We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900
Open access books available

185,000
International authors and editors

200M
Downloads

Our authors are among the

154
Countries delivered to

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Chapter 5

Nutritional Management of Cereals Cropped Under Irrigation Conditions

Juan Hirzel and Pablo Undurraga

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/56095

1. Introduction

Crop nutritional management must be oriented so as to achieve economically convenient yields for the producer along with an efficient use of resources and concern for the environment. The use of information about soil chemical properties and experience of the behavior of each species under fertilization conditions with variations in soil chemical properties allow adjusting nutrient rates for different production situations. This chapter provides basic information about the nutritional requirements of the main cereals cultivated in the world, nutritional management strategies, and the nutritional value of using residues. This information is a guide for the producer to determine a nutritional management strategy using information provided by analyzing soil chemical properties for different productivity scenarios.

1.1. Corn

Corn (*Zea mays* L.) is a crop that can develop in a range of soil and climatic conditions [1]. It exhibits high nutrient extraction [2] and notably surpasses other crops such as small grain cereals and grain legumes. This cereal is grown for different purposes, but mainly for animal feed (silage and grain), poultry (grains), and pigs (grains), as well as for human consumption as grain, sweet corn, or corn.

Silage corn is an important food supplement in pastoral systems, particularly in the dairy industry where the main characteristics are high dry matter (DM) yield and metabolizable energy content [3]. Dairy cow producers in the central south and south in Chile use silage corn as feed between summer and winter, which allows extending lactation and increase production. This is done year-round in the central zone.

INTECH
open science | open minds

© 2013 Hirzel and Undurraga; licensee InTech. This is an open access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

In the corn plant, the ratio DM grain:leaves + stem is considered as an important index of the nutritional value of the forage because of the high digestibility of the grain [3] as well as its starch content.

Nutrient concentration in the corn crop is highly variable just like in other crops and is associated with the genetic material used, the environment, and the agronomic management employed. [4] pointed out that the critical nitrogen (N) concentration in corn plants (aerial part) varied between 0.91 and 1.2% for corn with a development cycle that fluctuated between 141 and 154 d. [5] points out N concentrations between 0.72 and 0.80% for a semi-late corn hybrid in central Chile, which was fertilized with N rates similar to its extraction. For a similar experiment, this author indicates phosphorus (P) and potassium (K) concentrations that fluctuated from 0.10 to 0.11% and 0.60 to 0.64%, respectively, in fertilization conditions with increasing rates of these nutrients [6]. Meanwhile, [2] showed nutritional fluctuations between 0.57 and 1.15% for N; 0.13 and 0.23% for P; 0.74 and 1.2% for K; 0.18 and 0.40% for calcium (Ca); and 0.10 and 0.17% for magnesium (Mg) in two mid-season silage hybrids cultivated during two consecutive seasons with different fertilization treatments in central south Chile. The same study includes the high variability found in the N, P, Ca, and Mg concentrations between both genetic materials used as has also been corroborated in other fertilization experiments conducted in the same crop.

For sweet corn, macronutrient concentrations in ears of eight hybrids in the harvest stage evaluated in the United States corresponded to 1.35-2.10% for N; 0.24-0.32% for P; 0.98-1.24% for K; 0.037-0.083% for Ca; 0.10-0.15 for Mg; and 0.09-0.15 for sulfur (S), whereas concentrations of these nutrients in the aerial residue corresponded to 1.96-2.49 for N; 0.19-0.27% for P; 2.35-3.26% for K; 0.33-0.41% for Ca; 0.21-0.28% for Mg; and 0.18-0.22% for S [7].

For grain corn, fertilization experiments carried out by Instituto de Investigaciones Agropecuarias (INIA) in central Chile indicate N concentrations from 0.77 to 1.18%; P concentrations from 0.13 to 0.17%; and K concentrations from 0.29 to 0.30% [5,6]. Meanwhile, experiments conducted on different commercial hybrids in central south Chile (2003 to 2010) indicate that macronutrient concentration in the grains at the harvest stage fluctuated between 1.13 and 1.77% for N; 0.31 and 0.52 for P; 0.37 and 0.58 for K; 0.010 and 0.037 for Ca; 0.14 and 0.19 for Mg; and 0.11 and 0.15 for S (n = 160 samples).

While there are many commercial hybrids with differences in earliness in their crop cycle, in general all of them exhibit a marked extraction of nutrients that is accentuated at the sixth leaf as shown in Figure 1.

It should also be noted that the high K extraction in this crop, which is expressed as K_2O, is far superior to the N requirements, which also occurs in many plant species.

As for nutrient extraction carried out only for corn grain, [1] point out N:P:K extractions of approximately 16:3:3.3 for each ton of grain, respectively. [5,6] indicates N:P:K extractions with means of 9:1.4:2.5 for each ton of grain, respectively. The differences identified by these authors are due to the abovementioned variations in the genetic materials used.

Experimental records generated by fertilization studies of the corn crop for grain and silage allow estimating the nutritional requirements shown in Table 1. Requirements in this table are

http://dx.doi.org/10.5772/56095

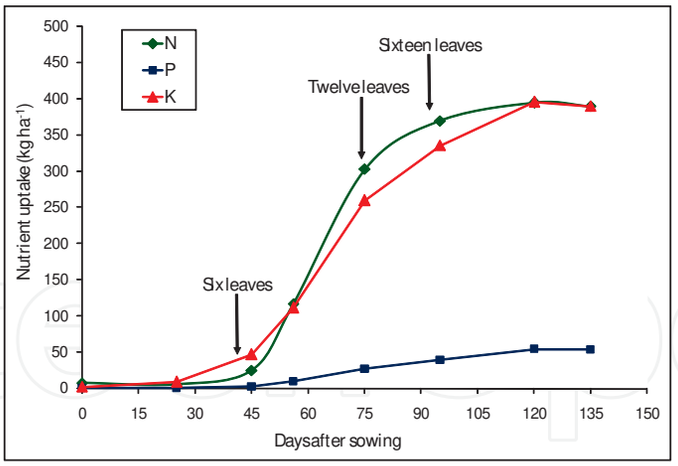


Figure 1. Nutrient extraction in corn crop [8].

shown as a function of the yield unit. Nutritional requirements in Table 1 are highly variable and this variability depends on many factors among which are genetic material, soil physico-chemical properties (nutrient availability in the environment), and also climatic conditions as pointed out by [4-6,9].

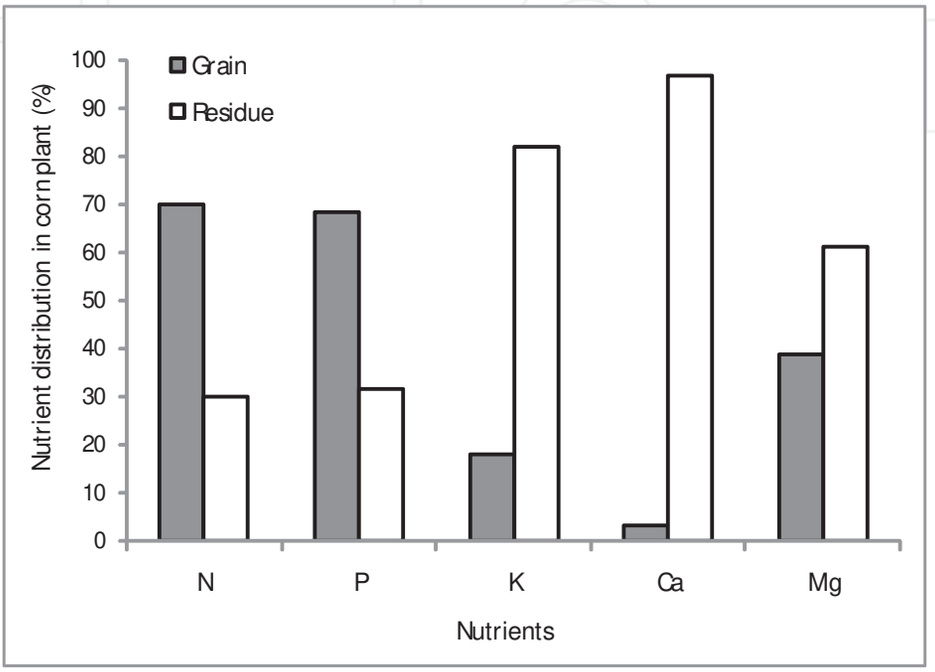
Nutrient	Type of corn and nutritional requirement	
	Grain (kg Mg^{-1})	Silage (kg Mg^{-1} MS)
N	14 – 26	6.9 – 14.5
P_2O_5	6 – 13	3.1 – 6.9
K_2O	16 – 38	8.2 – 23.2
CaO	3.0 – 7.5	1.5 – 4.5
MgO	3.2 – 7.4	1.7 – 4.0
S	1.4 – 2.6	0.8 – 1.3
Fe	0.24 – 0.41	0.109 – 0.185
Mn	0.04 – 0.06	0.019 – 0.029
Zn	0.03 – 0.05	0.013 – 0.021
Cu	0.002 – 0.009	0.001 – 0.004
B	0.016 – 0.018	0.007 – 0.008

Source: Adapted from [10].

Table 1. Nutritional requirements of rice crop for grain or silage expressed as a function of the yield unit (n = 240 samples of six commercial hybrids).

Nutrient distribution in the corn plant is shown in Figure 2. This figure shows that a large part of N and P extracted by the corn plant is concentrated in the grain, whereas the aerial residue

concentrates an important part of K and Mg absorbed by the plant, this was also pointed out by [5,6]. In turn, Ca is mainly concentrated in the aerial residue. Therefore, when incorporating corn residues, a large part of K, Ca, and Mg are recycled, which contributes to reducing the requirements of these nutrients in the next crop to the extent that the incorporated residue achieves its biological decomposition in the soil.



Source: Adapted from [10].

Figure 2. Nutrient distribution in corn plant.

Regarding the effect of applying different nutrients to the crop, various authors have demonstrated positive effects of applying N, P, K, Ca, and Zn [4,5,10-16]. The favorable effect of organic amendments as a fertilizer source has been demonstrated on grain and dry matter yield for silage using fresh amendments (for example, poultry and swine litter) and composted manures (pig compost, dairy compost, and others), leaving a positive residual effect on nutrient availability for the next crop [2,10,17-24].

Another management factor to consider in corn crop fertilization is residue management. Some theoretical models indicate that the N contained in the residues is gradually mineralized by the soil microbial biomass once it has been incorporated into the soil and is available for the next crop. However, this availability has not been evidenced under experimental field conditions since residue decomposition is also due to initial fractionation thereof (trituration) and soil temperature. Furthermore, soil biomass tends to generate humic compounds [5], which exhibit a C/N ratio that fluctuated between 18 and 22 [25]; therefore, an important fraction of N contained in the residue will be part of the humic compounds that will be synthesized by the soil's biological activity, situation that allows increasing soil organic matter content and improve its physical, chemical, and biological properties.

http://dx.doi.org/10.5772/56095

[26] indicate that superficially applying three residue levels (including a control without residues) in a corn grain monocrop fertilized with increasing N rates (from 0 to 225 kg ha^{-1}) through various fertilization sources, reduced soil inorganic N availability with a slightly negative effect on yield as compared with the treatment with no residues. In addition, soil temperatures were negatively affected by the increasing residue rate. For evaluated N sources, the best effect was achieved by ammonium nitrate over the use of urea.

[27] indicate that using three residue levels (including a control without residues) in a corn grain crop managed with two tillage systems (chisel and no-till) and two increasing N rates (between 67 and 268 kg ha^{-1}) exhibited a variable effect on yield according to the rainfall level and tillage practice used. Thus, for low rainfall and tillage conditions, total residue removal (control) produced a higher grain yield than using residues at the highest rate. Residues applied at high rates with no-till for this low rainfall level had a positive effect on yield. In summary, for normal rainfall conditions, the level of residues used in tillage conditions had no effect on yield, while for no-till management, the total (control) or partial removal of residues produced a higher grain yield than using residues at the highest level.

