Nutritional recommendations for

RICE

Haifa

Pioneering the Future

Nutritional recommendations for:

RICE

Botanical name: *Oryza sativa L.*
French: Riz; Spanish: Arroz; Italian: Riso; German: Reis

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1. Growing rice

1.1 The importance of growing rice

Rice in Asia and the global food supply

Sources: IPI, 2006 and FAO, 2008

Rice is the main staple food in Asia, where about 90% of the world's rice is produced and consumed. China is the world's biggest producer, growing one-third of Asia's total on 29 million ha (Table 1.1). India produces nearly a quarter on 43 million ha. Other top rice-producing countries in Asia are mentioned in table 1.1 too. Average yields in these countries range from 2.6 to 6.5 t/ha*.

Table 1.1: Average annual rice production, area harvested, and yield in most important rice-producing countries

Country or region	Production (million tons) *	Area harvested (Million ha)	Yield (t/ha)
China	188.5	28.7	6.5
India	142.5	42.8	3.3
Indonesia	58.3	11.7	5.0
Bangladesh	42.5	10.9	3.9
Vietnam	36.0	7.5	4.8
Thailand	30.5	9.9	2.6
Myanmar	32.0	8.9	3.6
Philippines	17.5	4.6	3.8
Japan	10.9	1.7	6.4
Other Asian countries	35.8	10.9	3.3
Asia	594.5	137.6	4.3
Brazil	12.1		
World	597.8	155.0	3.9

*** All tonnage terms in this publication are metric, unless otherwise indicated.**

Worldwide, around 79 million ha of rice is grown under irrigated conditions. While this is only half of the total rice area, it accounts for about 75% of the world's annual rice production. In Asia, nearly 60% of the 138 million hectares devoted to rice production annually is irrigated, where rice is often grown in monoculture with two to three crops a year depending upon water availability. Other rice ecosystems include the rainfed lowland (35% of total rice area), characterized by a lack of water control, with floods and drought being potential problems, and the upland and deepwater ecosystems (5% of total rice area), where yields are low and extremely variable.

Thailand is the world's major rice trader, exporting an average of 8 million tons of rice annually (Figure 1.1). Vietnam and India export a total of 7 million tons. A positive trade balance for rice has been maintained by Asia, Australia and the United States. Latin America, Africa, and Europe, are net importers of rice.

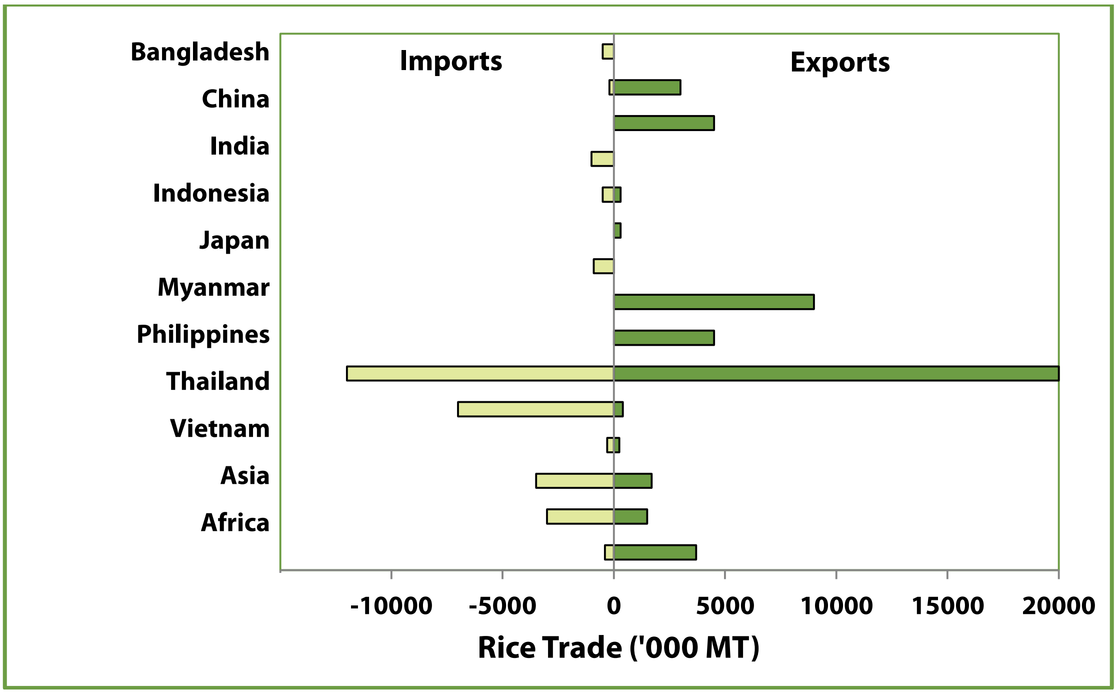


Figure 1.1: Global rice trade – average of data for 2000 to 2004 *(FAO 2006)*

The demand for rice is expected to grow for many years to come largely because of population growth, particularly in Asia, where population is expected to increase 35% by 2025 (United Nations, 1999). An increase in total rice production may come from an increase in the area planted, increased yields, and increased cropping intensity. However, the scope for expansion of rice-growing areas is limited because of loss of agricultural land to urbanization, land conversion, and industrialization. Therefore, future increase in rice supply must come from increased yields and intensified cropping, particularly in the irrigated rice ecosystem.

There is substantial scope to increase current rice yields as farmers in Asia, on average, achieve only about 60% of the yield potentially achievable with existing varieties and climatic conditions. The main limitation to achieving higher yields and associated higher profitability for rice farmers per unit of arable land is often the ineffective use of inputs (particularly nutrients, seed, and pesticide) in an environmentally sustainable fashion. If the demand for food is to be met, rice production will need to become more efficient in the use of increasingly scarce natural resources. Better crop, nutrient, pest, and water management practices, along with the use of germplasm with a higher yield potential, are required in order for rice production to be profitable for producers and to supply sufficient affordable staple food for consumers.

1.2 History

Many historians believe that rice was grown as far back as 5000 B.C.

Archaeologists excavating in India discovered rice, which they were convinced, could be dated to 4530 B.C. However, the first recorded mention originates from China in 2800 B.C. Around 500 B.C. cultivation spread to parts of India, Iran, Iraq, Egypt and eventually to Japan. Although China, India or Thailand cannot be identified as the home of the rice plant (indeed it may have been native to all), it is relatively clear that rice was introduced to Europe and the Americas, by travelers who took with them the seeds of the crops that grew in their homes and in foreign lands.

In the West, parts of America and certain regions of Europe, such as Italy and Spain, are able to provide the correct climate thereby giving rise to a thriving rice industry. The first cultivation in the U.S., along coastal regions from S. Carolina to Texas, started in 1685. Some historians believe that rice travelled to America in 1694, in a British ship bound for Madagascar.

1.3 Plant description

Rice plant is an annual warm-season grass (monocot plant) with round culms, flat leaves and terminal panicles.

Rice is normally grown as an annual plant, although in tropical areas it can survive as a perennial and can produce a ratoon crop up to 20 years. The rice plant can grow to 1–1.8 m tall, occasionally more, depending on the variety and soil fertility. The grass has long, slender leaves 50–100 cm long and 2–2.5 cm broad. The small wind-pollinated flowers are produced in a branched arching to pendulous inflorescence 30–50 cm long. The edible seed is a grain (caryopsis) 5–12 mm long and 2–3 mm thick.

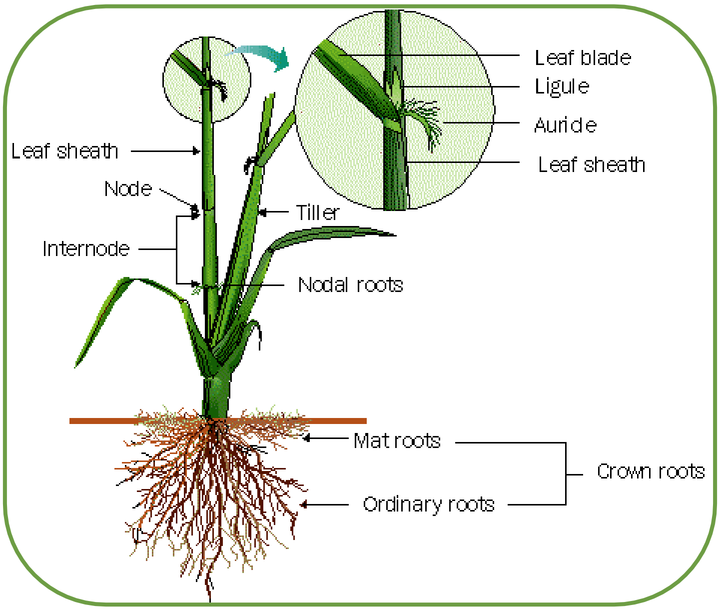


Figure 1.2: *Oryza sativa* morphology

The grain

The single seed is fused with the wall, which is the pericarp of the ripened ovary forming the grain. Each rice panicle (which is a determinate inflorescence on the terminal shoot), when ripened, contains on average 80-120 grains, depending on varietal characteristics, environmental conditions and the level of crop management. The floral organs are modified shoots consisting of a panicle, on which are arranged a number of spikelets. Each spikelet bears a floret which, when fertilized, develops into a grain.

Rice grain structure

A kernel of rice consists of a hull and a bran coat, both of which are removed on polishing "white" rice. In general, each rice kernel is composed of the following layers:

- Rice shell, hull or husk: encloses the bran coat, the embryo and the endosperm.
- Bran Coat (layer): a very thin layer of differentiated tissues. The layer contains fiber, vitamin B, protein and fat. The most nutritious part of rice resides in this layer.
- Embryo: The innermost part of a rice grain consists mainly of starch called amylase and amylo pectin. The mixture of these two starches determines the cooking texture of rice.

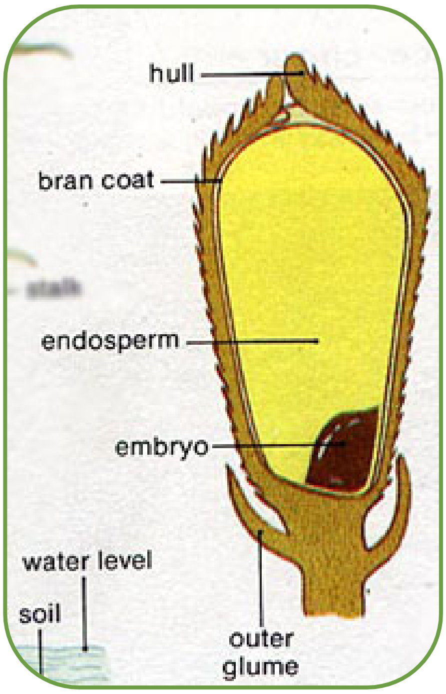


Figure 1.3: Cross section of a rice seed

A crop producing on average 300 panicles per m^2 and 100 spikelets per panicle, with an average spikelet sterility of 15 % at maturity and a 1000-grain weight of 20 g will have an expected yield of 5.1 t/ha.

Rice roots (and many other wetland plants) have special anatomy: aerenchyma vessels to get oxygen down to cells in root tissue (because wetlands have little dissolved O2 in the water.

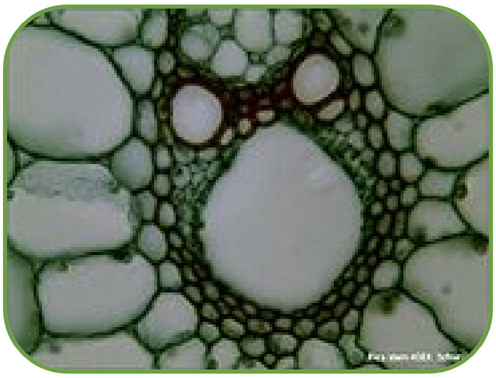


Figure 1.4: Rice stem cross section magnified 400 times

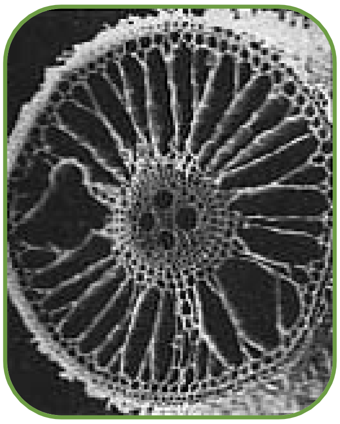


Figure 1.5: Aerenchyma vessels

Genotypes of rice

- *Oryza sativa var. indica:* mostly long grain types, grown in the southeast US.
- *Oryza sativa var. japonica:* mostly short and medium grain types, grown in Asia and California, preferred types in the Asian markets.
- *Red rice. Oryza sativa:* a weed.

1.4 Growing methods

1.4.1 Ecosystem types

Figure 1.6: Upland

Figure 1.7: Lowland

1.5 Soil

Soil type: A rice paddy needs to hold water well. Ideally, soil needs to include about 50% clay content. Also, soil underlain with an impervious hardpan or clay-pan helps to hold water.

1.6 Irrigation

Rice can grow in either a wet (paddy) or a dry (field) setting. (Rice fields are also called paddy fields or rice paddies).

About 75% of the global rice production comes from irrigated rice systems because most rice varieties express their full yield potential when water supply is adequate.

In cooler areas, during late spring, water serves also as a heat-holding medium and creates a much milder environment for rice growing.

A pond could hold irrigation water to use in the summer, when demand for water is the greatest.

The bulk of the rice in Asia is grown during the wet season starting in June-July, and dependence on rainfall is the most limiting production constraint for rain-fed culture. Rice areas in South and Southeast Asia may, in general, be classified into irrigated, rain-fed upland, rain-fed shallow water lowland and rain-fed deep water lowland areas.

The productivity of well-managed, irrigated rice is highest, being in the range of 5-8 t/ha during the wet season and 7-10 t/ha during the dry season if very well managed, but the average is often only in the range of 3-5 t/ha. The productivity of rain-fed upland and deep water lowland rice, however, continues to be low and is static around 1.0 t/ha.

1.7 Varieties

There are more than 40,000 varieties of cultivated rice (*Oryza sativa L.*), but the exact figure is uncertain. Over 90,000 samples of cultivated and wild rice species are stored at the International Rice Gene Bank and these are used by researchers all over the world.

There are four main types of rice: Indica, Japonica, aromatic, and glutinous. Rice seeds vary in shape, size, width, length, color and aroma. There are many different varieties of rice: drought-resistant, pest-resistant, flood-resistant, saline-resistant, tall, short, aromatic, sticky, with red, violet, brown, or black; long and slender; or short and round grains.

Extensive studies of the varieties have demonstrated that they were independently derived from the wild rice species *Oryza rufipogon*. The domesticated varieties show much less variation (polymorphism) than the wild species.

Rice cultivars (*Oryza sativa L.*) are divisible into the Indica and Japonica types, or subspecies *indica* and *japonica*, which differ in various morphophysiological traits. These two main varieties of domesticated rice (*Oryza sativa*), one variety, *O. sativa indica* can be found in India and Southeast Asia while the other, *O. sativa japonica*, is mostly cultivated in Southern China.

In general, the rice family can be broken down into three main categories:

- <u>Long Grain</u>: Approx. 6-8 mm long, about 3-4 times longer than thick. The endosperm is hard and vitreous. The best long grain varieties come from Thailand, Southern US, India, Pakistan, Indonesia and Vietnam.
- <u>Medium Grain</u>: Approx. 5-6 mm long, but thicker than long grain rice. The endosperm is soft and chalky. It releases about 15% starch into water during cooking. Medium grain rice is mainly grown in China, Egypt and Italy.
- <u>Short Grain</u> or <u>Round Grain</u>: Approx. 4-5 mm long, only 1.5-2 times longer than thick. The endosperm is soft and chalky. This variety is grown in subtropical areas like California, Egypt, Italy, Japan, Korea, Spain and Portugal.

1.8 Yields

Yield gap is literally defined as the difference between yield potential of rice and yields that are actually obtained by farmers.

Yield potential of traditional ***Indica*** **varieties** is about 5 t/ha, while yield potential of crossbreeding ***Japonica varieties*** x with high-yielding ***Indica*** **varieties**, is about 10 t/ha Yield potential of high-yielding *Japonica* varieties is about 15 t/ha while the yield potential of hybrid varieties is about 18 t/ha.

The yield gap in irrigated rice production is graphically presented in Figure 1.8. It shows the gap of about 4-6 t/ha in both Tropical (e.g. Philippines) and sub-tropical climate (e.g. Japan).

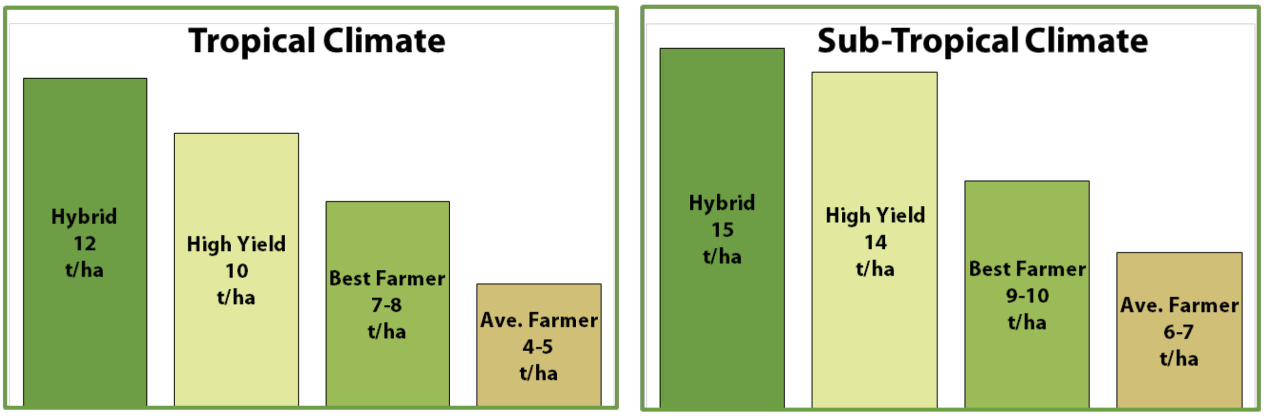


Figure 1.8: Average yields in two different climate conditions under different growing regimes

After the development of IR8 and other high-yielding rice varieties, considerable efforts have been devoted to the development and dissemination of improved technologies for cultivation technologies, in order to fully benefit from the yield potential of the developed varieties.

The Green Revolution

New ***'Super Rice'*** was released in 2000, featuring a 35% yield increase. Genetic material from corn was inserted into rice plant. This raised the efficiency of photosynthesis. The new varieties consist of fewer but stronger tillers carrying more grains per inflorescence. Half of the IR8 plant's weight is grain and half is straw, whereas the new ***Super Rice*** plant is 60% grain and 40% straw.

Figure 1.9 shows that from 1970 to 1985, rice yields in Australia stagnated at around 6 t/ha.

After the dissemination of the Rice-Check system in 1986, the Australian national yield increased rapidly and steadily from about 6 t/ha in 1987 to above 9 t/ha in 2000.

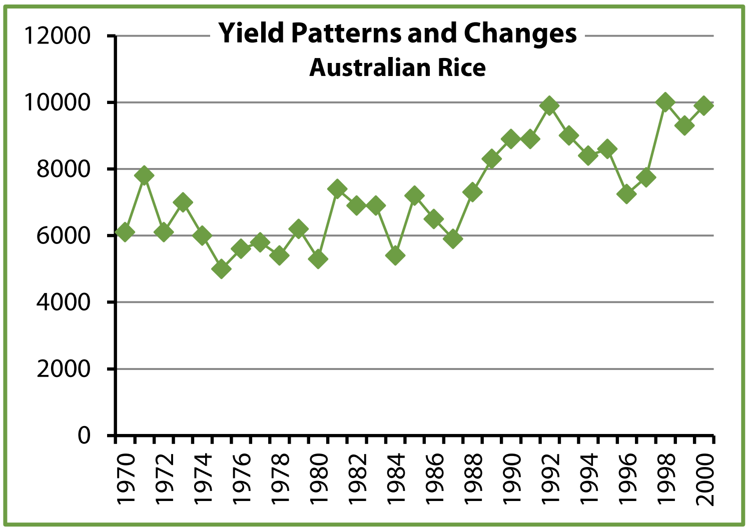


Figure 1.9: Australian rice yield, 1970 to 2000
(Source: FAOSTAT)

It was reported that application of the Rice-Check system also increased the nitrogen fertilizer usage efficiency.

The rice production systems in Australia and their conditions, however, are very different to those in developing countries.

Rice yields vary enormously across ecosystems and countries. Yields of 4–6 t/ha are common in irrigated settings, as are yields of 2–3 t/ha in rain-fed ecologies. Where rainfall is unreliable and drainage is poor, farmers still grow traditional varieties and use fertilizers in suboptimal amounts because of the uncertainty of obtaining adequate returns from investment in inputs.

Recent analyses suggest that growth rates of yields are increasingly differing between and within countries. In three out of four major rice-producing countries, the growth in average yields over the past 20 years is higher than the standard deviation of yield growth by provinces in the respective countries (Table 1.2).

Table 1.2: Yield differences of rice within countries in the 1980s and 1990s.
Average annual growth rates (%) in national average cereal yield and sub-national variation

Country	Average growth per annum (%)	Standard deviation (sub-national variation)
Bangladesh	1.8	5.1
Brazil	4.6	2.3
China	2.1	1.7
India	2.3	2.4

Source: Schreinemachers (2004)

Table 1.3: Average yields of rice varieties *

Variety	Average grain yield	
	bushels/acre	t/ha
Bengal	170	8.5
Cocodrie	165	8.3
Cypress	150	7.5
Drew	160	8
Jefferson	145	7.3
Kaybonnet	150	7.5
LaGrue	175	8.8
Madison3	160	8
Priscilla3	155	7.8
Wells	170	8.5

*Arkansas rice performance trials of a 3-year study

1.9 Seeding and planting

Several seeding and planting methods are practiced:

- Dry seeding with drill.
- Dry seeding by broadcast or air. Most of the rice, in large fields, is sown by aircraft. Experienced agricultural pilots use satellite guidance technology to broadcast seed accurately over the fields.
- Water seeding with pre-germinated seed.
- Seedlings are transplanted by hand (Figure 1.11), or by machines (Figure 1.13) to fields which have been flooded by rain or river water.
- Seedlings 25-30 days old, grown in a nursery are usually transplanted at 20 x 15 or 20 x 10 or 15 x 15 cm spacing in a well prepared main field and normally this will have a population of 335,000 to 500,000 hills/ha (33 to 50 hills/m^2), whereby each hill contains 2-3 plants.

Figures 1.10 & 1.11: Traditional field preparation and transplanting

Figure 1.12: Germinating seeds for seedling transplanting

Figure 1.13: Rice seedling transplanter

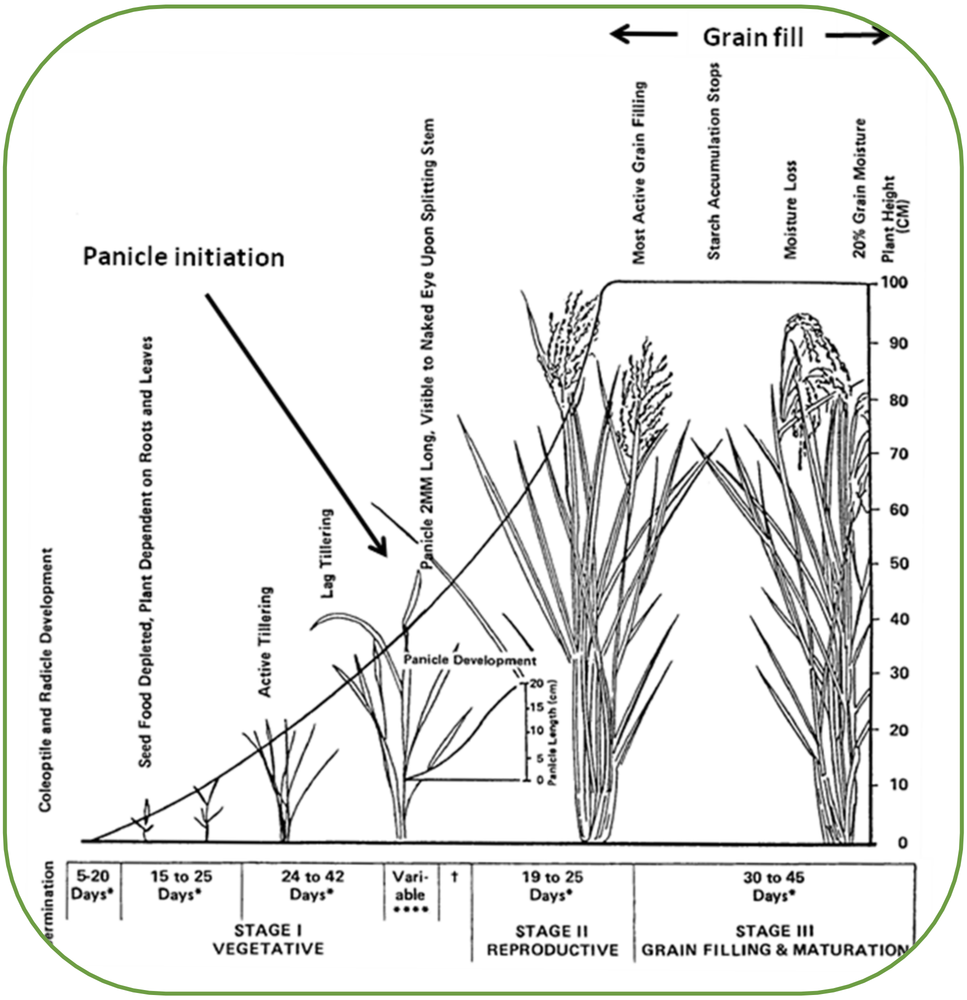
1.10 Why flooding rice fields?

