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CropKit

Specialty Plant Nutrition Management Guide

Tobacco

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I hereby would like to thank all my SQM as well as the following institutions for having provided excellent figures:

- North Carolina State University.
- The University of Georgia.
- Yara (Norway).

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Foreword

SQM is the worldwide leader in the production of **Specialty Plant Nutrition** fertilizers which are environmentally friendly processed. **SQM** also greatly contributes to the development of the global agricultural and because the company constantly gathers new agronomic information, **SQM** has decided to edit a range of **Crop Kits,** which can serve as professional guides to obtain better production methods and improved quality in several crops. This particular **Crop Kit** treats tobacco crop and addresses producers, agronomists and distributors.

We also would like to thank all the mentioned agronomic research institutes, because they provide the necessary scientific rigorousness to this publication.

The main purpose of this **Crop Kit** is to contribute to the agronomic management of tobacco crop. However, given the very different crop conditions worldwide, it is recommended to contact SQM's technical teams, in order to obtain specific, detailed information in function of optimal quality and yield.

Table of Contents

Introduction

This Crop Kit deals with all the aspects of tobacco crop and features ten chapters. The booklet starts (Chapter 1) with highlighting the importance of the nutrition aspect and its effect on high yield. Chapter 2 provides information on the major producing countries, yields and a description of the crop, including its climatic, soil and water requirements. In this chapter are also treated the plant's morphology and physiology, the different tobacco varieties and their respective quality parameters and finally the most important illnesses.

Further on, in Chapter 3, a description is given of the role each nutrient plays in the crop, followed by information regarding adequate nutrition management, with emphasis on the specific role of each nutrient in the crop (Chapter 4). Chapter 5 features comments and descriptions about the main nutrition deficiencies, in order to easily recognize them in the field, whereas Chapter 6 highlights different alternatives of available fertilizers for their use in potato, including their individual main characteristics, advantages and disadvantages.

Chapter 7 lists the major technical considerations in view of an adequate a complete nutrition and proposes several nutrition alternatives. Chapter 8 features some research results on tobacco crop, with emphasis on how to obtain yield and quality by means of complete nutrition programmes. Finally, Chapter 9 presents several field trial results on tobacco, whereas Chapter 10 features an overview of the quoted literature.

Note on booklet value-expression convention:
(.) Period: indicates thousands.
(,) Comma: demarcates the place of the decimal.
The number 1.500,5, stated in words, is
"One thousand five hundred and five tenths".

1 Crop Nutritional Status as it Relates to Performance

Today's agricultural activity which is very dynamic and highly competitive enables producers anywhere in the world to produce and to export their harvests. It is also the reason why farmers must systematically increase their efficiency; that is to say, increasingly produce bigger quantities and better qualities at the lowest possible cost. In order to reach this objective, multiple variables must be managed properly like for instance the correct selection of the crop to be cultivated, the variety which is best adapted to the area, adequate irrigation, plant health, etc. Because apart from the above mentioned aspects, a well-balanced nutrition management plays a fundamental role in obtaining improved production and quality, this Nutrition Management Guide treats specific technical recommendations to that respect.

In today's agricultural it is impossible to consistently maintain good harvests season upon season without appropriate nutritional soil reconditioning, whether it be by plant absorption, volatilization losses, leaching, adsorption, etc. A well-balanced management of the nutrients implies several aspects like the integrated application of the thirteen elements which are defined as being essential for the plant's growth, but also applying them taking into account the soil conditions, which can influence the availability of the nutrients in the soil. On the other hand, it is also important to apply these elements at the right moment and in the right doses, which implies knowing the different phenological stages and the extraction by the plant during each one of them, knowing the most adequate sources and how to use them during each stage of the crop's growth. We like to enphasize these factors, because a correct and balanced management of the nutrients will result in a healthy plant, capable of expressing all of its genetic potential. That way the plant's growth can be boosted during each stage to the extent that is most relevant to meet the grower's objectives for each stage. Or in other words: shall result in a plant capable to produce higher yields of optimal quality.

On the contrary, i.e. without a well-balanced nutrition programme, the plant's development shall be hindered, which in turn shall lead to a reduced economic yield of the crop, such as lesser production or plants more inclined to catch diseases, which of course leads to increased costs and applications, and/or a reduction of the harvest quality; costs that come on top of the initial production cost. Because the nutrition costs are not the highest in the total mix of the production cost, it is feasible to obtain a better cost: benefit relation by means of an adequate nutrition management. Therefore, investing somewhat more in nutrition shall generate a better economic environment for the producer, i.e. initial production costs shall be reduced while at the same time quality shall be maintained.

2 Crop Description

2.1 Origin

The centre of origin of Nicotiana tabacum L. (Espino, 1988), i.e. from where the crop spread, starting from its wild stage, is considered to be the Peruvian-Ecuadorian-Bolivian high plateau, in the neighbourhood of Lago Titicaca, settling place of the old Inca and Chincha civilizations, which were the first to cultivate tobacco and to incorporate it into to their crop and mythology.

Although the origin of tobacco (Nicotiana tabacum L.) is located in the high Andean plateaus, in the neighbourhood of the Titicaca lake, the commercial spreading of the crop took off from the Antilles (Cuba and Dominican Republic) and the east coast of the United States (Florida and Virginia). Tobacco production and consumption by the Indo-Americans, especially with regard to the Nicotiana tabacum species, dropped all over South America and the Antilles; the same applying to the Nicotiana rustica species in Mexico, the United States and Canada. Tobacco was taken to Europe, by two crewmembers of the first expedition of Christopher Columbus, Rodrigo de Xerez and Luis de Torres, at the beginning of November of the year 1492.

The chronology of the worldwide tobacco spreading seems to be well noted. In the first years after its discovery, the main tobacco references seem to be related to its spreading and ways of use by the inhabitants of the New World; but already in 1556 tobacco is also present in France, in 1558 in Portugal and in 1559 in Spain and as from 1565 in England. By the end of the 16th century tobacco arrived in Italy, Germany, the Netherlands, Scandinavia, Russia, Persia, Western Africa and the Far East. A century later, tobacco had already reached New Zealand and Australia and has thus become a worldwide crop to be found in the five continents. Tobacco cultivated in France and Spain was of the Nicotiana. tabacum species and of Antillean origin, whereas in Portugal and in England the Nicotiana. rustica species was introduced with origins in respectively Brazil and Virginia.

Some authors believe that the spreading of tobacco from its centre of origin started around 2.000 - 3.000 years before our era and that as a result of contacts between native crops, maize was spread southwards and tobacco northwards. The production, the commercialization and the consumption of tobacco was sustained, especially of the Nicotiana tabacum L. species, and to a lesser extent the Nicotiana rustica L. species which was only cultivated locally in Russia and in some Asian countries. The rest of the 64 species of the Nicotiana genus, are only interesting from a scientific point of view; and some of them are only ornamental.

2.2 Botanical Description

Tobacco (Nicotiana tabacum L.) is a natural amphidiploid between the Nicotiana sylvestris Spegazzini species and Comes and one of the species of the Tomentosae section, being the species Nicotiana tomentosa Ruix and Pavon, Nicotiana. tomentosiformis Goodspeed and Nicotiana Otophora Grisebach, most frequently considered to be the second ancestor. It is a perennial plant that is cultivated annually. Its chromosome pattern consists of twenty-four pairs of chromosomes.

After meticulous investigations, Gerstel (1960) was able to determine that the genome of Nicotiana Tomentosiformis is more closely related to Nicotiana tabacum, according to the segregation frequency. Other evidencaes seem to support the hypothesis that the tobacco ancestors are the Nicotiana sylvestris and the Nicotiana tomentosiformis species (Espino, 1988; Sheen, 1972). Kung (1976), on the basis of the electrophoretic analysis of fraction I of tobacco proteins, established that the Nicotiana tabacum species arose as a result of the hybridization under natural conditions of Nicotiana sylvestris and Nicotiana tomentosiformis, from which first the feminine ancestor and then the masculine one resulted. Goodspeed (1954) has classified the Nicotiana genus in three subgenera, 14 sections and 64 species, of which 45 are of American origin and 15 originate from Australia. (Garner, 1946).

2.3 Types of Tobacco

According to the use of its leaves, different types of tobacco have been established throughout the years, each having proper characteristics and relatively differentiated on the basis of their morphology, and their chemical and organoleptic properties.

The distinguishing characteristics of the main types of tobacco are:

Virginia
The Virginia variety, also referred to as flue-cured or blonde, has high plants with big, spear shaped leaves that acquire a characteristic yellow tonality when dried in an artificial atmosphere of between 60 °C and 70 °C. The flavour and aroma are smooth; the nicotine content is medium and the sugar level is high. The smoke of its combustibility is sweet and acid. It is used for the production of blond cigarettes and blends for pipes. The leaves are picked one by one as they ripen; they are cured in barns with flues carrying the heat into the barn to bake the leaves slowly.

Burley

The Burley variety has high-growing plants with big leaves, which acquire beautiful reddish tonalities when dried to the air and conditioned to the heat. They are characterized by their physical properties: good combustibility, good stuffing capacity and their capacity to absorb the flavouring sauces in the blond cigarette blends. Its flavour is neutral, which is an advantage when used in blends at the tobacconist and for pipe tobacco. The complete plant is harvested and is air-dried or air-cured.

Fire-cured

These are plants of good bearing and leaves of variable size, that acquire dark tonalities and a strong flavour when dried to the open. They are used in blends for pipes, in the production of snuff and for chew tobacco.

Dark

The dark variety also has high-growing plants with big leaves that acquire tonalities that shift from coffee with milk to dark brown, when air-dried under natural conditions and after having undergone a fermentation process. Usually they have a strong flavour and aroma; are high in nicotine and there's an alkaline reaction of the smoke. Its cultivation under reduced light conditions produces the layer which is used for rolling cigars, which is the most specialized of all productions in the tobacco universe. They are used at the tobacconist, in pipe tobacco blends and mainly for rolling cigars.

Eastern

The plants are lower, with numerous small leaves, that acquire yellow tonalities when sun-cured. The main quality of this variety is the characteristic aroma that is most appropriate for blending cigarette tobaccos and pipe tobaccos.

As can be observed in Figure 1, Virginia tobacco is cultivated on 60% of the total crop surface; followed by Burley tobacco (13%), the Eastern variety (12%), and Dark tobacco (6%). The total of the remaining varieties only reaching 9% of the total production.

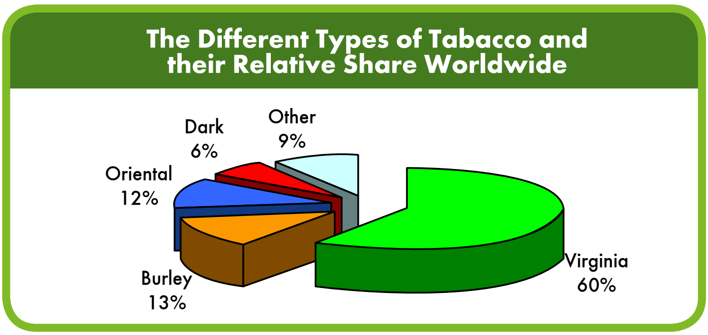


Figure 1. *The different types of tobacco and their relative share worldwide.*

From the point of view of the parts of the cigar, tobacco is cultivated for production of:

The filler

The filler is the blend of the leaves that form the inside of the cigar. In this part hides the force of the cigar because it is the part where each brand applies the secret combinations of leaves to get its specific flavour.

The filler is made by plying the leaves in the shape of a fan, thus creating horizontal air passages that facilitate the draught, and which assure that each drag contains all of the tobacco flavours. It is shaped by means of long tobacco leaves that occupy the overall length of the cigar (in the mechanically produced cigars, the filler is shaped using leaves cut to small pieces); in quality cigars, the filler is made using long leaves in order to obtain the same flavour throughout the cigar and to obtain consistent ashes.

The binder

The binder consists of tobacco leaves that enclose the filler in such a way that it keeps the binder together and contributes to a good combustibility. The binder is enclosed by a leaf which is called the wrapper and which has a strong impact on the flavour, the aroma and the combustibility of the cigar. Its flavour must be compatible with that of the filler and the wrapper.

The wrapper

The wrapper is the outer skin of the cigar. It is made by special leaves that give tobacco its aspect, colour and flavour. It must be attractive and well veined, with a uniform texture and a smooth touch.

Figure 2. *The parts of a cigar: filler, wrapper and binder.*

2.4 Areas of Cultivation

Tobacco is cultivated in more than 120 countries and is thus widely spread all over the world. The total cultivated area on the five continents reaches almost 3,9 million hectares with a worldwide average yield of 1,64 ton/ha. The 20 countries with the largest agricultural areas together total 87,7% of the worldwide surface and 87,6% of the worldwide production, as can be observed in Table 1.

Table 1. *The 20 countries with the largest tobacco cultivation areas.*

Producing Country	Area (ha)	Production (ton)	Yield (tonnes/ha)
China	1.352.000	2.409.500	1,78
Brazil	469.678	928.338	1,98
India	438.000	598.000	1,37
Turkey	183.954	160.000	0,87
United States of America	165.130	398.810	2,42
Indonesia	145.000	141.000	0,97
Malawi	122.000	69.500	0,57
Argentina	66.000	118.000	1,79
Greece	56.006	121.000	2,16
Pakistan	46.800	83.700	1,79
Korea, Dem People's Rep	45.000	64.000	1,42
Bulgaria	40.000	60.000	1,50
Zimbabwe	40.000	80.000	2,00
Thailand	39.500	80.000	2,03
Italy	36.500	102.765	2,82
Tanzania, United Rep of	34.000	24.500	0,72
Cuba	33.942	34.494	1,02
Philippines	33.771	47.800	1,42
Bangladesh	33.000	40.000	1,21
Myanmar	26.000	49.000	1,88
Nigeria	22.000	9.200	0,42
TOTAL OF COUNTRIES WITH THE LARGEST TABACCO CULTIVATION AREAS	3.428.281	5.619.607	1,64
WORLD TOTAL	3.906.897	6.416.067	1,64

Source: *FAOSTAT, 2004.*

Together, China, Brazil and India account for more than 65% of the cultivated area. Tobacco cultivation takes place in tropical, subtropical and mild climate zones, located between 45° north latitude and 37° south latitude and stretching from sea level up to 2.000 metres (of altitude).

2.5 Soil

Talking about soils for tobacco is in fact talking about specific edaphic particularities, which depending upon the locality, shall lead to obtaining a specific type of tobacco of exceptional quality. Nevertheless, there are common characteristics that are always present in soils apt for cultivating tobacco.

To begin with, tobacco requires good physical properties such as an appropriate air: water balance and above all a good internal drainage, because this crop is very susceptible to a deficient oxygenation in the radical surroundings and reacts as badly to an excess of water, as to a lack of water. On the other hand, tobacco does not tolerate the presence of water tables nearby the surface. As a rule, tobacco requires a soil reaction ranging from moderately acid to neutral. In acid soils, the toxicity due to aluminium and manganese lowers the yields and, above all, reduces the quality of the leaves; whereas in soils containing carbonates relative potassium deficiencies, affecting the combustibility of the leaf, may appear.

The optimal pH for tobacco production varies between 5,2 and 6,5. As can be observed in Figure 3, subacid to neutral pH values allow for greater nutritional availability.

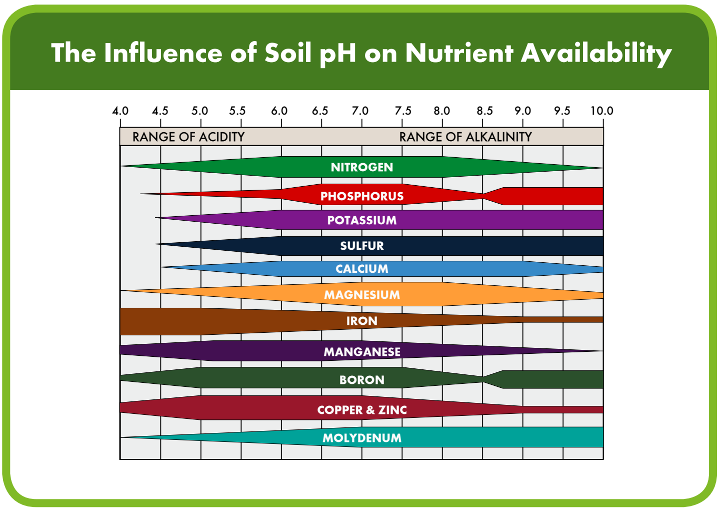


Figure 3. *Influence of soil pH on the availability of nutrients.*
Souce: Yara

At high pH values (more than 7,5), Phosphorous (P), Iron (Fe), Zinc (Zn), Manganese (Mn), Copper (Cu) and Boron (B), remarkably lower their availability. When pH is lower than 5,5, the general availability of the nutrients in the soil diminishes; which is particularly true for Phosphorous (P) (minimum availability) and Molybdenum (Mo) (zero availability). Moreover, with these pH values (acid) the crop may suffer from toxicity caused by Manganese (Mn), Aluminium (Al) or some heavy metals. This Manganese (Mn) toxicity is common in acid soils, provoking slow plant growth, chlorotic leaves or even the fall of these. In addition to the high absorption of this element, the plant diminishes its absorption of other cations such as Iron (Fe), Calcium (Ca) and Magnesium (Mg), (Sims and Wells, 1985).

On the other hand the behaviour of fertilizers in the soil allows for certain pH modifications, through its acidity or alkalinity reaction, which is measured by means of the acidity-alkalinity index (AAI) and which can vary the availability of the nutrients in solution (within certain limits). If the fertilizer has an acid reaction, the AAI has a negative reading and is equivalent to the kg of $CaCo_3$ necessary to neutralize the acidifying effect of the application of 100 kg of that product. If the fertilizer has an alkaline reaction, the AAI has a positive reading which is equivalent to the kg of $CaCo_3$ generated by the fertilizer in question when applied. Table 2 shows an AAI comparison table for different fertilizers.

Table 2. *AAI comparison table for different fertilizers*

Fertilizer	AAI/100Kg	AAI/Kg N
Boronat 32 AG	55	
Potassium chloride	0	
Diamonic phosphate	-70	-3,9
Monoamonic nitrate	-65	-5,9
Ammonium nitrate	-61	-1,8
Calcium nitrate	20	1,3
Potassium nitrate	26	1,9
Sodium nitrate	29	1,8
Simple potassium nitrate	28	1,9
Ammonium sulphate	-110	-5,2
Calcium sulphate	0	
Potassium sulphate	0	
Zinc sulphate	0	
Iron sulphate	0	
Sulpomag	0	
Triple super phosphate	0	
Urea	-83	-1,8

Source: Ortega R. SQM Mexico 2000.

Aside from the requests tobacco has from the soil, the different types of tobacco can be split up in two major groups: on the one hand the clear tobaccos, which include Virginia and Eastern and, on the other hand the dark tobaccos, which are air-cured or fire-cured. The Burley variety has to be situated somewhere in the middle, because it relates to clear tobacco through its physical and texture requirements and because it also relates to the dark ones through its nutritional requirements.

The clear tobaccos prefer soils of lighter textures, with less cationic interchange capacity (CIC) and less availability of nutrients. The dark tobaccos respond better in soils of heavier textures, wiht high content of clay in the soil, with average contents of organic matter (OM), whereas its reaction can approach neutrality. In any case, the application of organic matter to the soil is very important to improve its physical characteristics (structure), to stimulate the increase of the cationic interchange capacity (CIC) as can be observed in Figure 4, to increase the microbiological activity, to improve the water retention capacity, and to avoid the leaching of nutrients in solution.

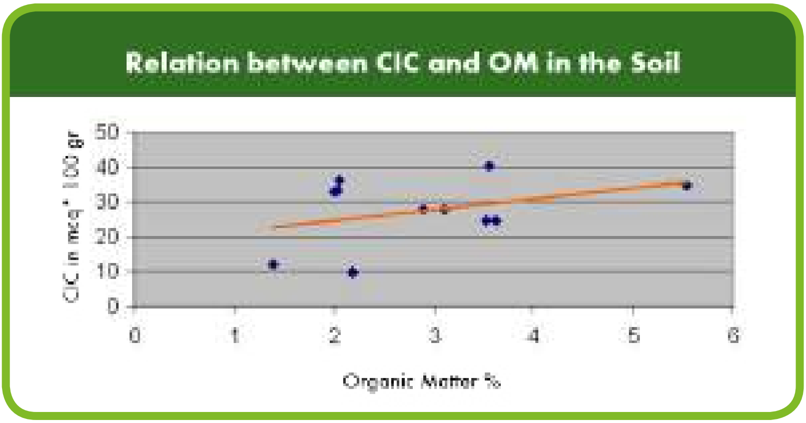


Figure 4. *Relation between CIC and OM in the soil.*
Source: Casanova, O., 1999 - Faculty of Agronomy, Montevideo, Uruguay.

At the same time, a better cationic interchange capacity can generate a pH increase in the soil (also see Figure 5), leading to an increase of the availability of the elements in the soil to be absorbed by the parts of the plants.

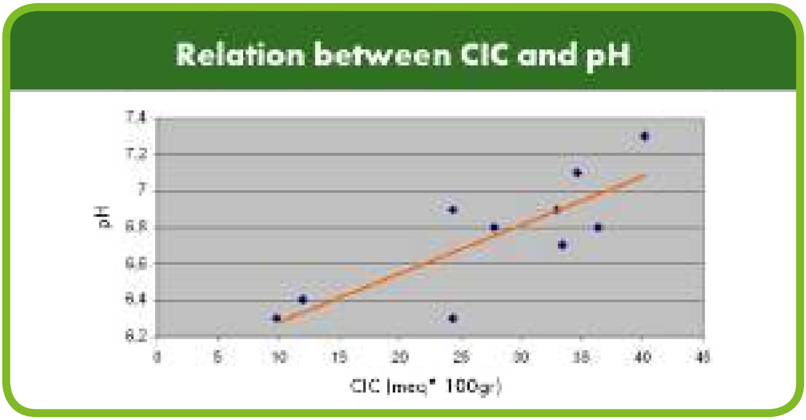


Figure 5. *Relation between CIC and pH in the soil.*
Source: Casanova, O., 1999 - Faculty of Agronomy, Montevideo, Uruguay.

