 23 plants per square meter. As row width increases, uniform stand density also increases. Plant populations beyond the optimum density can increase both disease incidence and plant height, leading to increased lodging. Plant populations below the optimum density can result in lower yields, more weed problems, and lower nitrogen fertilizer utilization efficiency.

Factors affecting the establishment of a uniform stand include: field history, soil texture, tillage method, variety, seed treatment, seeding / planting date, and insect problems. Stand reduction, seedling stress, potentially increased production costs, and reduced yields may be affected by seeding date. Seed treatments contain growth hormones to increase the hypocotyls elongation length, particularly on semi-dwarf varieties, protect the seedling from seedling diseases and insects, and aid in stand establishment.

The vegetative parts of the rice plant include the roots, stems, and leaves. The length of the vegetative phase determines growth duration of varieties, e.g. early-maturing varieties have a shorter vegetative growth phase. This phase is characterized by seed germination, seedling emergence, leaf emergence, tillering, and plant height growth. The length of this stage determines the varietal season length group and occurs from germination until panicle differentiation. There can be short vegetative and reproductive stages or only a short vegetative stage depending on the variety.

3.1.1. Seed Germination

The length of time from seed germination to emergence depends on the variety, and it may take between 7 and 28 days for the seedling to emerge depending on soil temperature and soil-moisture.

Newly harvested rice seeds typically go through a dormancy (rest period) before they germinate. Two methods can be employed to shorten this period and to break seed dormancy prior to the completion of the rest period:

- Expose seeds to a 38° C temperature for 48 hours. Use a 0.1 N solution of nitric acid for 16 to 24 hours after which the seeds are dried for 3 to 5 days prior to storing until they are needed for planting;

- Testing the viability of seed can be accomplished by means of a germination test. This test determines the suitability of seed for planting and the need for extra seed to be planted to achieve the desired plant population.

- The presence of oxygen and moisture are important at this stage of development for germination and emergence. If either of these is lacking, germination will not occur. There are two types of seed germination:

- Germination before sowing as is the case in water-seeded or transplanted rice production.

- Germination after sowing in the case of dry land, direct / drill-seeded rice production.

In some rice-producing countries, rice seed is pre-germinated and then planted in a seedbed from which the seedlings are removed by hand, and then transplanted in the field. When using this method of planting, the rice seedlings are usually inserted into the soil approximately 1.5 to 3.0 cm. This is only done in countries where labor is plentiful. In developed countries such as India transplanting rice is mechanized. Transplanting machines have been developed due to the lack of laborers. With a transplanting machine four people can now do the work of 75 people in the same amount of time.

3.1.2. Seedling Emergence

When the seed has imbibed water and germination begins, the seed radical emerges to anchor it in the soil which subsequently leads to plumule emergence in dry land, direct seeding. Seedling emergence is when the coleoptile emerges above the soil surface in dry seeded rice or when it emerges from the water surface in the case of water-seeded rice. This occurs between 10 °C and 42 °C, optimum temperature 31 °C. This may take between 5 and 28 days based on the growing environment.

Planting principles used in dry- or direct-seeded situations include planting to a depth between 0.5cm and 2cm. When planting semi-dwarf varieties, it is recommended that a growth regulator be included in the seed treatment to increase the mesocotyl length to help the plant emerge faster. Planting depth is important, particularly in the case of the semi-dwarf varieties, which should not be planted more than 2cm deep or they will not emerge.

3.1.3. Leaf Development

Leaf development occurs at regular intervals once the plant emerges from the soil. The development of the primary and secondary leaf, up to the fourth leaf leading up to tillering is called the *pre-tillering phase* and usually requires between 15 and 25 days. During this phase of growth the secondary or lateral-root development begins from the emerged radical, and seminal roots form soon after germination. Secondary root development continues until the permanent flood period.

3.1.4. Tillering

Tillering occurs when a sprout or stalk is produced from the crown, which forms just below the soil surface or from the axils of the lower leaves. Tillering begins usually three weeks after emergence, i.e. as the fourth-leaf fully emerges, and ends as the fifth-leaf stage appears (approximately three weeks). A rice plant may develop from two to five tillers depending on the seeding method. Direct seeding may result in two to five panicle-bearing productive tillers while transplanted rice may have 5 to 30 productive tillers. It is from the surviving tillers that the potential panicles per unit area are determined, which has an impact on yield. The late tillers may die due to competition with the earlier established tillers. During tillering, the crown roots of each plant continue to develop growing downward and it is only at flooding that roots begin to develop laterally and vertically in response to the oxygen available on the water surface.

The vegetative lag phase occurs as tillering ends, and the reproductive phase of plant development begins to be expressed in the plant. During this time, the number of tillers decreases while the plant height and stem diameter increases slowly. In short-season varieties (110-day maturity) this is not as evident as in longer-season varieties (150-day maturity). Since the plant is not actively growing during this period it may appear yellow. In most cases this is not due to a lack of nitrogen.

3.2. Reproductive Development

The reproductive phase occurs from panicle initiation to anthesis and is characterized by a decrease in tillering activity, panicle initiation, then by internode elongation and jointing. The boot stage and flag leaf emergence are followed by heading and flowering. The reproductive phases of plant growth take 30 days depending on variety and environmental conditions.

Panicle initiation starts when the panicle primordial begins to differentiate. The first sign of this is the “green-ring” stage when a bright green band is observed just above the top node. Once this stage concludes, the internode elongation begins. Panicle differentiation is a critical stage in yield build-up as the number of grains per panicle is set at this time.

The internode elongation, also known as the jointing stage, continues until the full plant height is achieved. Panicle initiation means that the panicle itself begins to differentiate into the number of potential grains for each panicle. The number of grains per panicle is the second yield component (number of culms being the first).

Once stem internode elongation is close to completion the panicle begins to increase in size causing a swelling of the flag leaf sheath (boot stage). During this time the flag leaf is completely extended and meiosis occurs in the ovules (immature and unfertilized kernels). At this stage any environmental stress may reduce the grain yield by affecting the number of potential grains.

Heading occurs after the panicle begins to swell in the boot and as the panicle emerges from the boot. Panicle emergence may take 10 to 14 days depending on how many tillers there are on the plant. Heading date is when 50 percent of the panicles have emerged from the boot. There are several types of panicle emergence based on how much of the panicle exert from the boot, from well exerted to enclosed. Once exertion begins, anthesis / flowering are initiated. Anthesis is depicted when the floret opens allowing the stamens to extrude, and the pistil becomes visible between the floret lemma and palea.

In most cases, pollen is shed from the anthers first while the floret is closed and then sheds more after it opens. The majority of pollen shed occurs between 9 am and 3 pm. Flowering proceeds from the tip of the panicle downward to the base of the panicle as it emerges from the boot. This takes six to 14 days**.** At this time the second factor of yield, seeds per panicle, is set. Factors that may negatively impact the seed set at this point in the reproductive phase include temperature, wind, rain, and pesticide applications. If ambient temperatures are less than 10 °C or greater than 35 °C some of the seed may be empty.

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Biographical Sketch

Donn H. Beighley, Ph.D., is a Research Fellow in the Department of Agriculture at Southeast Missouri State University in Cape Girardeau, Missouri, USA. He has more than 26 years of plant-breeding experience with cotton, rice, soybeans, and wheat. His main interest is plant breeding and its relationship to crop production and management. His major focus has been on the breeding, development, and release of varieties for particular growing areas of the mid-South region of the U.S. including Arkansas, Louisiana, Missouri, Mississippi, and Texas. He has participated in multiple collaborative studies related to rice including the USDA-ARS CREES RiceCap Project.