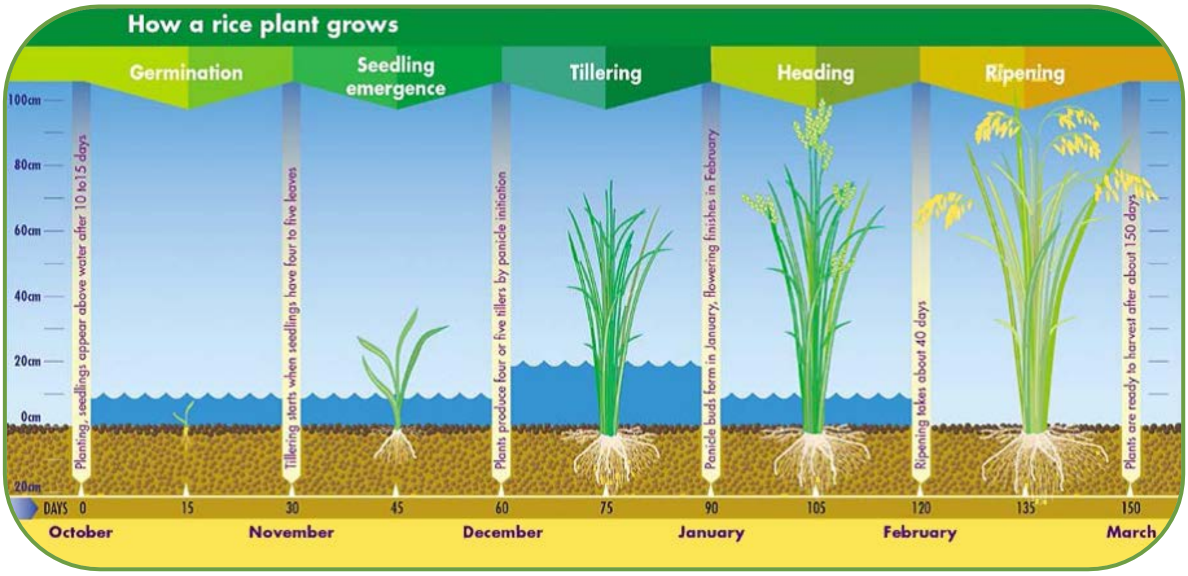
The traditional method for cultivating rice is flooding the fields while, or after, setting the young seedlings. This simple method requires sound planning and servicing of the water damming and channeling, but reduces the growth of less robust weed and pest plants that have no submerged growth state, and deters any rodents and pests. Consistent water depth has been shown to improve the rice plants' ability to compete against weeds for nutrients and sunlight, reducing the need for herbicides. Rice crops are grown in 5–25 cm of water depending on growing conditions. While with rice growing and cultivation the flooding is not mandatory, all other methods of irrigation require higher effort in weed and pest control during growth periods and a different approach for fertilizing the soil.

1.11 Growth stages

Rice plant grows a main stem and a number of tillers. Each rice plant will produce four or five tillers. Being a crop that tillers, the primary tillers (branches) grow from the lowermost nodes of the transplanted seedlings and this will further give rise to secondary and tertiary tillers. Every tiller grows a flowering head or panicle. The panicle produces the rice grains.

See Figures 1.14 and 1.14a.





Figures 1.14 and 1.14a: Development stages of the rice plant

1.12 Rice maturation and harvesting

Rice seedlings grow 4-5 months to maturity.

The plants grow rapidly, ultimately reaching a height of 90 cm (3 feet). By late summer, the grain begins to appear in long panicles on the top of the plant. By the end of summer, grain heads are mature and ready to be harvested. When still covered by the brown hull rice is known as paddy.

Depending on the size of the operation and the amount of mechanization, rice is either harvested by hand or machine. The different harvesting systems are as follows:

Figure 1.15: Rice plants just before harvest, Vietnam, 2005

1.12.1 Manual harvesting

Methods of growing differ greatly in different localities, but in most Asian countries the traditional hand methods of cultivating and harvesting rice are still practiced. The fields are allowed to drain before cutting. Manual harvesting makes use of sharp knives or sickles, traditional threshing tools such as threshing racks, simple treadle threshers and animals for trampling.

1.12.2 Combine harvesting

Combine harvester combines all operations: cutting, handling, threshing and cleaning. In the United States and in many parts of Europe, rice cultivation has undergone the same mechanization at all stages of cultivation and harvesting as have other grain crops.

The soil dries out in time for harvest to commence. Farmers use large, conventional grain harvesters to mechanically harvest rice in autumn. Because quality is so important, these harvesters are designed to both gently and rapidly bring the grain in from the fields.

1.12.3 Quality of the harvested rice

Harvest management preserves rice quality and yield that contribute directly to profit. Timing field draining and harvest are keys to high head rice yields.

Other harvesting factors that affect head rice yield include grain moisture content, field rewetting of grain, severe threshing impacts and excessive foreign matter (trash) in rice.

Rice quality may be lower if rice is harvested either at high or low moisture contents. The ends of wet rice kernels grind off and become dust as they are processed. Rice may crack if it dries to below 15 percent moisture content. Rapid rewetting, once rice reaches 15 percent or less moisture content, is a key cause for lowered head rice yields. The recommended harvest range to avoid quality or yield reductions is 17 to 21 percent moisture.

2. Plant nutrition

2.1 Chemical properties of flooded soils

Since rice is predominantly grown under wetland conditions, it is important to understand the unique properties of flooded soils for better management of fertilizers for this crop. When a soil is flooded, the following major chemical and electrochemical changes take place:

a) Depletion of molecular oxygen
b) Chemical reduction of soil
c) Increase in pH of acid soils and decrease in pH of calcareous and sodic soils
d) Increase in specific conductance
e) Reduction of Fe^{3+} to Fe^{2+} and Mn^{4+} to Mn^{2+}
f) Reduction of NO_3^- to NO_2^-, N_2 and N_2O
g) Reduction of SO_4^{2-} to S^{2-}
h) Increase in supply and availability of N, P, Si and Mo
i) Decrease in concentrations of water-soluble Zn and Cu
j) Generation of CO_2, methane and toxic reduction products, such as: organic acids and hydrogen sulphide

These will have a profound influence on soil nutrient transformations and availability to rice plants.

2.2 Patterns in symptomology of nutrients deficiency symptoms in rice

Influence of nutrient mobility on symptomolgy:

Mobile Nutrients:

- Nitrogen
- Phosphorus
- Potassium
- Magnesium

Deficiency symptoms appear in oldest (lower) leaves first, because their mobile nutrients contents move to the youngest leaves, which act as sinks.

Immobile Nutrients:

- Calcium
- Iron
- Manganese
- Zinc
- Sulfur

Deficiency symptoms appear in youngest (upper) leaves first, because these nutrients become part of the plant compounds.

2.3 Nitrogen

Nitrogen increases plant height, panicle number, leaf size, spikelet number, and number of filled spikelets, which largely determine the yield capacity of a rice plant. Panicle number is largely influenced by the number of tillers that develop during the vegetative stage. Spikelet number and number of filled spikelets are largely determined in the reproductive stage.

Farmers use split applications for N. The number and rate of application can be varied. Ability to adjust number and rate allow the synchronization to real time demand by the crop. Leaf color charts allow farmers to estimate nitrogen demand of the crop by comparing the leaf color to the chart (Figure 2.1).

Figure 2.1: Leaf color chart

The initial symptom of nitrogen deficiency in rice is a general light green to yellow color of the plant. It is first expressed in the older leaves because nitrogen is translocated within the plant from the older leaves to the younger ones. Prolonged nitrogen deficiency causes severe plant stunting, reduced tillering (Figure 2.2) and yield reduction (Figure 2.3).

Figure 2.2: Nitrogen-deficient plant (left) versus a well-fed plant of same age (right)

Figure 2.3: Pale green color indicates N deficiency

2.3.1 Nitrate-nitrogen (NO_3^-) promotes uptake of ammoniacal-nitrogen (NH_4^+)

Nitrogen (N) is one of the essential macronutrients for rice growth and one of the main factors to be considered for developing a high-yielding rice cultivar. In a flooded paddy field, ammonium (NH_4^+) rather than nitrate (NO_3^-) tends to be considered the main source of N for rice. However, in recent years, researchers have paid more and more attention to the partial NO_3^- nutrition of rice crops, and their results have shown that lowland rice was exceptionally efficient in absorbing NO_3^- formed by nitrification in the rhizosphere. The NO_3^- uptake rate could be comparable with that of NH_4^+, and it could amount to one-third of the total N absorbed by rice plants. Therefore, although the predominant species of mineral N in bulk soil for paddy rice fields is likely to be NH_4^+, rice roots are actually exposed to a mixed N supply in the rhizosphere. The growth and N acquisition of rice is significantly improved by the addition of NO_3^- to nutrition solution with NH_4^+ alone. The increased N acquisition could be attributed to the increased influx of NH_4^+ by NO_3^-.

2.3.2 Fertilizer N-use efficiency

In lowland rice losses of applied N take place through: a) ammonia volatilization, b) denitrification, c) leaching, and d) runoff. The recovery of fertilizer N applied to rice seldom exceeds 30-40 %. Fertilizer N use efficiency in lowland rice may be maximized through a better timing of application to coincide with the stages of peak requirement of the crop, and placement of N fertilizer in the soil. Other possibilities are the use of controlled-release N fertilizer, e.g. **Multicote®** and **CoteN®** (see Chapter 6.3) and the exploitation of varietal differences in N efficiency utilization.

In the anaerobic environment of lowland rice soils, the only stable mineral form of N is NH_4^+. Nitrate (NO_3^-) forms of N, if applied, will enter the anaerobic zone and be subjected to heavy denitrification losses. At planting time, the base-dressing of N should never be supplied as nitrate. For topdressing the growing plants, however, NH_4^+ and NO_3^- forms may be used with almost equal efficiency. Fully established rice can rapidly take up applied NO_3^- before it is leached down to the anaerobic soil layer and can become denitrified.

2.3.3 Early N application and management

The early N application (65 to 100 percent of the total N rate) should be applied as an ammonium N (NH_4^+) source onto dry soil, immediately prior to flooding at around the 4- to 5-leaf growth stage (Table 2.1). There is not an exact time to apply early N, but actually a window of a couple of weeks that the early N can be applied. Once the early N is applied, flooding should be completed as quickly as possible, preferably within five days of the N application. The flood incorporates the N fertilizer into the soil where it is protected against losses via ammonia volatilization and/or nitrification/denitrification as long as a flood is maintained. The flood should be maintained for at least three weeks to achieve maximum uptake of the early applied N (Table 2.2).

Table 2.1: Effect of pre-flood nitrogen application timing, and soil moisture on rice grain yields

Time before flood (days)	Soil moisture	Uptake of applied N		N Use Efficiency* (%)	Grain Yield	
		Pounds/A	kg/ha		bu/A	kg/ha
10	dry	85	95	71	124	6255
10	mud	46	52	42	102	5145
5	dry	100	112	82	129	6507
5	mud	71	80	59	105	5296
0	**dry**	**107**	**120**	**83**	**132**	**6659**
0	mud	68	76	64	111	5599
0	flooded	37	41	31	75	3783

* 130 kg/ha of N applied at the 4- to 5-leaf stage.

Source: Norman, et al., 1992. p. 55-57. Ark. Soil Fertility Studies 1991. Ark. Ag. Exp. Sta. Res. Ser. 421

Table 2.2: Percent Nitrogen Uptake by Rice Crop at Different Times after N Application

N Application Timing	Sampling Period, days after application	% N Plant Uptake
Preflood: Urea applied on a dry soil surface and flooded immediately	7	11
	14	27
	21	63
	28	**65**
Midseason: Urea applied into the flood	3	70
	7	67
	10	**76**

Source: Wilson, et al., 1989. SSSAJ 53:1884-1887

2.3.4 Pre-flood application or split applications?

In order to answer this question, results of a field trial from Missouri, US, are supporting split applications although inconclusive results whether one or two split applications should be applied, as presented in Table 2.3. All treatments received a total N of 170 kg/ha. The first treatment, which had the recommended nitrogen application, yielded 6,003 kg/ha (119 Bu/acre). The second treatment, which only had one midseason application, yielded 6,053 kg/ha (120 Bu/acre). The third treatment yielded 5,953 kg/ha (118 Bu/acre). The treatment that received 67 kg/ha (=60 lbs/acre) of

N, only yielded 5,549 kg/ha (110 Bu/acre) and the treatment that received 168 kg N/ha (150 lbs. N/acre), all at pre-flood, yielded 5,398 kg/ha (107 Bu/acre).

Table 2.3: Nitrogen timing applications*

Preflood		Midseason		One week after midseason		Yield	
(lbs/A)	kg/ha	(lbs/A)	kg/ha	(lbs/A)	kg/ha	(Bu/A)	kg/ha
90	100	30	34	30	34	119	6,003
90	100	60	67	0	0	120	6,053
105	118	45	50	0	0	118	5,953
60	67	45	50	45	50	110	5,549
150	168	0	0	0	0	107	5,398

The rice produced in a dry-seeded, delayed flood cultural system in which the permanent flood is not established until the rice is 15 to 20 cm tall, optimum N fertilizer use efficiency has been achieved by applying at least 50% of the total N immediately prior to permanent flood establishment, and the remaining N applied within the interval beginning with internode movement to 10 days after internode movement of 1.2 cm.

Some new cultivars produce yields that are comparable, and sometimes greater, when a single pre-flood application is made as opposed to a two- or three-way split of the total applied N. Rate and timing of N are critical in terms of their effect on yield.

2.3.5 When is N application required?

Nitrogen is the most limiting nutrient for rice production in many countries. Unlike plant nutrients such as P, K, and zinc (Zn), no suitable soil test method has been established and implemented for determining the N-supplying capacity for soils used to produce rice.

Rice plants require N during the tillering stage to ensure a sufficient number of panicles. The critical time at active tillering for N application is typically about midway between 14 days after transplanting (DAT) or 21 days after sowing (DAS) and panicle initiation.

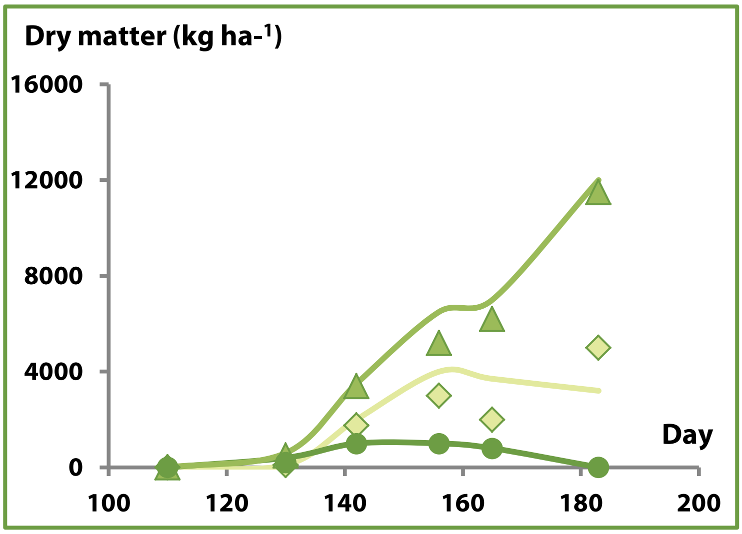


Figure 2.4: Observed biomass (lines) of total above ground dry matter (▲), green leaves (●), and stems (◆), *Rain fed IR64 Jakenan, Indonesia, 1995.*

At panicle initiation (about 60 days before harvest of tropical rice), it is critical that the supply of N and K are sufficient to match the needs of the crop. Insufficient N at panicle initiation can result in loss of yield and profit through reduced number of spikelets per panicle. Insufficient K supply at panicle initiation can result in loss of yield and profit through reduced spikelets per panicle and reduced grain filling.

2.4 Yield response to N fertilization

An experiment *(Bollich and Linscombe)* regarding timing of N application has shown the clear superiority of preplant N application as shown in Table 2.4.

Table 2.4: Yield response to time of N application in water-seeded flooded cypress rice

Method/Timing*	Grain Yield** (kg/ha)
Preplant	**7,548**
Pre-flood	6,124
Post-flood	5,778

* 100 kg/ha of N applied in each treatment
** Yields are three-year average

The least N losses due to leaching or volatilization took place when the only application was closer to the flooding time (Table 2.5).

Table 2.5: Rice yield response to time of N application in dry-seeded rice

N Timing	Yield (kg/ha)	Yield Loss (%)
9 days pre-flood	7,415	8
6 days pre-flood	7,525	7
3 days pre-flood	7,559	6
0 days pre-flood	**8,117**	–
3 days post-flood	6,484	21
6 days post-flood	6,140	24

Nitrogen fertilization improves yields. Field trials responses are 28.4 and 18.9 kg rice per kg N for 25 and 50 kg/ha rates, respectively (Table 2.6). Yield increase is affected by variety, soil N supply capacity, amount of radiation during the reproductive phase, and management practices such as weed control and plant density.

Table 2.6: Mean yield response to N fertilization, *Entre Ríos*

Varieties	**N rate**	**Mean N response**	
	kg/ha	**Rice yield (kg/ha)**	**kg of rice / kg N applied**
San Miguel INTA	25	453	18.1
	50	550	11.0
El Paso 144	25	540	21.6
	50	870	17.4
Don Juan INTA	25	710	28.4
	50	779	15.6
IRGA 417	25	632	25.3
	50	946	18.9

Table 2.7 gives the recommended N rate and application timing for the most commonly grown rice varieties in the Mississippi Delta. These recommendations were derived from numerous on-farm tests conducted on various soil types. Lodging can be reduced by applying 50% of the total N prior to establishing the permanent flood and splitting the remaining 50% into two midseason applications. For varieties that are not sensitive to lodging, two-thirds of the total N should be applied prior the permanent flood and it is not necessary to split the remaining one-third at midseason. More information about reducing lodging rate is given in the chapter dealing with potassium nutrition, see Figure 2.16, following.

Table 2.7: Nitrogen recommendations by cultivar and soil type
Source: Rice fertilization - Mississippi Agricultural & Forestry Experiment Station, 2003

Cultivar	**Clay soils**				**Silt loam soils**			
	Total	**Pre-flood**	**Midseason**		**Total**	**Pre-flood**	**Midseason**	
			First	**Second**			**First**	**Second**
	(kg/ha)				**(kg/ha)**			
Cocodrie	200	135	67	–	179	129	50	–
CL-121	200	135	67	–	179	129	50	–
CL-141	200	100	50	50	179	90	45	45
CL-161	200	135	67		179	118	50	
Francis	200	100	50	50	179	90	45	45
Priscilla	200	135	67		179	129	50	
Wells	200	100	50	50	179	90	45	45
XL7	200	135	67	–	168	100	67	–
XL8	200	135	67	–	168	100	67	–
CL-XL8	200	135	67	–	168	100	67	–

As Baldo (an Italian variety) is very sensitive to over fertilization, special attention must be paid to the management of this crop. A study was conducted to determine the effect of different pre-flood nitrogen rates on lodging and yield of Baldo rice. At nitrogen rates less than 110 kg/ha lodging was 3% and lower. At nitrogen rates at 135-170 kg/ha lodging increased significantly and respectively from 39% to 82%.

For each treatment there were varying rates of pre-flood nitrogen applied and 35 kg N/ha applied at mid-season on all treatments. As Figure 2.5 indicates an increase in nitrogen up to 135 kg N/ha caused yields to increase. When applied nitrogen levels were higher than 100 kg/ha though, lodging increased significantly.

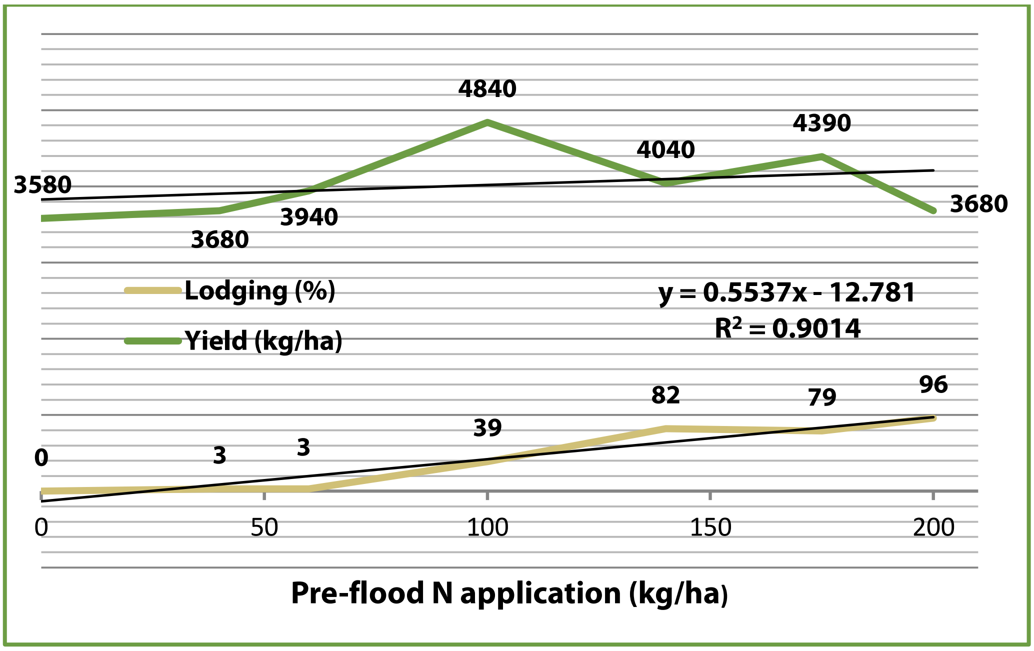


Figure 2.5: Effect of pre-flood nitrogen rates on grain yield and plants lodging. All treatments received mid-season N applications at the same time (35 kg/ha of N). *Source: Effects of Nitrogen on Baldo Rice, University of Missouri-Delta Center*

2.5 Time and method of nitrogen fertilization in water-seeded rice

Urea is generally the N fertilizer of choice.

Most of the nitrogen fertilizer should be applied pre-flood and pre-plant in water-seeded rice if the soil is not allowed to dry during the growing season. Nitrogen fertilizer should be placed either on dry soil and flooded in immediately or shallow incorporated and flooded within 3-5 days.

If several days elapse between the period of nitrogen application in ammoniacal form and flooding, much of the nitrogen will convert to nitrate. When the soil is flooded, nitrate is broken down by bacteria and released to the atmosphere as a gas, a denitrification process.

Denitrification losses can be avoided by flooding soils within 3-5 days after nitrogen application. These losses are greatest when nitrogen is applied into water on young rice. When most of the nitrogen is applied preplant, rice fields should not be drained, or drained only temporarily. In this situation, if a field must be drained during the growing season, the field should not be allowed to dry out before re-flooding. The field should be maintained in a saturated condition to protect the pre-plant nitrogen.

From internode elongation (green ring) through the beginning of head formation, nitrogen must be available in sufficient quantity to promote the maximum number of grains. Nitrogen deficiency at this time reduces the number of potential grains (florets) and limits yield potential.

Sufficient nitrogen should be applied pre-plant or pre-flood to assure that the rice plant needs no additional nitrogen until the panicle initiation (green ring) or the panicle differentiation (2 mm panicle) stage. When additional nitrogen is required, it should be topdressed at either of these plant stages or whenever nitrogen deficiency symptoms appear.

2.5.1 Second crop fertilization

Ratoon or second crop rice should be fertilized with 50-85 kg/ha of nitrogen, when first crop harvest is before mid-summer. When first crop harvest is after mid-summer, fertilize with 35-50 kg/ha of nitrogen. Higher rate of nitrogen should be applied when conditions appear favorable for good second crop production (minimal field rutting, little or no red rice, healthy stubble).

2.5.2 Recommended N rates

Nitrogen rates range 70-200 kg/ha (60–180 lbs/acre) depending upon variety and soil history.

N applied in a 2 or 3-way split: first time just before flooding, then again at about 1 cm internode elongation.