1.2. Wheat

This crop is one of the three most important cereals for human consumption along with corn and rice. History indicates that wheat (*Triticum aestivum* L.) was first cultivated by ancient hunter-gatherers in Southwest Asia, and archeological remains have been found of bread wheat from Turkestan in 6000 B.C. It has been established that the first domesticated wheat in the world goes back to 7500 to 6500 B.C. The wheat crop, along with other cereals, was first introduced to Chile by Pedro de Valdivia in 1540 and since then it has become the most widespread crop in Chile [28]. In nutritional terms, the wheat crop is characterized by its high N and K requirement as well as other essential nutrients such as P, S, and Ca [29,30]. In general, N and K represent about 80% of total nutrients in wheat plants; together P, S, Ca, and Mg make up 19%, while total micronutrients are less than 1% [31].

Wheat plants absorb the N nutrient as nitrate ion or ammonium ion. The way in which N translocation occurs depends on the absorbed N source and root metabolism [9]. Absorbed N is transported by the xylem to the leaves as nitrate ion or could be reduced in the roots and transported in inorganic form as amino acids or amides. A large part of the absorbed ammonium has to be incorporated in organic compounds in the roots [32]. In terms of phloem, N is a mobile nutrient, thus under deficiency conditions this element can be retranslocated from the older to the younger leaves and then translocated from there to the developing grains. The principal forms of organic N in the phloem sap are amides, amino acids, and ureides [33]. The nitrate and ammonium ions are not present in this sap, but mainly in the xylem. Nitrogen in the wheat crop is the major component of proteins, amino acids, enzymes, and nucleic acid [9]. It is also part of the mature grain, mainly concentrated as proteins in the endosperm which is the part that makes up the flour [28].

A deficiency of N in plants greatly reduces growth rate. In the case of cereals [9], tillering is poor and the leaf area is small; both the number of spikes per unit of area and the number of grains per spike are reduced. Since this nutrient is a component of chlorophyll, its deficiency

is seen as a generalized yellowing or chlorosis of the leaves, appearing first on the lower leaves while the higher leaves remain green. In cases of severe deficiency, a generalized chlorosis is noticeable in the whole plant. Finally, it decreases crop yield and the grain protein content [33]. Excesses of N are less evident than its deficiency. They include prolonged plant growth, dark green coloration of foliage, increased plant susceptibility to the attack of phytopathogens, and a delay in crop maturity.

The concentration of N in the wheat plant decreases over the phenological periods reaching values of 3.5-4.2% at the full tillering stage to 0.9-1.2% at the harvest maturity stage [34]. The adequate concentration in the higher leaves before the spike formation stage fluctuates between 1.75 and 3.0% [29]. In the case of wheat grain, N concentration fluctuates between 1.6 and 2.4% at harvest and surpasses other nutrients. Phosphorus deficiency restricts plant development, delays growth, tillering, root development, and maturity. Deficiency symptoms normally start in the oldest leaves and are characterized by a blue-greenish to reddish color, which can lead to a reddish color and bronze tints that normally start from the edges. Leaves often have a darker green color than normal plants. This is because the expansion of cells and leaves is delayed more than chlorophyll formation, so that the chlorophyll content per leaf area unit is higher [32]. A symptom of P deficiency is the decrease of the stem/root ratio and less growth of all the growth points. Extremely high P levels can result in toxicity symptoms, which generally occur as aqueous points in the leaf tissue, eventually becoming necrotic [33]. In very severe cases, P toxicity can provoke plant death.

Wheat plant P concentration decreases with the maturity process and can vary between 0.23 and 0.30% at the full tillering stage and decrease to values of 0.12-0.18% at harvest maturity stage [34].

Potassium deficiency is produced as chlorosis along the edge of the leaf followed by burning and bronzing of the old leaf tips. The affected area is curled when the deficiency of this element increases. The symptoms of K deficiency appear in the old leaves due to nutrient mobility. The affected plants are generally stunted and have shortened internodes. These plants exhibit slow and stunted growth, weak culms susceptible to lodging, higher incidence of pests and diseases, lower yields, curled grains, and low grain quality [33]. Plants with K deficiency can lose the control of the respiration rate and exhibit internal water deficit. High K concentrations contribute to increasing plant tolerance and resistance to diseases and pests.

Wheat plant K concentration decreases with crop maturity, fluctuates from 3.8-4.5% at the full tillering stage, and decreases to 0.9-1.2% at the harvest maturity stage [34].

Calcium deficiency produces small, twisted, dark green leaves [33]. Although all the growth points are sensitive to Ca deficiency, the root meristems are the most affected. Calcium is a non-toxic mineral nutrient even in high concentrations and is very effective to detoxify high concentrations of other mineral elements in plants [32]. Moreover, high Ca contents within the plant raise tolerance and resistance against diseases and pests.

Wheat plant Ca concentration decreases with maturity and reaches values of 0.28-0.30% at the full tillering stage to levels of 0.08-0.10% during harvest maturity.

http://dx.doi.org/10.5772/56095

Magnesium is an element that easily translocates from the older parts to the younger parts; therefore, its deficiency symptoms first appear in the oldest parts of the plant. A typical symptom of Mg deficiency is interveinal chlorosis of the old leaves in which the veins remain green but the area between them turns yellow. When the deficiency becomes more severe, leaf tissue uniformly turns chlorotic, then brown and necrotic. Leaves are small and break easily [33].

Wheat plant Mg concentration tends to decrease with maturity [34] and can fluctuate from 0.14-0.16% at the full tillering stage to values of 0.05-0.07% at harvest maturity.

Common Zn deficiency symptoms in wheat are arrested plant growth, poor tillering, light green coloring, yellowing, whitened spots, chlorotic stripes on both sides of the central vein, and small leaves. The internodes are short and the flowering, fructification, and maturity processes can be delayed. A high soil P concentration can induce Zn deficiency [9]. The toxicity of Zn can be translated in a reduction of root growth and leaf expansion followed by chlorosis. This is associated with concentrations higher than 200 mg kg^{-1} Zn in the tissue. The excess of Zn can induce Fe deficiency, which is recognized by interveinal chlorosis in the new leaves of the plant.

Wheat plant Zn concentration decreases with maturity and reaches levels of 12 to 20 mg kg^{-1} at the full tillering stage and 10 to 12 mg kg^{-1} at cereal harvest maturity [34].

Regarding the nutritional management of the wheat crop, it must be considered that the higher the yield level, greater the requirement of nutrients for the crop will be. However, in the case of the wheat crop, it is fundamental to also consider the cultivar (commercial variety) and the growth habit. For the cultivar, differences are observed in the accumulation of proteins in the grain, thus indicating variations in plant N requirement. Each cultivar exhibits a unique genetic base that gives it unique attributes for potential yield and grain quality [35]; [36]. For growth habit, winter habit cultivars generally produce higher total nutrient extractions than those of spring habit, mainly because it is more permanent in the soil. Other factors affecting variability in the nutritional requirements of the wheat crop are soil physicochemical properties, climatic conditions, and agronomic management. In this way, the same wheat cultivar sown at different sites will also exhibit different nutritional requirements for the same yield levels. Therefore, to define nutrient quantities to apply to this crop and in other crops, factors that influence these nutritional requirements must be considered.

Wheat crop nutritional requirements can be observed in Figure 3 with nutrient extraction in wheat cv. Dollinco-INIA (cultivar with alternative habit) showing gradual extraction that reaches its maximum near the end of the cultivation period, and where N is the most extracted nutrient. Nutrient extraction of this cultivar in its maximum accumulation period is 30.6; 5.7; 24.7; 7.9; and 4.1 kg Mg^{-1} N, P_2O_5, K_2O, CaO, and MgO, respectively, for a grain yield of 8 Mg ha^{-1}. For the highest extracted nutrient, other cultivars exhibit a higher K extraction, for example, the cvs. Tukán-INIA and Domo-INIA with nutrient extraction of their maximum accumulation period is 26.4-31.1; 6.0-7.4; 30.7-32.5; 4.0-8.6; and 2.1-4.2 kg Mg^{-1} N, P_2O_5, K_2O, CaO, and MgO, respectively, for a grain yield of 7 and 9 Mg ha^{-1} for each cultivar, respectively [31].

The nutrient extraction curves allow adjusting and harmonizing better the fertilization criteria with the growth rate of the wheat crop. For example, in the initial phenological stages of cv.

Kumpa-INIA (Table 2) a large part of the extraction of evaluated nutrients is produced. Thus, nearing the end of the vegetative stage (flag leaf visible) there has been an extraction of 80.3% N; 76.6% P; 98.4% K; 62.6% Ca; and 67.1% Mg, while for cv. Dollinco-INIA (Table 3) nearing the end of the vegetative stage (flag leaf visible) there has been an extraction of 56.9% N; 33.9% P; 62.2% K; 53.8% Ca; and 38.4% Mg. However, the accumulated absorption values are less than those of cv. Kumpa-INIA [31].

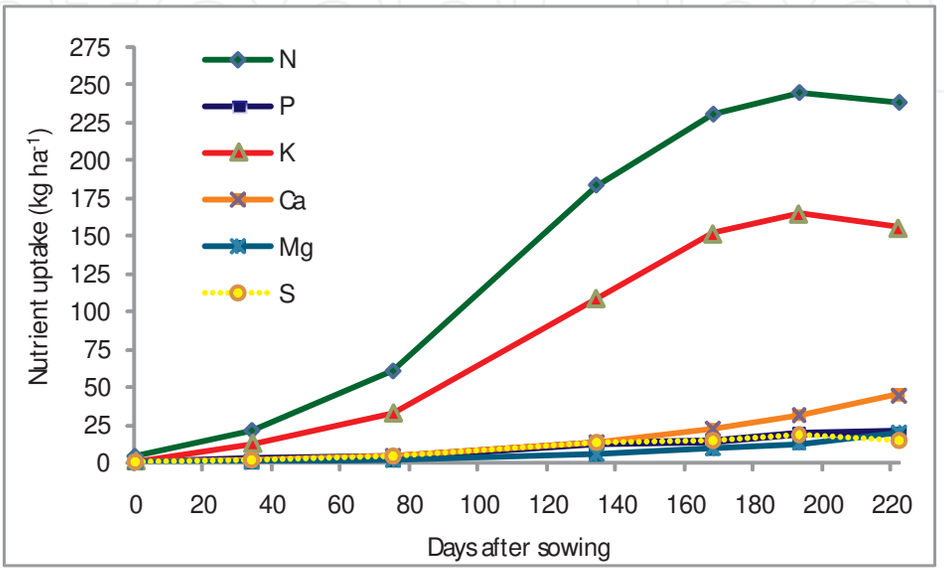


Figure 3. Seasonal nutrient uptake of winter wheat crop cv Dollinco-INIA.

Phenological stage	Days after sowing	Accumulated percentages[1]				
		N	P	K	Ca	Mg
End of tillering	111	27.3	16.1	36.2	18.3	15.4
Two nodes	133	46.3	38.6	51.0	33.5	30.1
Flag leaf visible	153	80.3	76.6	88.4	62.6	67.1
Emergence	174	98.5	95.9	97.2	93.1	95.1
Anthesis	182	100.0	100.0	100.0	100.0	100.0

[1]Maximum extraction obtained during the evaluated crop development cycle corresponded to 269 kg N, 26 kg P, 249 kg K, 36 kg Ca, and 14 kg Mg.

Table 2. Percentage extraction of N, P, K, Ca, and Mg in winter wheat cv. Kumpa-INIA.

As for the effect of applying different nutrients to the crop, various authors have demonstrated positive effects of applying N, P, Zn, and liming [28,31,37-41]. For wheat crop nutrient partialization many experimental studies have demonstrated that there is a response to

http://dx.doi.org/10.5772/56095

Phenological stage	Days after sowing	Accumulated percentages[1]				
		N	P	K	Ca	Mg
End of tillering	118	27.1	11.4	29.6	13.9	10.6
Two nodes	140	43.6	30.5	53.1	35.7	28.8
Flag leaf visible	160	56.9	33.9	62.2	53.8	38.4
Emergence	167	98.9	89.5	100.0	100.0	100.0
Anthesis	181	100.0	100.0	100.0	100.0	100.0

[1]Maximum extraction obtained during the evaluated crop development cycle corresponded to 286 kg N, 33 kg P, 244 kg K, 36 kg Ca, and 16 kg Mg.