The bases of the cation exchange capacity (CIC) that are usually encountered in the soil are shown in Table 3.

Table 3. *The bases of the cation exchange capacity (CIC).*

The bases of the cation exchange capacity (CIC)	
Base	**Proportion of the CIC**
Calcium	65-85%
Magnesium	6-12%
Potassium	2-5%
Aluminium	Less than 5%
	mg/kg
Zinc	0,5-1
Iron	4-5
Copper	0,5-1
Manganese	0,2
Boron	1,0

On the other hand the salinity affects the crop in two different ways, through total saline content and by specific toxicities of different ions (chloride, sulphates and carbonates). The tobacco crop is very sensitive to salt excess which is expressed by less growth of the plants and leaves as a result of increased difficulty to absorb water. The higher contents of salts (chloride) in the leaves are also detrimental for the quality of the harvested tobacco. Therefore, a rational use of fertilizers is very important because of their impact on the soil, since all fertilizers with a saline index are salts, as shown in Table 4. In order to avoid soil salinity it is therefore recommended to use fertilizers of low salinity.

Table 4. *Saline index of fertilizers.*

Fertilizer	N	$P_2 O_5$	K_2O	Saline Index
Potassium chloride	0	0	60	116
Ammonium nitrate	34	0	0	102
Sodium nitrate	16	0	0	100
Urea	46	0	0	73
Ammonium nitrate	21	0	0	69
Potassium nitrate	13	0	45	66
Anhydric ammonium	82	0	0	47
Potassium sulphate	0	0	50	43
Diamonic phosphate	18	46	0	29
Monoamonic phosphate	11	52	0	26
Triple super phosphate	0	46	0	10

Source: Adapted from Rader L., White L. and Whittaker C. 1943

2.6 Climatic Conditions

Tobacco is a tropical crop and therefore it is sensitive to low temperatures and frosts. It is cultivated in a wide range of climates. Nevertheless it requires 90 to 120 frost-free days for a proper development. In the seedbed stage it requires temperatures higher than 16 °C, whereas during the development of the crop in field, the ideal temperatures rank between 19 °C and 28 °C, says Burke, quoted by Comis (1996). Temperature has a great impact on the crop, in such a way that it influences the foliar area of the plant (also see Figure 6).

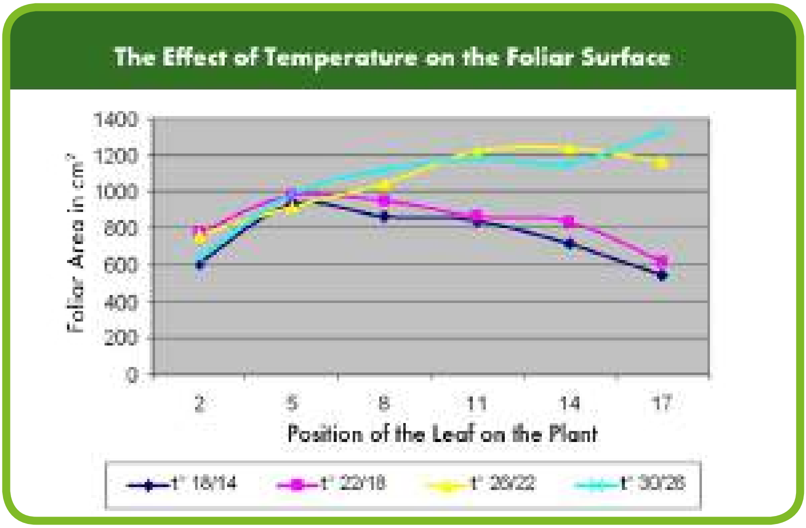


Figure 6. *The effect of temperature on the foliar surface.*
Source: Raper et al and Agron J., 1971.

More precisely, crops under a regime of higher temperatures (between 26 °C and 30 °C) have a greater foliar surface, compared to plants cultivated in lower temperatures (between 14 °C and 18 °C). This particularly applies to the superior part of the plants i.e. as from leaf n°8 upwards to the top of the plant. In the lower part of the plant (as from leaf n° 8 downwards), such differences do not appear and as such independent of the environmental thermal regime.

At the same time, higher temperatures generate more leaves, i.e. the number of leaves increases proportional to a temperature increase, as can be observed in Figure 7. It is possible to surpass 40 leaves per plant when the average day temperature is 34 °C and the average night temperature is 30 °C.

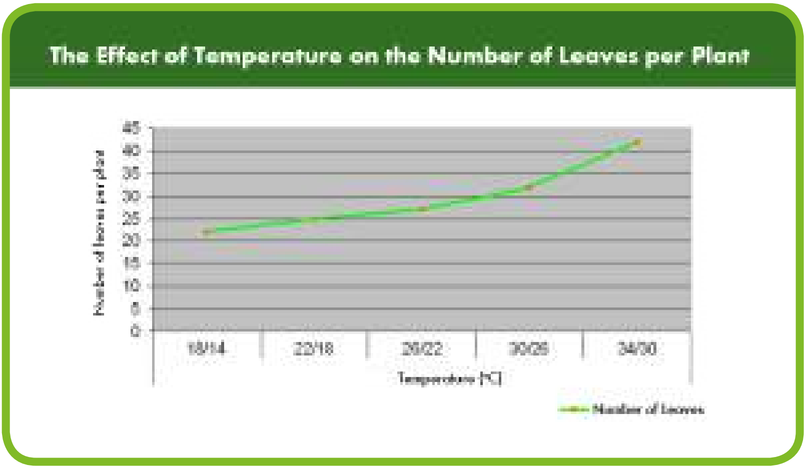


Figure 7. *The effect of temperature on the number of leaves per plant.*
Source: Raper et al and Agron J., 1971.

The effect of temperature on the specific weight of the leaf has also been studied and the results can be observed in Figure 8.

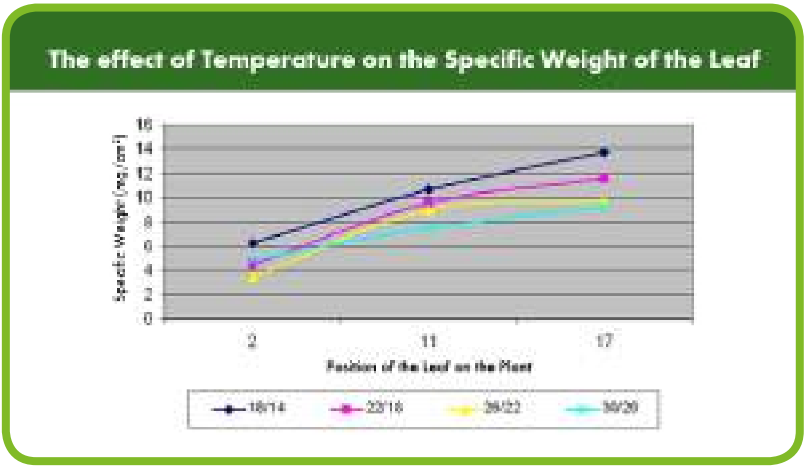


Figure 8. *The effect of temperature on the specific weight of the leaf.*
Source: Raper et al and Agron J., 1971.

In Figure 8 we can learn that plants cultivated at temperatures between 14 °C and 18 °C produce leaves with a higher specific weight than those cultivated at higher temperatures and as such independent of the position of the leaves on the plant. As the temperature regime increases, the specific weight of the leaves diminishes.

Tobacco is a neutral day crop, which is why it is not influenced by the length of day to develop its processes or phenological stages. Nevertheless tobacco requires clear days in order to optimize its production potential. It also needs a dry climate during harvesting, which facilitates the aromatic expression of the plant, as well as the drying process of the leaves.
Climate, aside from influencing the duration of the vegetative cycle, affects the quality of the product and the yield of the harvest (Martinez, 2005).

2.7 Irrigation

Tobacco is a plant with a great vegetative development and a short growth cycle and has a high demand for water as well as for nutriments. Irrigation is an important factor in the production of quality tobacco. Generally the plant is considered to be drought tolerant and it better tolerates water shortage than excess, because the root is very susceptible to the condition of saturated soils. Nevertheless, both phenomena i.e. lack or excess of water, are problematic to the crop. Lack of water generates yield decrease and little combustibility, while an excess generates a decrease of the protein nitrogen contents in the leaves, an increase of the potassium content and a decrease of calcium and magnesium levels.

Irrigation can modify physical and chemical properties of the leaf curing. It can increase the sugar content of tobacco leaf and can diminish the nicotine content. According to Jones G., 1996, a drought tends to cause an increase of the nicotine content and a better flavour in the leaf, whereas to the contrary, an excess of water generates a decrease of the nicotine content and a much thinner leaf with less flavour.

Irrigation leads to a bigger development of the roots as a result of more absorption of water and nutrients, which can lead to 15% more harvest. Bigger leaves are produced compared to a crop that only uses precipitation for its development. An adequate irrigation management in view of maximum harvest implies conditioning the soil at 50% of its field capacity in the first 60 centimetres of depth. Thus, the plant does not have great difficulties to extract the water and on the other hand is not flooded. The field capacity (also see Figure 9) is variable for each soil, but is approximately 30 kPa and can vary between 5 and 40 kPa. For optimal control i.e. to establish when the soil needs water, the use of tensiometers is recommended.

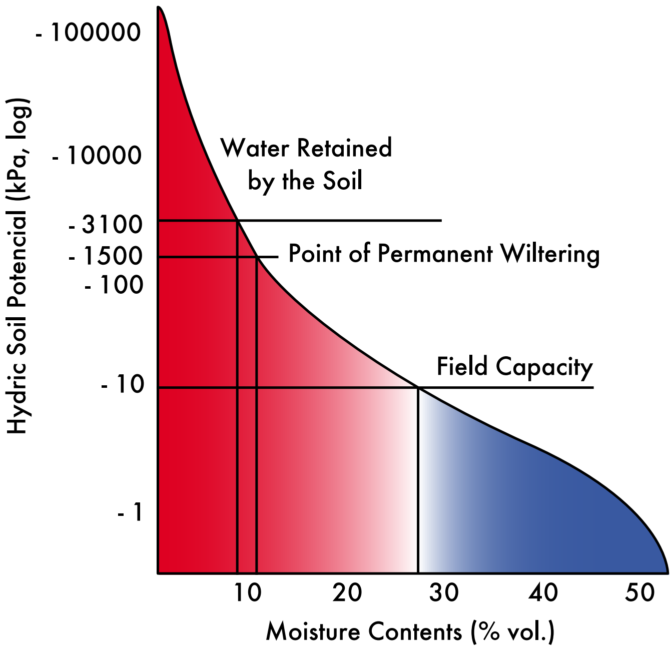


Figure 9. *Hydric soil potencial.*

Moore and Tyson, 1998, report that irrigating tobacco plants generates earlier flowering and a smaller secondary sprouting after cutting the floral inflorescence. The same authors point out that post-transplant, valid for the Georgia (USA) conditions, the irrigation of the plant can be split up in several stages. Early growth, i.e. from transplant to plants of 30 cm of height (2 to 4 weeks post-transplant), where the demand of water is increasing, but without reaching its maximum. Fast growth, i.e. from more than 30 cm of height (4 to 10 weeks post-transplant) until floral button where there is a maximum demand for water and where an adequate supply assures a good production. Finally the stage harvest, where irrigation is again reduced.

The first irrigation is preferably to be applied post-transplant to avoid compacting of the soil. In that case it is also recommended to apply medium duties of water (12,5 mm) in order to humidify the profile deeper under the roots. Afterwards it is recommended to continue with 15-20 mm per week; after which the water supplies are increased (5 to 6,5 mm per day) until the period of highest demand, which runs from the 6th week to the 10th week post-transplant (also see Figure 10). In that period and adequate hydric management is vital for a good production and good quality.

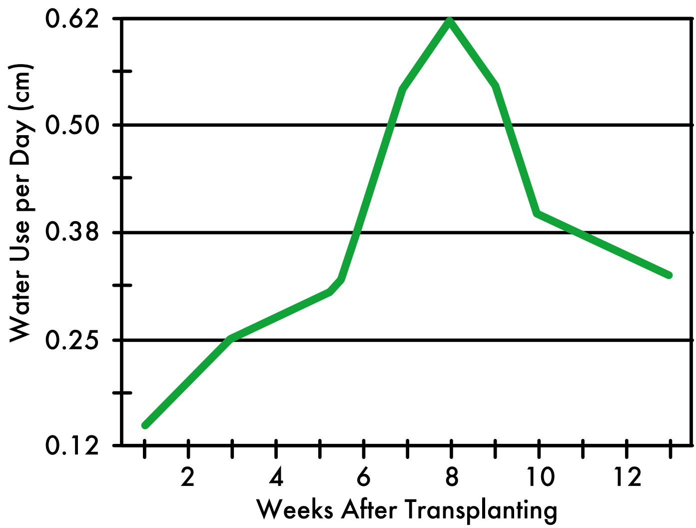


Figure 10. *Water management in tobacco.*
Source: Harrison and Whitty, 1971, quoted by Moore and Tyson 1998.

When the plant has reached its final size and during the period of harvest, it must receive a hydric supply, although in smaller amounts compared to the previous stages, as this contributes to producing a thicker leaf with more body. The entire crop can consume between 4.000 and 6.000 cubic metres of water per hectare, depending on the duration of the crop, the soil characteristics, the climatic conditions and the handling. One way to define when to water the crop is by using the evapotranspiration tray class A, whose correct way to install has been defined internationally.

The water to be applied to the crop corresponds to the evapotranspiration value of the crop (ETc) which is calculated by using the formula ETc = Kc x Kp x Eb, with Eb = tray evaporation (mm per day), Kc = a crop coefficient, and, Kp = a tray coefficient.

For the different tobacco stages, the following crop coefficients (Kc) are applied:
- 0,3 to 0,4 during the initial stage (first 10 days)
- 0,7 to 0,8 during the development stage (between 20 and 30 days)
- 1,0 to 1,2 half way the crop development (between 30 and 35 days)
- 0,75 to 0,85 at the end of the crop development (between 30 and 40 days)

The tray coefficient (Kp) is normally set between 0,6 and 0,8.

On the other hand, Maw, Standell and Mullinix, 1997, produce an evapotranspiration curve for tobacco (also see Figure 11), valid for the Georgia (USA) conditions, where the minimum temperature was 10 °C at the beginning of the season and reached 22 °C at the end of it. The maximum temperature was 26 °C at the beginning of the season and 35 °C at the end of it. The precipitation reached 371 mm during the 20 weeks following transplant.

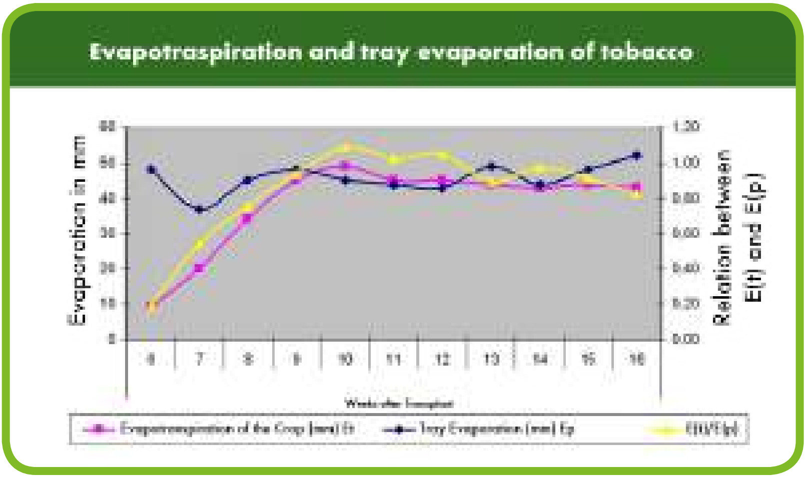


Figure 11. *Evapotranspiration and tray evaporation of tobacco.*
Source: Maw, Standell and Mullinix, 1997.

In this case, the authors directly indicate the evapotranspiration of the crop E(t), but also the tray evaporation E(p). When dividing E(t) by E(p) we can immediately obtain the product of Kc x Kp (the multiplication of both constants) which enables us to directly calculate the water volume to be applied, i.e. only by using the tray evaporation and the constant that features in Table 5.

Table 5. *The constant (Kc X Kp) for tobacco in Georgia*

Week	E (t)/E(p)=Kc*kp
6	0,19
7	0,54
8	0,76
9	0,94
10	1,09
11	1,02
12	1,05
13	0,90
14	0,98
15	0,92
16	0,83

Source: Proper table based upon Maw, Standell and Mullinix, 1997

In this case we must take into account that the climatic conditions are different and that therefore these values can vary, but nevertheless they can be an excellent reference guide to work with.

2.8 Morphology of the Plant

The main root of the tobacco plant quickly branches out to form a radicular system that is densely fasciculated, as is shown in Figure 12. Under appropriate crop conditions it can reach up to 1,5 metres of depth and radius (lateral growth).

Figure 12. *Tobacco has a densely fasciculated radicular system.*

The development of the radicular system and its morphology are strongly influenced by the soil properties and the transplant techniques; and maybe for this reason between 90 and 100% of the roots in terms of weight are found in the first 30 centimetres of the soil. The weight of the roots is determined by the characteristics of the variety, the soil fertility and the cultivation practices, among which fertilization, irrigation, thinning, and, the shape and the timing of hilling are very important. The stem has a poliedric section, which is frequently defined as a result of the employed phytotechnics. Its mechanical resistance is not high and frequently does not resist the volume of the leaves developed by the plant. Under normal crop conditions, the plant reaches a height of 1 up to 2 metres with a leaf production between 15 and 25 leaves per plant (Martinez, 2005).

The tobacco plant has the property to produce endogenous axillary buds, which can turn into perfect flowers when developed. The inflorescence of tobacco is a terminal panicle. The corolla grows to a great distance of the calyx, which is very characteristic; it is whithout petals and shaped like an elongated cylinder, divided in five lobes at its distal end. The colour of the petals of the Nicotiana tabacum species is pink, less frequent pale white or pale yellow. The five stamens are attached to the corolla tube and bear oval-shaped anthers. The stigma is at the end of a long style that rises to just about the mouth of the corolla. The length of stamens is variable, but they are generally above the stigma. The tobacco leaves are predominantly oval-shaped and are borne directly on the main stem. The leaf surface has a matte appearance with abundant pilosity. Its colour varies from light green in the "Virginia" variety to intense green in the "Dark Air-Cured" varieties. The leaf shape, the leaf angle to the stem, the kind of attachment to the stem (petiolated or sessile), the leaf symmetry, the leaf dimensions and the relation between length and width are the most important leaf particularities that characterize and differentiate the different tobacco types, and, often also the varieties within a same type.

Tobacco is a dicotyledonous and vivacious plant that sprouts again after pruning. The leaves are lance-shaped, alternating and petiolated, as can be observed in Figure 13. The flowers are hermaphrodite, frequently regular. The roots are penetrating, although the majority of the fine roots are encountered in the most fertile topsoil.

***Figure 13**. Aereal part of Tobacco plant.*

Because of its dimensions, the density of the commercially exploited plantation varies from 10.000 up to 25.000 plants per hectare; depending on the latitude, the type of tobacco, and the purpose of the production. For example, in Flue-Cured around 16.000 plants per hectare are considered to be standard. Smaller distances between plantation rows (greater density) generate smaller, much thinner tobacco leaves with less nicotine contents, while smaller plantation densities generate the opposite effect (Jones G., 1996).

The height and the position of the leaves on the plant are also very important, because a difference in height or position generates a different yield. As can be observed in Figure 14, almost 80% of the production is generated from the area between leaf n° 5 and leaf n° 18.

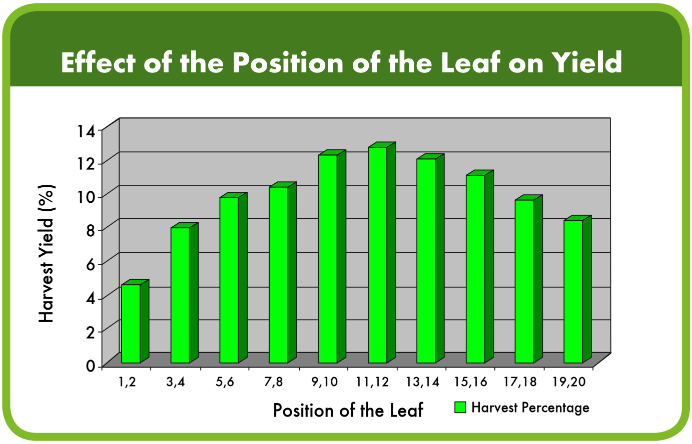


Figure 14. *Effect of the leaf position on yield.*
Source: Brown and Terril, 1972.

2.9 Phenology of the Plant

2.9.1 Germination and Preparation of the Seedling

The growth and development process of the tobacco plant starts with the germination of the seeds. These seeds are very small; the total of 10.000 seeds only weighing 1 gram (Agenda del Salitre, 2001). For a germination of over 90% it is necessary to use seed pellets of high quality, with a high percentage of guaranteed germination (Smith, Peedin, Yelverton and Saccer, 1988).

The same authors indicate that for a good germination the seed requires humidity and a uniform temperature between 21 °C and 24 °C during a period between 7 and 10 days. As soon as most of the seeds have emerged, the temperature can vary between 13 °C and 15 °C during the night and between 27 °C and 29 °C during the day.

The process of germination and the first growth stage until having a seedling which is ready to be transplanted in the field varies between 6 and 8 weeks, as can be observed in Figure 15.