The early N application (65-100 % of the total N rate) should be applied as an ammonium N source onto dry soil immediately prior to flooding at around the 4- to 5-leaf growth stage. The University of Missouri recommendations for nitrogen are variety specific. Table 2.8 gives the nitrogen recommendations for 4 popular varieties.

Table 2.8: Nitrogen recommendations for 4 rice varieties (kg/ha)

Variety	Total N	Preflood	Mid-season
Cypress	168	101	34+34
Drew	151	84	34+34
Lamont	202	135	34+34
Cocdrie	168	101	34+34

Table 2.9: Nitrogen recommendations by variety

Variety	N Rate* (kg/ha)
Gulfmont, Lemont, Dellrose, Dixiebelle, Jefferson	110-185
Cypress, Bengal, Cocodrie, Jodon, Lafitte, Riscilla, Wells	110-170
Drew, Maybelle, Toro-2, Jackson, LaGrue, Madison	110-160
Mars, Jasmine 85	90-135
Rico 1, Della, S102	80-110
Saturn, Dellmati	70-100

*Usually only 20-50 kg/ha are required if the earlier nitrogen application was sufficient. If nitrogen deficiencies are observed prior to these growth stages, apply nitrogen topdressing immediately. Early nitrogen deficiency may greatly reduce yields.

Based on the site-specific nutrient management (SSNM) approach for fertilization of rice (IRRI 2006), a rice crop requires about 50 kg/ha of N fertilizer for each ton in additional grain yield. The optimal amount of fertilizer N required to attain the yield targets of 5.5 MT/ha in the dry season and 6.5 MT/ha in the wet season. This amount of fertilizer N can be split into three applications with an early N application of about 20 to 30 % of the total requirement. The remaining 70 to 80% is split into two applications based on the need of the rice crop, as determined from leaf color using the leaf color chart (Figure 2.1).

Table 2.10: General guidelines for efficient N management in rice

Situation	Strategy
Upland (dryland)	Broadcast and mix basal dressing in top 5 cm of surface soil. Incorporate top-dressed fertilizer by hoeing-in between plant rows and then apply light irrigation, if available
Rainfed deep water	Apply full amount as basal dressing
Lowland (submerged)	Use non-nitrate sources for basal dressing
Soil very poor in N	Give relatively more N at planting
Assured water supply	Can topdress every 3 weeks up to panicle initiation. Drain field before topdressing and reflood two days later
Permeable soils	Emphasis on increasing number of split applications
Short duration varieties	More basal N and early topdressing preferred
Long duration varieties	Increased number of topdressing
Colder growing season	Less basal N and more as topdressing
Over aged seedlings used	More N at planting

High-pH soil conditions increase N volatility when urea (46-0-0) is used as the N-source.

The source of N can increase N efficiency under certain situations. On newly precision-leveled fields, or on low-organic-matter soils, ammonium sulfate (21-0-0-S24) may offer a yield benefit when compared with urea. Ammonium sulfate is also less volatile on high-pH soils compared with urea.

2.6 Phosphorus (P)

2.6.1 The role of P in rice

Proper phosphorus (P) nutrition is critical for producing maximum rice grain yields. Phosphorus is very important in the early vegetative growth stages. Phosphorus promotes strong early plant growth and development of a strong root system. It is important to rice plants because it promotes tillering, root development, early flowering, and ripening.

Often P deficiency in rice is referred to as a "hidden hunger" because the symptoms are not apparent unless P-deficient plants are directly compared with plants that have sufficient P. When compared with healthy rice of the same age, P-deficient rice is characterized by an abnormal bluish green color of the foliage with poor tillering and plants that are slow to canopy and slow to mature. When plant comparisons are not available, plant tissue testing is the best tool for diagnosis of P deficiency.

Rice plants that are deficient in P are stunted and dirty-dark green, and they have erect leaves, relatively few tillers, and decreased root mass.

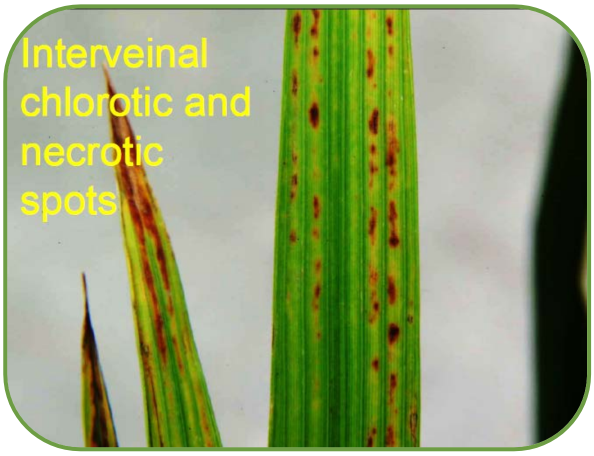


Figure 2.6: Phosphorus deficiency

2.6.2 The effect of soil pH on P availability

Phosphorus (P) fertilizer recommendations for rice are currently based on soil testing for available P and soil pH. **Phosphorus availability to rice is optimum when the pH is below 6.5.**

For upland crops, P availability is usually optimal when the soil pH is between 6.0 and 6.5.

In acid soils (pH < 6.0), the P is associated ("tied up" or "fixed") with iron and aluminum compounds that are slowly available to most plants. In acid soils, P availability increases following establishment of the permanent flood due to the chemical changes that occur to the iron phosphate. Thus, more P is available for rice following the flood than is measured with routine soil test methods.

In soil where pH is greater than 6.5, the P is primarily associated with calcium and magnesium. Not all calcium and magnesium phosphate compounds are slowly available to plants since their availability declines as pH increases. As a result, P is usually not limiting on acidic soils. In contrast, the availability of calcium phosphates tends to be low and remains low after flood establishment in alkaline soils (pH > 6.5).

Under Flooded Conditions:

- P is released to the soil solution as Fe^{3+}-phosphate compounds, which become reduced and convert to Fe^{2+}-phosphate compounds under low oxygen conditions
- On soils low in active Fe or low in total P, sufficient P may not become available
- On high pH soils (>7.0), with an abundance of calcium (Ca), the Ca-phosphate compounds may not release adequate P to the soil solution

Research has shown that soil pH is a better predictor of rice response to P fertilization than soil test P. However, soil pH is not static and can vary by as much as 1 pH unit, depending on sample time, environmental conditions and other factors. Application of P fertilizer to undisturbed acid soils that test low in P has failed to show significant yield increases and in some cases has increased lodging, caused rank vegetative growth and/or decreased yield.

Flooding rice soils generally moderates the pH towards a neutral pH condition, thus promoting the availability of soil P.

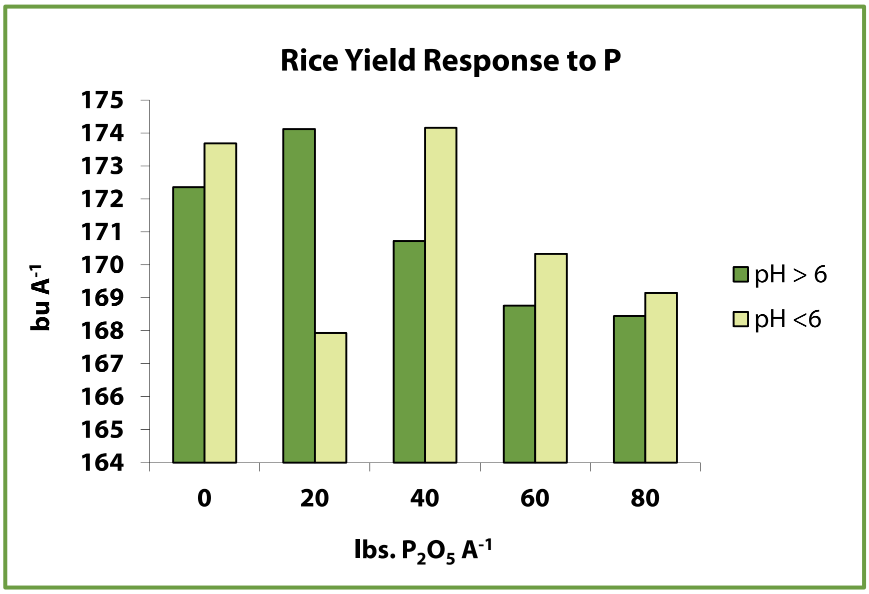


Figure 2.7: Rice yield response to P on clayey soils in Mississippi

In cases, when soil P content is less than 8 ppm, a yield response is not associated with soil P content. When soils are flooded, reducing conditions mobilize P from ferric iron (Fe_3^+) and aluminum (Al) phosphates to more labile forms and increases P mineralization from soil organic matter, both acting to satisfy the crop's P requirement.

Table 2.11: P recommendations based on Olsen P in soil tests and target yields

	Olsen P in soil tests		
	10	**20**	**30**
Target yield (t/ha)	**Phosphorus application P_2O_5(kg/ha)**		
4.5	52	32	16
5.0	62	42	26

Source: Perumal Rani et al., 1985

Factors like soil texture, P fertility status, seasonal conditions and duration of the variety are often taken into consideration (Table 2.12).

Table 2.12: Recommended rates of P for wet rice production

Available P (Bray I)		**P_2O_5 rate, (kg/ha)**	
ppm	**Rating**	**1st crop**	**2nd crop**
0- 4	Very low	70-80	50-60
5-10	Low	60-70	40-50
11-20	Medium	40-60	20-40
21-50	High	20-40	0-30
Over 50	Very high	0-30	0-20

Source: Lian, 1989 (Taiwan)

2.7 P deficiency symptoms

Phosphorus fertilizer should be applied only when recommended by soil test results or when deficiency has been diagnosed.

Visual symptoms of P deficiency may not be present in yield-limiting cases. Tissue test whole plants at the preflood stage to ensure that adequate P is available to rice plants. Tissue levels should be at least 0.18 percent P to ensure maximum yields.

Phosphorus (P) **deficiency symptoms** normally appear in the lower part of the plant and results in: (1) decreased leaf number, (2) decreased leaf blade length, (3) reduced panicles/plant, (4) reduced seeds per panicle, and (5) reduced filled seeds/panicle. **The reduced tillering capacity for rice planted in a P impoverished soil is usually greatest factor responsible for reduced yields.**

Normal Deficient

Deficient Normal

P deficiency in field

Figures 2.8 – 2.10: P deficiency symptoms

2.7.1 Recommended P rates and application timing

A rice crop will remove 0.35 kg of P_2O_5 per 50 kg rice per hectare. To account for this loss a crop removal, factor is included for soils testing 35-60 kg/ha of P.

Phosphorus is best applied pre-plant or pre-flood at rates determined via soil tests and yield expectations.

When needed, phosphorus fertilizer should be soil applied when land is prepared for planting. It is recommended to apply all phosphorus before planting in both water-seeded and dry-seeded rice. If phosphorus fertilizers could not be applied pre-plant, they can be applied before establishing the permanent flood.

2.8 Potassium (K)

2.8.1 The role of K

Modern high-yielding rice varieties absorb potassium in greater quantities than any other essential nutrient. In farmers' fields across Asia, total K uptake rates of a crop yielding 5 t/ha are in the range of 100 kg/ha, of which more than 80% are concentrated in the straw at maturity. (*Dobermann and Fraihurst, 2000*). For yields greater than 8 ton/ha, total K uptake may even exceed 200 kg/ha.

2.8.2 K uptake process throughout the rice life cycle

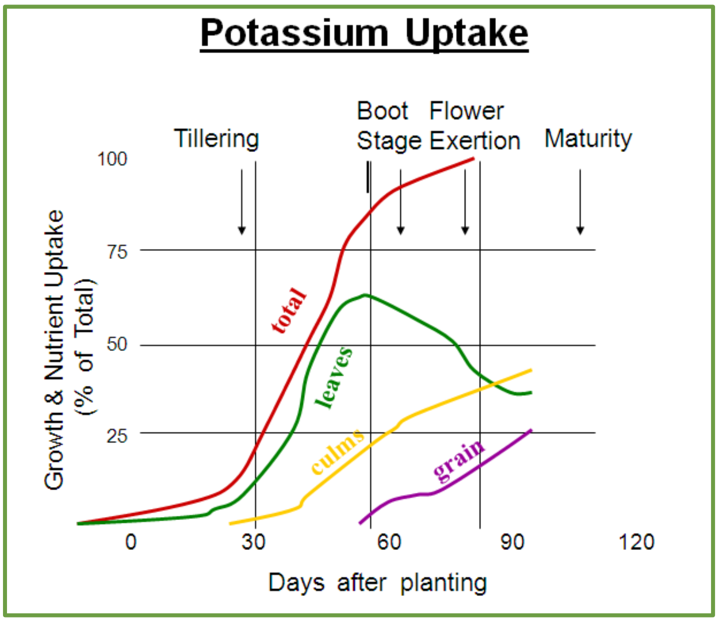


Figure 2.11: Potassium uptake process throughout the rice life cycle

Figure 2.11 shows that potassium is continuously taken up by the rice plant at a rate described by a sigmoidal curve, which gets to its maximum value during flowering. The potassium is firstly used for building the leaves biomass, then for the culms and later for the grains.

Proper potassium (K) nutrition in rice promotes:

- Tillering
- Panicle development (see Figures 2.12 – 2.14)
- Spikelet fertility
- Nutrient uptake of nitrogen and phosphorus
- Leaf area and leaf longevity
- Disease resistance
- Root elongation and thickness
- Culm (stem) thickness and strength
- Rice plant tolerance to diseases and pests
- Rice plant resistance to lodging

Recommended K rates are rarely sufficient to balance K removal rates under common commercial conditions. Therefore, most intensive rice production systems have been running under negative K balances and the negative effects of this have begun to emerge. The situation may be even more aggravated when all the straw is removed from the field with farmer practice in several countries. In some locations, the nutrients removed by crop are partly returned to the soil system in the form of farmyard manure (FYM).

Potassium deficiency occurs to a limited extent in lowland rice. Low potassium content or potassium deficiency is often associated with iron toxicity, which is common on acid latosolic soils and acid sulfate soils. Potassium deficiency also occurs on poorly drained soils, partly because toxic substances produced in highly reductive soils retard potassium uptake and partly because less soil potassium is released under poorly drained condition. The most important factors which determine the potassium balance of individual fields: soil characteristics, weather (climate), crops and cultural practices.

The yield of any grain crop depends on the number of ears per unit area, on the number of ripe grains per ear, and on the weight of the grain (frequently called "1000 grain weight"). Due to its influence on photosynthesis and assimilate transport, potassium is particularly effective in the improvement of grain number and grain weight. This has been confirmed in pot experiments and in numerous field trials with many cereal crops. See Figures 2.12 & 2.13.

Figure 2.12: Effect of K on panicle size of rice, *IPI-ISSAS project in Changsha, China. 9-2007. Source: IPI Coordination China.*

Figure 2.13: Effect of K on panicle size and number of grains per panicle. (The grains shown were harvested from three panicles.) *IPI-ISSAS project in Changsha, China. 9-2007.*

<u>Grain yield response</u> per kg of K_2O applied is higher in dry season than in wet season crop. In India, the following average responses have been recorded in commercial fields: 10 kg grain / kg K_2O in dry season, and 8 kg grain / kg K_2O in wet season.

Figure 2.14 shows two panicle samples and the grain removed from them, one taken from a plot not fertilized with K (left), and the other from a plot fertilized with K (right). Grains from each panicle were removed and categorized as: **a**) unfilled (top), **b**) partially filled (middle), and **c**) fully filled (top). Clearly, the sample from -K has a much larger proportion of unfilled and partially filled grain than does the sample from +K.

Figure 2.14: Effect of potassium on grain filling in rice. *Source: R. Buresh at an SSNM field, 2006, Indonesia. e-ifc No. 16, June 2008*

2.8.3 Rice response to K fertilization

Potassium fertilization field trials increased yields in 20 percent of the trial sites. The mean yield response was 10.6 kg rice per kg of K_2O applied. The general lack of response to K application is attributed to high (greater than 250 ppm) soil exchangeable K content of the rice-growing soils.

Only about 10-20% of the total K taken up by the plant is removed in the grain. An average rice yield of 7,567 kg/ha (150 bushels per acre) will only remove approximately 22 kg/ha of K, which is equivalent to about 27 kg/ha of K_2O. A mature rice crop, including grain and straw (all above-ground biomass), may weigh 6,800 to 9,000 kg/ha (dry weight) and contain on average 235 kg/ha K. Thus, total crop uptake at this yield level is 284 kg/ha of K_2O.

Proper potassium (K) nutrition is critical for maximizing rice grain yields. K is very mobile within the rice plant. Studies have shown that supplemental K can be supplied to the rice plant as late as Internode Elongation (IE) and still increase rice grain yields. **Whole plant K analysis at IE was better correlated to yield than flag leaf analysis at early boot.**

The application of sufficient fertilizer K to overcome deficiency of K can increase the efficiency use of N fertilizer. Figure 2.15 illustrates a situation where the rate of N fertilizer application (120 kg/ha was sufficient with adequate application of fertilizer P and K to achieve a rice yield of 5.7 t/ha. With insufficient K fertilizer the yield was 5.2- 5.4 t/ha only. The application of additional K fertilizer, through an increase in yield with no additional application of N fertilizer, increased the recovery efficiency of the N fertilizer by the rice crop to 37% of the applied N fertilizer.

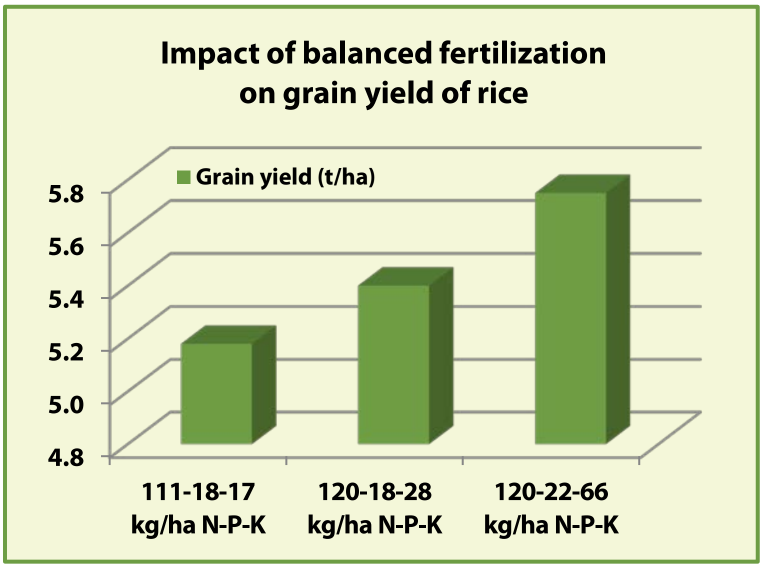


Figure 2.15: Impact of balanced fertilization on grain yield of rice

2.8.3.1 K reduces lodging

Foliar feeding has been shown (Better Crops, Vol. 89, 2005, #1) to markedly reduce lodging rates. Experiments were carried out by the University of Missouri, at the Delta Research Center. Two foliar applications of 30 kg/ha (34 lb/A) each, of **potassium nitrate** at midseason significantly reduced lodging (Figure 2.16), while **MOP (potassium chloride)** that was base- dressed pre-planting, or top-dressed at mid-season have not changed lodging rates.

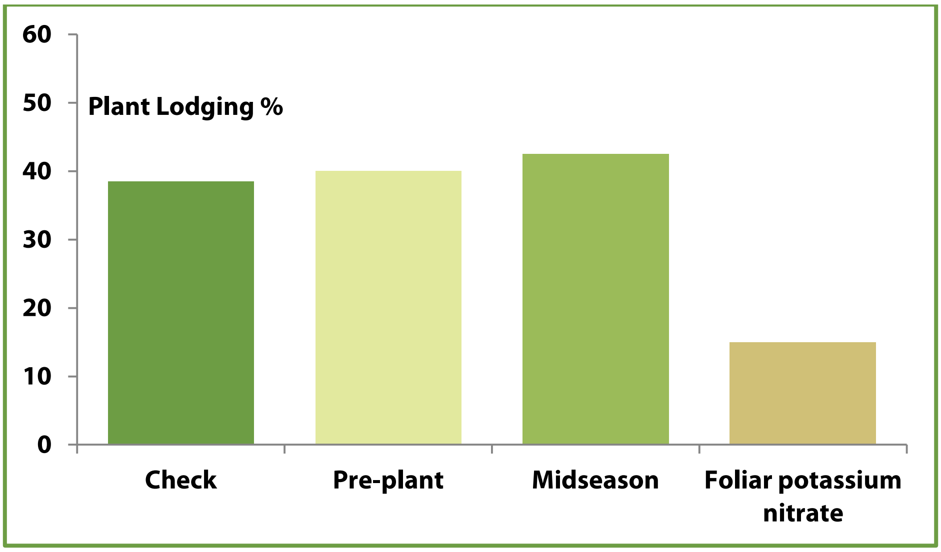


Figure 2.16: Reduced lodging of Baldo rice plants as a response to two foliar sprays of potassium nitrate at 30 kg/ha each

2.8.3.2 Lowland rice response to K fertilization and its effect on N and P

Potassium is absorbed in great quantities by rice, especially by high yielding cultivars, more than any other essential nutrient. Potassium fertilization at 70 and 100 kg/ha of K_2O significantly increases panicle development and yield.

N	P	K	S
(kg/ha)			
218	31	258	9

A single lowland rice crop produces 9.8 t/ha of grain in about 115-day uptakes.

2.8.4 K deficiency symptoms

Potassium deficiency symptoms include stunted plants with little or no reduction in tillering, droopy and dark green upper leaves, yellowing of the interveinal areas of the lower leaves, starting from the leaf tips, and eventually join together across the entire leaf and turn brown on all leaves (Figures 2.17 – 2.21).

The deficiency symptoms generally begin to appear near midseason and may be first observed when the plants do not “green up” after midseason N applications. As the deficiency progresses, the plants may develop severe disease infestation due to the plants’ reduced ability to resist infection. Diseases that are normally insignificant, such as brown leaf spot and stem rot may become severe in addition to diseases such as rice blast. While these diseases are typically more severe in K-deficient areas, they are not, by themselves, indications of K deficiency. **Potassium is**

highly mobile in the plant, and deficiency symptoms will always occur first and be most severe on the oldest leaves. Older leaves are scavenged for the K needed by younger leaves. Rice leaf tips of the upper leaves often turn yellow and then brown during hot dry periods, however, these symptoms should not be confused with K deficiency.

Potassium deficiency is also noted by decreased culm thickness,

K deficiency increases incidence of and physiological disorders. Poor root oxidation potential causes decreased resistance to toxic substances produced under anaerobic soil conditions, e.g., Fe toxicity. Typical diseases aggravated under K deficiency are: brown leaf spot (caused by *Helminthosporium oryzae*), cercospora leaf spot (caused by *Cercospora* spp.), bacterial leaf blight (caused by *Xanthomonas oryzae*), sheath blight (caused by *Rhizoctonia solani*), sheath rot (caused by *Sarocladium oryzae*), stem rot (caused by *Helminthosporium sigmoideum*), and blast (caused by *Pyricularia oryzae*) where excessive N fertilizer and insufficient K fertilizer have been used.

Figures 2.17 – 2.19: Rice K deficiency symptoms as shown on the leaves

Figure 2.20: Potassium deficient leaf (top) compared to healthy leaf (bottom). Note the severe brown spot and yellow/brown leaf margins of K deficient leaf.

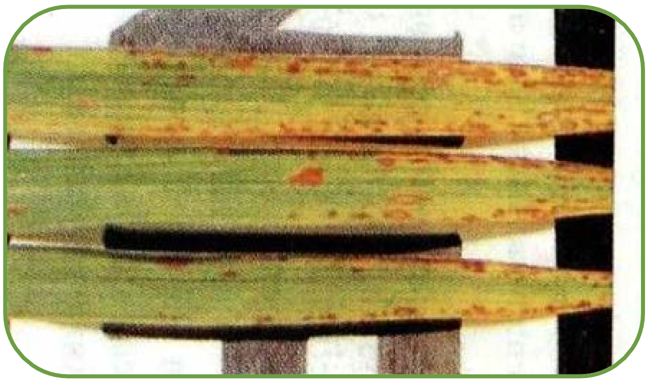


Figure 2.21: Typical deficiency symptoms of potassium (deficiency (rusty-brown spots, yellowing of the leaf tips and marginal necrosis) on the leaves of rice plants (variety IR 26).
Source: Bulletin 3, 1993, IPI, Horgen, Switzerland

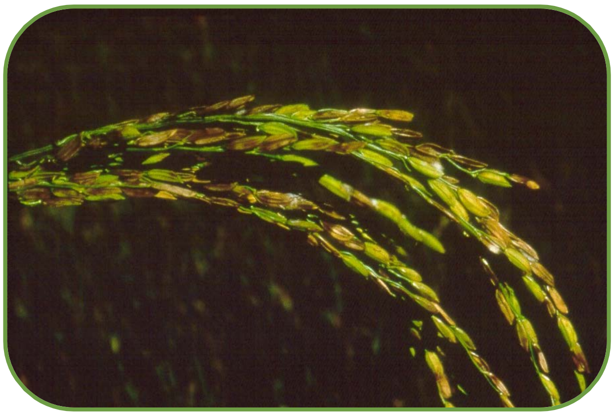


Figure 2.22: Typical potassium deficiency symptoms as manifested in a rice panicle

Figure 2.23: Typical potassium deficiency symptoms as manifested in a rice field

2.9 K fertilization requirements, timing and methods

The rice plant requires about 40 kg/ha K_2O just to achieve a plant that can produce a yield target of 6.5 t/ha in the wet season, and 25 kg/ha K_2O to attain a plant that can produce a yield of 5.5 t/ha in the dry season. Additionally, the optimal nutritional balance is achieved with an uptake of 14.7 kg N, 2.6 kg P and 14.5 kg K per ton of grain yield.