Table 3. Percentage extraction of N, P, K, Ca, and Mg in winter wheat cv. Dollinco-INIA.

partially applying N and that yield is generally maximized with three applications of this nutrient, which correspond to sowing (15-20% total N), start of tillering (40-50% total N), and start of nodes (30-40% total N) [28,31,41]. Experimental studies indicate that there are differences among cultivars and soil and climatic conditions for the rate of this nutrient, but that yield is generally maximized when the N rate is determined based on the absorption requirement of the crop (replacement rate) with a variation that can fluctuate between 90 and 120% of crop consumption [31,34]. The rates of the other nutrients must be adjusted to the nutritional requirements and soil chemical properties.

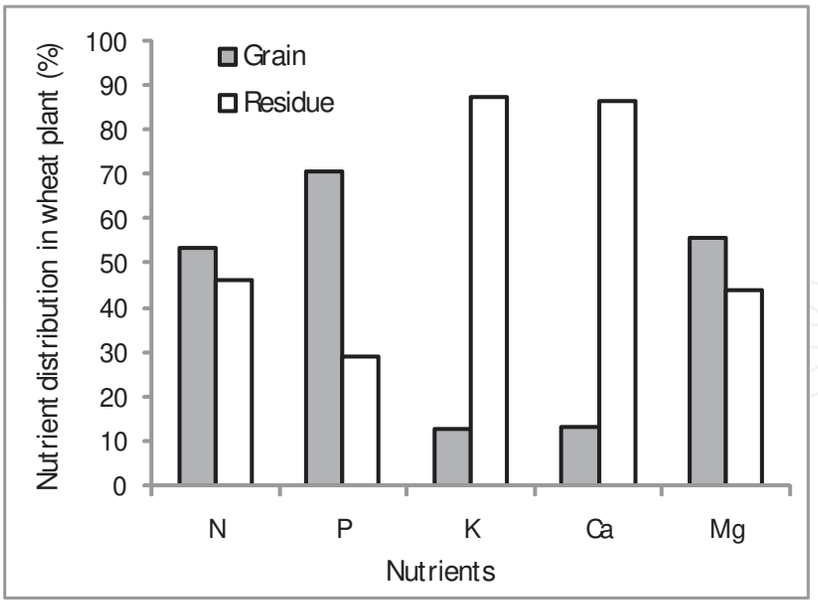
The incorporation of residues of the wheat crop is a practice that benefits physical, chemical, and biological soil properties. Figure 4 shows that an important fraction of N, P, and Mg along with the greater part of K and Ca extracted with this crop will be returned to the soil along with the incorporation of residues, which will have a significant effect on the reduction rate of some of these nutrients in the next crop. However, the required application of N should be considered to achieve an adequate decomposition of the incorporated residue so as not to affect N availability for the next crop.

1.3. Rice

Rice (*Oryza sativa* L.) is one of the most important cereals for development in the world and a basic food for at least half of its population. Generally, an annual semi-aquatic crop is considered and more than 20 species of the *Oryza* genus are recognized of which only two are cultivated [42,43], which can be aquatic, semi-aquatic, and dry land.

Among the cereals produced on a world level, rice occupies the greatest proportion of soils. Of the 147.5 million ha of soil dedicated to rice production in the world in 1989, developing countries contributed with 141.4 million ha, that is, 96% [44]. In the 1976-1980 period, a mean of 37.842 ha were sown [45], decreasing to 22.733 ha in the 2006-2009 period [46], which indicates a decrease of approximately 40% of the area in 25 years.

As for the nutritional functions and effects of the nutrients in the plant, N must be constantly supplied to the crop to achieve an adequate harvest, especially during panicle formation and



Source: [34].

Figure 4. Nutrient distribution in bread wheat plant (mean of cvs. Domo-INIA and Quelén-INIA).

development. The final yield of the crop is defined by the number of panicles per m^2 and number of tillers, which is defined within the first 10 d after maximum tillering. These components are influenced by N availability during these development stages [47,48]. Meanwhile, the number of spikelets per panicle is closely related to the N content of the leaf sheath during the weeks prior to flowering [47,49]. Nitrogen will later influence an efficient assimilation of carbohydrates on the part of the grain and in a correct filling thereof. The form of absorbed N during the first growth stages the rice plant prefers the ammonium forms (NH_4^+) [50,53], while in the stages near maturity it prefers N in nitrate form (NO_3^-). Nitrogen as ammonium is favorable up to the panicle initiation stage [51], and later nitrate absorption is promoted, especially during the panicle embryonic formation stage, stimulating the increase in the number of panicle flowers and grain weight [52,53]. Ammonium N increases the number of tillers and the number of panicles per plant [52]. Although in flooded soil conditions it is preferred to apply ammonium forms of N or those derived from ammonia (urea), depending on tilling depth, in the first 5-10 cm of soil an aerobic condition appears which would allow transforming ammonium to nitrate, a process that is accelerated by temperature accumulation. Notwithstanding the above, there is no scientific evidence in Chile about the modern varieties that indicates the advantages of applying N in the nitrate form after sowing. Nitrogen excesses, especially associated to abnormal climatic phenomena during the reproductive stage, particularly low temperatures [53], produce growth and internal distribution disorders of this nutrient that promotes vegetative growth and can delay harvest and reduce yield.

Internal distribution of N in the rice plant is established in studies conducted with N^{15} and which indicate that between 3 and 5% is found in the roots, between 30 and 44% is found in the aerial vegetative structures, between 37 and 40% is found in the panicle, and between 7 and 13% is found in the senescent structures [54].

http://dx.doi.org/10.5772/56095

Phosphorus is an element that promotes root growth; therefore, it improves the absorption of water and other nutrients. It also increases the resistance to periods of reduced water availability. An adequate supply of P improves grain flowering and fertilization, increases crop precocity, and increases 1000 grain weight [52]. The highest P absorption occurs during the vegetative development period and decreases after the panicle embryonic formation [53]. In turn, this absorption is promoted by temperature increases with an optimum temperature of 30 ºC. Availability of P in flooded soils is promoted by the redox processes and liberating part of the P retained as iron phosphate and aluminum [55].

Potassium plays an important role at the beginning of vegetative growth with an emphasis during tiller formation and has a direct influence on the determination of the final number of panicles. During the ripening stage it promotes synthesis and translocation of low molecular weight carbohydrates, is involved in activating phosphorylation processes (energy transport) to activate the transport of soluble N compounds to grains in formation, avoids their accumulation in other tissues, and also promotes 1000 grain weight [53,56]. Furthermore, K increases plant resistance to various diseases, such as stem rot detected in Chile [57], and adverse climatic conditions (high levels of solar radiation and temperature, or low temperature during tillering and flowering), playing an important role in the economy of use and loss of water by transpiration from the plant [53].

Moreover, K stimulates cell division, is involved in photon transport in photosynthesis, directs the synthesis of starch, inulin, amino acids, and proteins, modifies cell permeability, interferes with plasmolysis and turgidity mechanisms, and together with P and Mg is actively involved in carbohydrate metabolism [53].

Sulfur is an important element during the whole growth cycle of the rice plant; it strongly affects grain quality since it is part of some essential amino acids and part of N metabolism in synthesizing proteins and carbohydrates. It reduces nitrate, catalyzed chlorophyll formation along with Cu and Fe, acts as a hydrogen carrier, helps to regulate the tricarboxylic acid cycle, and is part of the sulfur radicals (SH) [53]. The quantities of S absorbed by the crop are relatively low as compared to other nutrients (N and K) since they are covered by the soil's natural contribution (organic matter mineralization), therefore, it is uncommon to apply S fertilizers in the rice crop. The availability of S is reduced in flooded systems as a result of redox reactions [55].

Calcium contributes to plant rigidity and resistance to lodging. Magnesium is located in the pyrrole rings making up chlorophyll and is a catalyst in the enzyme activity of nitrate reductases or self-induced enzymes that require molybdenum (Mo) [53]. The availability of Ca and Mg in flooded systems is improved as a result of redox processes [55].

Another important element for the rice crop is silicon (Si). Silicon extraction by the rice plant is higher than for any other mineral element with a concentration that can fluctuate between 2 and 9% of the plant dry matter [53]. This element is mainly deposited in the leaf epidermal cells and forms a siliceous double layer which is responsible for disease resistance. Studies conducted in Japan point out an extraction mean of 433 kg Si ha^{-1}. In quantitative terms, for each ton of paddy grain yield, the rice plant extracts 100 kg Si, of which a large part is concentrated in the rice husk [52].

Silicon is involved in the whole growth cycle of the rice plant, mainly affecting the stage between panicle formation and grain ripening. This essential element for rice cultivation promotes length development and oxidative activity of the root system in addition to protecting plants from Fe and Mn toxicity produced in anaerobic conditions of flooded soil. Finally, a good soil Si level improves P availability for the rice crop. With regard to the micronutrients, Fe participates in chlorophyll formation, prevents chlorosis, and is part of enzyme activity. The excess of Fe can inhibit K absorption [53]. Boron contributes to N uptake, participates in Ca metabolism, and stimulates meristematic activity and pollen formation [53]. Zinc stimulates initial plant development and its deficiency can affect potential crop yield. In flooded systems and as a result of redox processes, availability of Fe, Mn, and Mo increases and availability of Zn and Cu decreases [55].

Figure 5 shows the nutritional requirements of the rice crop. It can be observed that there is a gradual nutrient extraction in cv. Diamante-INIA (main cultivar used in Chile) between the initial and maximum tillering stages followed by slight increases in N and K accumulation unlike other nutrients that have an increased accumulation until later crop stages. In turn, the nutrient with the highest extraction is K. In productive terms, the nutritional requirements are 12 kg N; 8.4 kg P_2O_5; 22 kg K_2O; 6.2 kg CaO; and 5.6 kg MgO for each ton of yield. As additional information and as a guide, micronutrient requirements for this cultivar are 6.4 kg Fe; 1.88 kg Mn; 56 g Zn; 12 B; and 15 g Cu for each ton of yield.