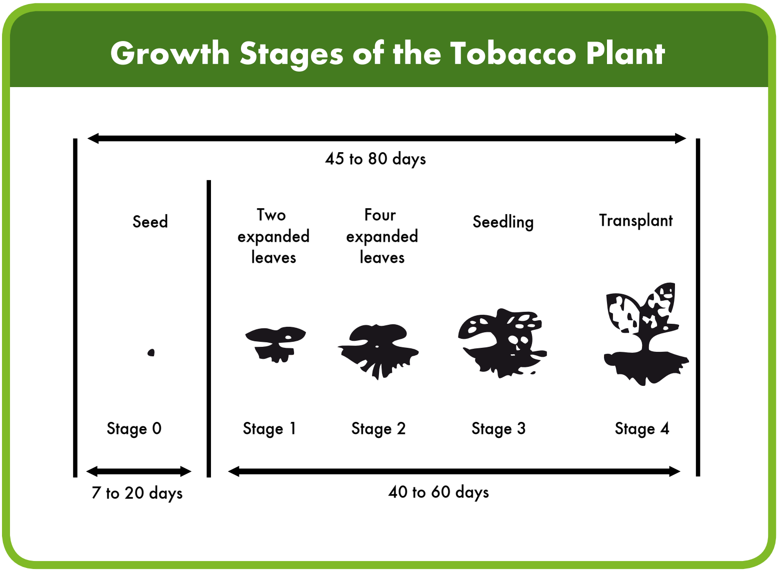


Figure 15. *Growth stages of the seedling.*
Source: North Carolina State University.

Advanced systems have been developed for the development of seedlings, such as for example the use of greenhouses, the floating system, or the system of aerial trays (also see Figure 16).

Figure 16. *Systems for seedling development.*

Seedlings can also be produced in seed beds, a low tech system with acceptable results. In this case it is recommended to have around 200 square metres of bed per hectare to be cultivated, with a density of 400 plants per square metre in order to assure a transplant in a short period time with plants of adequate size. In any case a sufficient amount of plants should be foreseen in order to counter possible germination problems.

At this stage, temperature, humidity and nutrition are fundamental. It is important to have a substrate that is able to drain flooding because during this period irrigations must be frequent to avoid plant dehydration. This substrate must be fully moisturized prior to planting.

Tobacco plant is sensitive to salt excess. It is therefore recommended to know the irrigation water characteristics in order to avoid the presence of bicarbonates, chlorides or sodium excess which could burn the foliage of the growing seedling.

During this stage, the seedling develops as much its aerial parts as its roots. The technical handling must look to intensify the development of the radicular system, to make sure it is able to support transplant stress and that the plant can rapidly root and develop in the field. According to studies made by Caruso, Pearce and Bush in the year 2000, a higher growth of the radicular system in seedlings, developed in greenhouses, took place between 24 and 40 days after emergence, at temperatures between 21 °C and 24 °C.

Based upon recent investigations, the nutrition as from the 2^{nd} week post-germination, is suggested to be with soluble elements in a relation $N:P_2O_5:K_2O$ (3:1:3) with between 100 and 150 ppm of Nitrogen 4 weeks later, the same relation is to be applied but with 100 ppm of Nitrogen.

The foliage of the plant is pruned during the first weeks of growth, as shown in Figure 17. According to Smith, Peedin, Yelverton and Saccer, 1988, this is recommended to increase the resistance of the plants to the transplant and to obtain uniformity in the length and diameter of the stem; the latter is especially important in case of mechanized transplants.

Figure 17. *Example about the prune on the foliage of the plants.*
Source: SQM's 10th Tobacco Seminar

The same authors indicate that pruning can also be applied to retard the transplant if the land is not in favourable conditions. And that to maximize the number of usable plants, 3 to 5 prunings are to be applied; despite the fact that there are producers who prune a lot more. Nevertheless, one should be careful not prune too severely, because investigations made in Virginia by David Reed, demonstrate that severe prunings (to 1,25 cm above the growth bud), diminish the length of the stem but do not increase its diameter, which can lead to less growth in the field and a delay in flowering.

At present it is recommended to initiate the pruning with intervals of 3 to 5 days when the seedlings are between 5,0 to 7,5 cm above the tray and to cut on 3,5 cm above the tray.

2.9.2 Transplant and Growth in the Field

Once the field and the seedlings are ready, the seedlings must be taken to the field (also see Figure 18).

Figure 18. *Different system of the seedlings.*
Source: Willani S. SQM's 10th Tobacco Seminar

A state of post-transplant stress may occur and can last up to 15 days depending upon the climatic conditions and the seedling. Once this process lies behind, the plant rapidly begins to develop its structure, as is shown in Figure 19.

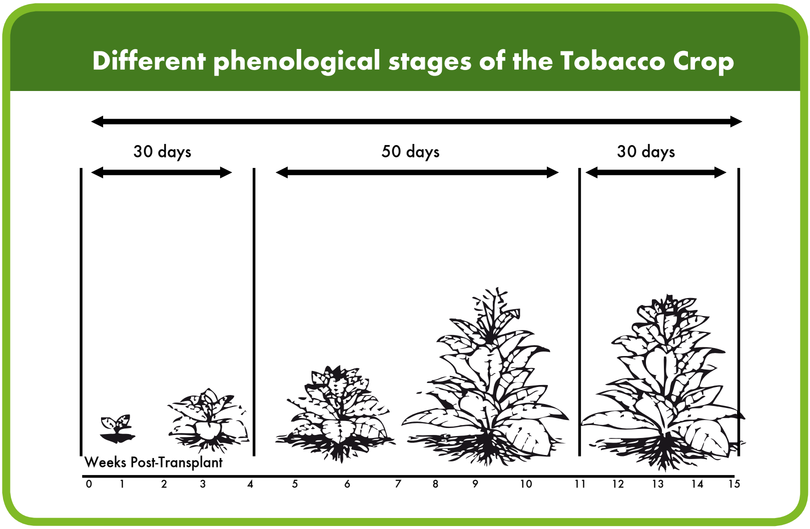
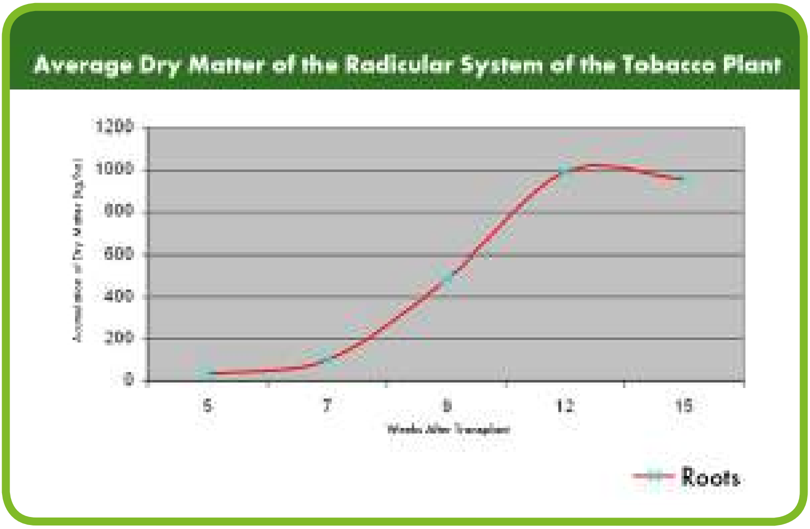


Figure 19. *Different phenological stages of the tobacco crop.*

The root grows at least the 3 first months of the growth cycle (also see Figure 20), and during which, in 5 weeks, i.e. from the 7th up to the 12th week, it almost quintuples its dry matter; which implies that there is a very high rate of growth during that period.

Figure 20. *Average dry matter of the radicular system of the tobacco plant.*



Source: Test by Anton Scholtz, South African Golden Leaf, South Africa.

The former is confirmed by tests performed in Brazil, where the roots of produced plants of different shapes, doubled their fresh weight between the 2nd and 4th month post-transplant (Sergio Willani, Tobacco Seminar - 2005). Also, tests performed in Georgia, by the authors Maw W., Stansell J. and Mullinix G, 1997, indicate that the principal time of roots growth happens before week 11 post-transplant (i.e. 2,5 months post-transplant).

The amount of developed roots determinates the growth of the next stage which is the aerial growth (Collins, 2001).

After the start of the growth of the roots, and given a certain time gap, the rapid development of the foliage begins, as from the 2nd month of post-transplant. This is also confirmed by a study made in Georgia, where the authors indicate that after the principal growth of the roots took place, the growth of the foliage was triggered, which emphasizes the necessity of roots growth to take place before aerial growth.
This aerial growth is intensified during this stage, reaching its biggest expression

between the 5th and the 12th week post-transplant (also see Figure 21). During this period, 86% of the aerial dry matter is formed, according to the information found in flue-cured tobacco in South Africa. It is again intensified after the emergence and pruning of the floral bud which appears in the 9th week, and during which an increase in the accumulation of dry matter in the leaves can clearly be observed. Only during this period (between 9th and 12th week) 40% of the aerial accumulation is surpassed.

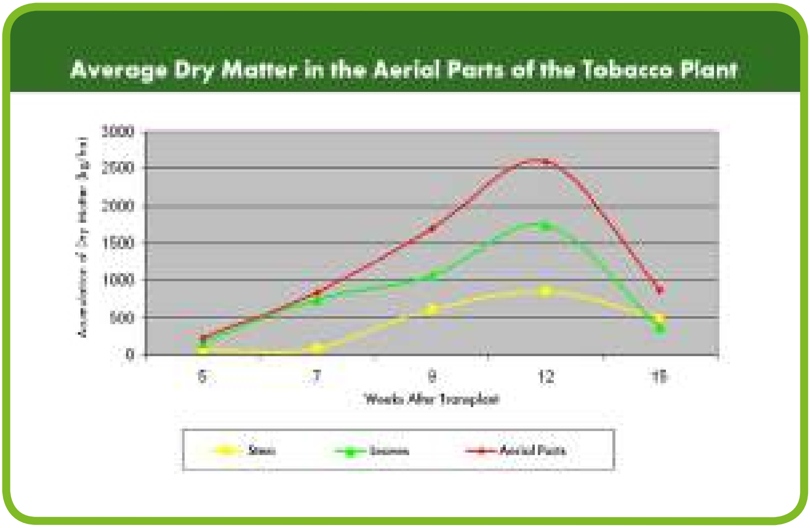


Figure 21. *Average dry matter in the aerial parts of the tobacco plant.*
Source: Test by Anton Scholtz, South African Golden Leaf, South Africa.

According to Collins, 2001, and with reference to Virginia tobacco, the topping (cutting of the floral button) and the control of the shoot must also begin when flowering initiates (also see Figure 22). And harvesting should start 2 weeks later.

Figure 22. *State of flower on tobacco.*

The removal of the floral button permits a greater growth of the rest of plant and consequently all the water and the nutrients needed for its development are distributed, as much in the root as in the foliage. At the same time, the removal of the appearing shoots (secondary growth), allows for a greater expansion of the growing leaf; and leads to stronger foliage. Upon completion of these manipulations, the plant goes through an important phase of aerial growth both in height and size and in terms of leaf extension.

Normally the Virginia tobacco plant has a growth cycle of around 90 days; the Burley tobacco plant one of around 120 days; after which harvesting can start.

Harvesting can last 5 to 7 weeks depending on the state of the crop and the climatic conditions. Under normal conditions, according to Hawks, 1980, tobacco leaves mature from the basal part to the apical part of the plant at a rate of 2 to 4 leaves per week, which means the harvest rate is of 2 to 4 leaves per plant per week. Or in other words, harvest extremities (depending on the density of plants and the number of mature leaves per week) can reach between 20.000 and 100.000 leaves per hectare per week. According to the same author, tobacco harvesting is a very labour intensive process, which is why it should be duly prepared in order to avoid delays. A tobacco leaf is ready to be harvested from the moment it has reached its maximum size and weight, and, when it has stared to feel "hunger for nitrogen", i.e. when it has begun to show signs of chlorosis, as is shown in Figure 23.

Figure 23. *Maturing stages of the leaves to be harvested.*

2.10 Quality Parameters

The quality of tobacco, which is a chemical, physical and organoleptic properties that transform during burning and which provoke a certain set of pleasant sensations, according to the smoker, is the result of the agricultural production of raw material (tobacco leaf); its transformation during the drying, curing and fermentation processes, and of the industrial technological process. It has often been considered that the tobacco production process, from the seeding to the industry (above all when they are destined for the manufacturing of cigarettes), is closer to art than to technology; although science and contemporary techniques can make substantial improvements to the traditional technologies.

Almost all agricultural work influences the quality of tobacco, starting from the selection of the ecosystem (climate, soil, landscape) in which the leaf will be produced, the selection of the type of tobacco and varieties, the fertilization applications, the plantation infrastructure, the irrigation applications, and, phytotechnical practices (technical handlings).

2.10.1 Objective Tobacco Quality Indicators

The indicators that characterize the quality of the different types of tobacco are diverse, but generally they can be grouped in 3 criteria groups (Tso, 1990):

Organoleptic criteria

- Size of the leaves
- Colour
- Uniformity
- Presence of foreign material
- Foliar damages
- Texture
- Body
- Maturity
- Scent
- Flavour
- Foliar level

Physical criteria

- Filling factor
- Mechanical resistance
- Hygroscopicity
- Yield in strand
- Combustibility

Chemical criteria

- Sugar content
- Nicotine
- Petroleum ether extract
- Alkalinity of the watery extract of the ash
- Total nitrogen
- Protein nitrogen
- Starch
- Non volatile acids
- Total volatile bases

The quality of the wrapper

In dark tobaccos, quality evaluation depends on the final industrial purpose of the product. Leaves for cigarette production have a different evaluation set, compared to leaves used for wrappers or for filling.

The production of wrappers to roll cigars is probably the most specialized of all productions in the tobacco agro industry. The leaf destined hereto is valued according to:

- Size
- Shape
- Colour
- Texture
- Body
- Combustibility
- Elasticity
- Fat
- Brightness
- Absence of damages and spots in the cloth

The quality of the filling

The leaves destined for fillings or fillers to roll cigars are evaluated by:

- Size
- Colour
- Combustibility
- Texture
- Body
- Strength
- Nicotine Content

There are many variables that influence the quality of tobacco leaves. And to those mentioned before we must add that each part of the cultivated plant produces leaves of different qualities, as is shown in Figure 24.

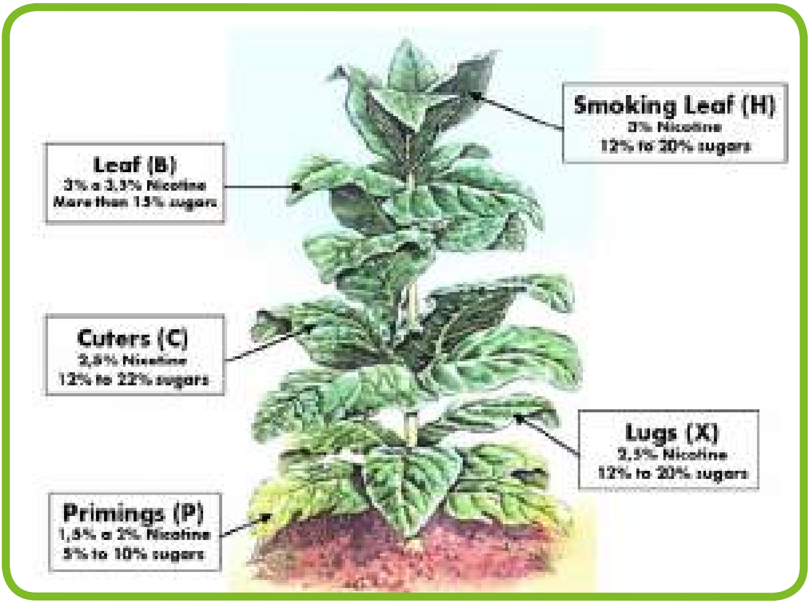


Figure 24. *Quality of the tobacco lieves.*

The group classification shows that leaves taken from the lowest part of the plant are called "Primings" (P) which contain 1,5% to 2% of nicotine and between 5% and 10% of sugars. The shape and the tip of these leaves are rounded and have a clear and pale colour. They mature prematurely as a lack of nutrients.

One stage higher we encounter the leaves called "Lugs" (X) which contain 2,5% of nicotine and 12% to 20% of sugars. These are leaves with a fine to medium body, somewhat flattened tips and more colourful than "Primings".

Above the "Lugs" we have the "Cuters" (C) with a 2,5% nicotine content and containing 12% up to 22% of sugars. These leaves grow right in the middle of the plant or just underneath. They are more than 40 centimetres long, have round tips and curly edges. Their body is fine to medium and they have a smooth to aromatic flavour.

Again one stage higher, we encounter the leaves called "Leaf" (B) which contain 3% to 3,5% nicotine and 15% of sugars. They develop in the higher middle part of the plant and are narrower compared to "Cuters". These leaves have pointed tips, present more colour, have more body and are rich in aromas and oil.

Finally, at the superior part of the plant, we can observe the "Smoking Leaf" (H) with 3% nicotine content and between 12% and 20% of sugars. These leaves have the highest combustibility due to their open structure and they have the highest degree of maturity which gives them their characteristic aroma. They leaves are very difficult to obtain.

It is important to mention that the latter classification can vary from one farm to another, i.e. the nicotine content of a B-leaf at one farm can be lower than the nicotine content of an X-leaf on another farm, which cannot occur when comparing leaves at one and the same farm.

On the other hand, Hawks Jr., 1980, indicates that in Flue-Cured tobacco, the quality as much as the amount of aroma can depend on the variety of the cultivated tobacco. And that the leaves of the inferior part of the stem have less aroma and flavour that the leaves of the superior part.

The same author indicates that the filling power of a tobacco is the expanding property once inside a cigarette. And that, in general, tobacco leaves from the inferior part of the stem have more filling power compared to leaves taken from the superior part of the tobacco plant, which in turn have more filling power compared to leaves with a central position on the stem.

Factors such as leaf size, leaf shape, leaf integrity, colour tonality and intensity, elasticity and the smoothness of the leaf when being touched, inform us about crop methods, curing, and the climatologic conditions under which tobacco has been produced and from which part of the stem the leaves were picked.

An important part of the quality of tobacco is field determined in function of the conditions of the crop, the soil and the climate. Nevertheless, after harvesting the quality of tobacco can vary depending upon the curing process.

2.10.2 Curing

According to Hawks, 1980, the objective of curing is twofold. On the one hand, to create the conditions of temperature and humidity that help to take place the desired chemical and biological changes in the leaf. On the other, to obtain that the leaf can maintain its quality potential, by means of an adequate drying.

Curing in Virginia tobacco (Flue-Curing).

The first condition to obtain a uniform curing is to start with uniformly matured tobacco. If maturation continues during harvesting, the quality may diminish, whereas if maturation is delayed the production may diminish. At the start of the curing process the leaf has between 80% and 90% of moisture; the remaining percentages being dry matter of which 25% are sugars and 75% are pigments, biochemical components, minerals etc.

With a proper curing, it is only possible to maintain the quality obtained in the field, not to improve it, whereas an inadequate curing may reduce the field quality. The curing of Virginia tobacco consists of three phases:

1. Yellowing
2. Leaf drying stage
3. Stem drying stage

During the "yellowing" stage the leaves become yellow, as they are losing moisture and as they are going through diverse biological processes. Yellowing is a result of the destruction of the chlorophyll in the leaf. For an adequate yellowing, it is necessary that oxygen can penetrate the leaf, which happens through stomas. This oxygen penetration accelerates the transformation of starch to simple sugars (glucose, fructose and saccharose).

A small part of these sugars is consumed as a result of the respiratory processes of the leaf, through which caloric energy is generated and which has an unwanted side effect, namely a warming up of the non cured tobacco; which is why good ventilation is indispensable. The processes of chlorophyll disappearance and of simple sugar formation happen simultaneously, which is why the change of colour can be a measurement of the formation of these sugars. At this stage the leaf loses very little moisture and the curing temperature does not exceed 35 °C. Curing lasts around 36 hours, as shown in Figure 25.

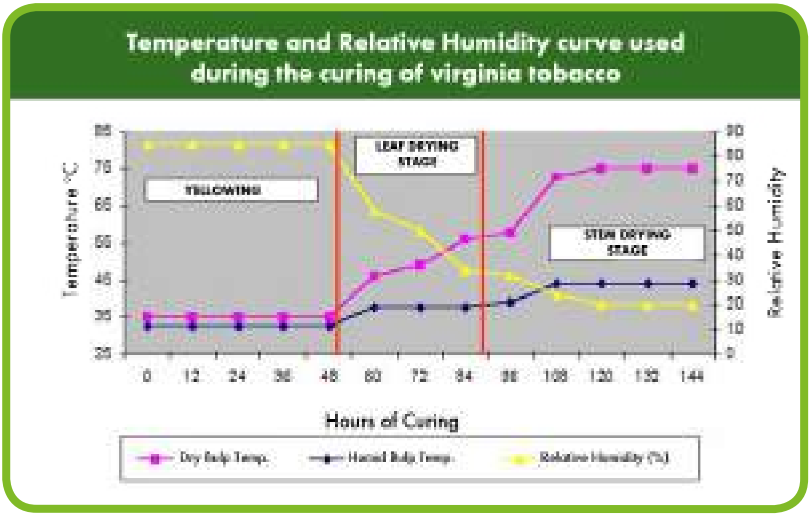


Figure 25. *Temperature curve of relative humidity used during the curing of Virginia tobacco.*

Conversion table:
°F = 1,8 (°C) + 32
0 °C equals 32 °F
100 °C equals 212 °F

During the "second" phase, which approximately lasts between 44 and 48 hours, the moisture of the leaf lowers considerably to some 40%. The drying temperature has the biggest impact between 35 °C and 54 °C. As soon as the leaf has lost between 40% and 50% of its moisture, it is possible to increase the curing temperature; not earlier, because then there is the risk of leaf scalding with leaves turning completely brown in a matter of a few minutes.