Therefore, the total K_2O requirements for a crop of 6.5 t/ha in the **wet season**, and a crop of 5.5 t/ha in the **dry season**, are **153** (40 + 6.5 * 14.5 * 1.2) and **121** (25 + 5.5 * 14.5 * 1.2) **kg/ha, respectively**.

Potassium application is recommended based on soil test results, **before rice shows K deficiency symptoms** during the season, as only low yield benefit, if any, is obtained from K fertilizer application to deficient rice in the mid-to-late boot stage. K fertilizer added at this time probably has little benefit for the current rice crop, but will remain in the soil for the future crops.

Silt and sandy loam soils have a very low buffering capacity and soil test K can decline rapidly if K fertilizer is omitted for several consecutive crops.

Although broadcasting and incorporating the whole K application at the time before planting or pre-flood is generally recommended, split application is also common in some areas. When needed, potassium fertilizer should be soil applied when land is prepared for planting. It is recommended to apply all potassium before planting in both water-seeded and dry-seeded rice. If potassium fertilizers could not be applied pre-plant, they can be applied before establishing the permanent flood.

Figure 2.24: Effect of N, P and K on rice plant size. *IPI-SWRI project in the Nile Delta, Egypt. 2006. Source: IPI Coordination WANA*

2.10 Effects of N, P and K on rice yield

As mentioned already, the optimal nutritional balance is achieved with an uptake of 14.7 kg N, 2.6 kg P and 14.5 kg K per ton of grain yield.

Results for 21 consecutive cropping seasons (during 10.5 years of intensive cropping in 1995 to 2005) indicate that with balanced fertilization of N, P, and K, grain yield averaged 5.5 t/ha in the dry season and 6.5 t/ha in the wet season. The accumulated loss in grain yield without application of N fertilizer was 40 t/ha (Figure 2.25). This corresponds to an average grain yield loss of 2 t/ha in each season if N fertilizer was not used. Thus, the use of N fertilizer with appropriate amounts of fertilizer P and K ensured an average additional grain yields of 2 t/ha in each season.

The corresponding figures for potassium were 10 t/ha yield loss for the experiment period, which mean a 1/2 t/ha yield loss for each season if K fertilizer was not applied.

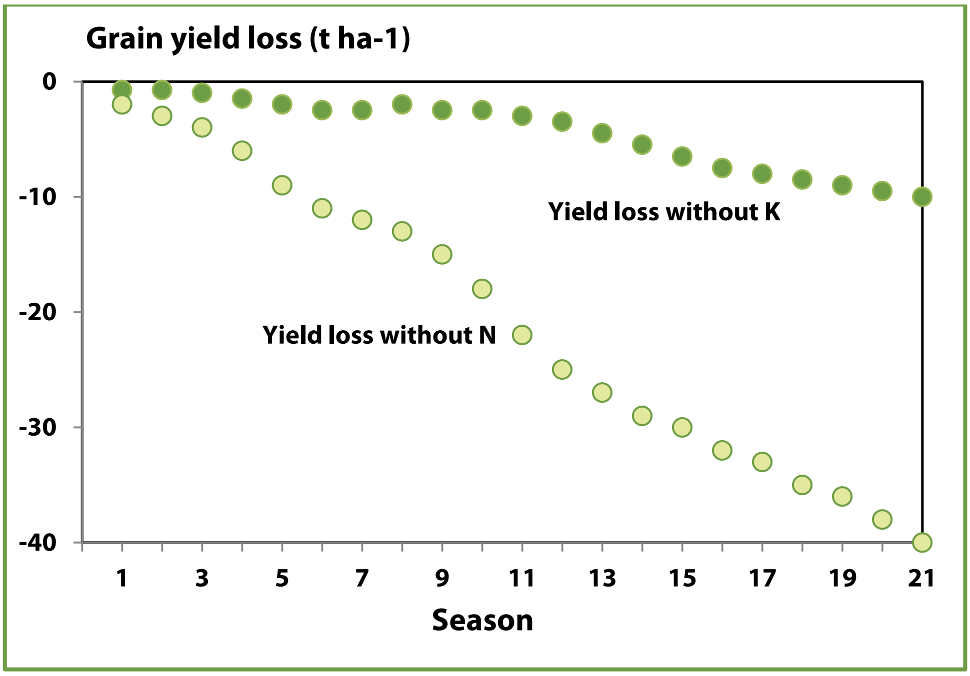


Figure 2.25: Loss in rice grain yield after 21 successive crops when nitrogen and potassium fertilizers are not applied. *(Long Term Fertility Experiment, Sukamandi Experiment Station, Indonesia)*

2.11 Secondary plant nutrients

2.11.1 Sulfur (S)

Sulfur plays an important role in the biochemistry and physiology of the rice plant, mainly in chlorophyll production, protein synthesis, and carbohydrate metabolism. S deficiency has been reported from Bangladesh, Burma, Brazil, Indonesia, India, Nigeria, Philippines and Thailand. Symptoms of S deficiency are very similar to N deficiency symptoms, producing pale yellow plants which grow slowly. However, the main difference is that sulfur is immobile in the plant; therefore, the yellowing will first appear in new leaves rather than older leaves.

Figure 2.26: Symptoms of sulfur deficiency on a rice plant

Most soil sulfur is contained in the soil organic matter. Sulfur deficiencies will frequently occur in the cut and deep-fill areas of newly land-formed fields. In such cases, sulfur deficiencies can usually be avoided by applying a minimum of 112 kg/ha of ammonium sulfate $(NH_4)_2SO_4$, between preplant and the 2-3 leaf plant stage. This treatment will provide 23 kg/ha of nitrogen and 26 kg/ha of sulfur.

In Bangladesh, 20 kg/ha S is generally recommended in the form of gypsum for dry season rice, the residual effect of which can often meet the S requirement of the succeeding wet season rice crop. In Bangladesh, application of S along with NPK increases the grain yield by 30-79 % above that obtained by using NPK fertilizers alone. In India, although S is yet to be introduced to the regular fertilizer schedule for rice, researchers have suggested application of 30 kg/ha S per crop at Delhi and 44 kg/ha S per two crops at Bhubaneswar, Orissa. In general, application of S-containing fertilizers is advocated during the final land preparation.

2.11.2 Calcium (Ca)

Calcium is important for the build-up and functioning of cell membranes and the strength of cell walls. Most calcium-related disorders of crops are caused by unfavorable growing conditions and not by inadequate supply of calcium to the roots. Rapidly growing crops in hot windy conditions are most at risk. Deficiencies can also develop under waterlogging, soil salinity, high potassium or ammonium supply, and root disease.

Calcium moves in the plants' transpiration stream and is deposited mainly in the older leaves. Deficiencies are found in the youngest leaves and growing points, which have low rates of transpiration. Youngest emerging leaves show the following symptoms only under severe Ca deficiency:

- Interveinal chlorosis (Figure 2.27) and leaf may bend downwards because the leaf margins have failed to expand fully (Figure 2.28).
- White or bleached, rolled, and curled tips of leaves
- Necrosis along the lateral margins of leaves
- Stunting and death of growing points
- Mature and older leaves are generally unaffected, but in severe situations old leaves turn brown and die too.

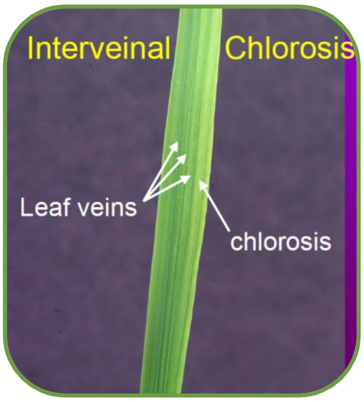


Figure 2.27: Interveinal chlorosis in calcium deficient rice leaves

Figure 2.28: Downward bending in calcium deficient rice leaves

Importance / Occurrence:

- Relatively rare in irrigated rice systems.
- Common in acid, strongly leached, low-CEC soils in uplands and lowlands, soils derived from serpentine rocks, coarse-textured sandy soils with high percolation rates and leaching, and leached old acid sulfate soils with low base content.
- Important throughout the growth cycle of the rice crop

2.12 Micronutrients (trace elements)

Micronutrient deficiencies typically do not occur on acid to slightly acid clay soils (pH = 5-6.5). However, silt and sandy loam soils, as well as any high-pH soils (>7.5), are subject to various micronutrients deficiencies. Soils with high available P and low organic matter are also subject to Zn deficiency.

2.12.1 Zinc (Zn)

2.12.1.1 Role of Zn

In plants, Zn is critical for many physiological functions, including the maintenance of structural and functional integrity of biological membranes and the facilitation of protein synthesis. Of all micronutrients, Zn is required by the largest number of enzymes and proteins. The zinc pathways have important roles in:

- Photosynthesis and sugar formation
- Protein synthesis
- Fertility and seed production
- Growth regulation
- Defense against disease.

2.12.1.2 Differentiating Zn deficiency from salinity and P deficiency

Zinc deficiency, P deficiency and salinity injury symptoms are easily and often confused. Zinc deficiency symptoms usually occur after flushing or flooding, whereas problems from salinity occur prior to flushing or flooding under dry soil conditions. Both salinity and Zn deficiency can be present in the same field. Phosphorus deficiency is also similar to Zn deficiency in that the symptoms typically occur after flooding. However, leaves are usually more erect and basal chlorosis (yellowing) is usually not present with P deficiency. Also, Zn deficiency appears much sooner after the flood is established, usually within a few days, whereas it generally takes a week or two after flooding to show P deficiency.

Rice is particularly susceptible to Zn deficiency, as it grows in waterlogged soils which are conducive to zinc deficiency. Flooding the soil reduces Zn availability to the crop and increases the concentrations of soluble P and bicarbonate ions, which can exacerbate problems of Zn deficiency. Symptoms are more severe in cold-water areas and where theflood is the deepest.

Visual symptoms, field history and soil pH and soil Zn determination are important methods for determining if Zn fertilizer may be needed. But, **plant tissue analysis** is the most effective means of correctly distinguishing which nutrient is the cause of the unhealthy rice.

2.12.1.3 Zn deficiency symptoms

The symptoms are often noted within 72 hours after flooding and are aggravated by deep and cold water. When they become severe enough, the flood must be removed in order to salvage the rice. If the soil pH is extremely high, deficiency symptoms may appear after a flush or a rain. Environmental factors, such as cool temperatures, may increase the severity of deficiency symptoms. Likewise, excessive P fertilizer applications may aggravate a Zn deficiency. Prior to flooding, the symptoms are usually subtle and difficult to observe without very close visual examination. Seedling rice can obtain sufficient nutrients from the seed for about 10 days after emergence. Therefore, Zn deficiency symptoms do not generally appear in seedling rice until at least 10 days after emergence, and it may take several weeks after emergence for the symptoms to appear. The Zn deficiency symptoms, whether subtle if observed before flooding or severe if observed after flooding, include:

Figure 2.29: Zinc deficiency symptoms

1. Basal leaf interveinal chlorosis – the portion of the leaf nearest the stem becomes light green while the leaf tip remains a darker green. Usually begins in the youngest leaf (Figure 2.29).
2. Pale-green color on the bottom half of the leaves 2 to 4 days after flooding;
3. Leaves become yellowish and start dying 3 to 7 days after flooding.
4. Abnormally-shaped leaves and leaf stunting.
5. Leaves may lose turgidity and tend to float on the water surface if the rice is flooded or being flushed. Flushing seedling rice can aggravate Zn deficiency, causing the visual symptoms mentioned to become more noticeable and enable visual diagnosis before flooding to avoid a salvage situation. So pay close attention to the young rice when flushing. The loss of leaf turgidity is a difficult symptom to evaluate since deep water may give leaf tissue a similar appearance.
6. Bronzing – consists of brown to red splotches starting on the surfaces of the oldest leaves. Bronzed leaf tissue may eventually turn brown. A bronzed appearance of the plants, and when closely examined the leaves often show an irregular rusty pattern; Bronzing normally follows basal leaf chlorosis.
7. Stacking of leaf sheaths or joints.
8. Stunting/reduced height

2.12.1.4 Zn deficiency during crop development

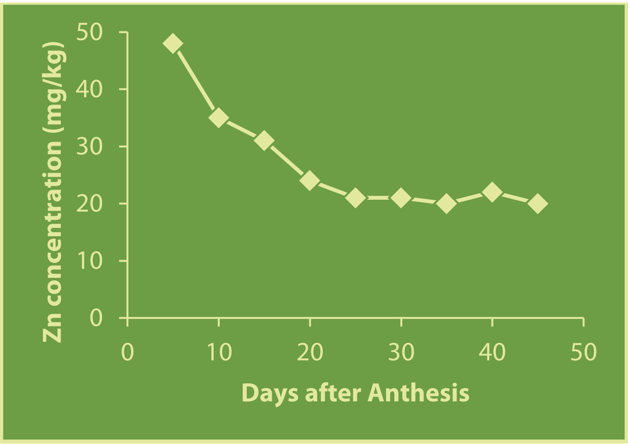


Figure 2.30: Change in brown rice Zn concentration during grain development

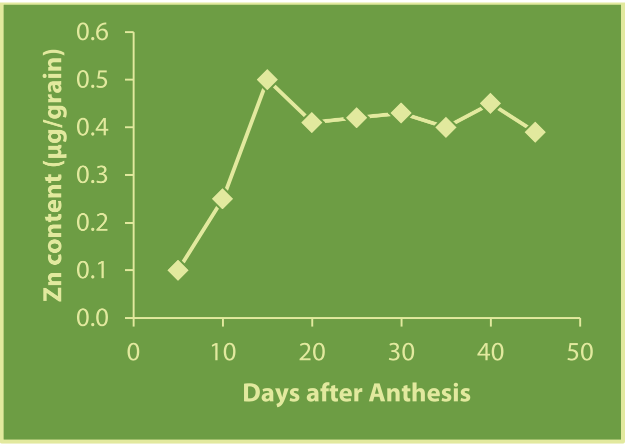


Figure 2.31: Zinc content in brown rice during grain filling

2.12.1.5 Effect of soil type on Zn deficiency

Zn deficiency is the most widespread micronutrient disorder in lowland rice and high-pH soils frequently require the addition of zinc for rice production.

Zinc deficiency normally occurs on silt and sandy loam soils or on precision graded fields. It is caused by a reduction in the availability of native soil Zn because the soil pH has been increased either by use of calcareous irrigation water or over-liming, not due to a lack of Zn in the soil. The correction of the problem requires either reduction of the soil pH or addition of a suitable Zn source. Zinc deficiency is not commonly observed on clay soils in Arkansas. Therefore, Zn fertilizer is only recommended on silt and sandy loam soils with soil pH greater than 5.9 and soil test Zn (Mehlich 3) < 7 pounds Zn per acre. Fields with high pH (>7.5) clay soils should be monitored carefully since Zn deficiency on clay soils is known to occur in many rice producing areas of the world.

2.12.1.6 Time and method of Zn application

If using soil-applied zinc in water-seeded rice, application of zinc should be just before flooding or with zinc sulfate.

If a soil test indicates a Zn deficiency prior to planting, broadcast-apply 8-11 kg/ha of Zn, in the form of 22-34 kg/ha (20-30 pounds/acre) of Zinc Sulfate. It can be applied this way starting before planting or into the water soon after flooding. Since rice roots develop near the soil surface, and seedling root growth is slow in the water-seeded system, it is important that most of the zinc will be on or near the soil surface. In the dry-seeded system, soil-applied zinc should be broadcast and shallow incorporated no more than 2.5-5 cm deep. Initial root development in the dry-seeded system is beneath the soil surface, and soil incorporated zinc is more available. Non-incorporated zinc should be located above the rooting zone in dry seeded rice.

If deficiency symptoms occur after rice emergence, apply a zinc chelate at 0.5-1 kg/ha as a foliar spray. Zinc chelate can be tank-mixed with propanil if the propanil is needed for weed control.

On alluvial soils with a neutral – slightly alkaline soil reaction, soil-applied zinc can be made unavailable by the soil. If zinc deficiency is a problem in these soils, foliar treatment or soil + a foliar treatment may be preferable to a soil treatment alone. If zinc deficiencies are observed, apply foliar sprays quickly.

Alternative recommendations:

1. Root dipping of seedlings in 1-4 % ZnO suspension before transplanting.
2. Foliar spraying of 1 - 3 % Haifa Bonus+Zn solution at 30, 45 and 60 days after planting or more frequently.

Zn along with NPK fertilizer increases the grain yield dramatically in most cases, see Table 2.13.

Table 2.13: Response of lowland rice to Zn application

Country	Soil characteristics	Zn application rate (kg/ha)	Grain yield increment (t/ha)
India	Calcareous red, pH 7.5	10	1.8
	Saline-alkali, pH 10.6	10	1.0
	Aquic Camborthid	11.2	1.4
Pakistan	Calcareous	100	2.6
Philippines	Calcareous	10	4.8
	Hydrosol	Root dipping in 2 % ZnO	4.4
Thailand		15	0.4
USA	Norman clay	9	**7.0 (!)**
	Crowley silt loam	27	0.7
	Crowley silt loam	8	2.4

Source: Jones et al., 1982

2.12.2 Boron (B)

Boron main functions in rice (and all other plants) are:

- Takes an important part in cell-wall biosynthesis
- Affects structure and plasma membranes integrity.

Boron deficiency symptoms in rice are:

- White and rolled leaf tips of young leaves
- Reduction in plant height
- Tips of emerging leaves are white and rolled (as in Ca deficiency)
- Death of growing points, but new tillers continue to emerge during severe deficiency
- If affected by B deficiency at the panicle formation stage, plants are unable to produce panicles

Boron deficiency correction methods

Optimum preplant B contents for some soils is 0.25-0.5 kg/ha, which corresponds with a critical level for hot-water extractable boron of 0.25-0.35 ppm.

In order to achieve this contents rate, a broadcast application of 0.75 kg/ha of pure boron is advocated. This can be achieved by application of 6.8 kg/ha of commercial Borax, ($Na_2B_4O_7 \cdot 10H_2O$, containing 11% pure B), or 4.3 kg/ha of commercial boric acid (H_3BO_3, containing 17.5% pure B).

Figure 2.32: The corrective effect of applying Borax at 1.0 kg/ha of pure boron, on Super Basmati and IR-6 rice cultivars. *Source: A. Rashid et al. NARC, Islamabad, Pakistan, 2005*

Rice yields increase by more than 500 kg/ha with 0.5-1.0 kg/ha added boron fertilizer, such as "Borax."

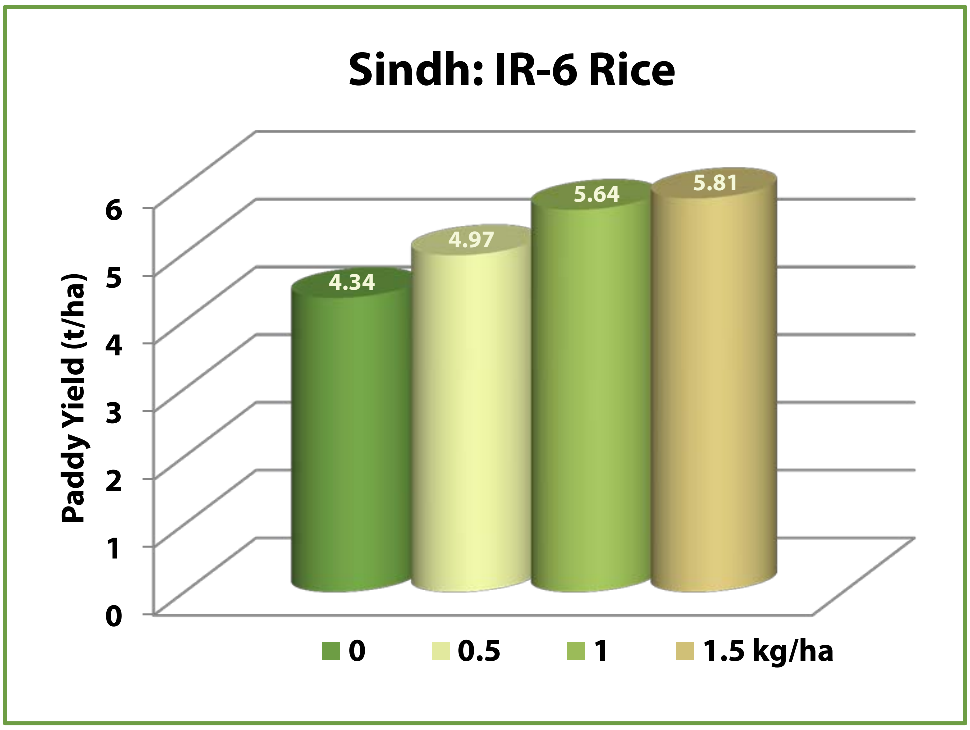


Figure 2.33: The corrective effect of applying Borax at 0.5-1.5 kg/ha of pure boron, on IR-6 rice cultivar. *(Source: A. Rashid et al. NARC, Islamabad, Pakistan, 2005)*

2.12.3 Iron (Fe)

2.12.3.1 Fe Deficiency symptoms

The symptoms of iron deficiency are yellowing or chlorosis of the interveinal areas of the emerging leaf (Figure 2.34). Later the entire leaf turns yellow, and finally turns white. If the deficiency is severe, the entire plant becomes chlorotic and dies. Iron deficiency can easily be mistaken for nitrogen deficiency. However, nitrogen deficiency affects the older leaves first, while iron deficiency affects the emerging leaves first.

Figure 2.34: Iron deficiency symptoms

2.12.3.2 Soil conditions likely to produce Fe deficiency in rice

The iron requirement of rice is greater than that of other plants. Iron deficiency is a common disorder of rice growing on well-drained (aerobic) soils, whether these are neutral, calcareous or alkaline. The severity of the disorder increases with the pH. Iron deficiency may also be observed in rice on upland acid soils.

In flooded rice paddies, iron deficiency is likely to be found in calcareous and alkaline soils low in organic matter, and in soils irrigated with alkaline water.

Iron deficiency may also be a problem in peat soils, especially if these are well-drained, and with a high pH.

2.12.3.3 Diagnosis by soil analysis

<u>Well-drained soils</u> with a pH>6.5 are likely to be deficient in available iron. The severity of the problem increases with a high pH.

<u>In flooded rice soils</u>, iron deficiency may occur if the redox potential of the soil at a pH of 7 is more than 0.2 volt. In this situation, the total soil iron content may be high, but the level of available iron in the soil remains low.

Iron deficiency is likely to be observed if the iron concentration in the soil is:

- Less than 2 mg/kg, extracted by ammonium acetate, with a pH= 4.8.
- Less than 4-5 mg/kg, extracted by DTPA-Calcium chloride, with a pH= 7.3.
- Diagnosis by plant analysis: the critical level for iron deficiency in rice is 50 mg/kg, in shoots sampled from the stages of tillering to panicle initiation.

2.12.3.4 Interaction with other elements

A high concentration of calcium carbonate in the soil or irrigation water is likely to make iron deficiency of rice more severe. Iron deficiency can sometimes be caused by too much nitrate, which raises the pH of the soil around the roots. High phosphate applications may cause iron deficiency, or make it worse, by precipitating iron in the soil solution. High phosphate levels may also hinder the uptake of iron by plants, and the translocation of iron from the root system to the shoots.

2.12.3.5 How to correct Fe deficiency in rice

Iron deficiency can be amended by applying a foliar spray of 2-3% ferrous sulfate ($FeSO_4$) solution. Another way of correcting the deficiency is to apply about 30 kg/ha of iron as ferrous sulfate to the soil. Because of the low mobility of iron in the plant, split applications may be necessary.

2.12.4 Manganese (Mn) toxicity of rice

Source: Corinta Quijano-Guerta, International Rice Research Institute, Philippines

2.12.4.1 Mn toxicity symptoms

Visual symptoms of manganese toxicity in rice appear as brown spots on older leaves (Figure 2.35). About eight weeks after planting the tips of leaves dry out. Vegetative growth is not appreciably affected, but grain yield is markedly depressed because of high sterility.