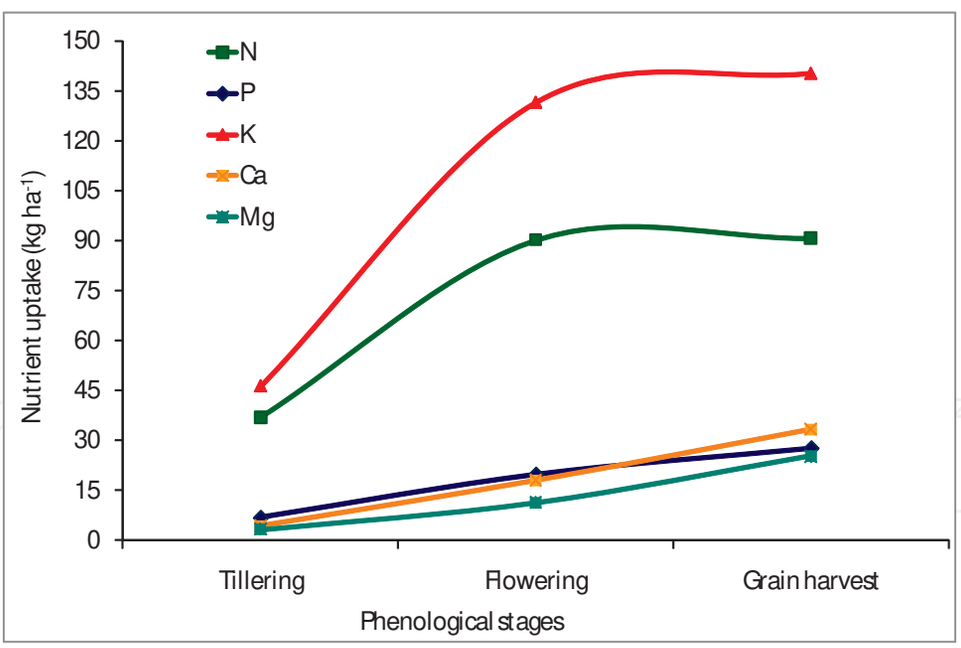


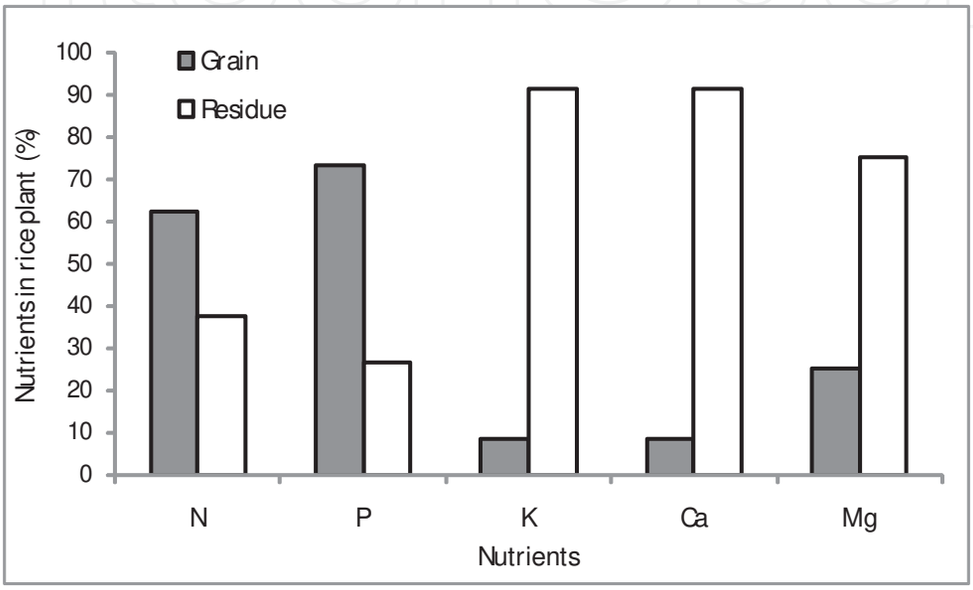
Figure 5. Seasonal nutrient uptake of rice crop cv Diamante-INIA for a 7.5 Mg ha^{-1} yield.

Although the nutritional requirements of the rice crop are high for some nutrients such as K, the harvested grain from the field is usually extracted and the residue left in place to be incorporated or burned in the following soil preparation. Incorporating residues allows replacing much of the K, Ca, S, and microelements: however, when residues are burned prior

http://dx.doi.org/10.5772/56095

to the following crop, there is a loss of N and S content in the residues through the volatilization process to the atmosphere.

Figure 6 shows the nutrient distribution in the rice plant and considers the grain and the residue; it estimates the nutritional contributions produced by incorporating residues and establishes the importance of carrying out this task. This figure shows that incorporating rice residues to the soil returns a large part of K, Ca, and Mg extracted from the previous rice crop and greatly reduces the nutritional requirements of the following crop.



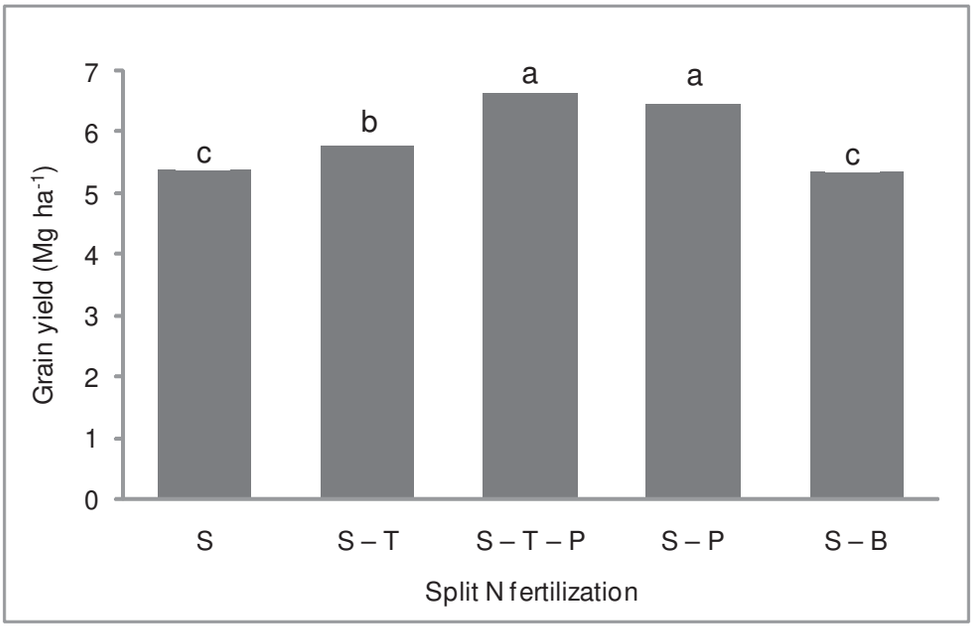
Adapted from [58].

Figure 6. Nutrient distribution in rice plant (grain and aerial residue).

Nutrient management of the rice crop should pay greater attention of the N rate and its form of partialization. The rate must be determined as a function of crop productivity that generates differences in N requirement and the ability of natural soil contribution (with differences between different soil taxonomic orders associated with the evolution of secondary materials and their relationship with active pools of organic matter) since N absorption is mainly from reserves (organic matter mineralization, microbial biomass dynamic cycles, and N-NH4 + fixed in clays) [59-62], N fertilization [63], as well as a small fraction derived from irrigation water and other environmental and biotic sources. The ability of is determined through mineralization in conditions that are similar to field conditions [64-68]. To determine this soil natural N supply ability, the samples must be incubated under optimal mineralization conditions; flooded soils with soil:water ratio of 1:2.5, a temperature from 20ºC to 40ºC for a period of 14 to 21 d without agitating the samples [69]. Using N rates that are higher than the crop requirements can generate phenological development disorders, increasing the vegetative period and producing the start of the reproductive period at a later time, which can increase flower sterility due to low temperatures that can occur in this period since in the final stage of the crop environmental temperatures start decreasing, negatively affecting grain ripening and ulti-

mately commercial yield. It is common to find situations in which production has not achieved adequate grain maturity associated with the incorrect N rate (rates higher than necessary for the particular edaphoclimatic situation). Furthermore, when crop development time is reduced, it also decreases yield potential and thus N requirements.

About N partialization, [70] indicated that the highest grain yield is produced when applying N in 2 or 3 phenological stages; (1) 50% at sowing and 50% at panicle initiation, or (2) 33% at sowing, 33% at tillering initiation, and 34% at panicle initiation. This can be observed in Figures 7 and 8. The partialization strategy that the producer must use will depend on the opportunity to carry out the tasks (sowing date and its relationship with the adequate date) and the area sown.



Different letters over the bars indicate differences between treatments ($p < 0.05$)
S = 100% N at sowing; S – T = 50% of N at sowing and 50% at tillering; S – T – P = 33% N at sowing, 33% at tillering, and 34% at panicle initiation; S – P = 50% N at sowing and 50% at panicle initiation; S – B = 50% N at sowing and 50% at boot stage.

Figure 7. Grain yield of rice with different N application times on a vertisol soil in the Chilean central south region with pooled date for 2007-08 and 2008-09 seasons.

Experiments conducted in Chile with other nutrients have reported a response when applying K, Zn, B, and liming [71]. Rates of P, K, Mg, S, B, and Zn in the rice crop must be adjusted to nutrient requirement (as a function of yield) and the level of availability of each element in the soil. Meanwhile, Ca contributions will be carried out periodically to the extent that liming is performed.

Regarding alternative fertilizers, using organic amendments such as poultry litter has produced crop yield increases as compared to conventional fertilizers with equal N rates [22], which responds to the accumulative loss of soil organic matter with continuous crop cycles. Adding organic matter to the soil, including as crop residues, modifies the redox potential of the soil system and produces higher availability of some nutrients [72].



Different letters over the bars indicate differences between treatments ($p < 0.05$)
S = 100% N at sowing; S – T = 50% N at sowing and 50% at tillering; S – T – P = 33% N at sowing, 33% at tillering, and 34% at panicle initiation; S – P = 50% N at sowing and 50% at panicle initiation; S – B = 50% N at sowing and 50% at boot stage.

Figure 8. Grain yield of rice with different N application times on an inceptisol soil in the Chilean central south region with pooled date for 2007-08 and 2008-09 seasons.

Finally, incorporating residues in the rice crop recycles a large part of the absorbed nutrients in the previous crop cycle [58] as can be observed in Figure 6 and reducing at the same time the rates of elements such as P, K, Ca, and Mg.

2. Nutritional management of main cereals cultivated as a function of yield and soil chemical properties

As abovementioned, the nutritional requirement of a crop is determined by its productivity, whereas the nutrient rate to be applied to the crop must be contrasted with the soil natural nutrient supply ability.

In a conceptual model for the same yield unit (Mg or other), the nutritional requirement can be expressed as a function of this yield unit and then be associated with the yield level as expressed in equation (1):

$$\text{Nutrient rate}\left(\text{kg ha}^{-1}\right) = \text{Nutritional requirement}\left(\text{kg Mg}^{-1}\right) * \text{Yield (Mg ha}^{-1}\text{)} \quad (1)$$

The nutritional requirement per yield unit is inversely proportional to the natural nutrient supply ability determined by the soil as shown in the conceptual model in Figure 9. Thus, to the extent that the nutrient concentration at issue exhibits a higher level in the soil, the fertiliza-

tion rate will be lower per yield unit to produce. In turn, there is a minimum and maximum rate for each nutrient, which means that when the nutrient concentration in the soil is less than the minimum value, the maximum rate is applied, whereas when the concentration of this nutrient in the soil is greater than the maximum value shown in the range (minimum rate per yield unit), the minimum rate will be maintained, which for some nutrients could be zero (not applied).

The nutrient rate in corn, wheat and rice crops is calculated in function of production level, expressed in Megagrams per hectare. In corn crop are utilized the figures 10, 11, 12, 13, 14, and 15 for N, P2O5, K2O, CaO, MgO, and S, respectively. For wheat are utilized the figures 16, 17, 18, 19, 20, and 21. And for rice crop are utilized figures 22, 23, 24, 25, 26, and 27, respectively.

Another variable to consider in the fertilization program is the correction soil acidity, for which liming is used by applying a rate determined by specific analyses in each soil and where it is determined if calcium carbonate ($CaCO_3$) is required to increase soil pH (acidity or alkalinity) in a given quantity. When liming is applied, the fixed Ca application is suspended by analyzing the soil. Likewise, if the amendment has to use Mg ($CaCO_3$*$MgCO_3$), the application of fixed Ca and Mg is suspended by analyzing the soil. In general, it is considered that when soil pH is greater than 6.0 liming is not necessary since there are no acidity problems (negative effect of aluminum (Al) on plant development under acid pH conditions, unless a nutritional imbalance in the soil that affects Ca and/or Mg needs to be corrected.

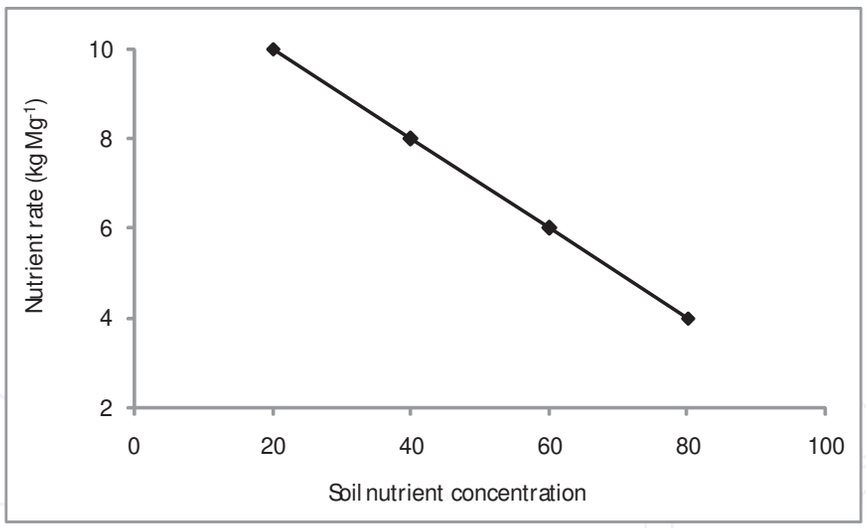


Figure 9. Nutrient rate ratio to apply to a crop (kg per yield unit) as a function of its concentration in the soil.