The "steam drying stage" process takes place at a temperature not exceeding 75 °C; though it is recommended not to exceed 71°C. At this stage, where the leaf is completely dry and the biochemical changes have already almost stopped, the aim is to extract the moisture from the vein without damaging the lamina of the leaf. The process lasts about 48 hours and is the most difficult part in terms of moisture extraction, which is why one works with a thermic differential of little more than 40 °C between the dry bulb thermometer and the humid bulb thermometer, through which a moisture level reduction from 40% to 20% is achieved.

During the curing process there are 3 determinative factors that must be carefully managed: the air temperature, the ambient humidity, and, the air circulation (as shown in Figure 26).

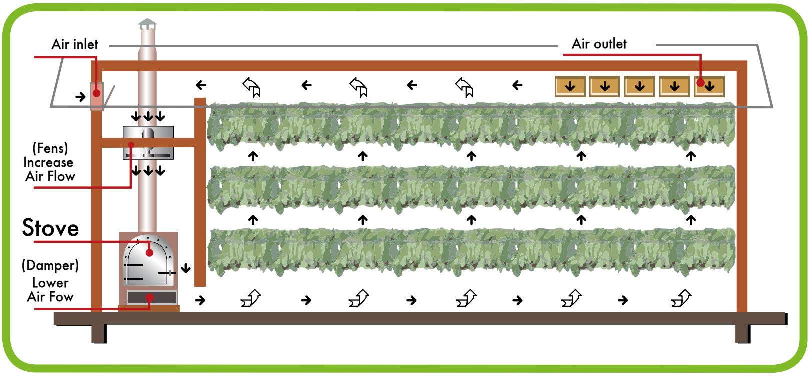


Figure 26. *During curing, the air temperature, the ambient humidity, and, the air circulation must be carefully managed.*
Source: SQM IX Tobacco Seminary.

At present, appropriate instruments such as the psychrometer ensure an accurate measuring of these variables. A psychrometer consists of a battery with two thermometers: one with a dry bulb and another one with a humid bulb which is connected to a water column (also see Figure 27). When the water of the column evaporates, it cools the bulb and thus the thermometer indicates a lower temperature than that of the dry bulb. This is of extreme importance because the difference between both thermometers indicates the drying potential; i.e. the higher the difference between both, the higher will be the drying potential.

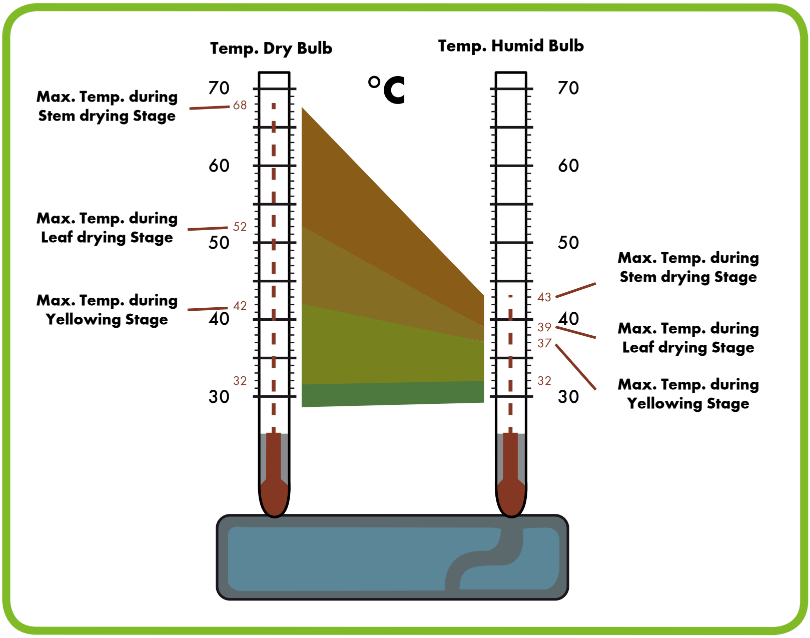


Figure 27. *Psychrometer.*
Source: SQM IX Tobacco Seminary.

Moreover, the humid bulb thermometer also serves to establish the temperature of the tobacco leaves, because in this case the water evaporation lowers the temperature in the humid bulb thermometer to the same extent as in the leaf. As a guideline we can mention here that during the yellowing process, the dry bulb thermometer reading must not exceed 38 °C; while the humid bulb thermometer reading should be 1 or 2 degrees lower than the temperature reading of the dry one.

During the drying of the leaf, the temperature is increased at a rate of 1 °C per hour. Attention should be paid to the fact that the dry bulb thermometer reading should not exceed 54 °C and that the humid bulb thermometer reading should stay around 40 °C.

During the "stem drying" stage, the temperature is also increased at a rate of 1 °C per hour but here the dry bulb thermometer reading should not exceed 71 °C and the humid bulb thermometer reading should stay 43 °C. It should be noted that the above mentioned values are only referential and must be reviewed according to the conditions of each place.

Curing in Dark Tobacco.

Dark tobacco is per definition a tobacco which is air-cured and this curing process differs from tobaccos of which the entire plant is dried, and of tobaccos which are dried leaf per leaf. During the first 8 to 15 days of the first stage of the curing process, the leaf rapidly loses moisture to such an extent that the initial moisture percentage of around 85%-90% is reduced to 20% - 25%. During this period the metabolic destruction, which is a rapid process, of the green pigments also begins; as well as the destruction of the yellow pigments, which happens much slower.

During the second phase of the curing, the fixation of the carmelite colours takes place. These colours are very characteristic for dark tobacco and are the result of oxidation of the polyphenols, mainly chlorogenic acid. During the curing, important chemical transformations in the dark tobacco leaf also take place, from which the tobacco derives its characteristic aroma and flavour. A drastic reduction of the content of proteins and carbohydrates, and, a slighter reduction of the content of alkaloids are also part of this process.

The final result of the curing also includes a loss of dry matter of the tobacco leaf. The curing of dark tobacco is performed in "curing barns" in which temperature and humidity are controlled by means of circulation of air which is drawn in from the outside. Over the last years, facilities have been introduced for curing controlled the cape tobaccos, in which, the variations of temperature and humidity are better adjusted to processing the wrapper. In these facilities, the curing process of dark tobacco is approximately 50% faster than under natural conditions. Moreover, the yield of leaves suitable as wrapper is considerably superior, which justifies the investment of the facilities and the high energy costs they entail.

2.10.3 Nitrosamines

Nitrosamines are chemical compounds which are found worldwide in innumerable products of which many are foodstuffs. These compounds constitute a risk for the human health because they are potentially carcinogenic, although their use is internationally permitted. In foodstuffs the problem is controlled by using these compounds in very small amounts; which reduces the risk without eliminating it.

If tobacco curing is not performed correctly, nitrosamines can be produced. Hence the importance of an adequate curing process in order not to produce nitrosamines during the tobacco production, so that their concentration lowers every time.

At present, we know that nitrosamines are synthesized starting from the nitrate which is present in the leaves at the moment of harvesting (also see Figure 28). However, this does not mean that eliminating nitric sources from the plant's nutrition reduces this problem; to the contrary, they should be increased, due to the fact that the ammonical sources are transformed in the soil into nitrate and are afterwards absorbed by the plant. But this absorption can be delayed, by which high nitrate levels in the leaf are obtained much earlier in the season.

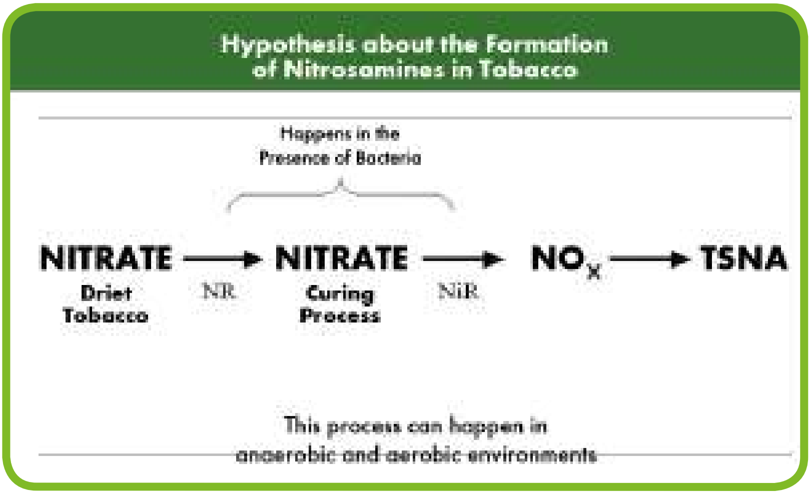


Figure 28. *Hypothesis about the formation of nitrosamines in tobacco.*

On the other hand, when applying nitric sources directly, the plant absorbs them a lot faster, and, has more time to transform them into organic compounds (proteins), which is why at the moment of harvesting the nitrate levels in the leaves can be much lower, due to the fact that the plant has absorbed the nitrogen earlier in the season.

In fact, the nutrition strategy of the companies focuses an early application of nitrogen to avoid the formation of these nitrosamines, among other reasons. Nitrosamines can also be produced when the product comes in direct contact with fire; which in fact happens during many foods processes, and which is why the indirect use of heat is recommended in the curing process of the leaf.

Nitrosamines also appear in tobacco as a result of the transformation of nicotine (alkaloid), as is shown in Figure 29. That is to say, from the nicotine which is present in the tobacco leaf the secondary alkaloids are formed and from them the nitrosamines are formed (NNK, NNN, NAB and NAT). It is also known that the veins of the leaves concentrate a higher amount of total nitrosamines than the lamina of the tobacco leaf. And that rain seasons or periods of high humidity during curing are important precursors of the formation of nitrosamines.

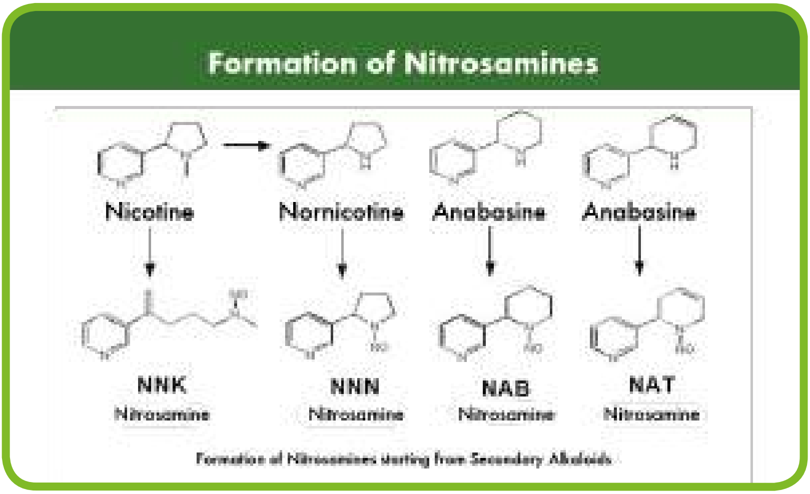


Figure 29. *Formation of nitrosamines starting from secondary alkaloids.*

2.11 Main Diseases

2.11.1 Fungal Diseases of the Root.

One of the diseases produced by phytopathogenic fungi of the soil is well-known in the Spanish speaking countries as "Pata Prieta" or "Pié Negro" (Black Shank). This disease, produced by the fungus Parasitic **Phythophtora var Nicotianae** primarily affects the roots and the basal parts of the stem, but under favourable environmental conditions and a strong inoculum´s pressure, all the parts of the plant can be affected. The symptoms vary with the age of the plantation: in young seedlings which are particularly susceptible, an overall blight appears in the roots, and, in the basal parts of the stem dark brown to black lesions can be observed (hence the name of the disease) which shall destroy the vascular system of the plant. Under favourable conditions, the disease spreads rapidly upwards the stem and gets to reach the superior leaves. The typical foliar blight affects all the leaves and progresses during the day, peaking around noon, though during the initial stages a recovery of the foliar swelling during the night has been observed. When the affectation progresses the leaves start turning yellow and hang withered along the stem. In its final stage the blackening reaches a height of 30 cm or more on the stem, above the plant neck.

Severe Black Shank affectations only occur when the soil temperature exceeds 20 °C; with the fastest affectation outbreaks to occur at temperatures between 28 °C and 30 °C. High humidity levels of the soil are also required for the development of the disease. Soil properties such as pH level, and, calcium, magnesium and aluminium contents, also affect the spreading of this fungal disease, which is extremely aggressive, as one propagula per gram of soil is enough to trigger an epidemic outbreak.

To control Black Shank in greenhouses and in open field, wide spectrum fungicides and disinfectants are systematically used, but the best results are obtained by integrated disease control systems, which include the use of resistant varieties, the rotation of crops to reduce the inoculum´s pressure, and other measures.

Diseases caused by **Pythium spp.** include the loss of plants in the greenhouses, stem-knot and root-knot in young plants and necrosis of the active roots in plants of any age. The losses in the greenhouses due to this disease can be severe and integrated control measures are imperative. The application of fungicides can be economic in accordance with the recommendations of the local authorities.

Black root-knot, caused by **Basicola Thielaviopsis** is a flagellum that occurs in many of the most important tobacco regions in the world. The disease was reported at the end of the 19th century in the United States and Italy. This disease is characterized by black rot of the roots, with discreet to severe lesions all over the root. When the affectations are light or in an initial phase, no symptoms are observed in the aerial part of the plant. As the disease progresses, the plants grow unevenly, and the most affected show more wilting during the day. The affectation of complete plantations is not characteristic for this disease.

To control black root-knot, integrated disease control systems, which include the use of resistant varieties, the rotation of crops, and the application of industrial pesticides are recommended. In areas where this disease is endemic the over - liming of acid soils must be avoided, since with superior pH values to 6 the stimulating effect on the pathogen overcomes any positive growth and development effect on tabacco.

In almost all tobacco regions, and especially in greenhouses, the effects of fungi presence are frequently observed; caused by the fungi **Rhizoctonia Solani** and other species of this genus and by several members of the Fusarium genus. In both cases theses diseases predominantly affect greenhouses, but quarantine measures, rotation of crops, etc. can keep them under control.

2.11.2 Fungal Diseases of the Aerial Parts

In this category, the most devastating disease is Blue Mould of tobacco, caused by the fungus **Tabacina Peronospora.** This disease can appear with epiphytic characteristics and can destroy, within matters of hours, an entire plantation in which the farmer has invested many efforts and resources. When appearing with epiphytic characteristics, Blue Mould can destroy complete harvests over huge territories. For instance, during the 1979 epidemic in Cuba more than 90% of the harvest of that year was lost. Similar situations have occurred in other countries of the region and throughout the entire world.

The symptoms of this disease vary with the age of the plant. In young seedlings we can observe spots on the dying seedlings with erected leaves. In bigger seedlings the disease manifests itself through circular yellow spots on the leaves, and in many cases we can also observe the presence of the fungus with a greyish to bluish colour from which it derives its name. In bigger plants in the field we can observe yellowish spots that grow together to develop a necrosis which first deforms the leaf and then disintegrates it. This affectation can become systematic and can destroy the plant partially or entirely.

The causal agent of this disease can live throughout the year and can travel considerable distances by air, which creates different disease dissemination patterns. Humid and fresh climates with cloudy skies favour the spreading of this disease. To control Blue Mould, integrated disease control systems are required, since the fungus is able to mutate and to become resistant to commonly used pesticides and to surpass the immunological barriers of the resistant varieties. In any case it is indispensable to follow the recommendations of the local authorities, which surely follow a policy of national coverage, since the fungus crosses the borders of many countries and requires a continental approach.

Mildiu or White Mould of tobacco is caused by **Erisiphe Chicoracearum** and is a disease that only occurs in some areas and that rarely affects dark tobacco, but which has devastating consequences. Its most characteristic appearance occurs when the leaves have finished their expansion upon which a greyish dust layer appears on both sides of the leaves and on the stems. Further development causes the appearance of spots that quickly grow on the inferior part of the leaf and brown dots on the superior side of the leaf. The affected leaves lose their body and are no longer suited for industrial use, especially not for wrapping.

Brown Spot, caused by **Alternaria Alternata** is the most characteristic among foliar diseases of tobacco. This disease first affects the inferior leaves of the plant, but under favourable conditions the disease moves upwards along the stem to reach the youngest leaves.

Its particular symptom is the appearance of small brown spots on the leaf surface, which under favourable conditions multiply and grow in size. A warm and humid climate with dense fog favours the development of this disease. Brown Spot frequently appears surrounded by a yellow halo, caused by the dissemination of the fungal toxins in the surrounding tissue.

The use of resistant varieties, as part of an integrated disease control programme, seems to be the key to fight this disease.

Another characteristic tobacco disease is Eye Spot which is caused by **Cercospora Nicotianae.** It appears in greenhouses as well as in open field and shows circular brownish or greyish lesions. During many years the most seasoned cigar smokers have been checking the layer looking for the presence of the characteristic cercosporosis spot, as an indication for the tobacco to have been produced under natural conditions and without pesticides. At present there are programmes for the chemical control of this disease, but the use of pathogen-free seeds is fundamental for its control in the plantations.

2.11.3 Bacterial Diseases

Wild Fire is the main bacterial disease affecting tobacco. Its causal agent is **Pseudomonas Tabaci** and the symptoms are spots with angular edges on the foliar surfaces. At first they are watery, then necrotic, then turning brown or black, until the tissues dry out. The individual spots are small, but they can overlap and create big lesions. The presence of a chlorotic halo around the lesions is typical. At the final stages of the disease the leaves have a destroyed appearance and have completely lost their commercial value. To control Wild Fire, the integrated application of quarantine practices, the use of resistant varieties and chemical control measures are necessary.

2.11.4 Viral Diseases.

Tobacco is affected by numerous viruses, among which more than 20 affect tobacco under natural conditions and among which more than 100 can affect tobacco under experimental conditions. Among these viruses only a few have economic importance for tobacco and there are important differences between localities. Nevertheless it is difficult to find trustworthy estimations of the economic losses caused by these diseases. The most frequent estimations vary between 1% and 10% of the totally predicted harvest.

In Central and North America the most spread viral tobacco disease is the Tobacco Mosaic Virus. This virus has a global impact and appears in almost all areas where susceptible varieties are cultivated. It is generally considered that plants affected by the Tobacco Mosaic Virus approximately lower their yields by 15%, but this damage can be important in the varieties of dark tobacco for wrappers, because the leaf that shows the symptoms of the disease can no longer be used as wrapper. The typical sintomathology is the classic mosaic, but it can develop damages in the veins of the leaves, necrotic lesions and deformations of the plant.

The Tobacco Mosaic Virus must be handled by means of quarantine measures, the rotation of crops and the use of resistant varieties. In the varieties for wrappers the cleaning of the affected plants is essential, because the Tobacco Mosaic Virus rapidly spreads from the hands of the workers and the agricultural equipment.

The Cucumber Mosaic Virus is also a problem that affects all tobacco regions, and though it has less economic impact, it is considered important in some regions of Asia and Spain. The visual sintomathology varies much, depending on the species and variety of the affected tobacco. Nevertheless the most frequent symptom is a mosaic which is frequently confused with the Tobacco Mosaic Virus. Its transmission is made by aphids. Controlling the vector and cleaning the plantations are imperative to control this disease.

The Curly foliar mosaic virus is also a worldwide problem, but important affectations are only reported in the tropics. The symptoms include the leaf curling of the leaves and dwarfism of the plants affected in the initial stages of the growth. Its vector is the white fly **(Bemicia Tabaci)** and its control is based on controlling that vector.

The Y virus of potato is encountered in every tobacco crop region and can be of economic importance in some areas. Its transmission happens by aphids and its control is based on the control of the vector.

3 Role of the Nutrients

Tobacco is a fast growing plant, even to an explosive extent, and the absorption of nutrients follows that same tendency. Therefore tobacco requires adequately available nutrients in an assimilable form throughout the entire vegetative period, but, mainly, from the first weeks post-transplant. Only through a balanced nutrition management a prominent harvest with leaves of high quality can be obtained.

Tobacco absorbs a relatively high amount of nutrients and this varies according to the kind of cultivated tobacco. Dark tobaccos accumulate a higher quantity of nutrients than the Virginia and Eastern varieties; a difference even more substantial in case of nitrogen.

The content of nutrients in the tobacco tissues is higher than that in other crops, being between 20% and 26% on the basis of the dry matter in dark tobaccos and near 15% for Virginia tobacco. (Bennett et al, 1954; Schmidt, 1951).

On the other hand, the fact that a great deal of tobaccos of higher quality is harvested leaf per leaf, or in groups of leaves, insofar as they reach their technical maturity, is an additional difficulty, for the practised nutritional tobacco processes limit the possibilities of translocation of some nutrients from the oldest leaves to the youngest ones, as normally occurs in all crops.

3.1 Nitrogen

Nitrogen is essential for the growth and development of the plant and tobacco leaves, which accounts for its responsible role in the photosynthesis process and its direct contribution to the production. Its individual impact is stronger than that of any other nutrient. Which is confirmed by Hawks, 1980, when he says that nitrogen is the element that most influences the development of tobacco plant.

Jones, 1996, maintains that nicotine is one of the most important quality factors in Burley, dark and in flue-cured tobacco; and as nitrogen is part of the nicotine molecule, the fertilization has a direct impact on the nicotine content in the plant. An adequate nitrogen management in the tobacco crop is therefore fundamental, because a lack as much as an excess of nitrogen entails production and quality problems. Nitrogen deficiency will generate slender plants with pale and small leaves that will grow in an acute angle to a thin stem. After curing, these leaves will remain pale, thin and with an undesirable texture and the tissues of the dry leaf will be fragile.

Contrarily, a nitrogen excess will cause the appearance of dark, intensely coloured leaves, a dramatic vegetative development and an increase of the relative proportion of stems and veins, but the former will have less mechanical resistance. A delay in maturation is also noted, as well as a lower foliar sugar contents. The cured leaf will acquire dark tonalities, an undesirable texture, not much body, excessive nicotine contents, low combustibility and bad flavour. (Akehurst, 1973). It is assumed that as soon the leaves reach their major growth, the nitrogen availabilities remain detrimental.