Figure 2.35: Typical symptoms of manganese toxicity in rice

2.12.4.2 Soil conditions conducive to Mn toxicity

Manganese toxicity is sometimes observed in dryland rice with soil pH < 5.5.

It rarely occurs in lowland paddy soils, but may occur if the soil contains very large amounts of easily reducible manganese, or in areas contaminated by manganese mining.

2.12.4.3 Diagnosis by soil analysis

The toxicity is probably related to the concentration of easily reducible manganese in the soil, but no critical level is known. An aqueous soil solution with a manganese level of more than 2 mg/L is considered toxic.

2.12.4.4 Diagnosis by plant analysis

Critical limits:

Plant organ checked	Physiological stage	Value (mg/kg DW)
Shoot	Tillering	7,000
Leaves	Flowering	3,000

2.12.4.5 Interaction with other elements

The solubility of manganese increases sharply in aerobic soils as the pH drops below 4.5, while that of iron hardly changes until the pH is down to 2.7-3.0. This fall in pH increases the ratio of manganese to iron, leading to manganese toxicity.

However, it does not follow that manganese toxicity induces iron deficiency, or vice versa.

Silica has been reported to alleviate manganese toxicity by decreasing the uptake of manganese, and by increasing the internal tolerance to manganese in the plant tissue. Manganese toxicity is usually accompanied by aluminum toxicity and phosphorus deficiency.

2.12.4.6 How to correct Mn toxicity

Liming is a common remedy for manganese toxicity. The application of ferrous sulfate ($FeSO_4$), gypsum and farmyard manure can also be helpful, as can be application of silica slag at a rate of 1.5 to 3 mt/ha. NPK fertilizer is often needed, but acidifying nitrogen sources should not be used.

2.12.5 Aluminum (Al) toxicity of rice

Source: Corinta Quijano-Guerta, International Rice Research Institute, Philippines

2.12.5.1 Description of symptoms

Rice suffering from aluminum toxicity shows interveinal white to yellow discoloration of the tips of older leaves, which may later turn necrotic (Figure 2.36). The roots of affected plants are stunted and deformed.

Figure 2.36: Typical white discoloration of aluminum toxicity in rice leaves

2.12.5.2 Soil conditions likely to produce aluminum toxicity

Aluminum toxicity commonly occurs in Oxisols and Ultisols as well as in other heavily leached soils such as lateritic soils of the humid tropics. It is an important growth limiting factor on upland soils with a pH < 5.

Aluminum toxicity in wetland rice is observed in most acid sulfate soils during the initial phase of soil flooding. The rise in pH of acid sulfate soils after submergence is very slow, so that toxicity may persist for many weeks.

Diagnosis by soil analysis
A soil pH < 4, and an aluminum concentration in the soil solution of more than 1 mg/L, indicate toxic levels of aluminum.

Diagnosis by plant analysis
An aluminum concentration over 300 mg/kg in the shoot at the tillering stage is generally considered toxic.

2.12.5.3 Interaction with other elements

Aluminum toxicity in upland rice is always associated with manganese toxicity and phosphorus deficiency. Aluminum toxicity hinders the uptake by rice of phosphorus, calcium and potassium (Figure 2.37).

2.12.5.4 How to correct Al toxicity

Liming will increase the soil pH. Growers should use dolomitic lime, if possible. It is necessary to apply phosphorus and potassium fertilizers. Acidifying nitrogen sources should be avoided.

Figure 2.37: Leaves symptoms from combined manganese and aluminum toxicities under severely acidic soil

Other cultivation practices

Early plowing is recommended, right after the recession of floods at the end of the rainy season. Acid sulfate soils should have a shallow drainage system.

The rice should be planted after prolonged soil submergence, and growers should select rice varieties with tolerance to aluminum toxicity.

3. Fertilization practices

3.1 The amounts of plant nutrients taken up and removed by rice crop

The amount of plant nutrients uptake by rice crop, based on the yield, is presented in Table 3.1. More plant nutrients uptake can be expected at higher yields.

Table 3.1: Nutrient Uptake

Yield	N	P_2O_5	K_2O	S	Mg
(kg/ha)					
7,847	126	67	188	13	16

The total plant nutrients removed from the field by grain rice is different from the amount plant uptakes during the growth period of straw and grain together (Table 3.2, Figure 3.1).

Table 3.2: Harvested plant nutrients

Yield	N	P_2O_5	K_2O
(kg/ha)			
7,847	78	49	31

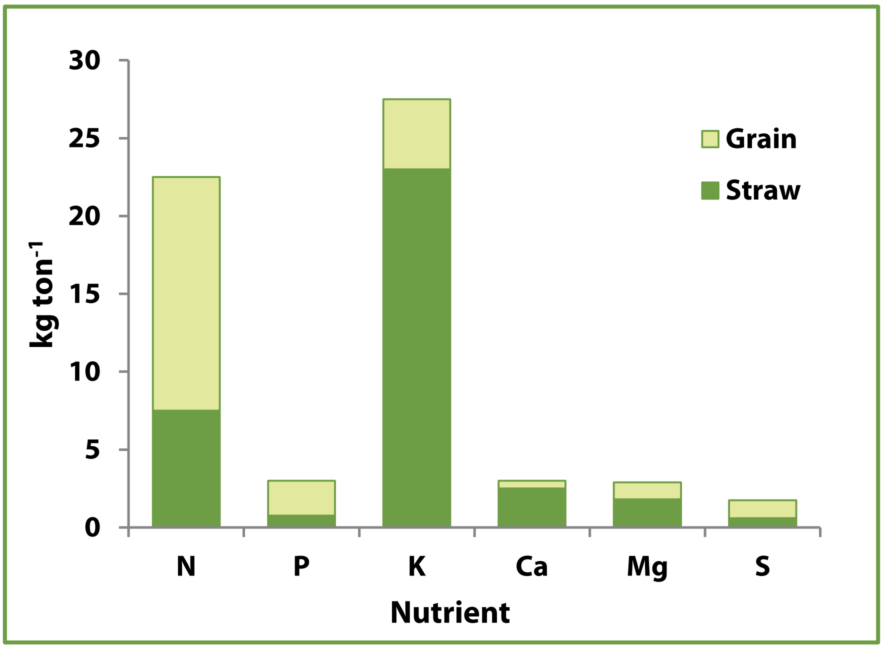


Figure 3.1: Nutrient content of rice straw and grain

3.2 Foliar feeding

3.2.1 What is foliar feeding?

Foliar feeding is a 'by-pass' approach, overtaking conventional soil applied fertilizer whenever it does not perform well enough. Foliar application overcomes soil fertilization limitations like leaching, insoluble fertilizer precipitation, antagonism between certain nutrients, heterogenic soils unsuitable for low rates, and fixation/absorption reactions like in the case of phosphorus and potassium. Foliar feeding can also be used to overcome root problems when they are suffering from limited activity due to low/high soil temperatures, lack of oxygen in flooded fields, nematode attack damaging the vascular system, and a decrease in root activity during the reproductive stages where more of the photosynthetic creation is transferred for reproduction with less for root respiration. Foliar feeding has proved to be the fastest way of curing nutrient deficiencies and boosting plant performances at specific physiological stages. With plants competing with weeds, foliar spraying focuses the nutrient application on the target plants. Foliar fertilizers are absorbed right at the site where they are used as quite fast acting, whereas, much of the soil fertilizers may never get used by plants. Foliar fertilization is widely used practice to correct nutritional deficiencies in plants caused by improper supply of plant nutrients to roots. Fertilizers have also been found to be chemically compatible with pesticides, thus saving labor costs.

3.2.2 Penetration of plant nutrients

Fertilizers applied through the plant leaf canopy have to face several structural barriers. Nutrients, which are salt based (cations/anions) may face some problems penetrating the inner plant tissue cells. General leaf structure is based on several cellular and non-cellular layers. The different layers support protection against desiccation, UV radiation and various kinds of physical, chemical and (micro) biological agents. Several layers can be seen in Figure 3.2.

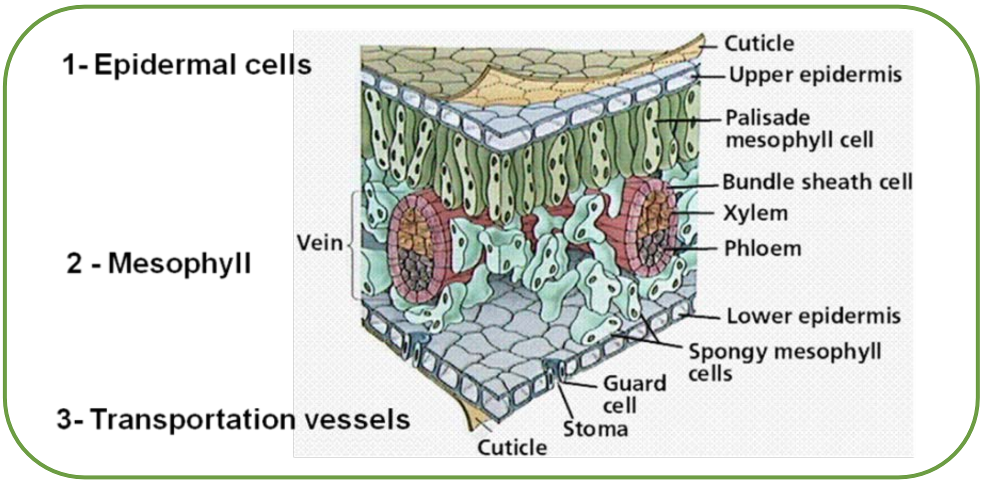


Figure 3.2: Three systems composing plant's leaf

The different layers are characterized by electrical negative charge, which influences the way and rate of penetration of different ions. Some layers are hydrophobic and therefore repulse water-based spray (Figure 3.3).

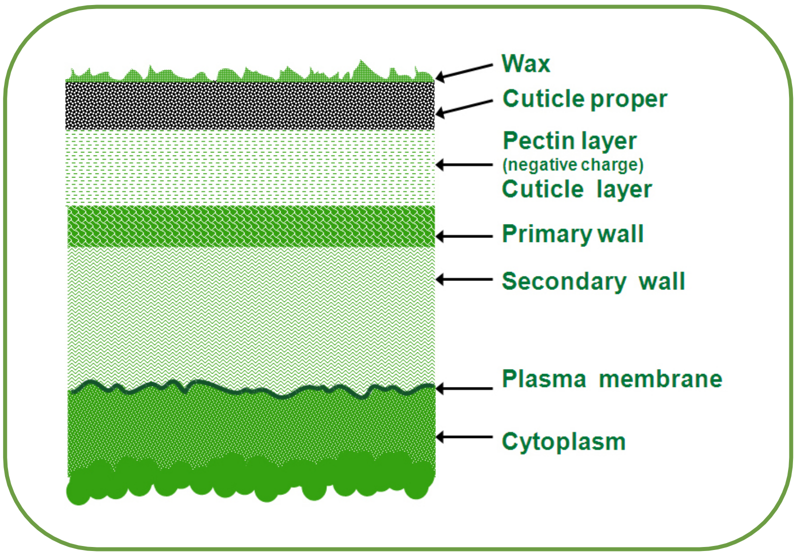


Figure 3.3: Scheme of the outer wall of epidermal leaf layers

The first layer from outside is a wax layer, which is extremely hydrophobic. The epidermal cells synthesize the wax and it crystallizes in an intricate pattern of rods, tubes or plates. The wax layer can change during the plant growth cycle.

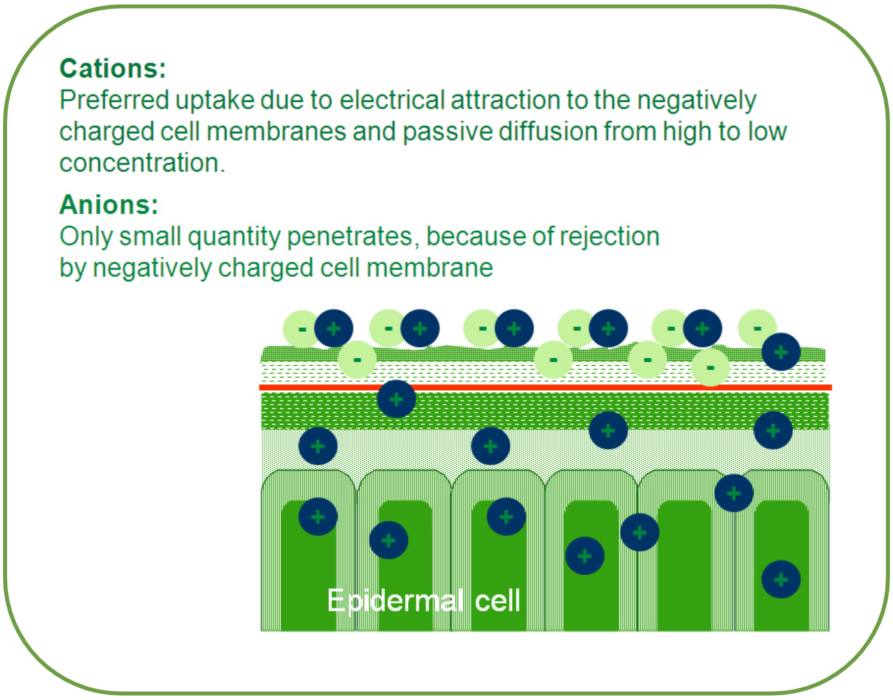
The second layer, referred to as the 'cuticle proper', is a non-cellular protective layer surrounded by wax to the upper side and the bottom one as well and made mainly from 'cutin' (macromolecule polymer consisting of long-chain fatty acids creating a semi-hydrophilic character).

The following layer is 'pectin', negatively charged and made of polysaccharides that form sugar-acid based gel-like tissue (cellulose and pectic materials).

Next is the outer side of the cells starting with the primary wall. The cuticle has negative charge density as well due to the pectin and cutin.

The penetration of nutrients can be split into two stages: 1) into the tissue from outside, which is referred to as absorption; and 2) movement from the point of penetration to other parts of the plant that is referred to as translocation.

Penetration/absorption can be done through several organ elements that exist in the tissue. Main penetration is done directly through the cuticle. The penetration is done passively. First to penetrate are the cations as they are attracted to the negative charge of the tissue, and they move passively in accordance to the gradient – high concentration outside and low one inside. After a certain period the cations that have moved inside change the electrical balance in the tissue causing it to be less negative and more positive. From this point on the anions start to penetrate the tissue in the same manner as described for the cations (Figure 3.4). Since the penetration is a passive one, the rate of diffusion across the membrane is proportional to the concentration gradient, therefore achieving a high concentration without scorching the tissue - which may dramatically improve the penetration.



Cations:
Preferred uptake due to electrical attraction to the negatively charged cell membranes and passive diffusion from high to low concentration.

Anions:
Only small quantity penetrates, because of rejection by negatively charged cell membrane

Figure 3.4: Anion and cation penetration and translocation pattern in the leaf tissue

Penetration also occurs through the stomata, which are aperture controlled for gas exchange and transpiration. It is known that these apertures differ between different plant species, their distribution, occurrence, size and shape. In broadleaf crops and trees, most of the stomata are on the lower leaf surface, while grass species have the same number on both surfaces. Size may differ, for example, sorghum stomata are four times larger than bean stomata. High penetration is estimated to be due to high cuticle pore density in cell walls between guard cells and subsidiary cells. In addition, the pores near the stomata guard cells seem to have different permeability characteristics. An opposite opinion exists, claiming that penetration through open stomata does not play a major role since a cuticle layer also covers the surface of the guard cells in stomata cavities and because ion uptake rates are usually higher at night when the stomata are relatively closed.

Another path that nutrients can penetrate is through hair-like organs known as ‘trichomes’, which are epidermal outgrowths of various kinds. The importance of this pathway depends on the trichomes rate and position, dependent on leaf age and its origin.

3.2.3 Translocation within the leaf tissue

After the ions have penetrated, transportation to different parts of the plant starts and this is referred to as translocation. Translocation is done through two mechanisms: cell-to-cell transport is referred to as ‘Apoplast movement’, and transport through the vascular channels is referred to as ‘Symplast movement’.

The Apoplast movement describes the ion movement from one cell to another. This is done by three mechanisms (Figure 3.5):

- Passive transport involves diffusion according to the gradient and mass flow through the water/fluid movement between cells.

- Absorption by cytoplasm membrane surface via plasmodesmata, which are microscopic channels connecting one cell wall to another, enabling transport and communication between them.
- Active transport (ATP) against the gradient, enabled due to energy investment of ATP molecules.

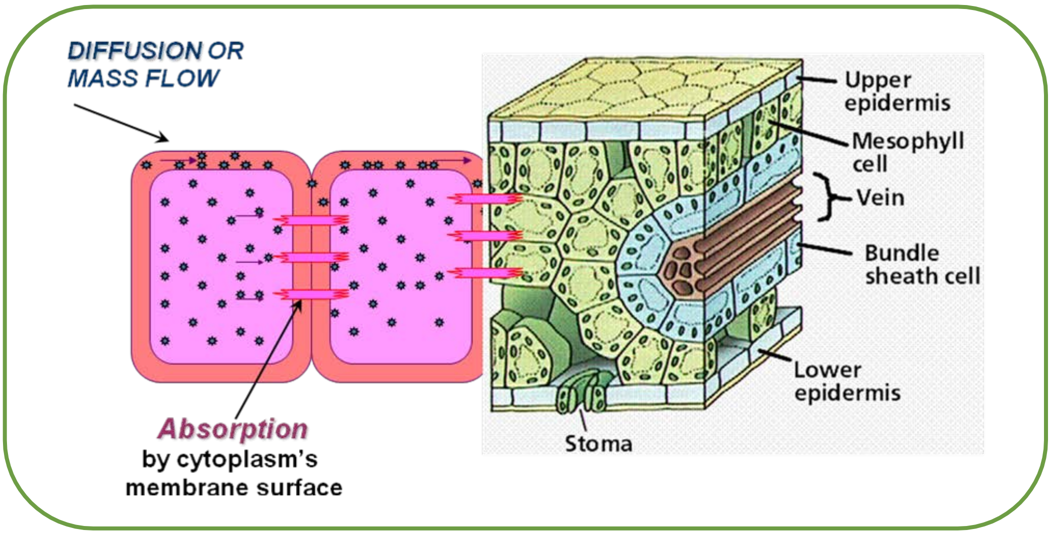


Figure 3.5: Schematic representation of cell-to-cell type transport processes

The symplast movement describes the ion discharge into the vascular system. This is done through two systems (Figure 3.6):

- Phloem – translocation is energy dependent and more suitable to the divalent cations (C2+); anions are very limited since the cell wall is negatively charged. Phloem transport is important for distribution from mature leaves to growing regions in the roots and shoots. Phloem movement regularly follows the 'sink-source' relationship, from locations where carbohydrates are created (source) to places where they are consumed (sink).
- Xylem – translocation is flux regulated and driven by water potential differences between soil, leaf and atmosphere.

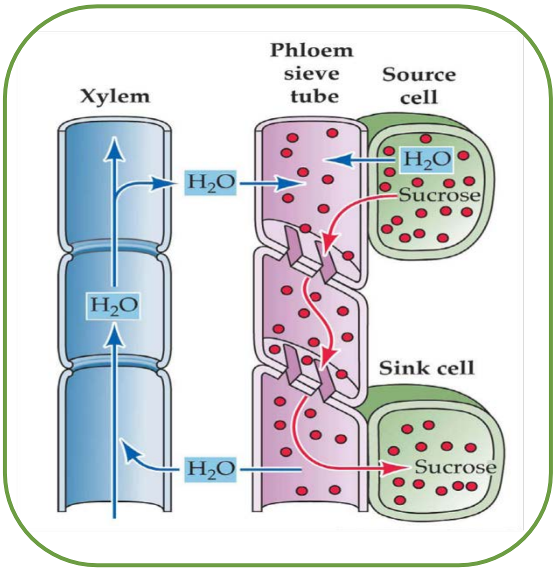


Figure 3.6: Translocation vessels, xylem and phloem, within the plant

Translocation differs between different ions, thus, nutrients are divided into three groups: mobile, partially mobile and not mobile.

Table 3.3: Mobility of plant nutrients within the plant tissue

Mobility	Plant nutrients				
Mobile	N	P	K	S	Cl
Partially mobile	Zn	Cu	Mn	Fe	Mo
Not mobile	Ca	Mg			

(Bukovac and Wittwer, 1957; Kunnan, 1980)

3.2.4 Haifa Bonus, a specially formulated foliar feeding fertilizer

Haifa launched **Haifa Bonus**, a foliar formulation developed to enable spraying of highly concentrated solution without scorching of the foliage.

Haifa Bonus consists of pure, fully-soluble nutrients only.

Haifa Bonus is free of harmful compounds such as chloride, sodium, perchlorate, excessive sulfate, etc.

Haifa Bonus is compatible for tank mixing with a large variety of pesticide and fungicides.

Haifa Bonus contains a specially developed adjuvant for better adhesion to the leaf surface, improved absorption and prolonged action.

1. **Haifa Bonus** is applied by foliar spray, possibly in combination with pesticides. A portion of the nutrients is absorbed immediately.
2. Due to the addition of the special adjuvant, fertilizer clusters form and adhere to the leaf surface. When the air becomes hot and dry, the fertilizer droplets dry and nutrient uptake is temporarily halted. **Haifa Bonus** the special adjuvant improves the adhesion of the fertilizer to the leaf surface and creates fertilizer clusters that release nutrients over a prolonged period of time.
3. During the night, when dew condenses on the leaves, the fertilizer is re-dissolved and nutrient uptake is renewed.
4. On the next day, when temperature rises, the fertilizer dries and nutrient uptake is halted again. Fertilizer uptake by this mechanism lasts for several days, depending on the air temperature and relative humidity.

3.2.5 How rice crops benefit from Haifa Bonus

Foliar fertilizers such as **Haifa Bonus+Zn™** are fast acting because they are absorbed right at the site where they are used. Foliar feeding of these fertilizers not only replenishes plant nutrients but also act as catalyst in the uptake and use of certain macronutrients.

Research showed that all foliar applied nutrients are absorbed by the leaves. By spraying **Haifa Bonus+Zn™** directly on the leaf, it increases the activity in the leaf, at the same time increasing chlorophyll and thus photosynthesis. Because of this increased activity, it increases the need for water by the leaf. In turn, this increases water uptake by the plants vascular system, which in turn increases the uptake of plant nutrients from the soil.

New rice varieties have higher photosynthesis capabilities and thus producing 35% more rice per hectare. The principle with foliar feeding is the same: increased photosynthesis.

A small amount of foliar fertilizer applied, actually increases the uptake in terms of total uptake by several fold over the amount of soil fertilizer applied. A small amount of foliar applied plant nutrients can increase the yield so significantly, actually providing a better return per dollar outlaid than soil applied fertilizer. This does not mean that the application of **Haifa Bonus+Zn™** replaces the soil applied fertilizer, but increases its uptake.

3.2.6 Optimal conditions to obtain best effects from spraying Haifa Bonus products

Numerous small-scale experiments and field trials with **Haifa Bonus** were carried out in many countries in order to determine: when to apply **Haifa Bonus**, at what concentrations (rate) and how many applications (Tables 3.4 & 3.5). A variety of such trials are detailed below.

A) Treatment conditions:

- Spray volume: 350-400 L/ha
- Application rate: 8.8 – 10.0 kg/ha (2.5%)
- Applications timing: 1st: at peak tillering ; 2nd at heading ; 3rd at milky stage

Treatments:

- Control, treated with water
- Haifa Bonus 19-19-19 + TE
- Haifa Bonus 15-15-30 + TE

Table 3.4: Effect of two **Haifa Bonus** formulas sprayed on rice grain yield

Treatment	No. panicles/m^2	No. full grains/panicle	% empty grains	Yield (t/ha)
Control	367	49	19.5 a	3.5 b
Haifa Bonus 19-19-19	388	66	13.5 b	4.18 a
Haifa Bonus 15-15-30	**380**	**68**	**12.9 b**	**4.21 a**

Conclusion: best results were obtained with the formula 15-15-30+TE.

B) Haifa Bonus13-2-44

Table 3.5: Effect of number of **Haifa Bonus** 13-2-44 treatments, and their timing, when sprayed at 3% concentrations, on yield

Treatment (DAS)*	Yield (t/ha)	Yield Increase (%)
Un-sprayed	4.56	–
40	4.98	9.2
60	5.17	13.3
40 & 60	5.22	14.4
40 & 60 & 75	5.29	16.0

* DAS = Days after sowing

Conclusion: Three sprays of Haifa Bonus at 40 & 60 & 75 DAS produced highest grain yield.