For the elements K, Ca, and Mg, which participate in cation exchange capacity of the soil (CEC) and given the phenomenon of competition or antagonism, the rate should be adjusted as a function of de percentage participation of each one of them in the CEC of the soil, considering that the element that must exhibit the highest participation in CEC is Ca, followed by Mg, and then K. Thus, the reference ranges of the saturation percentage of each one of these elements are shown in Table 4.

http://dx.doi.org/10.5772/56095

Element	Deficient range	Adequate range	High range
	———————— % over CEC ————————		
K	< 2	2 – 3	"/>3
Ca	< 55	55 - 65	"/>65
Mg	< 10	10 – 15	"/>15

Table 4. Reference ranges for K, Ca, and Mg saturation levels in the cation exchange capacity of the soil (CEC)

2.1. Nutrient rates in corn crop

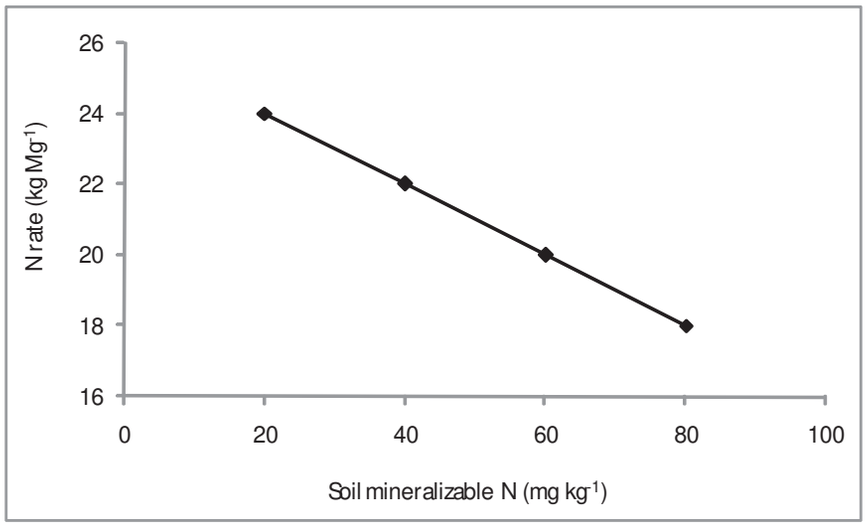


Figure 10. N rate to apply to corn crop for each yield unit as a function of soil mineralizable N concentration.

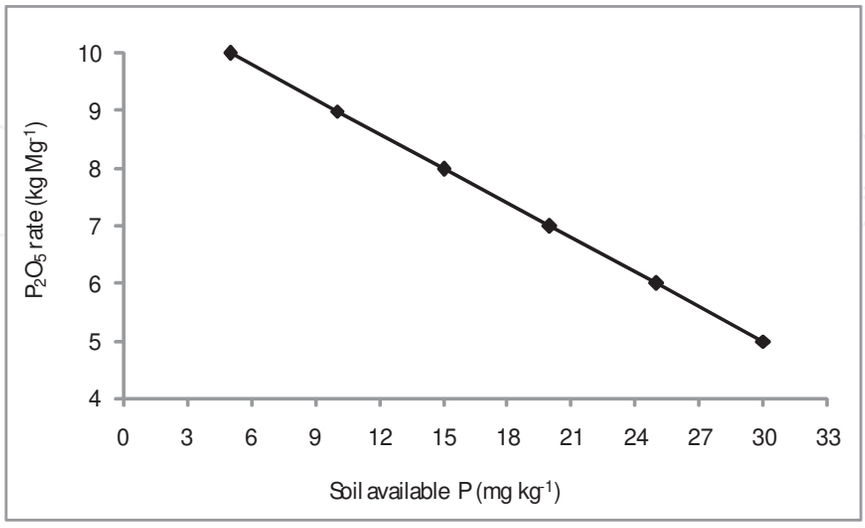


Figure 11. P_2O_5 rate to apply to corn crop for each yield unit as a function of soil available P concentration (Olsen method).

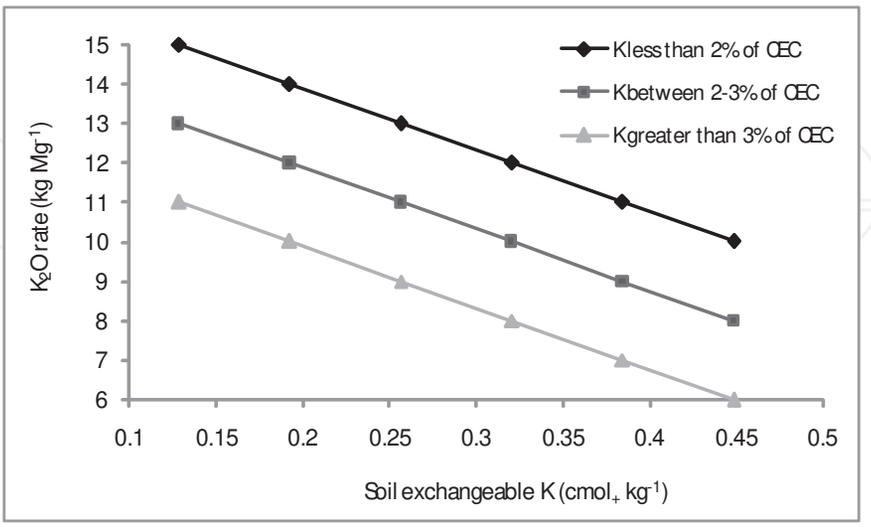


Figure 12. K_2O rate to apply to corn crop for each yield unit as a function of soil exchangeable K concentration.

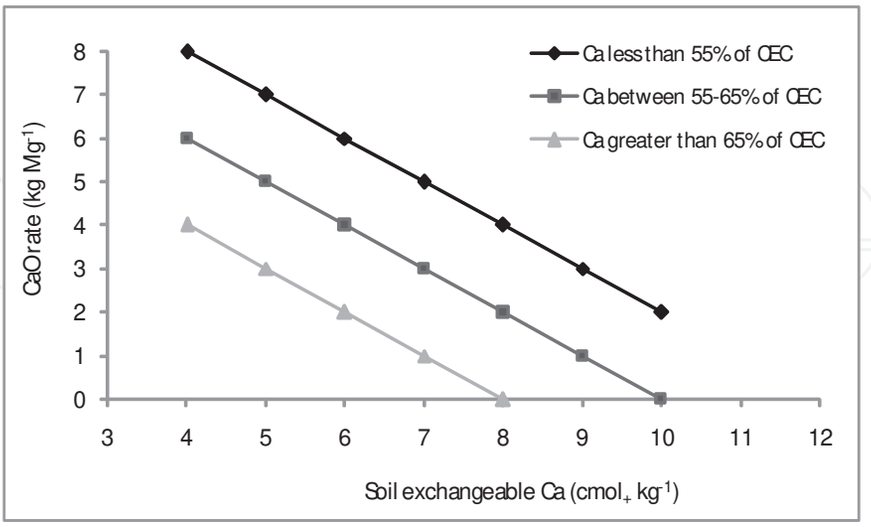


Figure 13. CaO rate to apply to corn crop for each yield unit as a function of soil exchangeable Ca concentration.

http://dx.doi.org/10.5772/56095

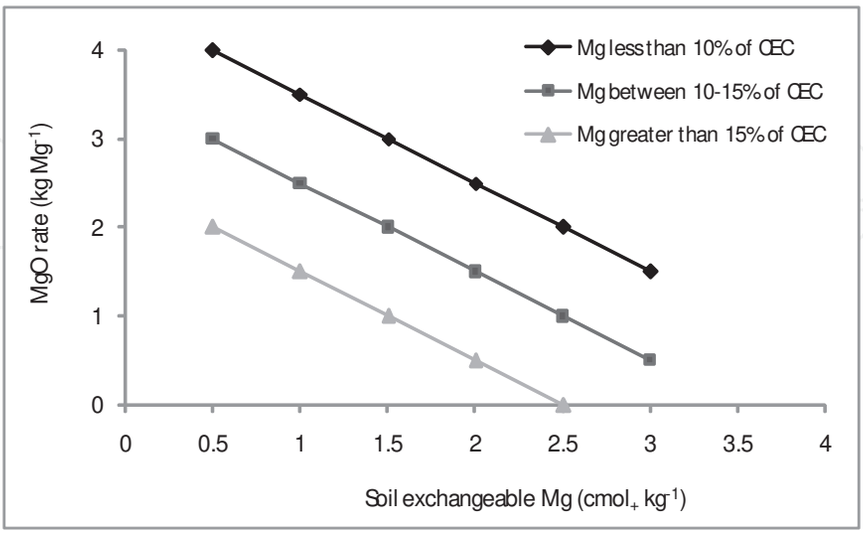


Figure 14. MgO rate to apply to corn crop for each yield unit as a function of soil exchangeable Mg concentration.

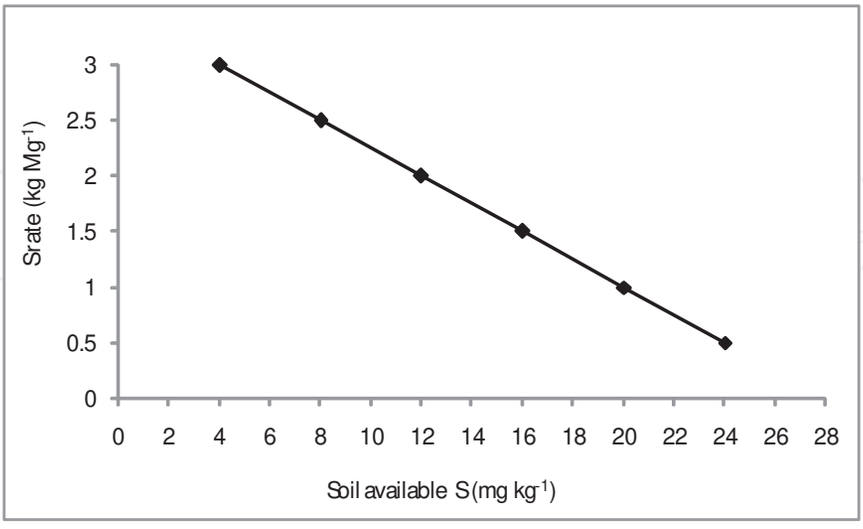


Figure 15. S rate to apply to corn crop for each yield unit as a function of soil available S concentration.

2.2. Nutrient rates in wheat crop

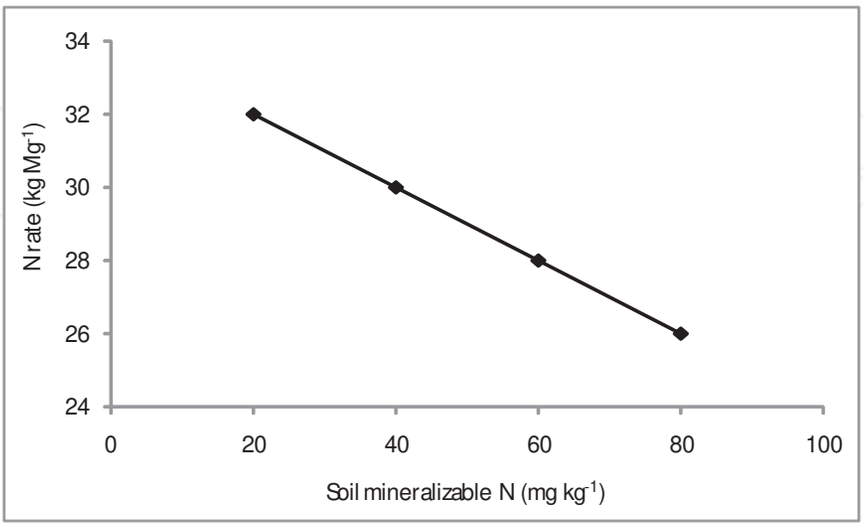


Figure 16. N rate to apply to wheat crop for each yield unit as a function of soil mineralizable N concentration.