3.2 Phosphorous

The photosynthesis, the phosphorisation and all vital processes related to the energetic metabolism of the plant are all subordinated to the effect of the phosphorous compounds. Also the metabolism of proteins depends on the presence of this element. The main function of phosphorous is to promote the maturation, to which an increase of carbohydrates is related.
Phosphorous accelerates the maturation of tobacco leaves (Whitey et al, 1966). Phosphorous deficiency, apart from delaying the maturation, causes a reduction of nitrogen and magnesium (McEvoy, 1951) and of the foliar abscission. (Leggett et al, 1971). It is assumed that phosphorous improves the colour of Virginia tobaccos and that there is a positive relation with its sugar contents. (Merker, 1959).

An extreme phosphorous deficiency can be the cause of a dark green tonality in tobacco leaves, which appear atrophied, with a pointed shape and with a tendency to increase their angle of insertion with the stem until assuming an almost horizontal position. The plant then appears to be somewhat flattened and diminished in height, and, with a substantial maturation delay. The cured leaves lack brilliance and frequently the superior ones have dark brown spots.

3.3 Potassium

Potassium is an essential element for tobacco, by which it is absorbed in great quantities, but the precise function of potassium in the plant's metabolism is still not yet totally explained. Potassium is the main component of tobacco ash and its function seems to be related to some enzymatic systems. Potassium deficiency reduces the weight and the length of the roots more than any other element does (Agenda del Salitre, 2001).

It is assumed that potassium definitely influences the colour of the leaf, its texture, its combustibility and its hygroscopicity. It is an established fact that potassium fertilization has a greater impact on quality that on yield. (Bowling and Bowman, 1947). The effect of potassium on the combustibility has been discussed and numerous authors have reached a consensus. (Coolhas, 1936; Chouteau J. and A. Reinier, 1959; Geus, de, 1967; Jacob, A. and H. von Uexkull, 1968; Llanosl, 1983).

Potassium is considered to be important in increasing the tolerance of tobacco against fungal diseases and to improve its hydric stress resistance, as a result of a better regulation of the physiological processes (Akehurst, 1973.). Potassium also participates in opening and closing of the stoma, as can be observed in Figure 30, and is the cation with the most interchanges in its concentration in the guardian cells, during opening and closing of the stoma.

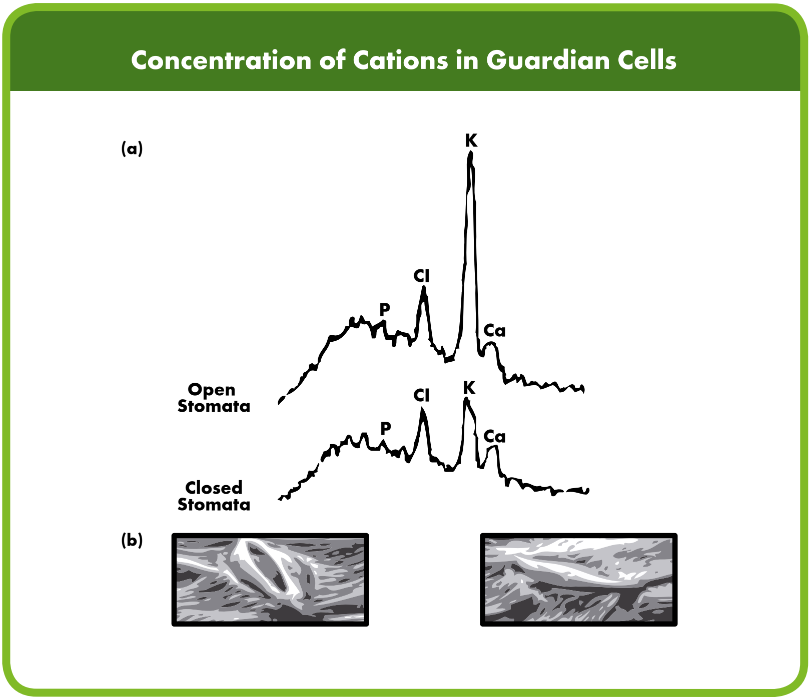


Figure 30. *Concentration of cations in guardian cells.*
Source: Langer et al, 2004, plant Journal, 37:828-838.

Potassium plays an important role in the synthesis and translocation of sugars and starch. It reduces the damage caused by frosts, as it is the most active ion in the cell, and reduces the freezing point of the cellular solution. Potassium also promotes the protein formation. As cation, K accompanies nitrate (anion) from the roots to the leaf where it is reduced to ammonium to be incorporated to amino acid. After which K returns to the roots together with the malate . (Marschner, 1995). An acute potassium deficiency causes the stocky appearance of the plant, along with a very peculiar chlorosis, that advances from the tip and the edges of the leaf towards the central vein; the foliar tissue being covered with necrotic spots where the tissue easily disintegrates. In case of less serious deficiencies, shortly before maturation a yellowish mottling of the leaf appears which concentrates towards the apex and the edges.

3.4 Calcium

Calcium is present in tobacco plant, mainly as insoluble salts of organic acids and in the cellular walls. In fact, 90% of the calcium which is present in the plant is encountered in the middle lamina of the cellular walls, being part of the pectins in the outer surface of the membrane and in the vacuole.

Calcium participates in numerous metabolic processes in the plant and is required for strengthening the support tissues and in the cellular division. The hypothesis has been formulated that this element plays a certain desintoxicating role (Chouteau J. and A. Reinier, 1959.) before the accumulation of other ions, resulting in an acid balance regulator - basis of the cellular metabolism. (Wallace et al, 1966; Wolts et al, 1949). Calcium is not very mobile the plant. (Kasai and Konishi, 1960).

Hawks, 1980, indicates that calcium, next to potassium, is the element most demanded in terms of quantity by the plant, and, that it is common for a cured leaf to contain between 1,5% and 2% of calcium. On the other hand, other authors indicate that nitrogen is the second important element in terms of quantity demand by the plant. Nevertheless, beyond any doubt, potassium, nitrogen and calcium are the three elements most demanded by the tobacco plant. There are indications of an inversed direct relation between the levels of calcic nutrition and the rapid and severe appearance of the infection symptoms caused by **Phytophthora Parasitica.** (Ferrario et al, 1989).

On the other hand, calcium improves the water infiltration and helps to aerate compact soils by stimulating the flocculation of soil particles. Severe calcium deficiency is accompanied by damages in the superior leaves, which become deformed with a heart-shaped appearance, with disappearance of the apex and severe damages at the edges. Increases in the radical growth are not observed. A late deficiency will provoke chlorosis in the leaves which at flowering will lead to necrosis of the corolla and the falling of flowers. In plants with a calcium deficiency one can observe an increase of the contents of the free amino acids, caused by the inhibition of the synthesis of proteins and the metabolical destruction of those already formed.

Calcium deficiency can appear in the plants during the periods of most intense growth and it has frequently been observed that there are differences between varieties in terms of severity and moment of appearance of the symptoms. (Peedin and McCant, 1977).

3.5 Magnesium

Magnesium is a chlorophyll component, hence its great importance in the photosynthesis, and influences the metabolism of carbon hydrates. In tobacco, the increase of the magnesium contents in the leaf up to some 2%, improves combustibility and the appearance (colour and texture) of the ashes. It gives rise to a clear-coloured porous, loose ash that improves combustibility, but a superior magnesium increase affects both indicators. (Anderson et al, 1929).

The great foliar surface and the rapid growth of the crop, make the plant really sensitive to magnesium deficiency. Leaves with magnesium deficiency, when being cured, have a dull colour, lack brightness, have a clear brown tonality, and, are abnormally thin, non-elastic and with a paper-like texture. (Hawks, 1980).

The response of tobacco to magnesium applications is very strong, and, in case of magnesium deficiencies both growth and development of the plants are affected; the colour of the leaves fades and the starch contents in the tissues diminish. The weight of the seeds, stems, roots and leaves is reduced in this order. The application of magnesium as fertilizer increases the fat contents in the seed. (Matusiewicz, 1964).

Magnesium deficiency frequently occurs in soils with a very slight texture. At the moment of appearance, a typical chlorosis manifests itself that affects the green and yellow pigments of the tobacco leaf. The chlorosis begins at the vertex and at the leaf edges and evolves towards the centre, whereby the major tissues remain green. Moreover, necrotic areas do not appear in the lamina of the leaf. The leaves to be cured have a dirty, matte appearance and lack brightness.

3.6 Sulphur

Sulphur belongs to some essential amino acids such a cystin and methionine. On the other hand, an excess of sulphur affects the combustibility of tobacco and there are evidences of sulphur reducing the alkalinity index of ashes (Oerti, 1966). The different tobacco types and varieties differ on the basis of their sulphur deficiency susceptibility. Sulphur excess can also affect the aroma, with levels of over 1% at foliar level, and this, is fundamental in the Virginia tobacco which is used as aromatizing and flavouring agent in cigarette blends.

Sulphur deficiency does not occur frequently under normal tobacco crop conditions, but when it does, the tips of the superior leaves manifest a chlorosis, which when dried appear clearer than the rest of the cloth. In case of a sulphur deficiency the normal contents of all organic compounds in the foliar tobacco tissues are affected. (Gilmore, 1954).

Summarizing: nitrogen, potassium and calcium account for 79% of the mineral absorption by the Virginia tobacco plant, whereas the rest of the macro-elements (phosphorous, magnesium and sulphur) account for the remaining 21%, as can be observed in Figure 31.

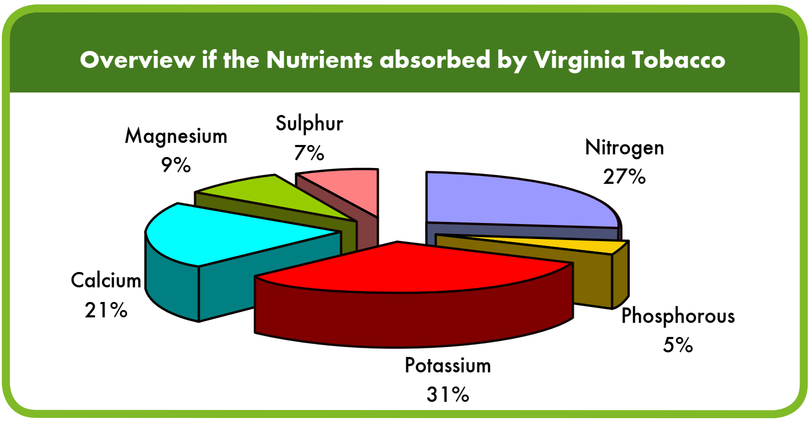


Figure 31. *Overview of the nutrients absorbed by Virginia tobacco.*
Source: Collins, W. and Hawks, Jr. 1983.

3.7 Micro-Elements

Boron

Normal administrations of boron lead to yield increases, improve combustibility and the colouring of the leaves, while at the same time reducing the nicotine contents. Boron deficiencies are normally related to soils with low contents of organic matter, acid soils, sandy soils and in regions with much pluviometry. Boron deficiencies are associated with periods of drought, during which the radicular activity decreases and when there is little transpiratory flow through the plant.

Boron acts on the metabolism of the nucleic acids, after which the boron deficiency interrupts the development and maturation of the cells. And it has been established that boron participates in the synthesis of nitrogenous bases such as uracil. Boron participates in the mechanism of the auxins and the tissues suffering from boron deficiency present a distinct accumulation of indole acetic acid (also known as IAA) which provokes a growth inhibition.

It has been established that the damage caused by aluminium in the plant in an acid soil, is due to induced boron deficiency, which can be corrected by administering boron during growth. This is due to the similarity between boric acid (H_3BO_3) and the form taken by aluminium in the plant, once it has entered it ($Al(OH)_3$). In the most severe cases, boron deficiency in tobacco plant can cause the death of the terminal bud, the appearance of stocky plants with short internodes and delayed development. Consequently an active sprouting of the axillary buds can be observed. The plant suffering from boron deficiency presents a faint radical development, has many less leaves, which are smaller and narrower and with fragile tissues; often of irregularly shaped, deviating from the typical shape of the variety in question. Chlorosis is also a characteristic phenomenon, though the veins keep their normal colour, while an off-white colouring moves from the base of the leaf towards the apex.

Zinc

Zinc influences the nitrogen absorption and the metabolism for starch formation. Apart from playing an important role in the promotion of the cellular division and elongation, and, in the promotion of the synthesis of auxins. Zinc deficiency has not been described in commercial tobacco plantations. Artificially provoked zinc deficiency causes the appearance of chlorotic spots in the leaf tissue, then becoming necrotic causing the destruction of the tissues. The oldest leaves are the first to be affected.

Iron

Iron is an essential micro-element; is part of the cytochromes and proteins and participates in oxide reducing reactions. In the leaves, almost all iron is encountered in the chloroplasts, where it plays an important role in the synthesis of chloroplastic proteins. Iron is also part of a great quantity of respiratory enzymes, such as peroxidase, catalase, ferredoxin and cytochrome - oxidasa. Iron deficiency is mainly encountered in soil with ph over 7.5 and some times in acid soils, which is generally not due to a lack of iron in the soil, but to an excess of manganese: the imbalance between both prevents the plant from absorbing iron.

Copper

It is considered (Llanos, 1983) that in the cured tobacco leaf copper acts like a catalyst that improves the combustibility in prolonging it. During the plantation stage, copper improves the growth and the health of the roots, while it stimulates the maturation of the leaves, which have a better colouring when cured. Its effect on the organoleptic properties is remarkable, since copper lowers the nitrogen contents and increases the sugar contents, which is desirable in Virginia tobaccos.

Manganese

At normal quantities (toxicity caused by manganese is frequent in acid soils) manganese stimulates the metabolic processes in the plant, activates the breathing of the roots, reduces the veins of the leaves, improves the elasticity of the cloth, and gives rise to clear-coloured ashes, as well as a clearer smoke. Manganese excess reduces the combustibility of tobacco and causes the appearance of spotted appearance, which remain after the leaf has been cured.

Chloride

The effect of chloride on tobacco is far better described in the professional literature, as well as with regard to the adverse consequences when accumulated, as with regard to the fact that chloride is an indispensable element for the growth and development of the plant. Chloride excess (more than 1% in the cured leaf) severely affects the combustibility of tobacco, wrinkles the edges of the leaves, and, considerably delays maturation. Higher contents also affect the colour, the texture and the aroma of tobacco.

Summary of the main functions:

Nitrogen (N)	Synthesis of proteins (growth, development and yield).
Phosphorus (P)	Cellular division, formation of energetic structures and promotes maturation.
Potassium (K)	Influences the colour, the texture and the combustibility of the leaf.
Calcium (Ca)	Improves resistance to diseases and strengthens the support tissues.
Sulphur (S)	Synthesis of essential amino acids, cystin and methionine.
Magnesium (Mg)	Better combustibility and appearance. Promotes clear-coloured, porous, loose ashes.
Iron (Fe)	Chlorophyll synthesis. Participates in oxide reducing processes.
Manganese (Mn)	Activates the respiration of the roots and metabolic processes.
Boron (B)	Better combustibility and nicer leaf colours. Synthesis of nitrogenous bases (uracil).
Zinc (Zn)	Synthesis of auxins; cellular division and elongation.
Copper (Cu)	Prolongs the combustion of the leaves; stimulates maturation and improves the leaf colour.
Molybdenum (Mo)	Component of the nitrate reductase and nitrogenase enzymes.

4 Information on Nutrition Management

The tobacco crop is extremely demanding in terms of the availability of nutrients. As from the preparation of the plants, the nutrition is extremely important, because the plant shows great growth rates as from these early stages; the roots, for example, grow very fast between the 24th and the 32nd day after the germination of the seed (Caruso, Pearce and Bus, 2000), as is shown in Figure 32.

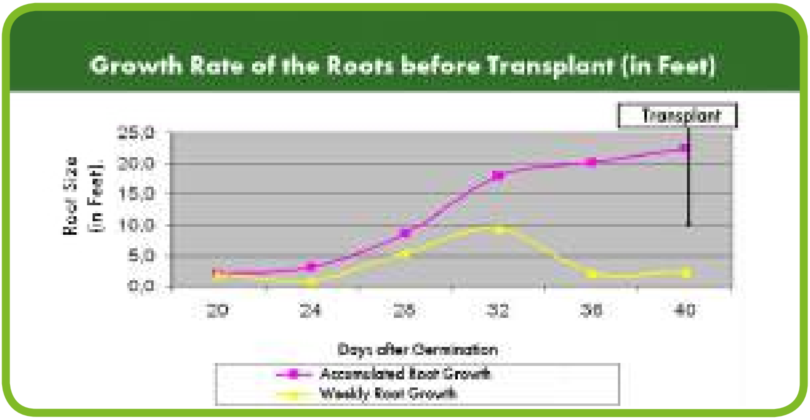


Figure 32. *Growth rate of the roots before transplant (in feet).*
Source: Caruso, Pearce and Bush, 2000.

Once the plants are transplanted in the field, one must be able to count on a fast provision of nutrients to sustain adequate plant growth. From the moment the transplant stress lies behind, the tobacco plant starts to quickly develop its radicular system, as can be observed in Figure 33.

Figure 33. *Growth rate of the roots (in feet).*
Source: Caruso, Pearce and Bush, 2000.

The main root of the plant branches out quickly to form a radicular system which is densely fasciculated and not very deep. This first, post-transplant radicular growth is fundamental to support the next aerial growth, which will be our harvest during the following weeks. And this growth of the roots continues at least during several weeks, because in measurements made in Brazil, the plant doubles its roots weight between the 60th and the 135th day post-plantation, as can be observed in Figure 34.

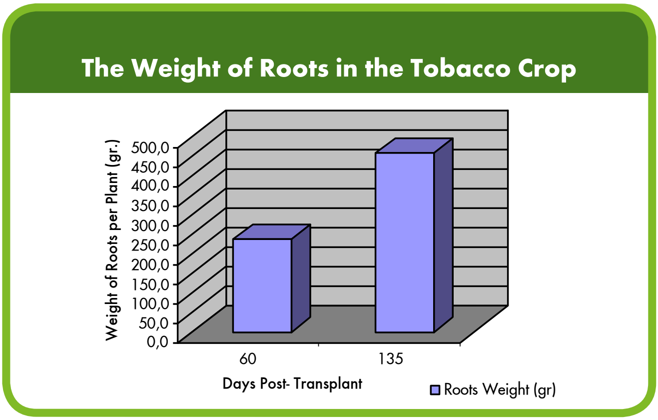


Figure 34. *The weight of roots in the tobacco crop.*

The development of the radicular system and its morphology are strongly influenced by the soil properties and the transplantation techniques, as between 90% and 100% of the roots' weight are concentrated in the first 30 centimetres of depth.

After the first month of growth, the plant begins to develop its vegetative area, which it continues to do so for the next 6 to 8 weeks. It should also be noted that during week 4 to week 8 post-plantation there is as much aerial growth as radicular growth.

Nevertheless, although both growths occur during the same period, the highest concentration of nutrients and accumulation of dry matter is found in the aerial part of the plant, as it shown by tests performed in South Africa, where by means of the presence of all macro-elements and inorganic micro-elements, at 12 weeks post-plantation, we can observe that the aerial part concentrates more than 75% of the total dry matter of the plant (also see Figure 35).

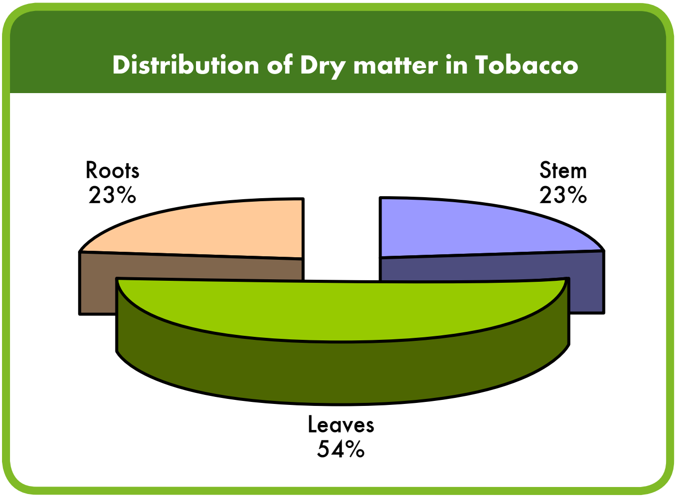


Figure 35. *Distribution of dry matter in tobacco.*
Source: Test of Antón Schultz, South African Golden Leaf, South Africa.

From a nutrition point of view, the most demanded elements are potassium, nitrogen and calcium. Especially potassium and nitrogen are required in high quantities during the first crop stages, according to the accumulation curve of these elements, as is shown in Figure 36. The tobacco crop lifecycle in the field lasts approximately 13 weeks, during which 85% of the potassium and more than 90% of nitrogen are absorbed before the 8th week post-transplant.

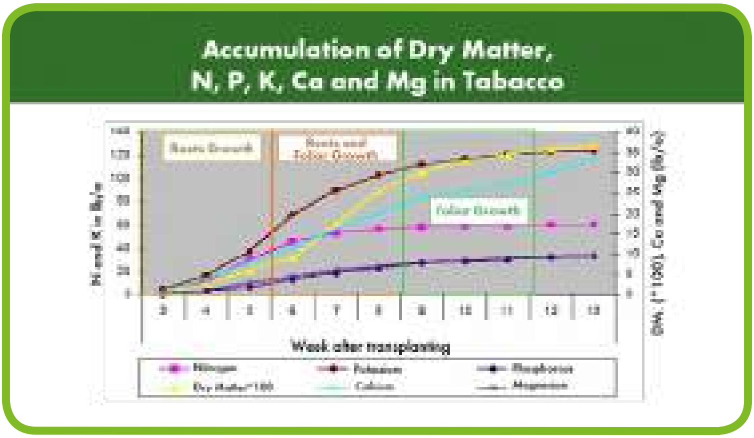


Figure 36. *Accumulation of dry matter, N, P, K, Ca and Mg in tobacco. Source: Raper and McCants, 1966.*

On the other hand calcium is demanded in a more uniform way by the plant between the 5th and the 10th week, with an absorption increase to 60% at the 8th week post-transplant.