C) Haifa Bonus+Mg (13-0-44+2% MgO)
Cuu Long, Mekong delta, Vietnam, 1997; Rice Research Institute, (Dr. Pham Sy Tan)

Table 3.6: Effect of rate of Haifa Bonus+Mg sprays on growth and yield

Treatment*	No. of full grains/panicle	Empty grains (%)	Grain yield (t/ha)	Grain yield increase	
				(t/ha)	%
Control (no spray)	46	15.7	4.56		
1%	52	17.5	4.88	0.32	7.0
2%	57	14.8	5.25	0.69	15.1
3%	59	12.7	5.29	0.73	16.0
LSD 5%	4.0		0.36		

* All **Haifa Bonus+Mg** sprays were done at 40, 60 & 75 DAS

Conclusion: Best results were obtained with 3 applications during 40, 60 and 75 days after sowing, at 3% spray solution.

4. Fertilization determination parameters

4.1 Removal of plant nutrients

Table 4.1: Varieties producing approximately 5 t/ha of grain will remove plant nutrients from the soil in the following amounts:

Plant Macronutrients	N	P_2O_5	K_2O	MgO	CaO	S
	(kg/h)					
	110	34	156	23	20	5

Plant Micronutrients	Fe	Mn	Zn	Cu	B	Si	Cl
	g/ha						
	2,000	2,000	200	150	150	250	25

Plant nutrients removal is specific for different plant parts; main sinks are straw and grain, as can be seen in Tables 4.2 and 4.3.

Table 4.2: Nutrient removal by a rice crop (cultivar IR36) yielding 9.8 t/ha of rough rice grains and 8.3 t/ha of straw *(De Datta, Philippines-1983)*

Plant Nutrients	Amounts of nutrient removed (at harvest)				
	Straw		Grain		Total
	kg/ha	%	kg/ha	%	kg/ha
N	75	21	143	70	218
P	5	1	25.5	12	30.5
K	232	65	26	13	258
Ca	27	7	1	0	28
Mg	13	4	10	5	23
S	3.3	0.2	0.5	0.2	3.8

Table 4.3: Nutrient removal by a high yielding rice variety ('IR64'), 12 t/ha rough rice grains and 8.3 t/ha of straw, by 2 - 3 crops per year *(Tan Pham Sy, Vietnam – 1997)*

Plant Nutrients	Amounts of nutrient removed (at harvest)				
	Straw*		Grain		Total
	kg/ha	%	kg/ha	%	kg/ha
N	63	**20**	137	**63**	200
P	10	3	24	**11**	34
K	168	**53**	36	**17**	204
Ca	46	**14**	6	3	52
Mg	31	10	13	6	44

Removal of Si and K_2O are particularly large if panicles and straw are taken away from the field at harvest. However, if only the grains are removed and the straw is returned and incorporated back into the soil, the removal of Si and K_2O is greatly reduced, although significant amounts of N and P_2O_5 are still removed.

4.2 Plant analysis data

Identification of the exact stage of growth is very important when determining the critical limits. A list of critical concentrations of various plant nutrients in the rice plant, which may be used as a rough guide for diagnostic purposes, is presented in Tables 4.4 & 4.5.

Table 4.4: Critically low (deficiency) concentrations of macro- and secondary nutrients

Plant part used for analysis	Growth stage	N	P	K	Mg	Ca	Si
		% of dry matter					
Leaf blade	Tillering	2.5	0.1				
Straw	Maturity			1.0	0.10	0.15	5.0

Table 4.5: Critically low (**D** = deficiency), and high (**T**=toxicity) concentrations of micronutrients

Plant part used for analysis	Growth stage	Fe	Zn	Mn	B	Cu	Al
		(ppm dry matter)					
Leaf blade	Tillering	300 (T)					
Shoot	Tillering		10 (D)	20 (D) 2,500 (T)			300 (T)
Straw	Maturity		1,500 (T)		3.4 (D) 100 (T)	6 (D) 30 (T)	

4.3 Soil analysis and critical nutrients levels

4.3.1 Soil sampling and soil analysis

There are three steps to any soil testing program including soil sampling, soil analysis and data interpretation. Each step is critical in obtaining optimum fertilizer and lime recommendations:

1. The most variable step is the process of soil sampling. Soils are inherently variable between fields and within fields. Therefore, correct soil sampling procedures should be followed so that soil test results for lime and other nutrient recommendations are representative of the entire field.
2. The second step in the soil testing process is the chemical analysis of the soil conducted by a soil testing laboratory. Availability of nutrients, such as phosphorus, potassium, calcium and magnesium, in some rice growing countries, are determined with the Mehlich 3 extraction. Some laboratories use different chemical methods to determine the availability of these nutrients. Therefore, the numbers that are generated may not be easily comparable. Also, the units in which the nutrients are expressed (such as kg/ha or parts per million) cause problems in comparing numbers if they are not understood.
3. The last step in the soil testing process is data interpretation and development of recommendations. Once the numbers have been generated by the laboratory, someone must decide what they mean. The two ideas that drive soil testing programs are “fertilize the crop” and “fertilize the soil.” The idea of “fertilize the crop” is that fertilizer recommendations are based on crop response at a given soil test level. The second idea of “fertilize the soil” is that fertilizer recommendations are based on the needs of the current crop with an additional amount recommended to attempt to build soil fertility levels.

Table 4.6: Guide for interpreting nutrient concentrations from plant tissue analysis

Nutrient	Plant Part	Growth Stage	Nutrients concentrations required for adequate growth***
Phosphorus (P)	Y-Leaf*	Mid-tiller	0.14% - 0.27%
		Panicle Initiation	0.18% - 0.29%
Potassium (K)	Y-Leaf	Mid-tiller	1.5% - 2.7%
		Panicle Initiation	1.2% - 2.5%
Calcium (Ca)	Y-Leaf	Mid-tiller	0.16% - 0.39%
		Panicle Initiation	0.19% - 0.39%
Magnesium (Mg)	Y-Leaf	Mid-tiller	0.12% - 0.21%
		Panicle Initiation	0.16% - 0.39%
Sulfur (S)	WS**	Mid-tiller	0.17%
		Panicle Initiation	0.15%
Iron (Fe)	Y-Leaf	Mid-tiller	89 - 193 ppm
		Panicle Initiation	74 - 192 ppm
Manganese (Mn)	Y-Leaf	Mid-tiller	237 - 744 ppm
		Panicle Initiation	252 - 792 ppm
Zinc (Zn)	Y-Leaf	Mid-tiller	22 - 161 ppm
		Panicle Initiation	33 - 160 ppm

* Y-leaf = youngest fully-emerged (uppermost) leaf blade on the rice plant (Figure 4.1)

** WS = whole shoot, entire above-ground portion of plant

*** The range of concentrations listed for the specific plant parts is considered normal for plant growth and production. Concentrations lower than those listed may limit production and result in visual nutrient deficiency symptoms (ppm = mg/kg).

4.3.2 Soil analysis techniques and application rates for N, P, K and micronutrients

Among the soil analysis techniques, determination of soil pH is the simplest and most informative analytical technique for diagnosing a nutrient deficiency or toxicity problem.

The determination of:

- Available N by the waterlogged incubation and alkaline permanganate method
- Available P by the Olsen and Bray P1 methods
  - Bray-1 and Mehlich-3 phosphorus extraction:

    Soil test results from a given field vary depending on what type of extraction solution is used. Soil test P values which use Bray-1 P extraction solution, will differ from values reported that use Mehlich-3 extraction. As a rough approximation, multiplying Mehlich-3 P values by 0.75 will compare with Bray-1 P levels.
- Available K by exchangeable potassium
- Available S with $Ca(H_2PO_4)_2 H_2O$
- Available Zn by extraction with buffered chelating agents or weak acids
- Available Si by extraction with sodium acetate

4.3.3 Determination of P level in the soil

Precise prediction of fertilizer P requirements of soils used for the production of rice has been difficult. Experiments have shown that rice yield in many flooded soils was not increased by P application despite low soil test-extractable P as measured by common soil test methods (ammonium acetate-EDTA (AA-EDTA), Bray 1, Olsen). Conventional soil test methods frequently do not accurately assess the capacity of flooded soils to supply P.

Phosphorus availability increases under flooded conditions. The causes of increased P availability following reduction have been described as reductive dissolution of Fe^{+3} oxides and the liberation of sorbed and occluded P, changes in soil pH that affect solubility of P-compounds, and the desorption of P from surfaces. However, the effects of mineralization of soil organic P and reductive dissolution of Mn oxides are considered minor or negligible sources of P release during flooding.

Phosphorus deficiency occurs widely in rice soils with a high native P-fixing capacity that is associated with poorly crystalline Fe oxides. P transformation, sorption, and desorption are controlled by changes in the levels of amorphous Fe. More native insoluble P is released under reduced than under oxidized conditions and there is a significant correlation between P-sorption parameters and all forms of Fe. Rice response to P fertilizer is common in soils that do not have high P-fixing capacities and in soils with a rice-wheat system. Increased available P supply in flooded rice soils is attributed mainly to the large quantities of reductant-soluble soil P residing in poorly crystalline Fe oxides. Accurate prediction of rice response to applied P is possible by measuring soil test-extractable P under reduced (anaerobic) soil conditions by common soil test methods or by measuring oxalate extractable P (that associated with poorly crystalline Fe oxides) under oxidized or reduced soil conditions. One particular explanation for the failure of soil test methods to identify P-deficient soils may be increased P diffusion through soils to rice roots after water saturation or flooding a soil. Rates of P transport to roots are more limiting than the rates of P uptake at the root surface. The root-uptake mechanism actually constrains P-use efficiency.

Rice plants (*Oryza sativa L.*) grown on soils containing low soil test extractable P frequently do not respond to fertilizer P application under reduced conditions. The lack of rice response to fertilizer P in soils with low extractable P has been attributed to increased solubility of Fe-associated P upon flooding. The increased solubility of Mn oxides and release of Mn-associated P in flooded soils may also increase P availability to rice plants.

Phosphorus bonds easily to soil minerals, forming compounds that are insoluble. Its availability to plants is largely controlled by soil pH. At pH< 5.0, phosphorus binds to iron minerals, while at a pH> 7.4 it readily binds to calcium minerals. Phosphorus bound to iron or calcium is not available to plants. Generally only 10 percent of the total phosphorus in the soil is available to plants at any given time. The other 90 percent, while not immediately available, will gradually become available as soil bacteria break it down. Soil test will reveal only the plant-available phosphorus, but fertilizer recommendation also reflects the other 90 percent.

4.3.4 P availability in different soil pH

Soil P availability under dryland conditions is influenced by several factors, not the least of which is soil pH. Optimum availability of P occurs in the pH range of 6.0-6.5.

With acidic conditions, P is predominantly sorbed by iron (Fe) and aluminum (Al) oxides.

The sorption of P by Fe and Al oxides decreases as soil pH increases, and more P is sorbed by calcium (Ca) and magnesium (Mg). At either extreme, P is not readily available.

When a permanent flood is established, redox reactions result in reduction of trivalent Fe (Fe^{3+}) to divalent Fe (Fe^{2+}). As this occurs, the solubility of the Fe oxides increases. This leads to a subsequent increase in P availability to rice.

On alkaline soils, however, more P is sorbed as Ca and Mg phosphates.

Because Ca and Mg are not influenced by redox reactions associated with flood establishment, the solubility and subsequent availability of P are not necessarily increased substantially after flooding. Therefore, **soils that have limited available P prior to flooding will continue to have limited available P after flooding.**

Table 4.7: Phosphorus recommendations for rice based on the Mehlich 3 soil test method:

Soil pH	Soil test P (kg/ha)	Recommended application of P_2O_5 (kg /ha)
< 6.5	≤ 35	20
	> 35	0
> 6.5	≤ 35	70
	35-55	45
	> 55	0

4.3.5 Recommended P rates

Soil testing is the key to profitable phosphorus fertilizer use. Research shows that when soil contains more than 35 kg Bray-1 P per hectare of phosphorus, the addition of more phosphorus will probably not increase rice yields. However, rice will remove 0.35 kg phosphorus per 45 kg of grain. This will need to be replenished, so soil test recommendations often include a maintenance addition reflecting anticipated yield goal.

4.4 Leaf K and soil analysis

Flag leaves were found to have greater tissue levels than lower leaves for each K fertilization level. This difference is greater at 10% heading than at internode-elongation zone. The tissue K levels of lower leaves are better correlated to yield than flag leaves.

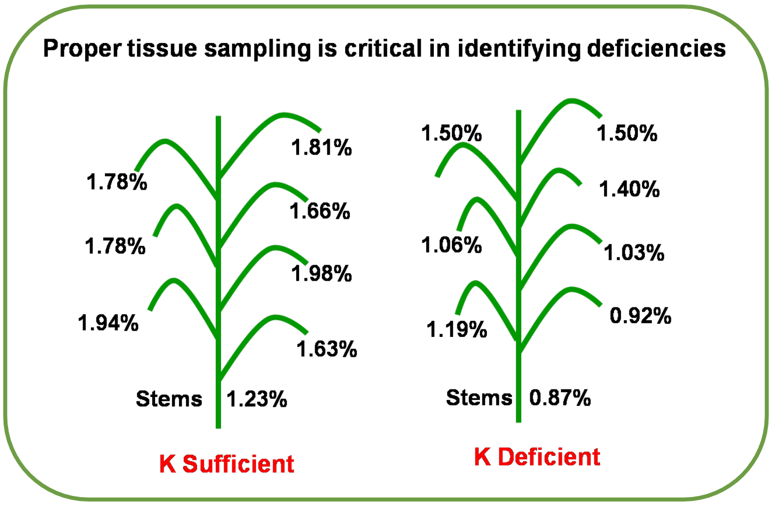


Figure 4.1: Effect of K status on K concentration in different parts of the rice plant. *Source: N. Station, U. of Arkansas 2002*

Potassium fertilizer is recommended on soils that test less than 200 kg/ha of K (Table 4.8). Potassium fertilizer recommendations are based solely on soil K levels, regardless of soil salinity. The salts added by recommended amounts of K fertilizer are small compared to the amount of salts in an existing saline soil.

Soils that test < 140 kg/ha of K are very susceptible to K deficiency and should get extra fertilizer to satisfy crop requirements and build soil test K (Table 4.8).

Table 4.8: P and K recommendations for rice, based on the Mehlich 3 soil test

Soil pH	**Soil test P (kg/ha)**	**Soil test K (kg/ha)**		
		≤ 140	**140 - 200**	**> 200**
		Recommended P_2O_5-K_2O (kg /ha)		
< 6.5	≤ 35	20-100	20-65	20-0
	> 35	0-100	0-65	0-0
> 6.5	≤ 35	65-100	65-65	65-0
	35-55	45-100	45-65	45-0
	> 55	0-100	0-65	0-0

Recommendations are based on soil test K and should help build soil K levels when soil test K is low, because rice removes a low amount of the total K that is taken up. It should be remembered that immediately after harvest of any crop the K not removed by grain may still be in the straw. Thus, soil test K should increase as K leaches from straw back into the soil with time.

4.5 Required plant nutrient levels in soil

Table 4.9: ***Guidelines*** for N, P and K application requirements based on soil analysis

Total N (%)	**N application requirement**
< 0.1	high
0.1-0.2	moderate
> 0.2	low

Available N (ppm)	**N application requirement**
50-100	high
100-200	moderate
> 200	low

Available P (Olsen, ppm)	**P application requirement**
< 5	high
5-10	moderate
>10	low

Exchangeable K (meq/100 g)	**K application requirement**
> 0.2	low

The critical limits for micronutrients using soil analysis are presented in Table 4.10.

Table 4.10: Critical deficiency levels for micronutrients in rice soils

Element	Method	Critical level (ppm)
B	Hot water	0.1 - 0.7
Cu	DTPA + $CaCl_2$ (pH 7.3)	0.2
Fe	DTPA + $CaCl_2$ (pH 7.3)	2.5 - 4.5
	$NH_4C_2H_3O_2$ (pH 4.8)	
Mn	DTPA + $CaCl_2$ (pH 7.3)	1.0
	0.1 N H_2PO_4 & 3 N $NH_4H_2PO_4$	15 - 20
Mo	$(NH_4)_2(C_2O_4)$ (pH 3.3)	0.04 - 0.2
Zn*	0.5 N HCl	1.5
	Dithizone + $NH_4C_2H_3O_2$	0.3 - 2.2
	EDTA + $(NH_4)2CO_3$	1.5
	DTPA + $CaCl_2$ (pH 7.3)	0.5 - 0.8

Source: Adapted from S.K. De Datta, 1989

* If the soil pH> 6.8, Zn-deficiency is most likely to occur, particularly if the variety grown is not tolerant and has low Zn usage efficiency.

4.6 Nutrient absorption and translocation

A clear understanding of the different stages of growth and development of the crop and its nutritional requirements at these important stages is a pre-requisite for nutrient management.

In the case of N, the accumulation of N in the vegetative body is high during the initial growth stages and declines with age towards the later growth stages. Translocation of N from the vegetative organs to the grains becomes significant only after flowering. There is some translocation of carbohydrates from the vegetative plant parts to the grains after flowering and a large amount of carbohydrates accumulates in the grains. Protein synthesis is active during the vegetative stages and during the reproductive stage. Synthesis of cell wall substances (cellulose, lignin, etc.) becomes active, although the pace of protein synthesis also continues. It is only at the ripening stage that starch synthesis becomes active.

Nutrient mobility in the rice plant is in the sequence P > N > S > Mg > K > Ca. The elements that form immediate components of proteins have a high rate of mobility, while those that are continuously absorbed until senescence have a relatively low mobility. Thus, N, P and S, which are essential constituents of proteins, are absorbed rapidly during the active vegetative growth stage and are subsequently translocated to the grain after flowering. Other nutrients like Ca and K on the other hand, are absorbed at a rate matching the rate of dry matter production over the growth period.

4.7 Nutrient uptake at different growth stages

Based on temperate climate, a summary of nutrient uptake at different growth stages is as follows:

- The content of N, P and K at the seedling stage increase progressively with growth and then decrease after reaching a maximum.
- The content of N in the plant decreases marginally after transplanting and then increases until the initiation of flowering. Subsequently the N content decreases continuously until the dough stage and then remains constant until ripening.
- The content of P declines rapidly after transplanting, then increases slowly and reaches a peak at flowering and then decreases until the dough stage.
- The content of K and Ca decreases gradually during the earlier growth of the plant but increases from flowering until ripening.
- The content of Mg is high from transplanting to the mid-tillering stage and then decreases gradually.
- The content of S decreases with growth.

5. Haifa's field trials and research

For many years, Haifa carried out laboratory and field trials with its products and unique fertilization programs in rice crop. These agronomical activities were performed in several important rice growing countries, as can be seen in the following examples:

5.1 Vietnam

5.1.1 Scientific work – Mekong Delta

Research treatments with **Haifa Bonus+Mg** were carried out in the Mekong Delta to determine the effect of rate and timing of **Haifa Bonus+Mg** spray.

Table 5.1 describes experiments done with the variety: *OM 1706* which has a typical 99 days life span from sawing to harvest.

Table 5.1: Effects of rate and timing of **Haifa Bonus+Mg** spray on growth and yield, *Cuu Long, Mekong Delta, Rice Research Institute, Vietnam - 1997 (Dr. Pham Sy Tan)*

Treatment*	Filled grains/ panicle	Empty grains (%)	Grain yield (t/ha)	Grain yield increase	
				(t/ha)	%
Control (no spray)	46	15.7	4.56		
Mean for **T1-T4** (1%)			**4.81**		
T1 40 DAS** @ 1%	47	14.5	4.73	0.17	3.7
T2 60 DAS @ 1%	48	16.8	4.78	0.22	4.8
T3 40 & 60 DAS @ 1%	50	14.9	4.83	0.27	5.9
T4 40, 60 & 75 DAS @ 1%	**52**	**17.5**	**4.88**	**0.32**	**7.0**
Mean for **T5-T8** (2%)			**5.05**		
T5 40 DAS @ 2%	49	15.9	4.85	0.29	6.4
T6 60 DAS @ 2%	48	13.7	4.90	0.34	7.5
T7 40 & 60 DAS @ 2%	54	15.2	5.19	0.63	13.8
T8 40, 60 & 75 DAS @ 2%	**57**	**14.8**	**5.25**	**0.69**	**15.1**
Mean for **T9-T12** (3%)			**5.17**		
T9 40 DAS @ 3%	49	14.2	4.98	0.42	9.2
T10 60 DAS @ 3%	50	13.1	5.17	0.61	13.4
T11 40 & 60 DAS @ 3%	55	16.5	5.22	0.66	14.6
T12 40, 60 & 75 DAS @ 3%	**59**	**12.7**	**5.29**	**0.73**	**16.0**
LSD 5%	4.0		0.36		

* **Haifa Bonus+Mg** spray at concentrations 1%, 2%, 3%, T = treatment

** DAS = days after sowing

Conclusions:

- The higher the Haifa Bonus concentration checked in this experiment, the higher the number of full grains/panicle and grain yield, and the lower the rate of empty grains.
- Generally, one treatment at 60 DAS was better than at 40 DAS regarding the above-mentioned parameters.
- Two treatments at 40 & 60 DAS were always better than one of any one of the two.
- Three sprays at 40 & 60 & 75 DAS were always better than the two at 40 & 60 DAS; hence the treatment of three sprays always produced the highest grain yield.

Table 5.2: The Effect of Foliar Sprays with **Haifa Bonus+Mg** at 3% on yield and the economical return *(Phạm Sỹ Tân, Rice Research Institute, Cantho, Việt nam (1997)*

Treatments	Grain yield (t/ha)	Grain yield increase		Haifa Bonus+Mg cost (US$/ha)	Labor cost (US$/ha)	Net return (US$/ha)
		%	(US$/ha)			
Control, unsprayed	4.56	–	–	–	–	–
40	4.98	9.2	49.2	8.4	6.25	34.5
60	5.17	13.3	71.4	8.4	6.25	**56.7**
40 & 60	5.22	14.4	77.3	16.8	12.5	47.9
40, 60 & 75	5.29	16.0	85.5	**25.3**	18.75	41.4

Conclusions:

- One treatment at 60 DAS was better than at 40 DAS regarding yield parameters.
- Two treatments at 40 & 60 DAS were better than one of any one of the two regarding yield parameters.
- Three sprays at 40 & 60 & 75 DAS were better than the two at 40 & 60 DAS, regarding yield parameters; hence, the treatment of three sprays always produced the highest grain yield. However, under the relative prices of rice labor and fertilizers, one spray at 60 DAS resulted in the highest return on investment.

5.1.2 Demo plots in the Mekong Delta in Vietnam

Approximately 100 field demo plots, in four regions in the Mekong Delta of Vietnam were conducted by the local extension services in growers' fields, coordinated with the Mekong Research Institute. At the end of each relevant growing season, field days and educational program were carried out (see Figures 5.1-5.3) and the local rice farmers saw and learned the benefits of spraying **Haifa Bonus+Mg** (Table 5.3).

Table 5.3: Distribution list of the 100 demo plots in the Mekong Delta, and the contribution of **Haifa Bonus+Mg** sprays to grain yields in them.

Region	Number of demo plots	Representative grain yield (t/ha)		Increase	
		Haifa Bonus+Mg	Control	(t/ha)	(%)
An Giang	30	**Mean: 6.57** Range: 5.06 – 8.02	**Mean: 5.99** Range: 4.48 – 6.83	**0.58**	**9.7**
Kieân Giang	20	**Mean: 6.70** Range: 6.13 – 7.20	**Mean: 6.21** Range: 5.53 – 6.80	**0.49**	**7.9**
Caàn Thô	30	**Mean: 6.83** Range: 5.54 – 8.46	**Mean: 6.39** Range: 4.90 – 8.00	**0.61**	**6.9**
Soùc Traêng	20	**Mean: 6.37** Range: 4.90 – 7.33	**Mean: 5.70** Range: 4.20 – 6.36	**0.64**	**11.8**

Conclusions:

- All the one hundred demo plots in all parts of the huge area checked, which serves as Vietnam's most important rice producer, yielded positive results to the spraying treatments with **Haifa Bonus+Mg**.
- The contribution to grain yields was between 0.5 and 0.65 t/ha, representing yield increment of 7-12%.

5.1.3 Scientific experiments in Northern Vietnam (Bac Giang, Nam Dinh)

All following data are based on the scientific work of Tran Thuc Son and Le Xuan Anh, as summed up in the paper: *Effect of foliar fertilizers (*KNO_3*, NPK1-ZN, NPK2-MG) for paddy rice on degraded soil of Vietnam.*

The comprehensive scientific research was done in Northern Vietnam, in two locations, by spraying three different **Haifa Bonus™** formulae: **Haifa Bonus™+ Zn** (12-6-38 +Zn), **Haifa Bonus+Mg** (12-6-38 +Mg) and **Haifa Bonus** (13-0-46). These fertilizer solutions were sprayed at a 3% concentration, by either two or three applications (Table 5.4) and the parameters that were carefully checked during the experiments were:

- Number of panicles/m^2
- Number of grains/panicle
- 1000 grain weight
- Foliar sprays on rice affected the yield. A significant response was achieved in spring rice also in number of panicles/m^2 (Table 5.4).