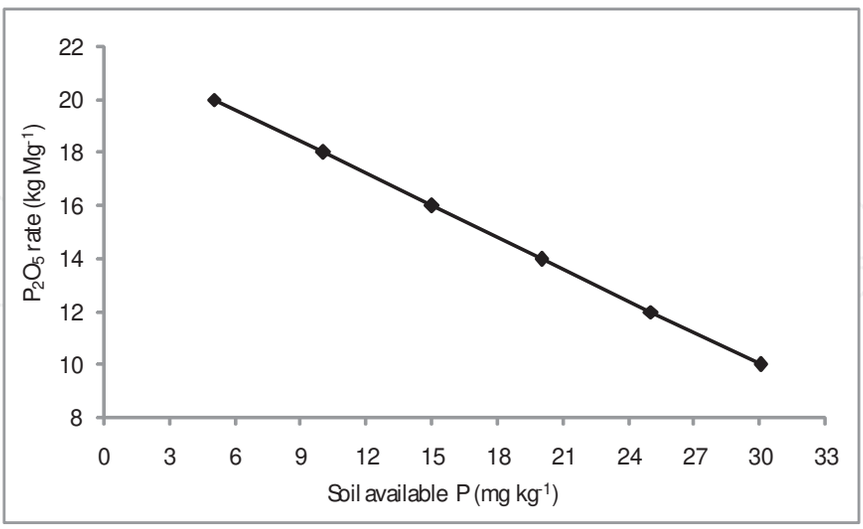


Figure 17. P_2O_5 rate to apply to wheat crop for each yield unit as a function of soil available P concentration (Olsen method).

http://dx.doi.org/10.5772/56095

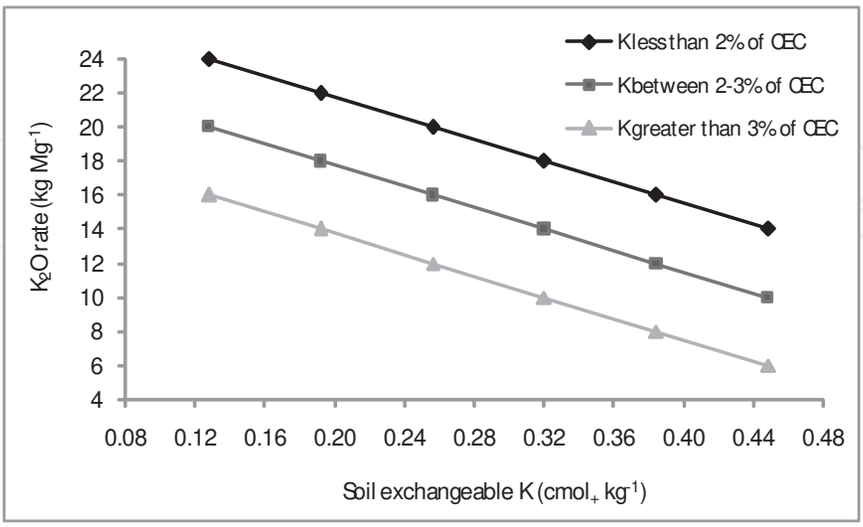


Figure 18. K_2O rate to apply to the wheat crop for each yield unit as a function of soil exchangeable K concentration.

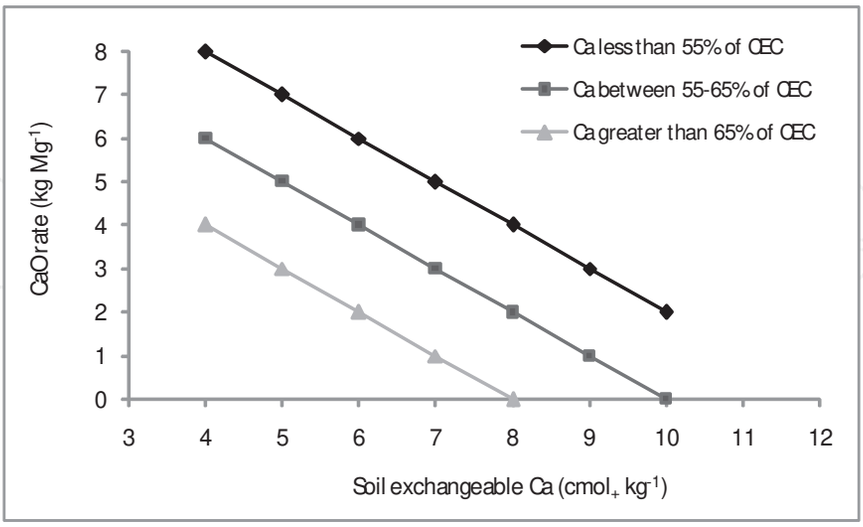


Figure 19. CaO rate to apply to wheat crop for each yield unit as a function of soil exchangeable Ca concentration.

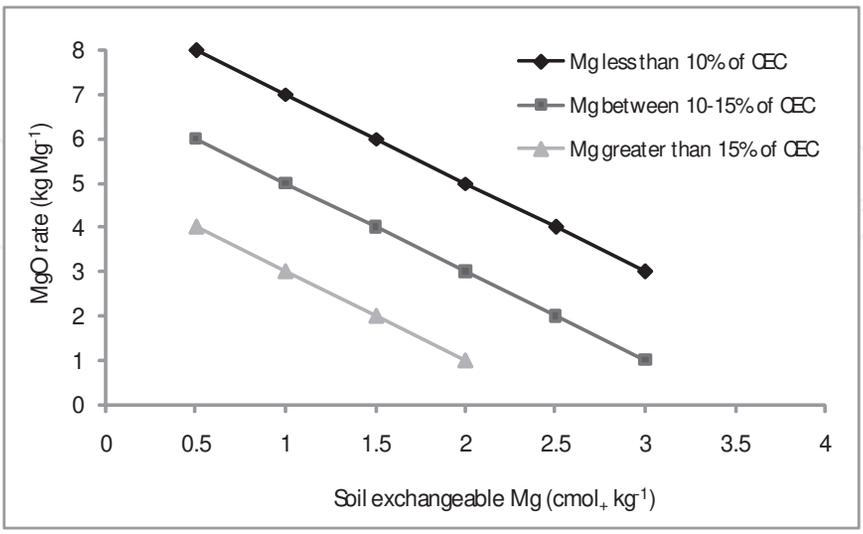


Figure 20. MgO rate to apply to wheat crop for each yield unit as a function of soil exchangeable Mg concentration.

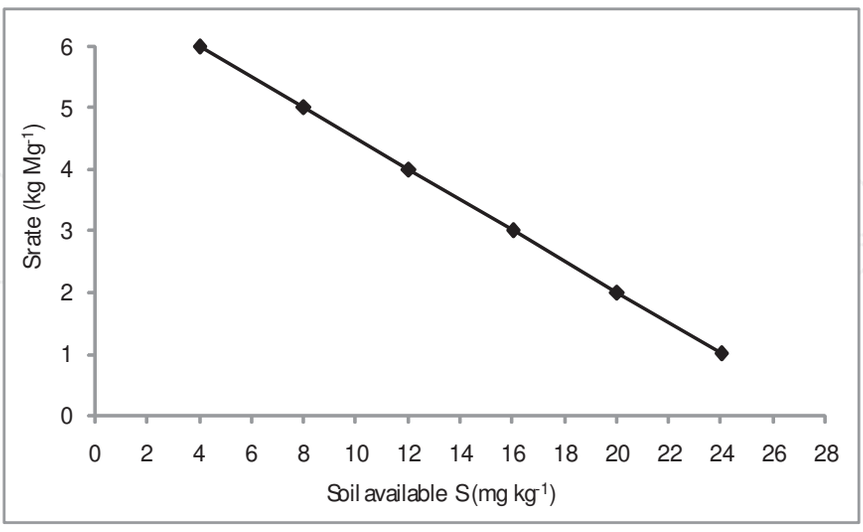


Figure 21. S rate to apply to wheat crop for each yield unit as a function of soil available S concentration.

http://dx.doi.org/10.5772/56095

2.3. Nutrient rates in rice crop

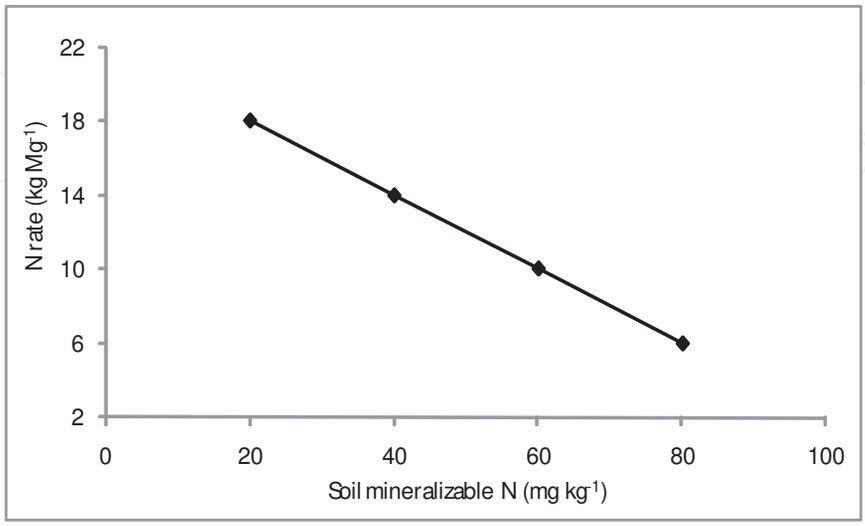


Figure 22. N rate to apply to rice crop for each yield unit as a function of soil mineralizable N concentration.

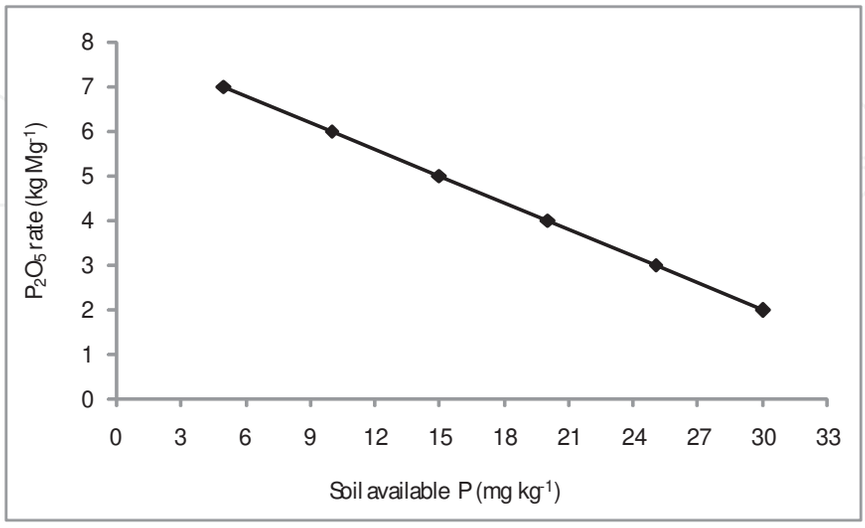


Figure 23. P_2O_5 rate to apply to rice crop for each yield unit as a function of soil available P concentration (Olsen method).