It must be noted that calcium does not have a phloematic movement, which is why it is not mobile in the plant (also see Figure 37); i.e. to make sure that all aerial parts absorb calcium, it is necessary to have calcium in the soil solution during the entire absorption stage.

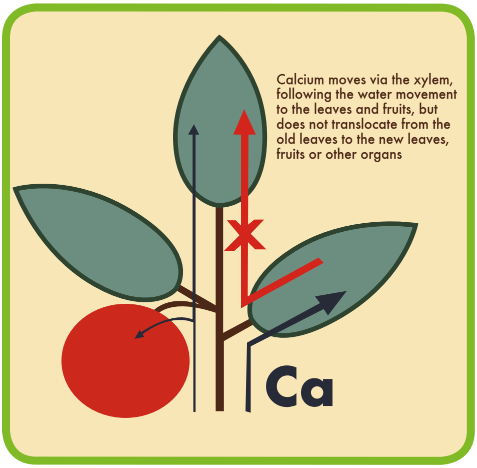


Figure 37. *Calcium moves via the xylem, following the water movement to the leaves and fruits, but does not translocate from the old leaves to the new leaves, fruits or other organs.*

Hawks, 1980 indicates that all nitrogen must be applied before the 3rd week post-transplant, because the plant has a very fast absorption between 4th and 7th week. Nitrogen applied after that period can be taken by the plant in its final growth stage, which retards maturation and can have a negative impact on quality. After the most important absorption of these nutrients, during the first weeks, the most important stage of accumulation of dry matter by the parts of the plant begins. The accumulation is concentrated between the 6th and 10th week post-transplant. During this period almost 75% of the total dry matter of the plant is concentrated, as can be observed in Figure 38.

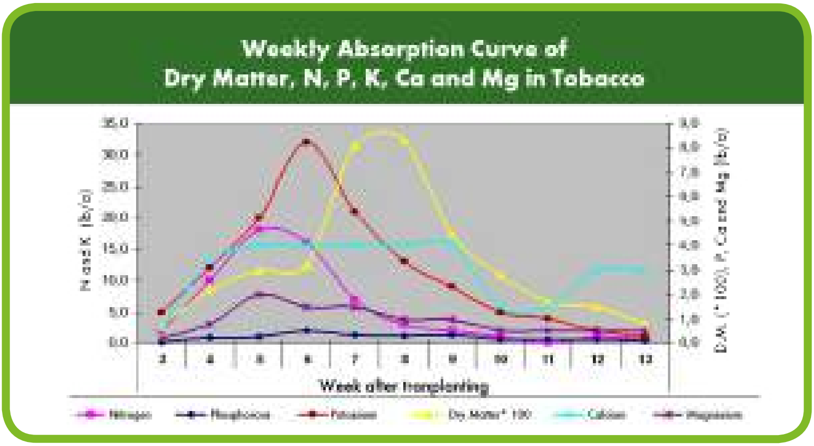


Figure 38. *Weekly absorption curve of dry matter, N, P, K, Ca and Mg in tobacco. Source: Raper and McCants, 1966.*

The remaining macro-elements are also important as much for the quality as for the production but they are required in smaller amounts. It should be noted that their application must also be concentrated in the first weeks of growth of the crop, because 70% of the magnesium and 66% of the phosphorous are absorbed before the 8th week post-transplant.

The nicotine contents of tobacco leaves depend on the applied fertilization, the phytotechnical procedures, the degree of maturation of the leaves at the time of the harvesting and the climate during the vegetative period (Watson, 1966). The nicotine contents sought after in the raw material depends on the projected use and the market trends. In the USA consumers prefer tobaccos with 2,0% to 2,5% of nicotine; whereas in Australia contents lower than 2,0% are preferred. At present, we can observe a trend to lower the nicotine contents in the raw materials, in response to multiple health regulations that have taken effect.

Research in the main tobacco zones has established that combustibility - an essential tobacco leaf quality - is defined by the relation between the potassium content in the foliar tissues and the calcium and magnesium contents. We have mentioned earlier that the contents of nutrients in tobacco tissues is higher compared to those of other crops; i.e. between 20% and 26% on the basis of the dry matter for dark tobaccos and around 15% for Virginia tobaccos. (Bennett et al, 1954; Schmidt, 1951). Table 6 shows the absorption of macro-element for different types of tobacco, related to a production of 2.913 kg/ha.

Table 6: *Absorption per macro-element for different types of tobacco (kg/ha).*

Nutrients	BURLEY (1)	VIRGINIA (2)	DARK (3)
Nitrogen	202	77	130-150
Phosphorous	22	13	30-40
Potassium	161	88	230-240
Calcium	146	60	200
Magnesium	11	24	25
Sulphur	28	20	10
Maganese	200gr/ha	0,8	
Boron	90gr/ha	0,08	
Iron	900gr/ha	Traces	
Zinc	200gr/ha	Traces	
Copper	70gr/ha	0,04	
Molybdenum	0.4gr/ha	Traces	

Sources:
(1) IFA. World Fertilizer User Manual. 1993 (for a production of 2.913 kg/ha).
(2) Principles of Tobacco Production. C.B. McCants and W.G. Woltz. N.C.S. University.
(3) Chouteau, 1969; Tobacco. (Prod. of 2.740 kg/ha at 27% of humidity). IIP, 1993. Bowl. 11.

Successive researches have made it possible to establish for a fact that each macro-element grants certain physical and/or quality characteristics to tobacco leaf. As can be observed in Figure 39, nitrogen is associated with the production of leaves and the concentration of alkaloids (nicotine) in them; phosphorous is associated with roots production and soluble carbohydrates in the plant; potassium is associated with the production of leaves and soluble carbohydrates; whereas calcium is associated with the concentration of alkaloids in the plant.

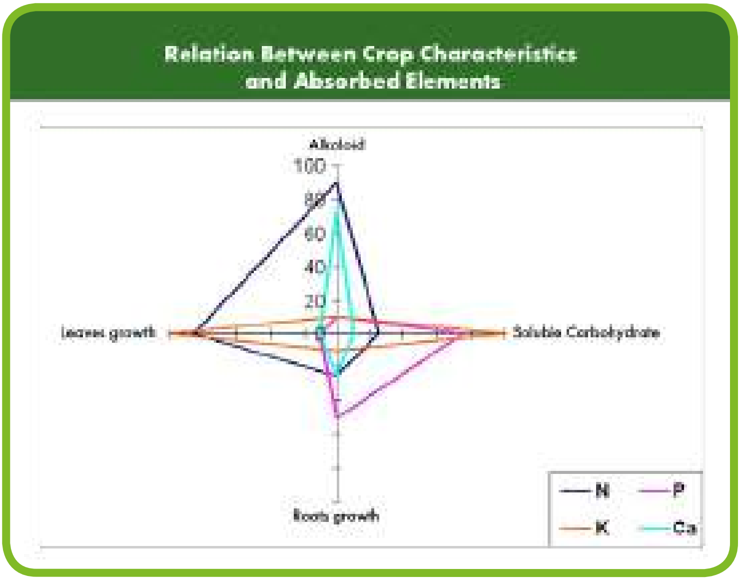


Figure 39. *Relation between crop characteristics and absorbed elements. Source: Bafalluy R., International Tobacco Seminar, SQM-2001.*

On the other hand, Hawks, 1980, mentions that the nicotine is synthesized in the apex of the roots from which it is translocated to the aerial parts of the plant and that therefore any root stress or root disease has a negative impact on the nicotine contents of the plant. On the other hand the same author indicates that the nicotine synthesis capacity increases after topping the plants.

For an appropriate maturation, it is essential that the nitrogen absorption rapidly and drastically diminishes after topping. When the plant has reached maximum leaf growth, the nitrogen which is easily assimilated by the soil should be fully consumed. The same author reports that due to the low soil temperatures at the time of transplant, it is recommended to have high phosphorous contents available at that moment, because it has been established that the plant grows rapidly when it can absorb phosphorous. It should also be noted that the availability of phosphorous is negatively affected by low temperatures (also see Figure 40).

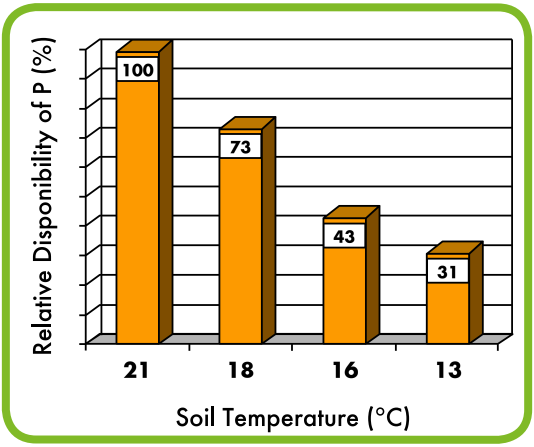


Figure 40. *Relation between soil temperature and phosphorous availability. Source: Phosyn, Yara workshop, 2003.*

When the soil temperature drops from 21 °C to 13 °C, the availability of phosphorous drops around 70%. On the other hand it is extremely important to apply phosphorous very close to the root at the moment of plantation and to use the sources with the highest absorptive power, as the plant only absorbs phosphorous at less than 2 mm from the root hairs.

It is evident that there is a correlation between the potassium content in the cured leaf and the combustibility. And in numerous studies where different potassium sources have been compared, the worst results were obtained with chloride, probably due to the unfavourable effects of the chloride ion on the crop (Hawks, 1980).

It is necessary to bear in mind that less than 2% of the potassium in the soil has the potential to be absorbed by the plant (also see Figure 41), which is why normally the plants have a distinct response to its being applied in the field. In clay soils with clays of type 2:1, the colloids have the property to adsorb some cations, among which potassium, which is why a bigger amount of interchangeable potassium is required to assure a normal absorption by the plant.

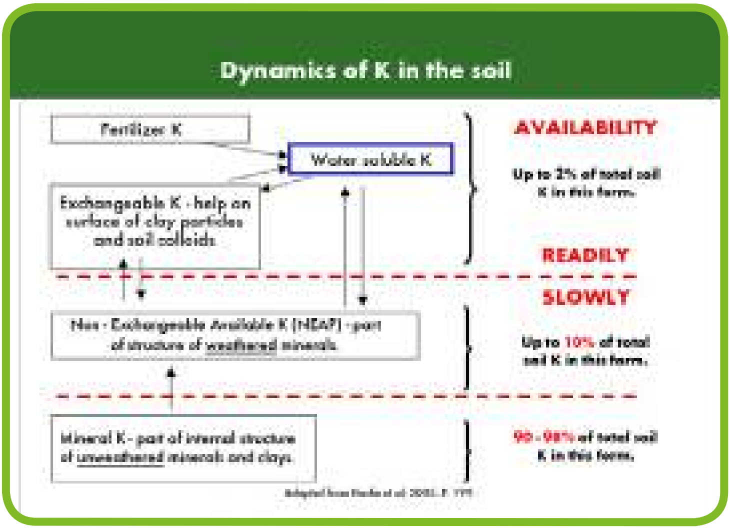


Figure 41. *Potassium dynamics in the soil.*

The normal foliar levels in Virginia tobacco plants, measured in the 10th leaf at the moment of topping, can be observed in Table 7.

Table 7. *Normal foliar levels in Virginia tobacco.*

Element	Normal Range in %
Nitrogen	2.0-2.75
Phosphorous	0.15-0.25
Potassium	1.8-2.0
Calcium	1.5-2.5
Magnesium	0.3-0.5
Sulphur	0.45-0.6
Element	**Normal Range in ppm**
Boron	20-35
Iron	200-800
Zinc	30-60
Manganese	0-150
Molybdenum	3.-6
Copper	5.-20

Source: Ontario Publication.

There are different mechanisms involved in the absorption of the nutrients (also see Table 8). It is therefore important to know that, for example, on cloudy days the absorption of nitrogen, calcium, sulphur and boron is negatively affected and that the opposite is true on clear days. It should also be noted that a good soil humidity level makes it easier for the plant to absorb phosphorous and potassium, because then these elements diffuse better in the soil.

Table 8. *Importance of the ways of absorption of the different nutrients in the plant (%).*

Importance of the Ways of Absorption of the Different Nutrients in the Plant (%)			
Nutrient	Interception by the Roots	Mass Flows	Diffusion
Nitrogen	1.-2	80-98	0-20
Phosphorous	2.-3	5.-6	90-92
Potassium	1.-2	17-20	78-80
Calcium	28-30	70-72	-
Magnesium	13	87	-
Sulphur	2.-5	95-98	-
Boron	3	65	32
Copper	70	20	10
Iron	50	10	40
Manganese	15	5	80
Molybdenum	5	95	-
Zinc	30	30	40

Source: Alarcón A. 2000.

As can be observed in Figure 42, tobacco plants absorb the nutrients with more or less difficulty depending on the distance between the ions in solution and the root hairs. The plant can absorb nitrogen from a maximum distance of 20 millimetres, whereas potassium, calcium and magnesium require a maximum distance of around 5 to 7 millimetres; and phosphorous can only be absorbed from a maximum distance of only 1 millimetre.

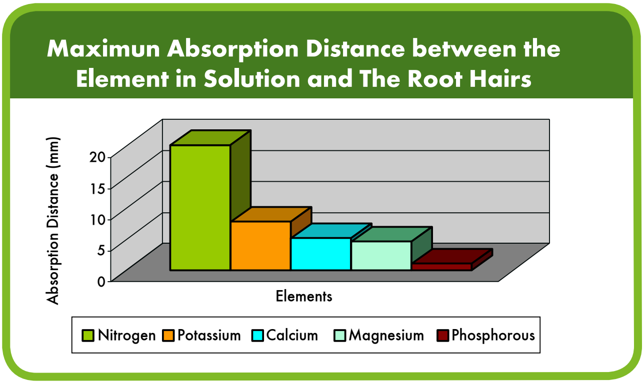


Figure 42. *Maximum absorption distance between the element in solution and the root hairs.*
Source: Adapted from Mendoza, H. 2003.

According to Westermann, 1993, an important interaction exists between the nutrients, which accounts for the fact that in case of a chloride excess, both the nitrate concentration in the leaf' petiole and the phosphate absorption are reduced. And, an excess of potassium reduces the absorption of calcium and magnesium, and vice versa. According to Hanks, 1980, high ammonium contents suppress the absorption of potassium, calcium and magnesium and facilitate the leaching of these cations in the soil solution. Excessive amounts of iron induce manganese deficiencies; whereas high phosphorous doses induce zinc deficiencies. Or also precipitates occur due to the high change affinity, which prevent absorption by the plant, for example between calcium and phosphate and calcium and sulphate, which is why it is fundamental to balance the crop nutrition in order to avoid any induced nutrition deficiency.

5 Visible Nutrition Deficiencies of the Tobacco Crop

McMurtrey (1933) has published a detailed key for the identification of the visual symptoms of nutrition deficiencies in tobacco. Generally speaking the symptoms can be classified in two groups: those that appear in the lower, older leaves, and which relate to the most mobile elements in the plant (nitrogen, phosphorous, potassium and magnesium) and those that appear in the superior, younger leaves, and, in more active growth zones, which relate to the relatively immobile elements in the plant (calcium, boron, manganese, sulphur and iron).

The key to identify the nutrition deficiencies in tobacco by means of the visual sintomathology is presented hereafter.

Nitrogen
Nitrogen deficiency is characterised by a general chlorosis. In addition a yellowing and drying of the lowest leaves can be observed. The plants turn pale green and the inferior leaves turn yellow, which when drying turn carmelite.

Figure 43. *Nitrogen deficiency.*
Courtesy of: J. Michael Moore, The University of Georgia.

Figure 44. *Nitrogen deficiency.*
Courtesy of: J. Michael Moore, The University of Georgia.

Phosphorous

In case of phosphorous deficiency the plants turn dark green, the leaves narrow in relation to their length, and plants are immature plants.

Figure 45. *Phosphorous deficiency.*

Potassium

The effects of potassium deficiency show in the oldest, lowest leaves or more or less all over the plant. Local effects are mottling or chlorosis with or without the appearance of necrotic spots on the lowest leaves; there are almost no dry low leaves. The low leaves appear curved with yellow mottling at the tips and the edges, necrotic in the tips and on the borders.

Figure 46. *Potassium deficiency.*

Figure 47. *Potassium deficiency.*
Courtesy of: The University of Georgia.

Calcium

The effects of calcium deficiency are located in the terminal buds and the superior leaves. Death of the terminal bud, which is preceded by a peculiar distortion and necrosis in the apexes or at the basis of the young leaves. The colour of the young leaves that form the terminal bud turns clearer; after which they twist downwards in the apex, followed by necrosis, so that when growth continues, the new leaves shall lack the apexes and the edges

Figure 48. *Calcium deficiency.*
Courtesy of: The University of Georgia.

Figure 49. *Calcium deficiency.*
Courtesy of: J. Michael Moore, The University of Georgia.

Magnesium

In case of magnesium deficiency, the low leaves are chlorotic between the main veins and the apexes and at the edges appears a light green or white colouring. The fact that there are no necrotic tips is characteristic for this deficiency.

Figure 50. *Magnesium deficiency.*
Courtesy of: J. Michael Moore, The University of Georgia.

Sulphur

When affected by sulphur deficiency, the young leaves do not present chlorotic spots; the chlorosis can or cannot reach the veins, to give them a dark green or dark appearance. The young leaves have light green veins or of the same shade as the interveinal tissue. The colouring is always pale green, never white or yellow. The inferior leaves never dry.

Figure 51. *Sulphur deficiency.*
Courtesy of: J. Michael Moore, The University of Georgia.

Boron

In case of boron deficiency, the young leaves appear to be cut back, have a pale green colour, followed by a certain decomposition at the basis. At later growth, the leaves have a twisted development, and, broken leaves show blackened vascular tissues.

Figure 52. *Boron deficiency.*
Courtesy of: J. Michael Moore, The University of Georgia.

Manganese

Manganese deficiency manifests itself as follows: the terminal bud remains alive, there is chlorosis of the superior leaves with or without necrotic tips, and the veins are light green or dark. Young leaves with distributed necrotic spots against a chlorotic background, with the smallest veinlets tending to remain green.

Figure 53. *Magnese deficiency.*
Courtesy of: J. Michael Moore, The University of Georgia.

Iron

Iron deficiency shows chlorotic young leaves; characteristically the main veins have a much more intense green colour than the tissue in between them. When the veins lose their colour, the surrounding tissues are white or yellow.

Figure 54. *Iron deficiency.*

6 SPN Main Characteristics of Fertilizers

For the tobacco crop there are several nutrition application methods:
Only with granular products.
Only with soluble products.
With granular and soluble products.
With granular and foliar products.
With soluble and foliar products.
With granular, soluble and foliar products.

And today, the worldwide agro industry offers fertilizers for all these applications. However, the most important is to understand the characteristics of these fertilizers, as well as the fundamental processes of transformation, volatilization, leaching, absorption, interaction, competition and adsorption which take place in the soil, in order to optimize their use, hence to optimize the yield of the crop.

Nitrogen

Nitrogen, in inorganic form, comes in three different forms: nitrate, ammonium and urea. Both urea and ammonium undergo changes in the soil made by the so-called nitrifying bacteria (nitrosomonas and nitrobacter) because these bacteria end up transforming ammonium and urea into nitrate. This transformation can last a few days or even a month, depending on the climatic conditions and the soil characteristics.

Plants in general and tobacco in particular, mainly absorb nitrogen in the form of nitrate (over 80%). Moreover, the tobacco crop can be affected by ammonium applications, since it is kept available for the plant in its final growth stage, which is an inappropriate moment to apply nitrogen.

As can be observed in Table 9, the most important nitrate sources are potassium nitrate, calcium nitrate, magnesium nitrate and ammonium nitrate; whereas the most important ammonium and urea sources are urea, ammonium sulphate, ammonia and ammonium nitrate.

Table 9. *Main nitrate, ammonium and urea sources.*

Main N- form in the fertilizer	Common Name	Formula
Nitrate	Potassium Nitrate	KNO_3
	Sodium Potassium Nitrate	$KNO_3.\ NaNO_3$
	Solid Calcium Nitrate	$(5(Ca(NO_3\ )2).\ NH_4NO_3)10\ H_2O$
	Liquid Calcium Nitrate	$Ca(NO_3)_2$ in solution
	Magnesium Nitrate	$Mg\ (NO_3)_2\ 6H_2O$
	Ammonium Nitrate	NH_4NO_3
	Nitric Acid	$HN0_3$
Ammonium	Ammonium Sulphate	$(NH_4)_2SO_4$
	Mono Ammonium Phosphate (MAP)	$NH_4H_2PO_4$
	Di Ammonium Phosphate (DAP)	$(NH_4)_2HPO_4$
Urea	Urea	$CO(NH_2)_2$
	Urea Phosphate	$CO(NH_2)_2\ H_3PO_4$

To select the most appropriate application methods, several aspects such as climatic conditions (temperature and precipitation) must be considered. This is because under low temperature conditions ammonium sources delay being transformed to nitrate (also see Table 10).

Table 10. *Nitrification rate of ammonium.*

Nitrification Rate of Ammonium	
Soil Temp. (°C)	Nitrification (%)
0	0
4	5
10	12,5
16	25
21	70
27	95
32	97
38	100

Source: The Fertilizer Handbook - Fertilizer Institute - Washington - p. 93.