Table 5.4: Effect of foliar spraying on yield and yield components of rice in Bac Giang, Vietnam (2009)

Treatment	Number of panicles/m^2	Number of grains/ panicle	Weight of 1000 grains (g)	Grain yield (Quintal/ha)
Spring crop				
Un-sprayed	340	90.8 a	20.0	59.0 a
Haifa Bonus (2 sprays)*	343	93.7 b	20.7	62.7 b
Haifa Bonus+Zn (2 sprays)*	335	95.6 b	20.8	62.8 b
Haifa Bonus+Zn (3 sprays)*	348	95.8 b	20.6	64.4 c
Haifa Bonus+Mg (2 sprays)*	344	90.6 a	20.8	62.6 b
Haifa Bonus+Mg (3 sprays)*	**330**	**101.0 c**	**21.0**	**66.1 d**
LSD 5%	42.0	10.6	0.5	0.8
Summer crop				
Un-sprayed	273	121	16.6	43.2 a
Haifa Bonus (2 sprays)*	313	117	17.0	50.3 b
Haifa Bonus+Zn (2 sprays)*	304	116	17.1	49.2 b
Haifa Bonus+Zn (3 sprays)*	298	118	17.6	50.4 b
Haifa Bonus+Mg (2 sprays)*	310	116	17.0	49.6 b
Haifa Bonus+Mg (3 sprays)*	296	121	17.0	49.6 b
LSD 5%	14.3	4.2	0.4	1.5

* Each spray treatment was done at 3% (w/v) solution in 300 L/ha of: **Haifa Bonus** (13-0-46), **Haifa Bonus+ Zn** (12-6-38 +Zn) or **Haifa Bonus+Mg** (12-6-38 +Mg).

Conclusions:

- In the spring crop, highest yields of 66.1 and 64.49 quintal/ha were recorded with Haifa Bonus+Mg and Haifa Bonus+Zn, respectively, 3 sprays each. Treatments with 2 sprays only, resulted in lower grain yields of 62.7, 62.8 and 62.6 quintal /ha, respectively. All spray treatments were superior to the unsprayed control. These results were statistically significant.
- The treatment of three sprays of Haifa Bonus+Mg was also significantly best from the point of view of number of grains/panicle and weight of 1,000 grains, but inferior to all other treatments regarding the number of panicles/m^2, this shows that this parameter has a relatively minor effect on the yield, when dealing with these high levels of yield.
- In the summer crop, as usual, yields were lower than the spring yields.
- Highest summer grain yield of 50.3 quintal/ha was achieved with 3 sprays of Haifa Bonus+Zn, and lowest yield of 49.2 quintal/ha was achieved with 2 sprays of 3% Haifa Bonus+Zn™. However, all spray treatments results were not statistically different among themselves, but were statistically significantly superior to the unsprayed control (Table5.4).

Table 5.5: Effect of foliar sprayed **Haifa Bonus+Zn** on rice yield on **degraded soil** in Bac Giang

Treatment*	Spring crop			Summer crop		
	Yield	Response		Yield	Response	
		Quintal/ ha	%		Quintal/ ha	%
Un-sprayed	53.8			39.2		
Haifa Bonus (2 sprays)	57.7	3.9	7.2	**46.5**	**7.3**	**18.6**
Haifa Bonus+Zn (2 sprays)	57.5	3.7	6.9	45.3	6.1	15.6
Haifa Bonus+Zn (3 sprays)	**59.0**	**5.2**	**9.7**	46.3	7.1	18.1
Haifa Bonus+Mg (2 sprays)	57.7	3.9	7.2	46.1	6.9	17.6
Haifa Bonus+Mg (3 sprays)	**58.9**	**5.1**	**9.5**	45.7	6.5	16.6
LSD 5%	0.8			2.7		

* Each spray treatment was done at 3% (w/v) solution in 300 L/ha of: **Haifa Bonus** (13-0-46), **Haifa Bonus+ Zn** (12-6-38 +Zn) or Haifa Bonus+Mg (12-6-38 +Mg).

Conclusions:

- In the spring crop, highest yields of 59.0 and 58.9 quintal/ha were recorded with Haifa Bonus+Zn and Haifa Bonus+Mg, respectively, 3 sprays each. Treatments with 2 sprays only, resulted in lower grain yields. All spray treatments were superior to the unsprayed control.
- In the summer crop, as usual, yields were lower than the spring yields.
- Highest summer grain yield of 46.5 quintal/ha was achieved with 2 sprays of Haifa Bonus.

Table 5.6: Effect of **Haifa Bonus** on N and K_2O uptake by paddy Rice in Bac Giang, Northern Vietnam (2009)

Treatment*	**N response**		**K_2O response**	
	kg/ha	**N %**	**kg/ha**	**K_2O %**
Spring crop				
Un-sprayed	83.3		108.1	
Haifa Bonus (2 sprays)	90.0	6.7	118.1	10.0
Haifa Bonus+Zn (2 sprays)	92.3	9.0	123.7	15.6
Haifa Bonus+Zn (3 sprays)	92.8	9.5	121.9	13.8
Haifa Bonus+Mg (2 sprays)	92.1	8.8	125.6	17.5
Haifa Bonus+Mg (3 sprays)	**96.4**	**13.1**	**127.9**	**19.8**

Treatment*	**N response**		**K_2O response**	
	kg/ha	**N %**	**kg/ha**	**K_2O %**
Summer crop				
Un-sprayed	67.2		89.4	
Haifa Bonus (2 sprays)	78.6	11.4	105.7	16.3
Haifa Bonus+Zn (2 sprays)	77.6	10.4	107.1	17.7
Haifa Bonus+Zn (3 sprays)	81.4	14.2	110.1	20.7
Haifa Bonus+Mg (2 sprays)	78.8	11,6	108.5	19.1
Haifa Bonus+Mg (3 sprays)	**82.4**	**15.2**	**110.5**	**21.1**

* Each spray treatment was done at 3% (w/v) solution in 300 L/ha of: **Haifa Bonus** (13-0-46), **Haifa Bonus+ Zn** (12-6-38 +Zn) or **Haifa Bonus+Mg** (12-6-38 +Mg).

Conclusions:

- N and K_2O uptake by rice plants were higher due to the foliar treatments in both growing seasons.
- The 3-spray treatment with **Haifa Bonus+Mg** increased N uptake from 83.3 to 96.4 kg/ha in the spring crop, and from 67.2 to 82.4 kg/ha in the summer crop;
- The said treatment also increased K2O uptake from 108.1 to 127.9 kg/ha in the spring crop, and from 89.4 to 110.5 kg/ha in the summer crop.

Experiments were conducted on paddy rice in North Vietnam by spraying **Haifa Bonus**, to determine the agronomic and economic their efficiency in two common soil types, namely, degraded and alluvial soils. See Tables 5.7-5.10.

Rice cultivar was *Khang dan 18.*

Table 5.7: Effect of foliar-sprayed **Haifa Bonus** (13-0-46) on yield and yield-components of rice grown on **degraded soil**, in Bac Giang, Northern Vietnam (**Spring crop -** 2009)

Treatment	Number of panicles/m²	Number of grain/ panicle	1000 grain wt. (g)	Grain yield (quintal/ha)
Un-sprayed	331	100.8	19.9	61.3
Haifa Bonus (1 spray: 1st stage)*	372	93.1	20.0	65.1
Haifa Bonus (1 spray: 2nd stage)*	375	93.5	19.7	65.2
Haifa Bonus (1 spray: 3rd stage)*	355	99.8	19.8	65.8
Haifa Bonus (2 sprays: 1st & 2nd stage)	385	97.5	19.6	66.8
Haifa Bonus (2 sprays: 2nd & 3rd stage)	359	95.5	19.8	67.0
Haifa Bonus (3 sprays)	**366**	**101.3**	**19.6**	**68.7**
LSD 5%	32.0	7.4	0.4	1.4

* 1st stage = Active Tillering (AT); 2nd stage = Panicle Initiation (PI); 3rd stage = Flowering (F)

Table 5.8: Effect of foliar-sprayed **Haifa Bonus** (13-0-46) on yield and yield-components of rice grown on **degraded soil**, in Bac Giang, Northern Vietnam (**Summer crop -** 2009)

Treatment*	Number of panicles/m²	Number of grains/ panicle	1000 grain wt. (g)	Grain yield (quintal/ha)
Un-sprayed	324	118	16.7	49.7
Haifa Bonus (1 spray: 1st stage)	324	121	17.1	52.6
Haifa Bonus (1 spray: 2nd stage)	328	119	17.0	52.6
Haifa Bonus (1 spray: 3rd stage)	330	119	16.9	52.1
Haifa Bonus (2 sprays: 1st & 2nd stage)	**330**	**126**	**17.1**	**55.0**
Haifa Bonus (2 sprays: 2nd & 3rd stage)	333	123	17.0	54.7
Haifa Bonus (3 sprays)	329	129	17.1	56.2
LSD 5%	7.6	4.6	0.34	0.93

* 1st stage = Active Tillering (AT); 2nd stage = Panicle Initiation (PI); 3rd stage = Flowering (F)

Table 5.9: Effect of foliar sprayed **Haifa Bonus** (13-0-46) on yield and yield-components of rice grown on **alluvial soil**, in Nam Dinh, Northern Vietnam (**Spring crop -** 2009)

Treatment*	Number of panicles/m²	Number of grains/ panicle	1000 grain wt. (g)	Grain yield (quintal/ha)
Un-sprayed	238	154.8	26.1	77.9
Haifa Bonus (1 spray: 1st stage)	233	156.0	26.7	79.7
Haifa Bonus (1 spray: 2nd stage)	241	156.3	26.7	82.7
Haifa Bonus (1 spray: 3rd stage)	237	149.3	27.3	79.9
Haifa Bonus (2 sprays: 1st & 2nd stage)	250	152.8	26.3	83.0
Haifa Bonus (2 sprays: 2nd & 3rd stage)	254	144.7	27.3	83.1
Haifa Bonus (3 sprays)	**240**	**160.0**	**27.5**	**86.8**
LSD 5%	18.8	15.0	0.8	5.8

*1st stage = Active Tillering (AT); 2nd stage = Panicle Initiation (PI); 3rd stage = Flowering (F)

Table 5.10: Effect of foliar sprayed **Haifa Bonus** (13-0-46) on yield and yield-components of rice grown on **alluvial soil**, in Nam Dinh, Northern Vietnam (**Summer crop -** 2009)

Treatment*	Number of panicles/m^2	Number of grains/ panicle	1000 grain wt. (g)	Grain yield (quintal/ha)
Un-sprayed	283.3	111.5	22.1	56.3
Haifa Bonus (1 spray: 1st stage)	261.0	128.8	22.0	60.2
Haifa Bonus (1 spray: 2nd stage)	266.8	128.3	21.9	61.3
Haifa Bonus (1 spray: 3rd stage)	292.8	114.3	22.1	60.6
Haifa Bonus (2 sprays: 1st & 2nd stage)	287.3	119.5	22.1	62.3
Haifa Bonus (2 sprays: 2nd & 3rd stage)	267.5	128.3	22.2	62.6
Haifa Bonus (3 sprays)	**279.0**	**128.8**	**22.1**	**65.9**
LSD 5%	23.2	8.3	0.39	3.7

* 1st stage = Active Tillering (AT); 2nd stage = Panicle Initiation (PI); 3rd stage = Flowering (F)

Conclusions:

- Foliar spray of 3% Haifa Bonus invariably increased the number of panicles/m^2, number of grains/panicle and 1000 seed weight. Same results were obtained in the two very different soil types (degraded and alluvial), and in both growing seasons (spring and summer crops).
- Highest yields were always achieved by spraying 3 times 3% Haifa Bonus at 300 L/ha/spray (total 900 liters) during AT, PI and F stages. Haifa Bonus treatments, on degraded soil, in Bac Giang, resulted in: additional 7.4 quintal/ha (12.1%) in spring rice, and additional 6.5 quintal/ha (13.1%) in summer rice, (Table 5.7 - 5.8). And on alluvial soil in Nam Dinh, these sprays resulted in additional 8.9 quintal/ha (11.4%) in spring rice and 9.6 quintal/ha or a record increase of 17.1% (!!) in summer rice (Tables 5.9 – 5.10).
- Somewhat smaller yield response was achieved by applying two sprays of 3% Haifa Bonus (total of 600 L/ha) during AT and PI stages or PI and F stages. The average additional yield achieved on degraded soil was 5.6 quintal/ha (9.1%) in spring rice, and 5.2 quintal/ha (10.4%) in summer rice. The average additional yield achieved on alluvial soil was 8.7 quintal/ha (6.6%) in spring rice and 6.2 quintal/ha (10.9%) in summer rice.
- Lowest yield response of (3.3-6.5%) was achieved by applying only one spray of 3% Haifa Bonus in 300 L/ha during AT or PI or F stages. There was no preferable application timing when comparing these growth stages.

5.2 Thailand

5.2.1 Research Project in TJC Research Center in Suphanburi

A research project of foliar treatments with **Haifa Bonus** was carried out on rice crop in 1998.

Figure 5.1: Research Center, Suphanburi, Thailand

Rice variety:	*Chainat-1*
Application rates:	400 or 600 g/20 liters (2% or 3% respectively)
Spray volume:	500 L/ha
Application timing:	40, 60 and 75 DAS
Design:	RCB 4 treatments with 3 replicates
Period:	June - September 1998

Table 5.11: The efficacy of **Haifa Bonus** (13-3-43) foliar fertilizer in direct-sown rice

Treatment	Rate g /20 L	Filled grains (%)	Yield	
			kg/ha	% over control
Unsprayed	–	79.7	5,763	N/A
1 spray @ 40 DAS	400 (2%)	81.1	6,010	4.3
2 sprays @ 60 & 75 DAS	600 (3%)	82.6	6,343	10.1
3 sprays @ 40, 60 & 75 DAS	**600 (3%)**	**86.0**	**6,706**	**16.3**
2 sprays @ 60 & 75 DAS of the local commercial foliar fertilizer 10-52-8	400 (2%)	80.2	6,093	5.5

Conclusions:

- Three foliar sprays of 3% Haifa Bonus (13-3-43) at 40, 60 and 75 DAS (days after sowing), produced the highest percentage of filled grains and highest yield.

5.2.2 Field trial in Nakornpatom by Haifa team

Figure 5.2: Haifa's active participation in carrying out field research in Thailand

Table 5.12: The effect of three foliar applications with **Haifa Bonus** (13-3-43) on two cultivars, on yield and net profit

Treatments*	Yield (t/ha)	Increased output / ha			Haifa Bonus cost (product + application (US$/ha)	Net profit ($ US/ha)
		kg	%	US$/ha***		
Cultivar: ***Photong*** (100 days)						
Unsprayed	6.63	–	–	–	–	–
30, 60 & 75 DAS**	**8.35**	**1,720**	**25.9**	**294**	**31.50**	**262.5**
Cultivar: ***Suphan 1*** (120 days)						
Unsprayed	7.03	–	–	–	–	–
30, 60 & 75 DAS	**8.20**	**1,170**	**16.6**	**200**	**31.50**	**168.5**

* Spray volume 375 liter/ha
** DAS = Days after sowing. Product concentrations were 2%, 3% & 3%, respectively.
*** Calculation based on yield value = 171 US$/t of rice grain

Conclusions:

- Three foliar sprays of 2%, 3% and 3% of Haifa Bonus (13-3-43) at 40, 60 and 75 DAS (days after sowing), produced markedly higher yield, and net profit to the grower. The cultivar with shorter growth cycle better profited from these treatments.

5.3 India

Table 5.13: The effect of **Haifa Bonus** (13-3-43) on rice, 1997

Treatment	Grain Yield (t/ha)	Increase over control (%)	Additional net income (Rs./ha)
Unsprayed	5.83 a	–	–
3 sprays of **Haifa Bonus** @ 1%, at 30, 60 & 75 DAS	6.32 b	8.4	1305
CD (p=0.05)	0.31	–	–

Conclusions:

- Three foliar sprays of 1%, of Haifa Bonus (13-3-43) at 40, 60 and 75 days after sowing, produced markedly higher yield, and net profit to the grower.

5.4 China

Table 5.14: The effect of **Haifa Bonus** foliar application on rice, *AAS, Shanghai, China, (1995)*

Treatment	Yield (kg/ha)	Yield increase / ha			Haifa Bonus (US$/ha)*	Net profit (US$/ha)*
		kg	%	US $*		
Unsprayed	12,930	–	–	–	–	–
Two **Haifa Bonus** sprays at 3% @ 30 and 60 days after transplanting **	14,340	1,410	11.5	215.6	21.1	194.4

* Rice price: 1.3 RMB/kg; **Haifa Bonus** price: 4 RMB/kg; Exchange rate: 8.5 RMB = 1 US$

** Spray volume: 750 L/ha

Table 5.15: The effect of 2 **Haifa Bonus** foliar applications on rice at days after transplanting, *Guangxi province, S&F Institute, (1994-1995)*

Treatment*	No. of grains/ ear	Grains filling rate (%)	Yield (kg/ha)	Increase/ha		Haifa Bonus Cost (US$/ha)**	Net Return (US$/ha)**
				kg	%		
Unsprayed	128	76.3	4,815				
Two **Haifa Bonus** sprays at **2%** at 30 & 50 DAT***	130	84.2	5,385	570	11.8	14.1	73.0
Two **Haifa Bonus sprays at** 4% at 30 & 50 DAT	132	84.4	5,557	742.5	15.4	28.2	85.3
Two Haifa Bonus sprays at 6% at 30 & 50 DAT	**135**	**86.4**	**5,812**	**997.5**	**20.7**	**42.3**	**110.2**

* Spray volume: 750 L/ha
Pre-plant fertilization: 240 kg/ha of N; 67.5 kg/ha of P_2O_5; 90 kg/ha of K_2O

** Rice price: 1.3 RMB/kg
Haifa Bonus price: 4 RMB/kg; Exchange rate: 8.5 RMB = 1 US$

*** DAT= days after transplanting

Conclusions:

- There was a clear-cut advantage to the treatment employing two foliar sprays of 6% **Haifa Bonus** (13-3-43) at 30 and 40 days after transplanting, over treatments of 2% and 4%. The 6% produced markedly higher (+21%) yield, and a considerable additional net profit to the grower.

5.5 Colombia

Table 5.16: The influence of number and timing of foliar sprays with **Haifa Bonus** (13-3-43), on yield of upland rice, cultivar: *Orizica Yacu 9*. (*Source: Ricardo Guerrero R., Armando Ortiz Gonzalez - Colombia, 1998)*

Treatments*		Grains filling rate (%)	Grain yield	
Haifa Bonus spray*	**Crop stage****		**kg / ha**	**Yield increment over control (%)**
Unsprayed		80.3 c	7300 e	–
3 Sprays	1 + 2 + 3	82.4 bc	8300 bc	14
2 Sprays	1 + 2	85.0 ab	8600 b	18
2 Sprays	**1 + 3**	**87.7 a**	**9200 a**	**26**
2 Sprays	2 + 3	83.0 ab	8000 cd	9

* All treatments received 'grower's practice' of soil applied fertilizers. Spraying rates were always 2% **Haifa Bonus** @ 350 L/ha.

** **Crop stages:** 1) Flower initiation; 2) Flowering; 3) Grain formation

Conclusions:

- Although this experiment took place in totally different conditions than the ones previously described for Asia, the results are very consistent.
- Treatments employing two foliar sprays of just 2% **Haifa Bonus** (13-3-43) at flower initiation and flowering, or grain formation added up to 26% to the grain yield.
- Grain filling rate was again in full accordance with grain yield.

5.6 Korea

An experiment with **Controlled Release Fertilizer** (CRF) for paddy rice was carried out by the Experiment Institute, Agriculture & Life Science Research Center, Seoul National University, Korea in 2002.

- Cultivar: *Chucheongbyeo* (ecotype Japonica)
- Commercial recommended nitrogen rate: 150 kg/ha

The composition of the CRF fertilizer checked (**Multicote®**) was 13-6-7+2MgO+0.2B_2O_3. Eight of the 13% N were coated urea granules, (**CoteN®**), while the balance of the 5% were uncoated urea granules. This advanced fertilizer was compared with local farmers' practice of the commercial compound fertilizer: 21-17-17. The application rates of the CRF fertilizer **Multicote®**, were comparable with the local farmers' practice (100% N recommended, treatment T3), or only 80% of this rate (T2).

Fertilization:

(T1) Control treatment:

- Base dressing (BD): 50% N recommended with 21-17-17, 357 kg/ha
- Topdressing at Tillering stage (TDT): 20% N with Urea at 14 DAT, 65 kg/ha
- Topdressing at Panicle Initiation stage (PI): 30% N with NK fertilizer, at 57 DAT

(T2, T3) Two CRF (**Multicote®**) base-dressing treatments:

- T2 (80% of recommended N), at 923 kg/ha
- T3 (100% of recommended N) at 1,154 kg/ha

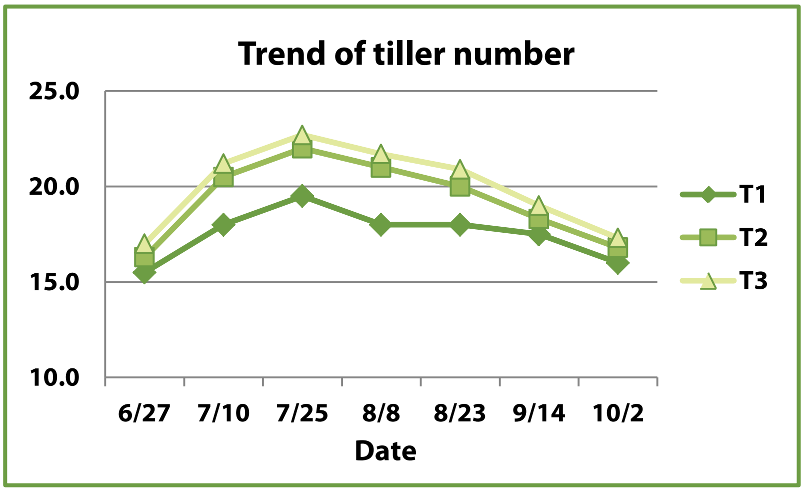
Treatment	**BD Fertilizer** **N-P_2O_5-K_2O-MgO-B_2O_3**	**Fertilization split N %**		
		BD	**TDT**	**FPI**
T1, control	21-17-17	50	20	30
T2, **Multicote®**	13(8)-6-7+2+0.2	80	0	0
T3, **Multicote®**	13(8)-6-7+2+0.2	100	0	0

Table 5.17: Yield components, yield and protein content

Treatment	**Panicles (no./m²)**	**Spikelets (no./panicle)**	**1000 grain weight (g)**	**RGR (%)**	**Yield (kg/10a)**	**Protein (%)**
T1	355	88	23.7	70	535	7.3
T2	376	89	23.6	73	582	7.3
T3	**384**	**99**	**23.2**	**70**	**612**	**8.0**
LSD 5%	21	ns	ns	ns	43	0.6

Conclusions:

- Comparing with the local commercial treatment control (T1), CRF treatments (T2 & T3) have shown earlier tillering, higher tiller number and higher panicle number at harvest.
- T2 and T3 were significantly higher than T1 regarding dry weight and N absorption rate. T3 had highest N content in the plant but there was no significant difference between T1 and T2.
- Yield was significantly higher in the CRF treatments (T2, T3) than in the control (T1), probably because CRF treatments bore more panicle and spikelets. There was no significant yield difference between the CRF treatments but protein content of milled rice was significantly higher in T3 than T2.
- As CRF fertilization has longer nutrient-effective period than the conventional fertilization, just one base dressing of the CRF, produced better nitrogen nutrition over the entire growth period. One CRF fertilizer application has proven advantageous in tiller number, panicle number and yield over the conventional fertilization, even though it has been split to three applications along the growth season. By applying 100% of recommended N fertilization in the form of CRF (T3), the grain protein content was too high which causes a reduced cooked taste quality.
- Therefore, the CRF treatment applying 80% of recommended N (T2 in the experiment) is the optimal fertilization recommendation bringing about higher yield but equal protein content level as conventional treatment.



5.7 Spain

Experiment series with **Controlled Release Fertilizer** (CRF) for rice were carried out in the rice department of the (Valencia Institute for Agricultural Research), Sueca - Valencia, Spain, in 2002-2003, *(Carreres, Pomares, and Ballesteros*).

Cultivars: *Ullal*, (semi-dwarf, medium grain) in 2002 and *Senia* (intermediate stature, medium grain) in 2003.

The CRF fertilizer checked was **CoteN®**, coated urea granules (40% N), and it was compared with five other N sources that were all applied at 130 kg/ha of N, including:

- Urea prills
- Urea combined with dimethyl pyrazole phosphate (DMPP) at three different contents rates (w/w), namely 0.5, 0.75 or 1% of the urea content.

Table 5.18 shows only the parameters in which the differences between the treatments were most obvious.