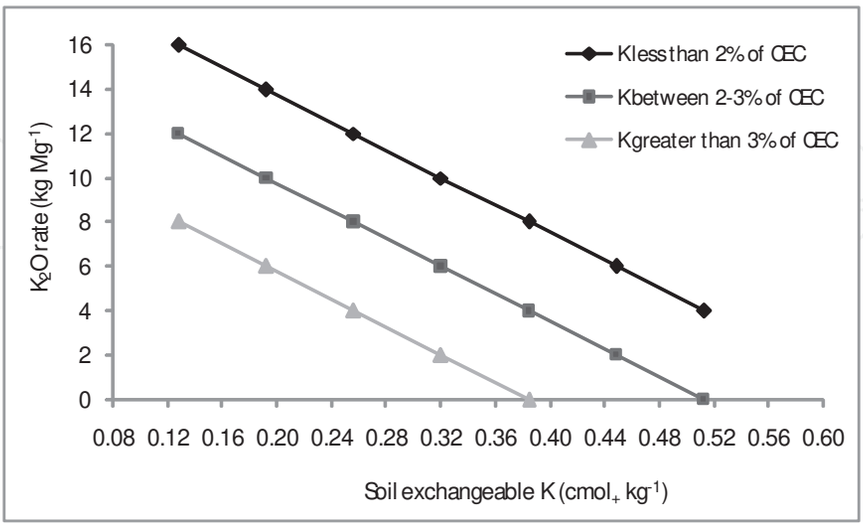


Figure 24. K_2O rate to apply to rice crop for each yield unit as a function of soil exchangeable K concentration.

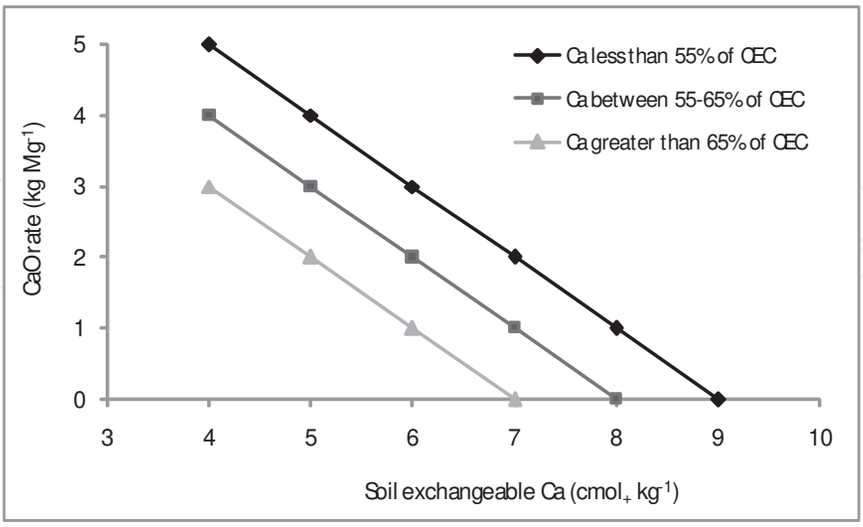


Figure 25. CaO rate to apply to rice crop for each yield unit as a function of soil exchangeable Ca concentration.

http://dx.doi.org/10.5772/56095

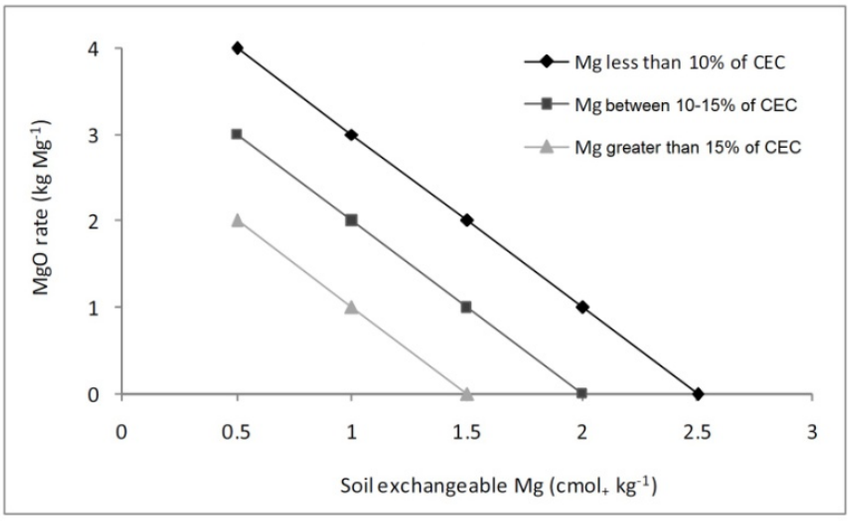


Figure 26. MgO rates to apply to rice crop for each yield unit as a function of soil exchangeable Mg concentration.

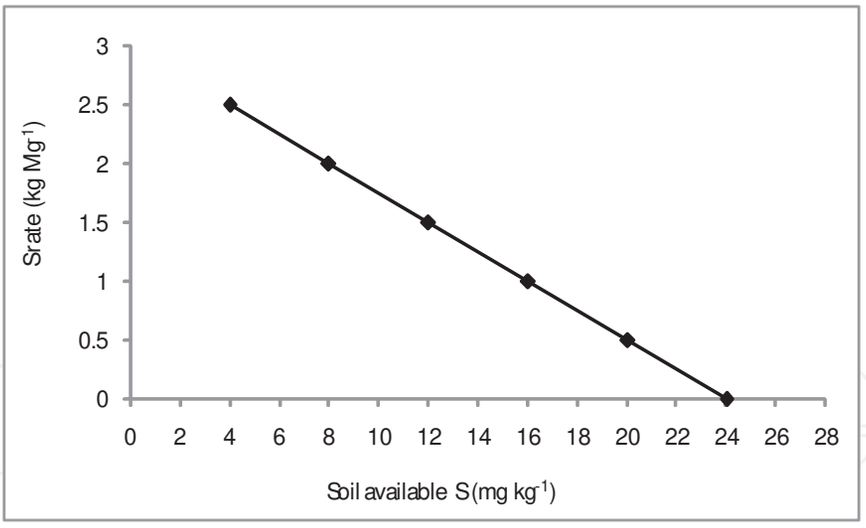


Figure 27. S rate to apply to rice crop for each yield unit as a function of soil available S concentration.

As an example of applying this methodology, sowing corn with an expected yield of 14 Mg ha^{-1} and its chemical properties are shown in Table 5. The rate of each nutrient to be applied as a function of expected yield and chemical soil properties are also found in the table. To determine the rate to use per yield unit (kg Mg^{-1}), Figures 10, 11, 12, 13, 14, and 15 have been used for N, P_2O_5, K_2O, CaO, MgO, and S, respectively.

Soil chemical property	Value	Nutrients to apply	Nutrient rates (kg ha^{-1})
pH	6.5	$CaCO_3$	0
Mineralized N, mg kg^{-1}	30.8	N	322
Available P, mg kg^{-1}	18.4	P_2O_5	104
Exchangeable K, $cmol_+$ kg^{-1}	0.35	K_2O	133
Exchangeable Ca, $cmol_+$ kg-1	8.4	CaO	22
Exchangeable Mg, $cmol_+$ kg^{-1}	0.6	MgO	55
Soil exchange capacity (CEC), $cmol_+$ kg^{-1}	14.5	-	-
CEC used by K, %	2.4	-	-
CEC used by Ca, %	57.9	-	-
CEC used by Mg, %	4.1	-	-
Available S, mg kg^{-1}	6.2	S	38

Table 5. Soil chemical properties and nutrient rates to apply based on such properties for sowing corn where a 14 Mg ha^{-1} yield is expected.

It can be observed in Table 5 for this example that it is liming is not necessary, and the total nutrient rates to be applied have been adjusted to both yield and soil chemical properties. In the case where residues are incorporated, their contributions must be considered as was mentioned in this chapter.

Finally, a fertilization strategy must be determined as a function of the dynamics of each nutrient in the soil-plant system, irrigation system (some nutrients can be applied via fertirrigation when there are pressurized irrigation systems), and the response of a partialized application of nutrients such as N.

3. Conclusion

Finally, the information provided in this chapter allows calculating fertilization rates in cereals using objective measurement tools, such as the productivity level and soil chemical properties, being interrelated contribute to achieving economically adequate yields with an environmental component that allows reducing the negative effects associated with incorrect nutrient use.

Author details

Juan Hirzel* and Pablo Undurraga

*Address all correspondence to: jhirzel@inia.cl

Instituto de Investigaciones Agropecuarias INIA, Centro Quilamapu, Chillan, Chile

References

[1] Laegreid, M, Bøckman, O. C, & Kaarstad, O. Agriculture, fertilizers and the environment. Wallingford, UK: CABI Publishing; (1999).

[2] Hirzel, J, Matus, I, Novoa, F, & Walter, I. Effect of poultry litter on silage maize (*Zea mays* L.) production and nutrient uptake. Spanish Journal of Agricultural Research (2007). , 5, 102-109.

[3] Millner, J. P, Villaver, R, & Hardacre, A. K. The yield and nutritive value of maize hybrids grown for silage. New Zealand Journal of Agricultural Research (2005). , 48, 101-108.

[4] Herrmann, A, & Taube, F. The range of the critical nitrogen dilution curve for maize (*Zea mays* L.) can be extended until silage maturity. Agronomy Journal (2004). , 96, 1131-1138.

[5] Fernández, M. Fertilización nitrogenada y su eficiencia en maíz de grano. Simiente (1995). , 65, 122-132.

[6] Fernández, M. Influencia de la fertilización de largo plazo en el cultivo de maíz y en la residualidad de P y K en un Mollisol calcáreo. Agricultura Técnica (Chile) (1996). , 56, 107-115.

[7] Heckman, J. Sweet corn nutrient uptake and removal. HortTechnology (2007). , 17, 82-86.

[8] Hirzel, J, & Best, S. Necesidades nutricionales del cultivo de maíz en el valle regado de la VIII región. Informativo Agropecuario BIOLECHE- INIA-QUILAMAPU (2002). , 1, 5-3.

[9] Mengel, K, & Kirkby, E. Principles of plant nutrition. 4th ed. International Potash Institute, Worblaufen-Bern, Switzerland; (1987).

[10] Hirzel, J. Estudio comparativo entre fuentes de fertilización convencional y orgánica, cama de broiler, en el cultivo de maíz (*Zea mays* L.). Tesis Doctoral. Universidad Politécnica de Madrid, Madrid, España; (2007).

[11] Balmaceda, M. Fertilización cálcica en el cultivo del maíz. Tesis Ingeniero Agrónomo. Universidad de Talca; (2008).

[12] Jordan-meille, L, & Pellerin, S. Leaf area establishment of a maize (*Zea mays* L.) field crop under potassium deficiency. Plant and Soil (2004).

[13] Kim, K, Clay, D. E, Carlson, C. G, Clay, S. A, & Trooien, T. Do synergistic relationships between nitrogen and water influence the ability of corn to use nitrogen derived from fertilizer and soil? Agronomy Journal (2008). , 100, 551-556.

[14] Plénet, D, Etchebest, S, Mollier, A, & Pellerin, S. Growth analysis of maize field crops under phosphorus deficiency. Plant and Soil (2000). , 223, 117-130.

[15] Sharma, P, Chatterjee, C, Sharma, C, & Agarwala, S. Zinc deficiency and anther development in maize. Plant and Cell Physiology (1986). , 28, 11-18.

[16] Soto, P, Jahn, E, & Arredondo, S. Población y fertilización nitrogenada en un híbrido de maíz para ensilaje en el valle regado. Agricultura Técnica (Chile) (2002). , 62, 255-265.

[17] Butler, T. J, Han, K. J, Muir, J. P, Weindorf, D. C, & Lastly, L. Dairy manure compost effects on corn silage production and soil properties. Agron J. (2008). , 100, 1541-1545.

[18] Cuevas, G, Martinez, F, & Walter, I. Field-grown maize (*Zea mays* L.) with composted sewage sludge. Effects on soil and grain quality. Spanish Journal of Agricultural Research (2003). , 1, 111-119.

[19] Eghball, B, & Power, J. Phosphorus and nitrogen based manure and compost applications: maize production and soil phosphorus. Soil Science Society of America Journal (1999). , 63, 895-901.

[20] Eghball, B, Ginting, D, & Gilley, J. E. Residual effects of manure and compost applications on maize production and soil properties. Agronomy Journal (2004). , 96(2), 442-447.