At the same time the absorption of ammonium happens faster under low temperature conditions, which can provoke toxicity since under these conditions the plant has low photosynthetic activity levels to produce enough carbohydrates in order to assimilate this ammonium. On the other hand, if there is a lot of precipitation, nitrate sources can easily leach (this can also happen with ammonium in areas with heavy rainfall, porous soil textures and low soil CEC (Cation Exchange Capacity).

In addition it is necessary to consider the effect on other cations of the soil, since ammonium can increase the leaching of potassium, as well as of calcium and magnesium, as is shown in Figure 56, because when applying this cation to the soil, a competition takes place to occupy the adsorption sites in the clays and when more concentrated, it moves from its positions to these other cations, leaving them in the solution of the soil and facilitating its leaching.

Base Losses in Relation to the Applied Notrogen Souce

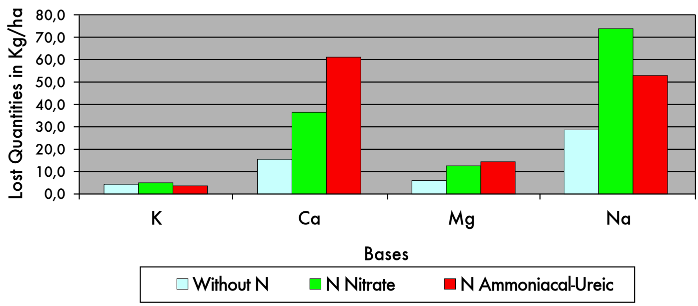


Figure 55. *Base losses in relation of the applied nitrogen source.*
Source: B. Silva et al, 1987 - Austral University of Chile.

Moreover, soil pH also influences the transformation speed of ammonium into nitrate, as well as the general soil nutrient availability, so this fact should also be taken into account. In general it can be affirmed that with ammonium applications of nitrogen, the control over the delivery moment of the element to the crop is lost, which is vital in tobacco.

Another aspect to be considered is the phenological state of the crop, since at certain moments the plant immediately needs nitrogen availability (rapid growth stage, between 4th and 9th week post-transplant) and cannot wait for transformations in the soil. In fact, tobacco absorbs 90% of nitrogen before the end of the 7th week of the crop being in the field.

At the same time, in case of crop initiation when the demand for nutrients is lower, the plant can wait for this transformation, as can be observed in Figure 57, and ammonium sources can be included.

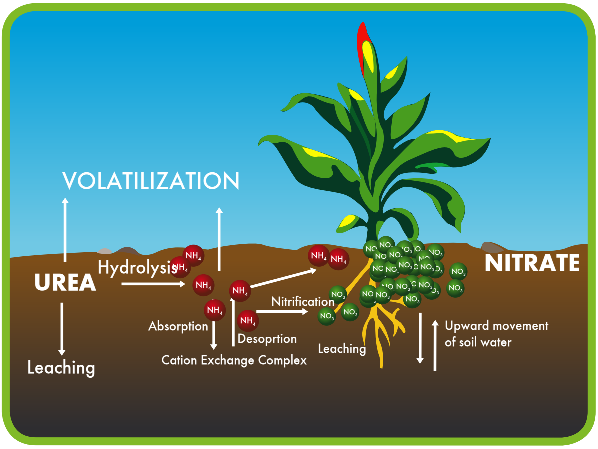


Figure 56. *The chemical transformation process in the soil when using urea, ammonium and nitrate containing fertilizers.*

On the other hand, with regard to competition between ions, it should be remembered that nitrate competes with chloride (a very detrimental ion in terms of tobacco quality) to enter the plant, and, that ammonium competes with potassium, calcium and magnesium, which are 3 essential macronutrients, as can be observed in Figure 58. On top of favouring its leaching. That is to say, if the ammonium proportion is increased, the absorption of potassium, calcium and magnesium is impeded, favouring the leaching of these cations, and, the absorption of chloride is facilitated, which is detrimental for the yield and quality of the crop.

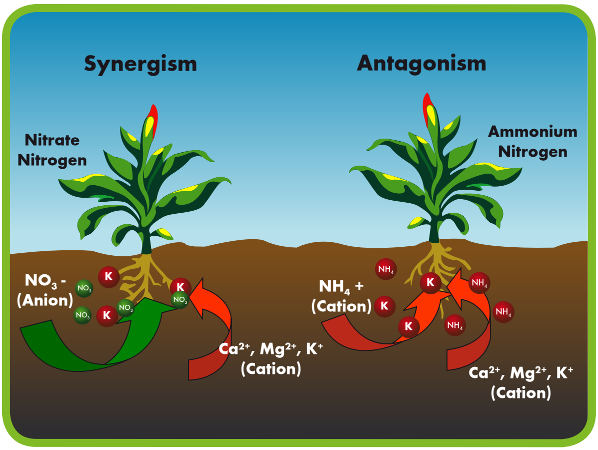


Figure 57. *Synergism and antagonism in the nutrient uptake in the rooting zone of the plant between cations and nitrate or ammonium as nitrogen source.*

Finally, in general, the cost of ammonium sources is cheaper compared to nitrate sources. Nevertheless it is necessary to consider the losses during nitrification and through ammonium volatilization, and, the adsorption of this cation in the soil colloids which reduce the actually absorbed units by the plant.

Many experiences have demonstrated that high ammonium contents in the soils generate a delayed absorption of nitrogen by the plant, which is detrimental for tobacco since his crop, because it slows down maturation and increases the nitrogen levels in the leaf, close to the moment of harvesting, which has a negative impact on the leaf quality.

Phosphorous

The main phosphorous sources are: diamonic phosphate, monoamonic phosphate, triple super phosphate, single super phosphate, urea phosphate, monoamonic phosphate (technical grade), monopotassic phosphate and phosphoric acid. In this case, the most important variable to consider is the soil pH, because with acid pH it is recommended to use the super phosphates; while in alkaline pH soils it is convenient to use monoamonic or diamonic phosphates. Through irrigation, the most suitable sources are: monoamonic phosphate (technical grade), urea phosphate, phosphoric acid and monopotassic phosphate if the soil and/or the water have an alkaline pH; whereas monoamonic phosphate (technical grade) and monopotassic phosphate are to be used if the soil has an acid pH (also see Table 11).

Table 11. *The main phosphorous sources.*

Common Name	Formula	Characteristics
Mono Ammonium Phosphate (MAP)	$NH_4H_2PO_4$	For soils with pH > 7.5
Di Ammonium Phosphate (DAP)	$(NH_4)_2HPO_4$	For soils with pH 6-7.5
Mono Potassium Phosphate (MKP)	KH_2PO_4	For all kind of soils
Triple Super Phosphate (TSP)	$Ca(H_2PO_4)_2$	For soils with pH < 6
Urea Phosphate	$CO(NH_2)_2.H_3PO_4$	Strong acidifier in solid form
Phosphoric Acid	H_3PO_4	Strong acidifier in liquid form

Phosphorous is immobile in the soil, and, at low temperatures all sources have problems to be absorbed. The pH is decisive in the absorption because in presence of acid soils phosphorous unites with aluminium and iron, forming compounds that cannot be absorbed. While, if the soil is alkaline, phosphorous unites with calcium; also forming insoluble compounds. In this case it is important to underline that phosphorous must be applied very close to the roots (without making contact with them), because absorption requires a distance not exceeding 2 mm from the root hairs.

Potassium

The main potassium sources are: potassium nitrate, potassium sulphate, sulpomag and potassium chloride (also see Table 12).

Table 12. *The main potassium sources.*

COMMON NAME	FORMULA	CHARACTERISTICS
Potassium Nitrate	KNO_3	Because of its high K concentration, potassium nitrate can be used base dressing re - fertilisations, alone or in blends. Provokes a rapid crop growth response. Ideal souce because of the importance of N and K in tobacco.
Simple Potassium Nitrate	KNO_3 - $NaNO_3$	Because of its high solubility and its N:K, 1:1 relation, simple potassium nitrate is ideal during re - fertilisations where a rapid response from the nutrient souce is wanted. Moreover, the presence of sodium, helps to increase the pH value in acid soils and avoids leaching of Ca and Mg.
Potassium Sulphate	K_2SO_4	Ideal fertiliser for the final growth phase when no N is required.
Magnesium and Potassium Sulphate	K_2SO_4 $2MgSO_4$	Because of its ow solubility, only recommended at crop initiation.
Potassium Bicarbonate	$KHCO_3$	Mainly used as a pH corrector to increase the pH value Has an alkalizing effect.
Potassium Chloride	KCl	Read the observations regarding chloride.

The fastest source in terms of plant availability is potassium nitrate, which is an essential and almost exclusive fertilizer during the rapid growth stage of the tobacco foliar. And thanks to its speed it can be immediately available to be dissolved in the soil. Due to the accompanying ion (nitrate) it is also essential in this growth phase and thanks to its high solubility it requires a minimum of soil humidity to be dissolved and to be available for the plant.

When applying other potassium sources, certain advantages of potassium nitrate are no longer valid. First example: potassium sulphate has a lower solubility than potassium nitrate. Second example: potassium chloride supplies large quantities of chloride but chloride is toxic for the plant when applied in large quantities. And has a negative impact on leaf combustibility. Third example: Sulpomag is far too slowly available. Due to all these facts, these sources (sulphate and Sulpomag) are recommended only in moderate quantities and only at crop initiation to provide enough time for availability.
Among the main disadvantages of the presence of chloride, and aside from the quality problems it entails in the harvested tobacco leaf, is that this ion competes with nitrate, phosphate and sulphates to enter the plant; i.e. the more chloride in the plant, the lesser the quantities of other anions. Chloride also increases the level of the salts in the soil and thus also increases the electric conductivity which in turn shall hinder the water absorption by the plant once certain salt levels have been surpassed. This phenomenon can give rise to moisture stress, resulting in smaller leaves and thus a lower yield.

Calcium

The main calcium sources are calcium nitrate and calcium chloride (also see Table 13), of which calcium nitrate is the fastest source in terms of plant availability. Calcium nitrate is also the most soluble source. Calcium chloride is generally a cheaper source but it has disadvantages which are related to its accompanying ion (chloride).

Table 13. *The main calcium sources.*

Common name	Formula	Charasteristics
Calcium Nitrate Solid	$(5(Ca(NO_3)_2).NH_4NO_3).10H_2O$	Worldwide the most used calcium souce, because of its high concentration and rapid disponibility for the plant. Contains nitrate nitrogen and a small part of ammonium nitrate.
Calcium Nitrate Liquid	$Ca(NO_3)_2$ en solución	Has the same characteristics as the solid version, but does not contain ammonium nitrate, so that it can be applied when no ammonium nitrate is requested.
Calcium Chloride	$CaCl_2$	Read the observations regarding chloride.

Magnesium

The main magnesium sources are: magnesium nitrate, magnesium sulphate and Sulpomag (also see Table 14). The fastest source in terms of plant availability is magnesium nitrate, which also has a better performance under low temperature conditions. Nevertheless, magnesium sulphate is more widely used because of its low cost and effectiveness. In fertirrigation applications, magnesium nitrate can be mixed with any other macronutrient, whereas magnesium sulphate must not be mixed in high concentrations with calcium nitrate (mother tank) because they deposit. On the other hand, Sulpomag in both formulations, for field or for fertirrigation, is the source with the lowest solubility, which means that it is the slowest source in terms of plant availability, once applied.

Table 14. *The main magnesium sources.*

Common Name	Formula	Characteristics
Magnesium Sulphate	$MgSO_4 . 7H_2O$	The most used my souce. Nevertheless, in fertirrigation in the mother tank, it must not be mixed with calcium formation of gypsum ($CaSO_4$).
Magnesium Nitrate	$Mg(NO_3)_2 . 6H_2O$	Has the highest solubility and can be mixed with all souces applied in fertirrigation.
Potassium and Magnesium Sulphate	$K_2SO_4 . 2MgSO_4$	Has less solubility. And slow disponibility.

7 Practices to Consider in the Nutrition Programme

7.1 Time of Application

In order to formulate the basic recommendations for a good nutrition programme, a maximum amount of information is needed. Also a soil analysis (of the nutrients in solution, soil texture, cationic Interchange Capacity, organic matter) and a water analysis (in case of irrigation) are fundamental for an appropriate planning. Afterwards, during the cultivation, a foliar analysis can help to correct nutrition problems should they arise.

7.1.1 Nitrogen

Nitrogen should be applied in doses. In case of granular nutrition, at least 2 applications must be made; for Virginia tobacco the first at transplant using 60% of the element, whereby both nitrate and ammonium sources can be used, since the plant will absorb nitrogen in the next 20 days. Nitrogen will thus be immediately available via nitrate and another one to be transformed for its use via ammonium. In case of Burley and Dark tobaccos it is recommended to make 3 applications; maintaining the criteria of the sources recommended for Virginia. When dealing with fumigated soils, the ammonium rates must be lowered, because during fumigation the bacteria colonies which are in charge of the nitrification process in the soil are surely reduced.

The second application for Virginia tobacco (no later than 3 weeks post-transplant) with the remaining 40% coincides with the start of the rapid foliar growth as from the week 4. At this stage nitrogen must be immediately available. Between week 4 and week 7 post-transplant, the highest nitrate absorption rates are noted, reaching close to 90% of absorbed nitrogen before the week 8 post-transplant. Between week 6 and week 10 post-transplant, the highest rates are noted for accumulation of dry matter, and, at that moment the radicular system has developed to such an extent that it is capable of absorbing high quantities of nutrients, thus reducing losses caused by leaching. With regard to Dark and Burley tobaccos, it is recommended to make the second application at 15 days post-transplant and the last one, no later than 30 days post-transplant.

7.1.2 Phosphorous

Phosphorous is absorbed during the entire growth cycle, but, because of its low mobility in the soil and the important role it plays in the growth of the roots, the element should be fully applied along with the first application of fertilizers (during transplant), for all tobacco varieties, and exactly in that spot where the plant will later develop its roots.

It is necessary to apply quantities far above the crop's demand, especially in soils with acid or alkaline pH, because under those conditions much of the initially applied phosphorous is fixed by the soil and thus unavailable for plant uptake.

7.1.3 Potassium

Potassium should be applied in doses: a first one during transplant (between 50% and 60%) and the second one before week 3 post-transplant, i.e. the remaining 40% or 50% in the case of Virginia tobacco.

The first application can be made with different kinds of potassium sources depending on the speed availability for the crop, since the plant will use potassium during sprouting and during the following 20 days. The plant will use this part of the application for the foliage growth as well as for the growth of the roots.

The second potassium application coincides with the moment of the fastest foliar growth (critical stage), which is why the only source to be used in this case is potassium nitrate because of its 100% immediate availability.

Without detracting the merits of both applications, the second one has however the advantage that it can be complemented with aerial potassium applications to safeguard a better quality of the leaves.

On the other hand, for Burley and Dark tobaccos, which have a higher demand for nutrients, and especially for potassium, it is also recommended to make 3 applications, maintaining the criteria of the sources recommended for Virginia.
Timing-wise, it is recommended to make the second application at 15 days post-transplant and the last one, no later than 30 days post-transplant.

Table 15. *Summary of sources and times of application to apply granular soil fertilizers for Virginia tobacco.*

Sources	Nitrogen		P_2O_5	K_2O	
Application Period	Source	%	(Soil pH)	Source	%
Pre-Planting or Transplant	NO_3 NH_4	30-40 20-30	as per pH < 6 = SFT 6 - 7.5 = DAP > 7.5 = MAP	KNO_3 K_2SO_4	30 30
2nd application (before week 3 Post - Transplant)	NO_3 NH_4	40 0		KNO_3 K_2SO_4	40 0

Table 16. *Summary of sources and times of application to apply granular soil fertilizers for Burley and Dark tobaccos.*

SOUCES	NITROGEN		P_2O_5	K_2O	
Per. Application	Souce	%	(Soil pH)	Souces	%
Pre-Planting or Transplant	NO_3 NH_4	35 65	as per pH < 6 = SFT 6 - 7.5 = DAP > 7.5 = MAP	KNO_3 K_2SO_4	50 50
1° Side Dressing	NO_3 NH_4	70 30		KNO_3	100
2° Side Dressing	NO_3 NH_4	100 0		15-0-14	100

Table 17. *Summary of the N-P-K doses recommended for Virginia, Dark and Burley tobaccos.*

Tabacco Variety	Expected Harvest	Nutrients (Kg/Há)		
		N	P_2O_5	K_2O
Dark and Burley	Medium	180	80	160
	High	240	100	220
Virginia	Medium	85	60	160
	High	100	80	190

7.1.4 Calcium

An important calcium application should be made at transplant to sustain general plant growth, especially in soils with acid pH values, since this element will be used by the plant in the first weeks of growth. Aside from the calcium transport to the leaf, calcium must be applied during side dressing, and as such by means of a rapid source such as calcium nitrate.

7.1.5 Magnesium

Magnesium should be applied in doses: a first one of 35 % at transplant and the second one (65%) before the period of rapid growth commences.

7.2 Alternatives for Balanced Nutrition Programmes

7.2.1 Granular Nutrition Programme

Recommendation for Dark and/or Burley tobacco

For this type of tobacco it is recommended to make three applications: where we can use nitrate and ammonium as nitrogen sources, while for the potassium use a very fast source and other with medium velocity, as can be observed in Table 18 (medium production levels) and Table 19 (high production levels).

Table 18. *Nutrition programme for Dark and/or Burley tobacco (medium production level).*

MEDIUM Production Level PRODUCT/FERTILIZER	APPLICATION PERIOD	Dose (Kg/ha)	NUTRIENTS (Kg/Há)						
			N	P_2O_5	K_2O	S	MgO	CaO	B_2O_3
Qropmix 12-18-18-5-2-5+B	Transplant	500	60	90	90	23	10	23	1
Qropmix 20-00-13-2Mg-7Ca	1° Side Dressing	500	100	0	65	0	10	35	
Simple Potassium Nitrate (15-0-14)	2° Side Dressing	300	45	0	42				
TOTAL FERTILIZATION		1.300	205	90	197	23	20	58	1

Table 19. *Nutrition programme for Dark and/or Burley tobacco (high production level).*

HIGH Production Level PRODUCT/FERTILIZER	APPLICATION PERIOD	Dose (Kg/ha)	NUTRIENTES (Kg/Há)						
			N	P_2O_5	K_2O	S	MgO	CaO	B_2O_3
Qropmix 12 - 18 - 18 - 5 - 2 - 5 + B	Transplant	600	72	108	108	27	12	27	1
Qropmix 20 - 00 - 13 - 2Mg-7Ca	1º Side Dressing	500	100	0	65	0	10	35	
Simple Potassium Nitrate (15-0-14)	2º Side Dressing	500	75	0	70				
TOTAL FERTILIZATION		1.600	247	108	243	27	22	62	1

The important thing is that the first application must be at transplant, the second 8 days later and the last one no later than 21 days post-transplant. This in order to avoid delayed nitrogen absorptions by the plant that can delay and harm the quality of the harvest.

On the other hand the use of simple potassium nitrate is recommended during the second side dressing, because this source has produced remarkable results in acid soils and under heavy precipitation (rain) conditions. This is basically due to the fact that the sodium which is present in this nutritional source, replace the calcium and the magnesium in the soil solution, thus avoiding its leaching and allowing for a greater absorption of these cations by the plant.

This recommendation comprises all the macro-elements plus some micro-elements with the intention to provide a complete and at the same time balanced nutrition programme, to assure high quality production.

Recommendation for Virginia tobacco

Virginia tobacco is less demanding in terms of nutritional contribution, which is why the programme is smaller as far as concerns the total units to apply. Nevertheless, the moments of application, as well as the used sources, comply to the same criteria of the above mentioned tobaccos (also see Tables 20 and 21) and which is why it is recommended to make the first application during transplant and the second before week 3 post-transplant.

Table 20. *Nutrition programme for Virginia tobacco (medium production level).*

HIGH Production Level	APPLICATION	Dose	NUTRIENTES (Kg/Há)						
PRODUCT/FERTILIZER	PERIOD	(Kg/ha)	N	P_2O_5	K_2O	S	MgO	CaO	B_2O_3
Qropmix 9 - 12 - 24 - 7S - 2Mg - 4Ca + B	Transplant	500	45	60	120	35	10	20	1
Simple Potassium Nitrate (15-0-14)	Side Dressing	300	45	0	42				
TOTAL FERTILIZATION		800	90	60	162	35	10	20	1

Table 21. *Nutrition programme for Virginia tobacco (high production level).*

HIGH Production Level	APPLICATION	Dose	NUTRIENTES (Kg/Há)						
PRODUCT/FERTILIZER	PERIOD	(Kg/ha)	N	P_2O_5	K_2O	S	MgO	CaO	B_2O_3
Qropmix 9 - 12 - 24 - 7S - 2Mg - 4Ca + B	Transplant	600	54	72	144	42	12	24	1
Simple Potassium Nitrate (15-0-14)	Side Dressing	300	45	0	42				
TOTAL FERTILIZATION		900	99	72	186	42	12	24	1

7.2.2 Nutrition Programme via Irrigation and Granular

It is recommended to make the applications until week 5 post-transplant in order to avoid delayed nitrogen absorption. In general an application via irrigation is much more efficient because they are periodic doses that cover the daily demand of the crop.
The recommendations (also see Tables 22 and 23) cover the totality of the macro-nutrients in appropriate and balanced amounts in order to assure a correct nutrition.