Table 5.18: Effect of nitrogen fertilizer source on agronomic performance, grain yield and N responses of rice plants

N source	Plant height (cm)	Lodging (%)	Grain yield (t/ha)	No. panicles/m^2	N uptake (kg/ha)	N recovery efficiency (%)
No N	74.0	0.5	3.61	274	44.6	–
Urea	95.7	23.0	6.73	385	82.7	29.3
CoteN®	**98.2**	**72.2**	**8.00**	**453**	**105.2**	**46.6**
Urea+ DMPP 1%	96.2	34.8	7.08	388	78.4	26.0
Urea+ DMPP 0.75%	96.2	26.0	7.14	399	87.1	32.6
Urea+ DMPP 0.5%	95.7	21.2	7.24	403	86.3	32.1
LSD 5%	3.6	15.7	0.66	46	9.4	7.0

Conclusions:

- The results showed that **CoteN®** applied before flooding was the best N source for grain yield and N recovery efficiency. Its intense effect was shown also by the high lodging rate of the intermediate stature cultivar only.
- Urea combined with DMPP was better than conventional urea
- N recovery efficiencies as high as 80%!!! were obtained at another series of experiments carried out by this research group, when several coating rates and pre-flood N application rates were checked.

6. Mineral nutrition recommendations

The recommendations appearing in this document should be regarded as a general guide only. The exact fertilization program should be determined according to the specific crop needs, soil and water conditions, and the grower's experience. For detailed recommendations, consult a local Haifa representative.

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6.1 Soil and leaf tissue analysis

6.1.1 Soil analysis

It is highly recommended to perform a soil analysis before planting, and leaf tissue analysis during the growing season, to assess the fertilization requirements of rice in real-time. Soil tests for phosphorus (P), potassium (K), and zinc (Zn) (Table 6.1), and leaf tissue analysis for nitrogen (N), P, K, and Zn are valuable aids in developing efficient plant nutrition programs (Table 6.1).

Table 6.1: Minimum soil levels of key nutrients necessary for satisfactory rice yields

Element	Soil test method	Critical value
Phosphorus	$NaHCO_3$	6 ppm PO_4-P (In cold years, may be as high as 9 ppm)
Potassium	NH_4Ac	60 ppm K
Zinc	DTPA	0.5 ppm Zn

Field research has established the critical concentrations of P, K, and Zn in the soil by correlating soil test values of these mineral nutrients and rice plant performance. The presence of critical or subcritical values (Table 6.2) of a given nutrient will generally result in a reduction of 10% or more of growth and grain yield. When soil test values are near or below the critical level, application of the deficient nutrient will usually prevent this reduction. Therefore, proper soil sampling, chemical analysis and interpretation help avoid plant nutrient deficiencies and are valuable guides in soil fertility management.

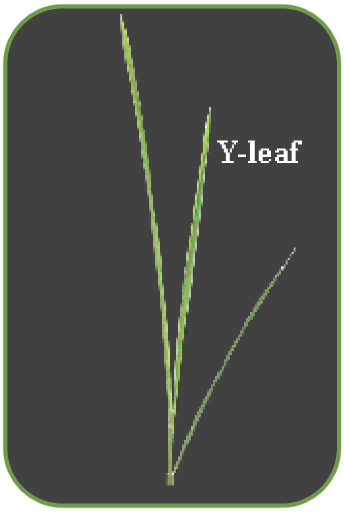


Figure 6.1: The "Y-leaf," the most recently fully expanded leaf of the rice plant, is the correct leaf to sample for tissue analysis.

6.1.2 Leaf analysis

Whereas soil analysis provides insight to preplant fertilizer needs, plant tissue analysis is valuable as a way of diagnosing the nutritional status of the growing crop. Tissue analysis serves as a guide for mid-season N application and for anticipating the need for N, P, and K applications for subsequent rice crops. The value of tissue analysis depends on representative sampling, selection of the proper plant part, generally-the most recently matured whole leaf blade, also known as the “Y-leaf”, (Figure 6.1), drying and handling of samples, analytical procedure used, and the correct interpretation of the relationship between the nutrient levels and crop growth and yield.

Table 6.2: Adequate and critical values of nutrients for leaf-analyses of rice plants of short statured varieties

Plant growth stage*	**Nitrogen (% total N)**		**Phosphorus (ppm extractable PO_4-P)**		**Potassium (% extractable K)**		**Zinc (% in whole seedling plant)**	
	critical	**adequate**	**critical**	**adequate**	**critical**	**adequate**	**critical**	**adequate**
Mid-tillering	4.6	4.6 - 5.2	1,000	1,000-1,800	1.4	1.4 - 2.8	20	22 - 80
Maximum tillering	4.0	4.0 - 4.6	1,000	1,000-1,800	1.2	1.2 - 2.4	–	–
Panicle initiation	3.3	3.3 - 3.8	800	800-1,800	1.0	1.2 - 2.4	–	–
Flag leaf	2.6	2.6 - 3.2	800	800-1,800	1.0	1.2 - 2.2	–	–

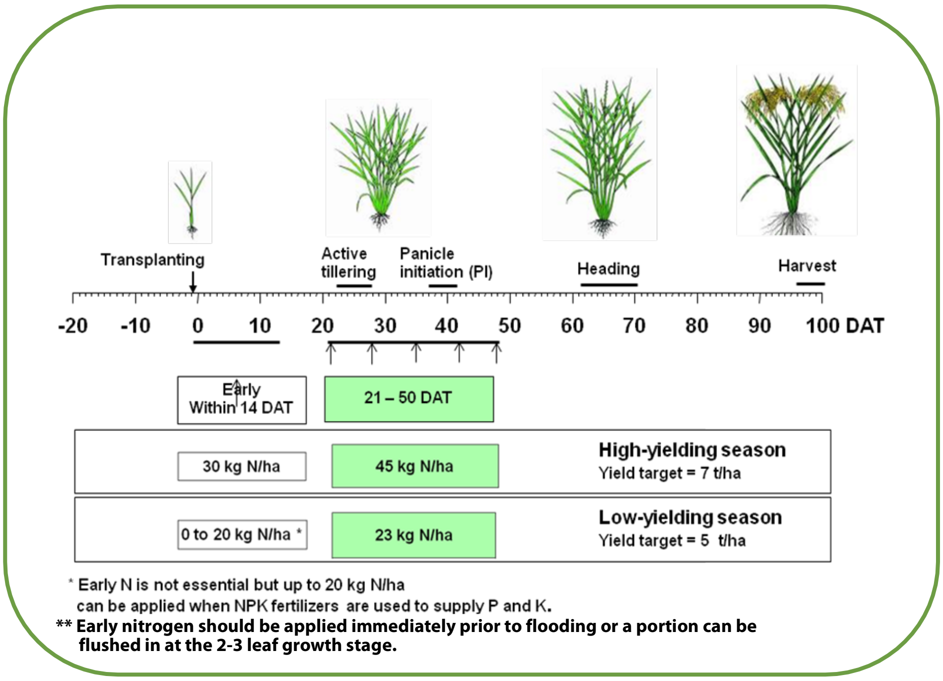
* Analysis on dry weight basis of most recently matured leaves for Kjeldahl N, 2% HAc extractable PO_4 and K

6.2 Soil N-P-K applications

Nitrogen

Optimal application rate of N fertilizer depends mainly on the variety and soil type. Therefore, the range of total N is wide (Figure 6.2). There are two application approaches:

- A single pre-flood application, where the entire N rate is applied at once. Such a treatment is not recommended for certain varieties, and under poor water management conditions.
- Split applications, whereby the total amount of N fertilizer can be split into three applications with an early N application of about 20-30 % of the total requirement. The remaining 70 to 80% is split into two applications based on the needs of the crop, as determined by leaf color by using the leaf color chart (Figure 6.3).



* Early N is not essential but up to 20 kg N/ha can be applied when NPK fertilizers are used to supply P and K.

**** Early nitrogen should be applied immediately prior to flooding or a portion can be flushed in at the 2-3 leaf growth stage.**

Figure 6.2: Example of split applications of recommended nitrogen

Figure 6.3: The leaf color chart (LCC) can be used to assess leaf N status and adjust N applications to rice.

Table 6.3: Nitrogen application rates by soil type and cultivar characters

Cultivars	Total N (kg/ha)	Pre-flood (kg/ha)	Mid-Season (kg/ha)
Clay			
Normal varieties	200	150-185	50-15
Semi-dwarf		135-175	65-25
Lodging-susceptible		100-135	65-100
Silt-loam			
Normal varieties	185	145-160	40-25
Semi-dwarf		135	50
Lodging-susceptible		100	85

Phosphorus

Phosphorus fertilizer application timing of is a critical factor affecting the P nutritional status of the rice crop. P fertilizer should be applied pre-flood on P deficient soils, because P uptake for biomass production takes place during the entire growth season. As rice crop will remove 0.35 kg of P_2O_5 per 50 kg rice grain, the following application rates apply for soils testing between lower than 35 and over 55 kg/ha of P. These recommendations take into account the said removal factor.

Table 6.4: Phosphorus recommendations for rice based on ***"Mehlich 3"*** soil test:

Soil pH	Soil test P (kg/ha)*	Recommended P_2O_5 (kg/ha)
< 6.5	≤ 35	20
	> 35	0
> 6.5	≤ 35	70
	35-55	45
	> 55	0

* In the event the soil test results in higher extractable P contents, Table 6.6 will provide more accurate recommendations.

Potassium

Table 6.5: Potassium recommendations for rice, based on the *"Mehlich 3"* soil test:

Soil test K (kg/ha)	**≤ 140**	**140 - 200**	**>200**
Recommended K_2O (kg/ha)	100	65	0

These recommendations are based on the assumption that the straw will be recycled into the soil after the harvest. However, if the straw is removed from the field, K_2O requirements for a yield of 6.5 t/ha and of 5.5 t/ha are 153 and 121 kg/ha, respectively.

Potassium application is recommended before rice shows K deficiency symptoms as only low yield benefit, if any, is obtained from K fertilizer application to deficient rice in the mid-to-late boot stage. K fertilizer added at this time probably has little benefit for the current rice crop, but will remain in the soil for the future crops.

Silt and sandy loam soils have a very low buffering capacity and soil test K can decline rapidly if K fertilizer is omitted for several consecutive crops.

It is recommended to apply all potassium rates by broadcasting and incorporating before planting in both water-seeded and dry-seeded rice. If potassium fertilizers could not be applied pre-plant, they can be applied before establishing the permanent flood. Split application is also common in some areas.

Table 6.6: Phosphorus (P_2O_5) and potassium (K_2O) fertilizer recommendations for grain yield goal of 8.5 t/ha

Soil pH	**P Soil test level**			**Soil test K level**				
				Very low	**Low**	**Medium**	**Optimum**	**High**
				<61 ppm	62-90 ppm	91-130 ppm	131-175 ppm	>175 ppm
				<137 kg/ha	137-200 kg/ha	201-290 kg/ha	291-390 kg/ha	>391 kg/ha
	Level	**ppm**	**lbs/A**	**P_2O_5- K_2O (kg/ha)**				
> 6.5	Very Low	<16	<36	100-135	100-100	100-70	100-0	100-0
	Low	16-25	36-55	70-135	70-100	70-70	70-0	70-0
	Medium	26-35	56-80	55-135	55-100	55-70	55-0	55-0
	Optimum	36-50	81-110	0-135	0-100	0-70	0-0	0-0
	High	>50	>110	0-135	0-100	0-70	0-0	0-0
< 6.5	Very Low	<16	<36	55-135	55-100	55-70	55-0	55-0
	Low	16-25	36-55	35-135	35-100	35-70	35-0	35-0
	Medium	26-35	56-80	0-135	0-100	0-70	0-0	0-0
	Optimum	36-50	81-110	0-135	0-100	0-70	0-0	0-0
	High	>50	>110	0-135	0-100	0-70	0-0	0-0

6.3 Controlled release fertilizer - CoteN®

6.3.1 What are Multicote® and CoteN®?

Multicote® is a polymer-coated controlled release fertilizer that releases plant nutrients slowly and continuously throughout the crop growth cycle. **Multicote®** is available in a wide range of formulas, and with release longevities of 2 to 16 months (at soil temperature of 21°C). **CoteN®** is the most suitable polymer-coated controlled release fertilizer for rice since it is a polymer coated urea with 4-month release longevity. One base-dressing application of **CoteN®** enables avoiding top-dressing application and prevents nitrogen loses by leaching.

Haifa produces a special **non-floating** **CoteN®** for paddy rice (Figure 6.4). This special fertilizer is heavier than the regular **CoteN®** which settles in the water on the flooded soil surface and will not be washed away with water current that may occur in a paddy field. It gradually releases available nitrogen to the rice plant. This controlled release procedure, prevents nitrogen loses and increases the uptake efficiency by the plant.

Figure 6.4: Standard **CoteN®** (left) and non-floating **CoteN®** (right)

6.3.2 CoteN® recommended application

1. **CoteN®** is suitable for base-dressing application. Continuous release of nitrogen from the encapsulated urea, ensures the supply of nitrogen according to plant growth and developing needs. **CoteN®** be applied as a part of the total recommended N, by blending it with the regular fertilizers or by using it as the sole source of the recommended nitrogen rate.

   Scientific research demonstrated that the continuous supply and reduced loses of nitrogen derived from **CoteN®**, enable a considerable reduction (20%) in the application rate of nitrogen. This will save on the fertilization costs and reduce the groundwater pollution.

2. Non-floating **CoteN®** is suitable especially when side-dressing is required. The higher specific weight of this special product will ensure that the product granules will remain on the bottom of the rice paddy and will continuously release nitrogen in accordance with the rate needed by the crop, preventing the need for a second top-dressing application.

6.4 Foliar feeding

Foliar Teaspoon-Feeding™ is a fast and highly effective method of supplementing and enriching plant nutrients when needed. Foliar application of **Haifa Bonus** water soluble fertilizer provides the exact composition of plant nutrients for optimal development of rice crop, when absorption of nutrients from the soil is disturbed. Precision-timed foliar sprays are a fast-acting and effective method for treating nutrient deficiencies.

Haifa Bonus, a high-K foliar fertilizer contains a special adjuvant, which improves the adhesion of the fertilizer to the leaf surface and creates fertilizer clusters that release nutrients over a prolonged period of time. Foliar application of the correct **Haifa Bonus** nutrients, in relatively low concentrations at critical rice development stages, contributes significantly to higher yields and improved quality.

Selecting the right Haifa Bonus fertilizer

Haifa Bonus fertilizers are available in various N-P-K-Mg-Zn ratios. The fully water soluble high K and chloride-free fertilizer, is suitable for rice crop wherever it is grown. Careful soil- and leaf analyses will help selecting the optimal **Haifa Bonus** formula.

Determine safe foliar applied rate:

To verify the safe rate under local conditions, it is advisable to spray recommended rate of **Haifa Bonus** on a few rice plants then, 3 to 4 days later, check the treated rice plants for scorching symptoms.

Preparation of tank-mix

Dissolve the entire required **Haifa Bonus** mass in water, at about double of the **Haifa Bonus** mass. Add this solution to the spray tank when it is half full with water. When tank-mixing with crop-protection agents, addition of wetting agents is not necessary. To ensure inter-compatibility of the two (or more) tank-mix components, a small-scale spray test should be performed on few rice plans several days prior to the commercial application.

Application rate of **Haifa Bonus**		
Concentration	grams per 8 liter sprayer*	grams per 16 liter sprayer **
2 %	160 g	320 g
3 %	240 g	480 g

** 4 – 5 sprayers of 8 liter/sprayer per 1000 m^2 will deliver 320 - 400 liters/ha.

*** 2 – 3 sprayers of 16 liter/sprayer per 1000 m^2 will deliver 320 - 480 liters/ha.

Compatibility

Usually, no compatibility problems should be expected while tank-mixing **Haifa Bonus** with fungicides and with insecticides, but hydrolysis may occur with dimethoate as it may break down, at pH 8 or higher, in one hour or less. Thus, a pH range of 5-6 should be maintained.

Recommended spray rates and timing of Haifa Bonus

Due to the fast action of **Haifa Bonus**, it is recommended to apply when the rice plant needs the boost of the nutrients. After numerous experiments all over the world (see chapter 5, it is fully established that spraying **Haifa Bonus** should take place two or three times during active growth season, at 2% or 3% (w/v) spray concentrations.

The exact number of sprays and their concentrations should be decided according to local balance between the prices of the rice, wages and fertilizers. The three optimal spray timings are:

- Tillering stage (for 90 - 100 days varieties- frequently at 30-40 DAS);
- Panicle Initiation stage (frequently at 60 DAS for 90 - 100 day varieties); and
- Two weeks after panicle initiation (frequently 75 DAS for 90 - 100 day varieties).

When spraying **Haifa Bonus+Zn**, application 5-10 days earlier is advocated.

Spraying Haifa Bonus to reduce lodging

As shown in chapter 2.8.2 spraying **Haifa Bonus** can markedly reduce yield loss due to lodging. In situations of lodging (lodging-sensitive varieties and over application of nitrogen), two sprays of **Haifa Bonus** at 2-3% in 300-350 L/ha each, 15 days apart, are recommended, starting at tillering stage.

6.5 Zn application

If a soil test prior to planting indicates a Zn deficiency, apply 8 to 11 kg of Zn in the form of 20-35 kg/ha of Zinc Sulfate. In the dry-seeded system, soil-applied zinc should be broadcast and shallow incorporated no more than 2.5-5 cm deep, in order to avail it to the seedlings.

If deficiency symptoms show after rice emergence, apply foliar sprays of **Haifa Bonus+Zn** at 1-3 % solution at 30, 45 and 60 days after planting. It can be tank-mixed with propanil, if the propanil is needed, for weed control or with any other pesticide.

Appendix I: Haifa specialty fertilizers

Pioneering Solutions

Haifa develops and produces **Potassium Nitrate** products, **Soluble Fertilizers** for Nutrigation™ and foliar sprays, and **Controlled-Release Fertilizers**. Haifa's Agriculture Solutions maximize yields from given inputs of land, water and plant nutrients for diverse farming practices. With innovative plant nutrition schemes and highly efficient application methods, Haifa's solutions provide balanced plant nutrition at precise dosing, composition and placing. This ultimately delivers maximum efficiency, optimal plant development and minimized losses to the environment.

Potassium Nitrate

Haifa's Potassium Nitrate products represent a unique source of potassium due to their nutritional value and contribution to plant's health and yields. Potassium Nitrate has distinctive chemical and physical properties that are beneficial to the environment. Haifa offers a wide range of potassium nitrate products for Nutrigation™, foliar sprays, side-dressing and controlled-release fertilization. Haifa's potassium nitrate products are marketed under the Multi-K® brand.

Multi-K® Products

Pure Multi-K®

Multi-K® Classic	Crystalline potassium nitrate (13-0-46)
Multi-K® Prills	Potassium nitrate prills (13-0-46)

Special Grades

Multi-K® GG	Greenhouse-grade potassium nitrate (13.5-0-46.2)
Multi-K® pHast	Low-pH potassium nitrate (13.5-0-46.2)
Multi-K® Top	Hydroponics-grade potassium nitrate (13.8-0-46.5)

Enriched Products

Multi-npK®	Enriched with phosphate; crystalline or prills
Multi-K® Mg	Enriched with magnesium; crystalline or prills
Multi-K® Zn	Enriched with zinc; crystalline
Multi-K® S	Enriched with sulfate; crystalline
Multi-K® B	Enriched with boron; crystalline or prills
Multi-K® ME	Enriched with magnesium and micronutrients; crystalline

Nutrigation™

Nutrigation™ (fertigation) delivers pure plant nutrients through the irrigation system, supplying essential nutrients precisely to the area of most intensive root activity. Haifa's well-balanced Nutrigation™ program provides the plant with their exact needs accordingly with seasonal changes. Decades of experience in production and application of specialty fertilizers for Nutrigation™ have made Haifa a leading company in this field. Haifa keeps constantly up to date with contemporary scientific and agricultural research, in order to continuously broaden its product line to better meet the requirements of crops and cropping environments.

Haifa offers a wide range of water-soluble fertilizers for Nutrigation™. All products contain only pure plant nutrients and are free of sodium and chloride

Multi-K®	Comprehensive range of plain and enriched potassium nitrate products
Poly-Feed®	Soluble NPK fertilizers enriched with secondary and micro-nutrients
Haifa MAP	Mono-ammonium phosphate
Haifa MKP	Mono-potassium phosphate
Haifa Cal	Calcium nitrate
Magnisal®	Our original magnesium nitrate fertilizer
Haifa Micro	Chelated micronutrients
Haifa VitaPhos-K™	Precipitation-proof poly-phosphate for soilless Nutrigation™
Haifa ProteK	Systemic PK fertilizer

Foliar Feeding

Foliar Feeding provides fast, on-the-spot supplementary nutrition to ensure high, top quality yields and is an ideal feeding method under certain growth conditions in which absorption of nutrients from the soil is inefficient, or for use on short–term crops. Precision-timed foliar sprays are also a fast-acting and effective method for treating nutrient deficiencies. Foliar application of the correct nutrients in relatively low concentrations at critical stages in crop development contributes significantly to higher yields and improved quality. Haifa offers a selection of premium fertilizers for foliar application. Haifa offers a selection of fertilizers for foliar application:

Haifa Bonus High-K foliar formulas enriched with special adjuvants for better absorption and prolonged action
Poly-Feed® Foliar NPK formulas enriched with micronutrients specially designed to enhance the crop performance during specific growth stages
Magnisal®, **Haifa MAP**, **Haifa MKP**, **Haifa Cal** and **Haifa Micro** are also suitable for foliar application.

Controlled Release Nutrition

Multicote®, Haifa's range of Controlled Release Fertilizers includes products for agriculture, horticulture, ornamentals and turf. Multicote® products provide plants with balanced nutrition according to their growth needs throughout the growth cycle. Multicote® products enhance plant growth, improve nutrients use efficiency, save on labor and minimize environmental impact.

Single, pre-plant application controlled-release fertilizer can take care of the crop's nutritional requirements throughout the growth season. Controlled release fertilizers are designed to feed plants continuously, with maximal efficiency of nutrients uptake. Controlled release fertilizers save labor and application costs. Their application is independent of the irrigation system, and does not require sophisticated equipment.

Taking advantage of MulticoTech™ polymer coating technology, Haifa produces Multicote® line of controlled release fertilizers.

Multicote® Products

Multicote® for nurseries and ornamentals; NPK formulae with release longevities of 4, 6, 8, 12 and 16 months
Multicote® Agri / Multigro® for agriculture and horticulture
CoteN® controlled-release urea for arable crops
Multicote® Turf / Multigreen® for golf courses, sports fields, municipals and domestic lawns

Appendix II: Conversion tables

From	To	Multiply by	From	To	Multiply by
P	P_2O_5	2.29	P_2O_5	P	0.44
P	PO_4	3.06	PO_4	P	0.32
H_3PO_4	H_2PO_4	0.9898	H_2PO_4	H_3PO_4	1.38
K	K_2O	1.20	K_2O	K	0.83
Ca	CaO	1.40	CaO	Ca	0.71
Mg	MgO	1.66	MgO	Mg	0.60
S	SO_3	2.50	SO_3	S	0.40
S	SO_4	3.00	SO_4	S	0.33
N	NH_4	1.28	NH_4	N	0.82
N	NO_3	4.43	NO_3	N	0.22

From	To	Multiply by	From	To	Multiply by
Acre	Hectare	0.405	Hectare	Acre	2.471
Kilogram	Lbs	2.205	Lbs	Kilogram	0.453
Gram	Ounces	0.035	Ounces	Gram	28.35
Short Ton	MT	0.907	MT	Short Ton	1.1
Gallon (US)	Liters	3.785	Liters	Gallon (US)	0.26
Kg/Ha	Lbs/acre	0.892	Lbs/acre	Kg/Ha	1.12
MT/Ha	Lbs/acre	892	Lbs/acre	MT/Ha	0.001

1 meq	Correspondent element (mg)	1 mmol	Correspondent element (mg)	Weight of ion
NH_4^+	14 mg N	NH_4^+	14 mg N	18 mg NH_4^+
NO_3^-	14 mg N	NO_3^-	14 mg N	62 mg NO_3^-
$H_2PO_4^-$	31 mg P	$H_2PO_4^-$	31 mg P	71 mg P_2O_5
HPO_4^{2-}	31 mg P	HPO_4^{2-}	31 mg P	35,5 mg P_2O_5
HPO_4^{2-}	15.5 mg P	K^+	39 mg K	47 mg K_2O
K^+	39 mg K	Ca^{2+}	40 mg Ca	28 mg CaO
Ca^{2+}	20 mg Ca	Mg^{2+}	24 mg Mg	20 mg MgO
Mg^{2+}	12 mg Mg	SO_4^{2-}	32 mg S	48 mg SO_4
SO_4^{2-}	16 mg S	Na^+	23 mg Na	–
Na^+	23 mg Na	Cl^-	35.5 mg Cl	–