[21] Hirzel, J, Walter, I, Undurraga, P, & Cartagena, M. Residual effects of poultry litter on silage maize (*Zea mays* L.) growth and soil properties derived from volcanic ash. Soil Science and Plant Nutrition (2007). , 53, 480-488.

[22] Hirzel, J, & Salazar, F. Uso de enmiendas orgánicas como fuente de fertilización en cultivos. In: Hirzel J. (ed.) Fertilización de Cultivos en Chile. Colección Libros INIA Nº28, Chillán, Chile; (2011). , 387-432.

[23] Pang, X. P, & Letey, J. Organic farming: challenge of timing nitrogen availability to crop nitrogen requirements. Soil Science Society of America Journal (2000). , 64(1), 247-253.

[24] Rees, R, & Castle, K. Nitrogen recovery in soils amended with organic manures combined with inorganic fertilisers. Agronomie (2002). , 22, 739-746.

[25] Navarro, S, & Navarro, G. Química agrícola: El suelo y los elementos químicos esenciales para la vida vegetal. Ediciones Mundi-Prensa, Madrid, España; (2003).

[26] Andraski, T, & Bundy, L. G. Corn residue and nitrogen source effects on nitrogen availability in no-till corn. Agronomy Journal (2008). , 100, 1274-1279.

[27] Coulter, J, & Nafziger, E. D. Continuous corn response to residue management and nitrogen fertilization. Agronomy Journal (2008). , 100, 1774-1780.

[28] Mellado, M. Importancia y evolución del trigo en Chile. In: Mellado M. (ed.) El trigo en Chile. Cultura, ciencia y tecnología. Colección Libros INIA Nº 21. Instituto de Investigaciones Agropecuarias, Chillán, Chile; (2007). , 15-35.

[29] Benton, J. Plant nutrition manual. CRC Press LLC, Washington, USA; (1998).

[30] Hewstone, C. Producción de materia seca y absorción de macro y micronutrientes en trigo cultivado en el sur de Chile. Agricultura Técnica (Chile) (1999). , 59, 271-282.

[31] Campillo, R, Hirzel, J, & Jobet, C. Fertilización del cultivo de Trigo Panadero. In: Hirzel J. (ed.) Fertilización de Cultivos en Chile. Colección Libros INIA Nº28, Chillán, Chile; (2011). , 11-80.

[32] Marschner, H. Functions of mineral nutrients: macronutrients. Part I Nutritional Physiology. In Marschner H. (ed.) Mineral nutrition of high plants. Academic Press Limited, London, England; (1990). , 195-267.

[33] Roy, R. N, Finck, A, & Blair, G. J. Tandon HIS. Plant nutrients and basics of plant nutrition. In: Roy RN. et al. (ed.) Plant nutrition for food security. A guide for integrated nutrient management. FAO Fertilizer and Plant Nutrition Bulletin 16. FAO, Rome, Italy; (2006). , 25-42.

[34] Hirzel, J. Fertilización del cultivo. In: Mellado M. (ed.) Boletín de trigo. Manejo tecnológico. Boletín INIA Nº 114. Instituto de Investigaciones Agropecuarias, Chillán, Chile; (2004). , 49-75.

[35] Johnson, V, Dreier, A, & Grabouski, P. Yield and protein responses to nitrogen fertilizer of two winter wheat varieties differing in inherent protein content of their grain. Agronomy Journal (1973). , 65, 259-263.

[36] Stone, P. J, & Savin, R. Grain quality and its physiological determinants. In: Satorre EH, Slafer GA (ed.). Wheat: ecology and physiology of yield determination. Food Products Press, New York, USA; (1999). , 85-120.

[37] Haynes, R. J, & Mokolobate, M. S. Amelioration of Al toxicity and P deficiency in acid soils by additions of organic residues: a critical review of the phenomenon and the mechanisms involved. Nutrient Cycling Agroecosystem (2001). , 59, 47-63.

[38] Halvorson, A. D, Nielsen, D. C, & Reule, C. A. Nitrogen fertilization and rotation effects on no-till dryland wheat production. Agronomy Journal (2004). , 96, 1196-1201.

[39] Campillo, R, Jobet, C, & Undurraga, P. Optimización de la fertilización nitrogenada para trigo de alto potencial de rendimiento en andisoles de la Región de La Araucanía, Chile. Agricultura Técnica (Chile) (2007). , 67, 281-291.

[40] Campillo, R, Jobet, C, & Undurraga, P. Effects of nitrogen on productivity, grain quality, and optimal nitrogen rates in winter wheat cv. Kumpa-INIA in Andisols of Southern Chile. Chilean Journal of Agricultural Research (2010). , 70, 122-131.

[41] Hirzel, J, Matus, I, & Madariaga, R. Effect of split nitrogen applications on durum wheat cultivars in volcanic soil. Chilean Journal of Agricultural Research (2010). , 70(4), 590-595.

[42] Juliano, B. O. Rice in human nutrition. In: FAO (ed.) Food and Nutrition Series Nº 26. FAO, Rome, Italy. International Rice Research Institute (IRRI), Los Baños, Laguna, Philippines; (1993).

[43] Chaudary, R. C, & Tran, D. V. Speciality rices of the world: a prologue. *In* Chaudary DC, Tran DV, Duffy R. (ed.) Speciality rices of the world. Breeding, production and marketing. Food and Agriculture Organization of the United Nations. Science Publishers, Enfield, New Hampshire, USA; (2001). , 3-12.

[44] FAOEstimaciones globales de las emisiones gaseosas de NH_3, NO y N_2O provenientes de las tierras agrícolas. FAO, Roma, Italia; 2004. Available from ftp://ftp.fao.org/docrep/fao/009/y2780s/y2780s00.pdf (accessed 10 April (2012).

[45] Alvarado, J. R. Arroz, su cultivo, situación y producción. In: Alternativas para la modernización y diversificación agrícola. Anuario del Campo. Publicaciones Lo Castillo, Sociedad Nacional de Agricultura, Asociación de Exportadores de Chile: Santiago, Chile; (1997). , 64-70.

[46] ODEPACultivos anuales: superficie, producción y rendimientos. Oficina de Estudio y Políticas Agrarias (ODEPA), Ministerio de Agricultura, Chile; 2010. http://www.odepa.gob.cl/servlet/articulos.ServletMostrarDetalle;jsessionid=17656C712C5932B9501ED4DA40DD29D5?idcla=12&idn=1736.accessed 15 January (2012).

[47] Kumura, A. Studies on the effect of internal nitrogen concentration of rice plant on the constitutional factor of yield. Proceedings of the Crop Science Society of Japan (1956). , 24, 177-180.

[48] Singh, J. N, & Murayama, N. Analytical studies on the productive efficiency of nitrogen in rice. Soil Science and Plant Nutrition (1963). , 9, 25-35.

[49] Shimizu, T. Processes of yield formation in rice plants from the point of dry matter production (in Japanese). Dry Matter Production in Crops (1967). , 4, 12-26.

[50] Grist, D. H. Rice. 5th ed. Longman, London, UK; (1975).

[51] Tanaka, A, Patnaik, S, & Abichandani, C. T. Studies on the nutrition of rice plant. III. Partial efficiency of nitrogen absorbed by rice plant at different stages of growth in relation to yield of rice (*O. sativa*, var. indica). Proceedings of the Indian Academy Of Science, Section B (1959). , 49(4), 207-216.

[52] Atanasiu, N, & Samy, J. Nutrición de la planta: fertilizantes y abonos orgánicos para el arroz. In: Arroz uso eficaz de los fertilizantes. Conzett + Huber AG., Zurich, Suiza; (1985).

[53] Tinarelli, A. El arroz. Ediciones Mundi-Prensa, Madrid, España; (1989).

[54] Sheehy, J. E, Mnzava, M, Cassman, K. G, Mitchell, P. L, Pablico, P, Robles, R. P, & Ferrer, A. Uptake of nitrogen by rice studied with a ^{15}N point-placement technique. Plant and Soil (2004). , 259, 259-265.

[55] Frageria, N. K, Carvalho, G. D, & Santos, A. B. Ferreira EPB, Knupp AM. Chemistry of Lowland Rice Soils and Nutrient Availability. Communications in Soil Science and Plant Analysis (2011). , 42, 1913-1933.

[56] Trolldenier, G. Nitrogenaseaktivitaet in der Rhizosphaere von Sumpfreis in Abhaengigkeit von der Mineralstoffernaehrung. Mitteilungen der Deutschen Bodenkundlichen Gesellschaft. Goettingen (1979). , 29, 334-337.

[57] Alvarado, R, Madariaga, R, & Gómez, A. Pudrición del tallo en arroz: Respuesta varietal. IPA Quilamapu (1991). , 50, 32-35.

[58] Cordero-vásquez, A, & Murillo-vargas, J. I. Removal of nutrients by rice cultivar CR 1821 under flood irrigation. Agronomía Costarricense (1990). , 14(1), 79-83.

[59] Jokela, W. E, & Randall, G. W. Fate of fertilizer nitrogen as affected by time and rate of application on maize. Soil Science Society of America Journal (1997). , 61, 1695-1703.

[60] Jensen, L. S, Pedersen, I. S, Hansen, T. B, & Nielsen, N. E. Turnover and fate of ^{15}N-labelled cattle slurry ammonium-N applied in the autumn to winter wheat. European Journal of Agronomy (2000). , 12, 23-35.

[61] Sainz, H. R, Echeverría, H. E, & Barbieri, P. A. Nitrogen balance as affected by application time and nitrogen fertilizer rate in irrigated no-tillage maize. Agronomy Journal (2004).

[62] Sahrawat, K. Organic matter and mineralizable nitrogen relationships in wetland rice soils. Communications in Soil Science and Plant Analysis (2006). , 37, 787-796.

[63] Wienhold, B. Comparison of laboratory methods and an in situ method for estimating nitrogen mineralization in an irrigated silt-loam soil. Communication in Soil Science and Plant Analysis (2007). , 38, 1721-1732.

[64] Angus, J. F, Ohnishi, M, Horie, T, & Williams, L. A preliminary study to predict net nitrogen mineralization in a flooded rice soil using anaerobic incubation. Australian Journal of Experimental Agriculture (1994). , 34, 995-999.

[65] Wilson, C. E, Norman, R. J, & Wells, B. R. Chemical estimation of nitrogen mineralization in paddy rice soils. I. Comparison to laboratory indices. Communications in Soil Science and Plant Analysis (1994).

[66] Bushong, J. T, Norman, R. J, Ross, W. J, Slaton, N. A, Wilson, C. E, & Gbur, E. E. Evaluation of several indices of potentially mineralizable soil nitrogen. Communications in Soil Science and Plant Analysis (2007). , 38, 2799-2813.

[67] Soon, Y, Haq, A, & Arshad, M. Sensitivity of nitrogen mineralization indicators to crop and soil management. Communications in Soil Science and Plant Analysis (2007). , 38, 2029-2043.

[68] Rodriguez, A, Hoogmoed, W, & Brussaard, L. Soil quality assessment in rice production systems: establishing a minimum data set. Journal of Environment Quality (2008). , 37, 623-630.

[69] Hirzel, J, Cordero, K, Fernández, C, Acuña, J, Sandoval, M, & Zagal, E. Soil potentially mineralizable nitrogen and its relation to rice production and nitrogen needs in two paddy rice soils of Chile. Journal of Plant Nutrition (2012). , 35, 396-412.

[70] Hirzel, J, Pedreros, A, & Cordero, K. Effect of nitrogen rates and split nitrogen fertilization on grain yield and its components in flooded rice. Chilean Journal of Agricultural Research (2011). , 71, 437-444.

[71] Hirzel, J, & Cordero, K. Fertilización del cultivo de Arroz. In: Hirzel J. (ed.) Fertilización de Cultivos en Chile. Colección Libros INIA Nº28, Chillán, Chile; (2011). , 167-198.

[72] González-rojas, R. Efecto en suelos inundados de la adición de materia orgánica sobre el fósforo y otros elementos extraíbles con Mehlich III. Tesis Licenciatura en Química. Universidad de Costa Rica, Ciudad Universitaria (Costa Rica); (1997).

IntechOpen