Table 22. *Recommendation for Dark and Burley tobacco.*

DEVELOPMENT PHASE	NUMBER OF DAYS	FERTILIZERS	Nº of Applicat.	Kg/ha to Apply	TOTAL (Kg/ha)	NUTRIENTS (Kg/ha)					
						N	P_2O_5	K20	S	Mg0	Ca0
Transplant root Development	0-14	Qropmix 12-18-18-5S-2Mg+4Ca+B	1	350	350	42	63	63	18	7	14
Development of roots and Vegetative	14-21	Ultrasol 15-30-15	8	5	40	6	12	6	0	0	0
		Magnesium Nitrate	8	10	80	9	0	0	0	12	0
		Ultrasol Production	10	8	80	10	5	32	0	0	0
Rapid Growth	21-28	Calcium Nitrate	6	15	90	14	0	0	0	0	23
		Magnesium Sulphate	6	15	90	0	0	0	12	15	0
		Ultrasol Growth	10	8	80	20	8	8	0	0	0
		Ultrasol Production	10	5	50	7	3	20	0	0	0
Rapid Growth	28-35	Calcium Nitrate	10	20	200	31	0	0	0	0	52
		Magnesium Sulphate	10	10	100	0	0	0	13	17	0
		Ultrasol 13-06-40	10	12	120	16	7	48	0	0	0
				Fertirrigation		112	35	114	25	44	75
				TOTAL		154	98	177	42	51	89

Table 23. *Recommendation for Virginia tobacco.*

Development Phase	Number of Days	Fertilizers	Nº of Aplicac.	Kg/ha to apply	TOTAL (Kg/ha)	NUTRIENTS (Kg/ha)					
						N	P_2O_5	K_2O	S	MgO	CaO
Transplant Root Development	0-14	Qropmix 12-18-18-5S-2Mg+4Ca+B	1	400	400	48	72	72	20	8	16
Development of roots and Vegetative	14-21	Ultrasol 15-30-15	6	5	30	5	9	5	0	0	0
		Magnesium Nitrate	8	12	96	11	0	0	0	14	0
		Ultrasol Production	8	8	64	8	4	26	0	0	0
Rapid Growth	21-28	Calcium Nitrate	5	10	50	8	0	0	0	0	13
		Magnesium Sulfate	6	10	60	0	0	0	8	10	0
		Ultrasol Production	8	5	40	5	2	16	0	0	0
Rapid Growth	28-35	Calcium Nitrate	8	12	96	15	0	0	0	0	25
		Magnesium Sulfate	10	8	80	0	0	0	10	14	0
		Ultrasol 13-06-40	10	8	80	10	5	32	0	0	0
				Fertirrigation		62	20	78	18	38	38
				TOTAL		110	92	150	38	46	54

8 Research Results

Conversion table:

1 acre (a) equals 0,4048 hectares (ha)
1 pound (lb) equals 0,454 kilogram (kg)
1 pound per acre (lb/a) equals 1,1215 kilogram per hectare (kg/ha)

The next research has been realized by the State University of North Carolina (USA) by McCants, C. and Woltz G. quoted by Hawks, Jr. and Collins W. 1983 and deals with the effect of the nitrogen source is investigated on the yield and on the calcium and potassium contents in flue-cured tobacco leaves.

The results show that an increase of nitrate-nitrogen in the crop consistently increases crop yield, as can be observed in Table 24.

Table 24. *Relation between nitrate-nitrogen and tobacco crop yield.*

Contents of the Elements in the Leaves			
Nitrate Nitrogen (%)	Ca	K	Yield (kg/há)
0	60,8	61,2	2.313
33	65,2	62,6	2.387
66	68,9	63,3	2.431
100	72,3	66,6	2.504

In addition, an increase of nitrate-nitrogen in the crop also increases to the calcium and potassium in the leaves, as is shown in Figure 58. Which is of extreme importance, given the fact that nitrogen, potassium and calcium are the elements most demanded by the tobacco crop; in fact, together they constitute 79% of all minerals absorbed by the plant.

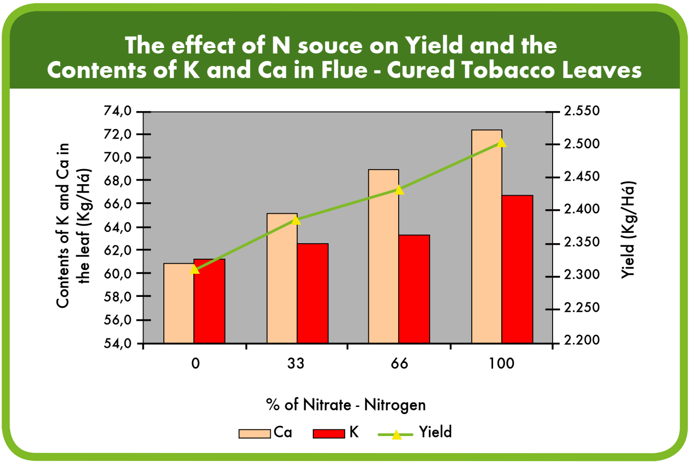


Figure 58. *The effect of N souce on Yield and the Contents of K and Ca in Flue - Cured Tobacco Leaves.*

The former has been endorsed by various authors, in relation to the fact that ammonium in the soil competes with some cations such as calcium, magnesium and potassium; favouring its leaching (particularly of calcium and magnesium), and, hindering its absorption by the plant.

The following test was performed in Brazil by the engineer Sergio Willani and was presented during the IX International Tobacco Seminar.

During that test 5 different increasing doses of nitrogen were applied (respectively 70, 100, 130, 160 and 190 kg/ha) on with 3 different flue-cured varieties (namely K-326, Ult-163 and Ult-106). The test was performed during the season 2000-2001, had randomized blocks and was repeated thrice. The plantation distance was of 1,2 metres by 0,5 metres (16.666 plants per ha). Pre-transplant, fertilization was performed with blend 10-16-20, in doses of 600 kg/ha; and during side dressing simple potassium nitrate (15-0-14) was used. Topping was performed on 18 to 20 leaves by plant.

The following results were noted (also see Table 25): All the varieties had high yields; in some cases even exceeding 3 tons per hectare. A direct relationship between nitrogen application and yield was also established: a higher nitrogen level produces higher yield.

Table 25. *Relationship between nitrogen doses, yield and quality.*

Nitrogen dose (Kg/Ha)	K 326 (Yield)	ULT 163 (Yield)	ULT 106 (Yield)	K 326 (Quality)	ULT 163 (Quality)	ULT 106 (Quality)
70	2214	2367	2479	79,1	77,3	76
100	2551	2647	2839	78,8	79,2	77,6
130	2837	3082	2864	78,5	78,2	77,5
160	3029	3252	3341	77,1	77,6	79,2
190	3315	3584	3671	75,8	77,2	76,6

On the other hand, regarding the percentage of leaves of superior quality (also see Figure 59), the answer is less obvious in the Ult-106 variety. Nevertheless in the other two varieties we can observe that there is a distinct inverse relation between the applied nitrogen level and the obtained quality. Whereas the best results in the 3 varieties that were studied, for this quality parameter, are obtained with 100 units of N per hectare.

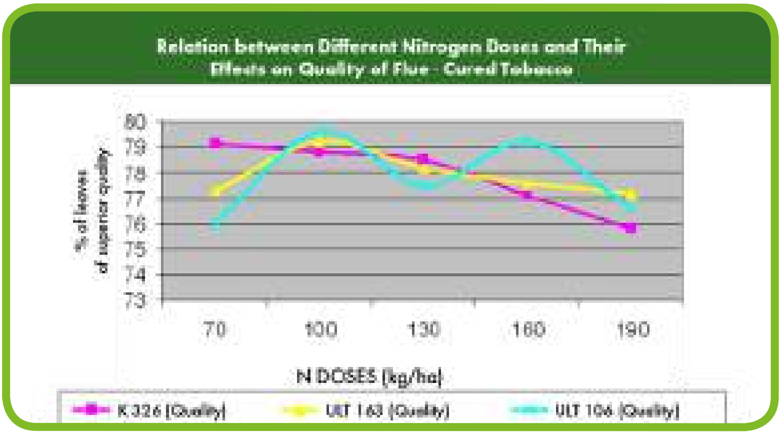


Figure 59. *Relationship between different N doses and their effect on the quality of flue-cured tobacco.*

On the other hand when measuring the total quantity of alkaloids and the total sugar contents in the leaves, all 3 varieties show a direct relation between the applied nitrogen levels and the total quantity of alkaloids in the leaves (also see Figure 60). Or in other words: the higher the nitrogen quantity, the higher the quantity of alkaloids in the leaves.

However, the opposite happens with regard to the sugar contents in the leaves, i.e. there is an inverse relation between the sugar levels in the leaves and the levels of the applied nitrogen. The interesting thing is that with levels of 70 to 100 units of N per hectare there are still more than 20% of sugars in the leaves. When applying more than 130 units of N, an important drop is noticed. Whereas the levels of alkaloids, with the doses of 100 to 130 units of N per hectare, exceed 2% in the leaves and only surpass 3% with the highest doses and in only one variety (Ult-163), as can also be observed in Figure 60. According to the author, the best chemical balance for the Brazilian crop conditions (climate and soil) were obtained with around 130 nitrogen units per hectare.

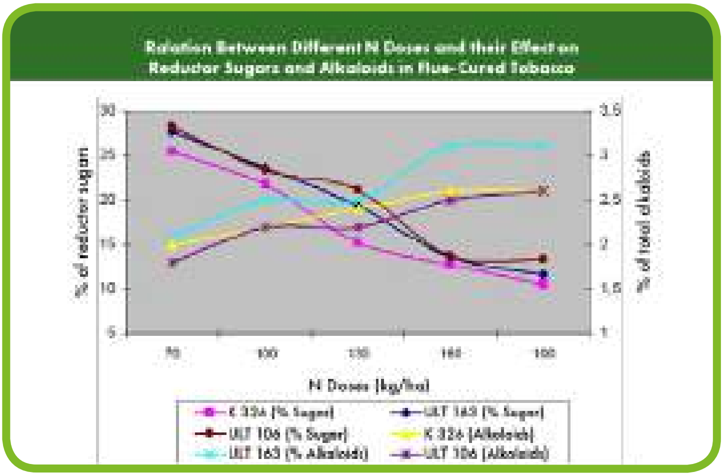


Figure 60. *Relationship between different N doses and their effect on reductor sugars and alkaloids in flue-cured tobacco.*

The next test was performed in Brazil by the same author (engineer Sergio Willani) for Burley tobacco. During that test 5 different increasing doses of nitrogen were applied (respectively 130, 170, 200, 230, 260 and 290 units per hectare) on 4 different varieties (namely TN-86, TN-90, Ult-661 and Ult-682). The test was performed on randomized blocks and was repeated thrice. The plantation distance was of 1,2 metres by 0,45 metres (18.518 plants per ha). Pre-transplant, fertilization was performed with blend 10-18-20, in doses of 600 kg/ha; and during side dressing simple potassium nitrate (15-0-14) was used. Topping was performed on 20 to 22 leaves by plant. The results can be observed in Table 26.

Table 26. *Relationship between nitrogen doses, leaf quality, alkaloids percentage and yield for Burley tobacco.*

Nitrogen Dose (Kg/Há)	% of leaves of superior quality				% of alkaloids in the leaves				yield in tonnes per hectares			
	TN 90	ULT 661	ULT 673	TN 86	TN 90	ULT 661	ULT 673	TN 86	TN 90	ULT 661	ULT 673	TN 86
140	95,1	93,9	95,0	94,4	3,8	3,3	3,7	3,0	2.085	2.318	2.088	2.163
170	94,8	95,2	94,1	95,1	3,4	3,7	3,6	3,5	2.159	2.220	2.189	2.244
200	96,1	95,0	95,5	95,2	3,3	3,4	3,9	3,0	2.416	2.106	2.229	2.358
230	94,0	95,8	95,6	95,6	3,5	3,8	3,2	3,1	1.949	2.148	2.150	2.207
260	96,1	95,3	95,4	96,8	3,9	3,4	3,5	3,2	2.583	2.498	2.586	2.532

3 out of the 4 varieties show an ascending yield curve, along with an increase of the applied nitrogen, as can be observed in Figure 61.

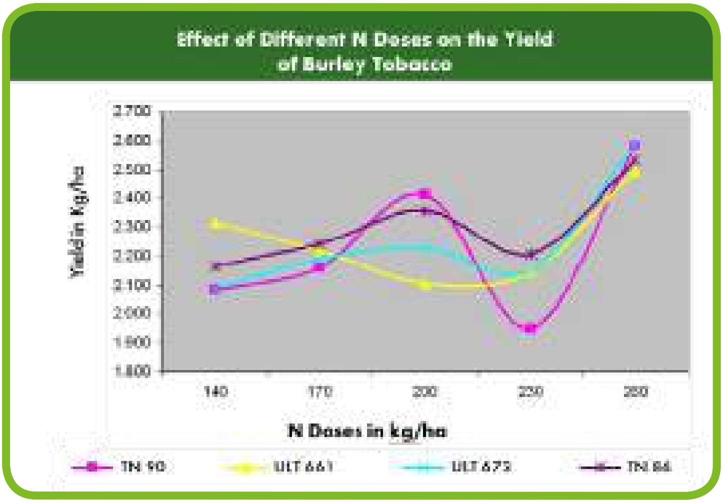


Figure 61. *The effect of different N doses on the yield of Burley tobacco.*

The only variety that shows a zigzag tendency is TN-90. When applying between 170 kg/ha and 200 kg/ha of nitrogen the yield increases, but when applying between 200 kg/ha and 230 kg/ha the yield drops, whereas yield increases again as from applications of 230 kg/ha. The other 3 varieties show an important yield increase between 230 kg/ha and 260 kg/ha.

With respect to the percentage of leaves of superior quality, the tendency indicates that as the applied nitrogen dose increased, also the percentage of leaves of superior quality increased, as is shown in Figure 62.

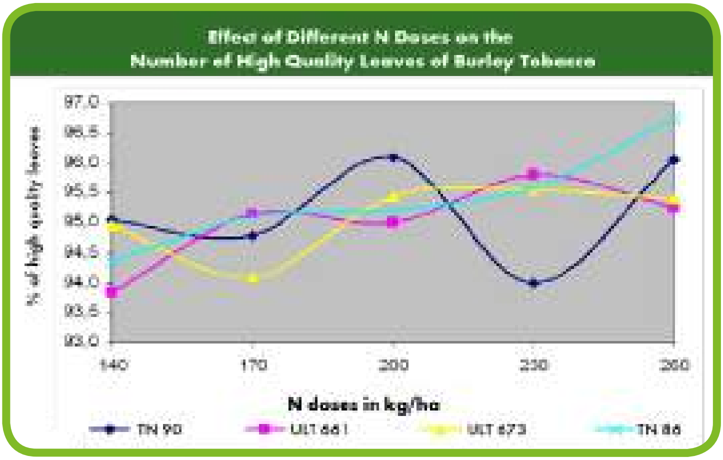


Figure 62. *The effect of different N doses on leaf quality in Burley tobacco.*

The only exception was again observed for the TN-90 variety, where an important drop can be observed when applying between 200 kg/ha and 230 kg/ha. And finally, when referring to the percentage of total alkaloids in the leaf, the different applied doses show similar results, that is to say, that the levels of alkaloids in the leaves stayed relatively stable (between 3% and 4%) independent of the applied nitrogen dose, as is shown in Figure 63.

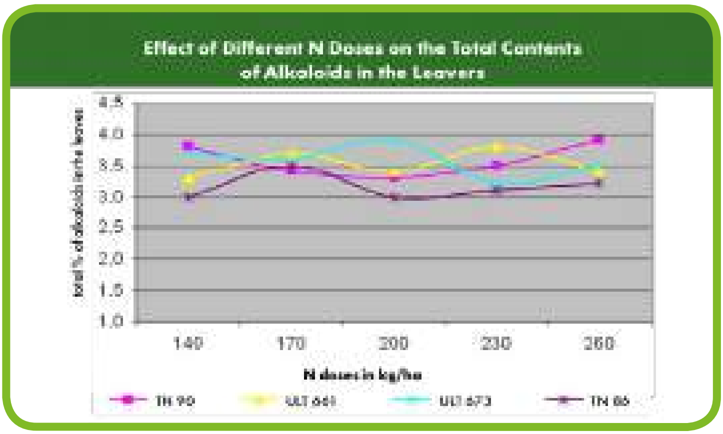


Figure 63. *The effect of different N doses on the total contents of alkaloids in the tobacco leaf.*

9 Field Trials

The following tests were performed in China during different seasons and were presented by Dr Hernán Tejeda at the 2001 International Tobacco Seminar.

During this test the response of flue-cured tobacco to different doses from nitrogen was measured in terms of yield (kg/ha), percentage of total alkaloids and harvest quality (% of leaves of superior quality). In both cases (also see Figure 64) we can observe that as the applied doses of nitrogen increased, there was also an increase of yield, of the percentage of leaves of superior quality, and of the percentage of total alkaloids.

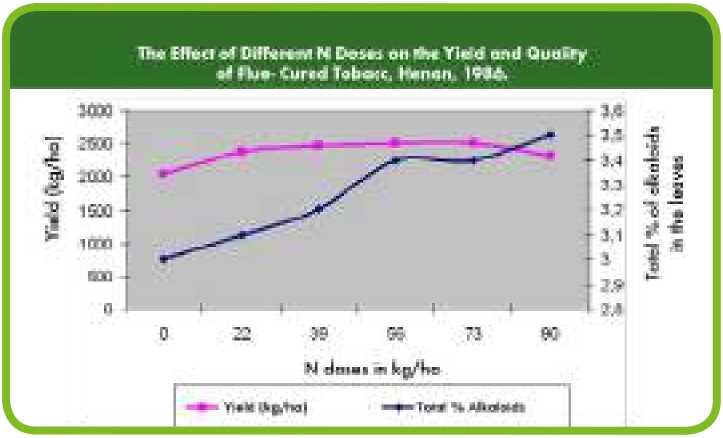


Figure 64. *The effect of different N doses on the yield and quality of flue-cured tobacco, Henan, 1986.*

From Figure 64 we can especially learn that as the applied nitrogen dose increases, yield also increases but only until the application of 73 units of nitrogen, after which the yield diminishes.
With regard to the alkaloids, we can observe an almost linear increase along with the increase of the applied nitrogen doses.

Figure 65 shows the relationship between increased doses of nitrogen and the yield and quality of the leaves. Here can be observed that increased doses of nitrogen, increase the yield and the percentage of leaves of superior quality, but the maxima are obtained at different doses, since yield was maximized when applying 67 nitrogen units per hectare, whereas 82 nitrogen units per hectare gave rise to the highest percentage of leaves of superior quality.

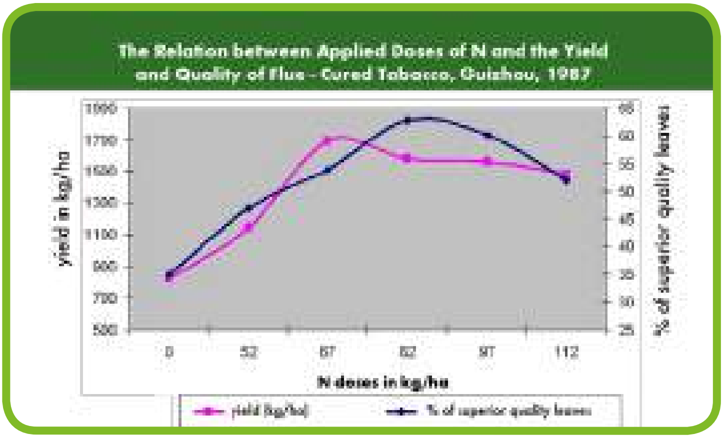


Figure 65. *The relationship between applied doses of nitrogen and the yield and quality of flue-cured tobacco, Guizhou, 1987.*

The following test was also performed in China during different seasons and was also presented by Dr Hernán Tejeda at the 2001 International Tobacco Seminar. Here the effect of the kind of nitrogen (nitrate and ammonium) was measured on yield and quality of flue-cured tobacco. During the first curing the nitrogen source was 100 % nitrate; during the second curing 75% nitrate and 25% ammonium were applied; the third application was done with 50% nitrate and 50% ammonium; the fourth had 75% ammonium and 25% nitrate; and finally, the fifth application was made with 100% ammonium. Both results indisputably indicate that as the crop-applied nitrate-nitrogen dose increases, so do yield and quality, as is shown in Figure 66. Therefore the use of these nitrate-nitrogen sources, which initially come at a higher cost, are highly recommended to the producer, since the increase in yield and quality, which generate a higher income, fully pay back the higher initial cost.

Figure 66. *Effect of different N doses on the number of hight quality leaves of burley tabacco.*

Both tests, performed in different seasons, also consistently show that as the applied dose of nitrate-nitrogen increases, so do the obtained yield and the percentage of leaves of superior quality, as is shown in Figure 67.

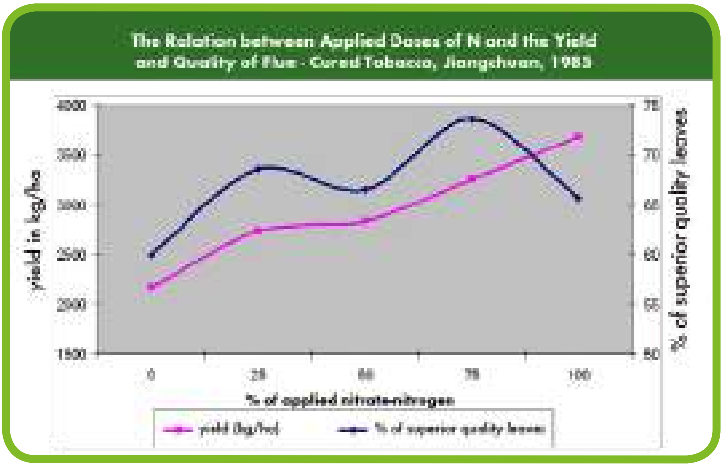


Figure 67. *The relation between applied doses of N and the yield and quality of flue cured tabacco, Juangchuan, 1985.*

Nevertheless maxima occurred at different nitrate-nitrogen doses: maximum yield with the greatest nitrate-nitrogen dose (100%), and, maximum percentage of leaves of superior quality with 75% of nitrate-nitrogen.

With respect to these results, it can be discussed if 75% or more than 75% of nitrogen in its nitrate form is to be applied, but what is certain, is that tobacco prefers nitrate-nitrogen as nutrient source, and that its application results in the best yields and quality.

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