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Action 3 – Development of alternative agricultural practices. Lab experiments (Spain)

"Guide for open field and greenhouse cultivation of the tested crops (Spain)"

CEBAS-CSIC

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Contents

Executive Summary

Along this Deliverable, the potential of organic wastes to supply macro and micronutrient to crops acting at the same time as soil improver is considered and some main considerations that must be taken into account before their addition to the soil as organic fertilizers are indicated. Suggestions for the calculation of the organic material application dose for crop cultivation are also given.

The use of organic wastes as alternative to commercial chemical fertilizers constitutes an energy saving apart from the benefit of avoiding soil erosion and degradation and loss of soil fertility. This aspect is also discussed in this Deliverable.

Recommendation about the fertilization of winter (wheat and barley) and spring (maize) cereals (open-field crops) and horticultural crops (cultivation on soil in green-houses) are given, as well as recommendations about the calculation of the amount of nutrients to be added on the basis of soil inputs and losses, the application of topdressing N fertilization, and time of fertilization.

1. INTRODUCTION

Organic materials such as animal manures and agricultural and forestall residues have been utilized for years in many countries for fertilizing and maintaining or improving the productivity and fertility of their agricultural soils. With the advent of chemical fertilizers, organic wastes were gradually replaced by mineral products due to the fact that they were relatively inexpensive, easily available and of easier transportation and application and often produced dramatic yield increase (Pomares and Canet, 2001). Consequently, the importance of organic matter in crop production received less emphasis and its proper use in maintaining soil productivity was neglected. As a result, and with failure to implement effective soil conservation practices, the agricultural soils in many countries have undergone extensive degradation and have declined in productivity. This degradation results in excessive soil erosion, nutrient runoff and loss of organic matter which consequently results in soil acidity, nutrients imbalance and low crop yields. Soil nutrient depletion is the result of increasing pressure on agricultural land, resulting in higher nutrient outflows that are not compensated for (Wopereis et al., 2006).

When the first world energy crisis began, chemical fertilizers had largely replaced organic sources of plant nutrients in many countries. The massive use of chemical fertilizers in intensive agriculture has greatly increased the concern for the declining fertility of soils, which have given rise to urge greater utilization of organic materials as fertilizers and amendments for improving the fertility and productivity of agricultural soils.

Nutrients contained in organic wastes are released more slowly and are stored for a longer time in the soil, thereby ensuring a long residual effect (Sharma and Mittra, 1991). Improvement of environmental conditions and public health as well as the need to reduce costs of fertilizing crops are also important reasons for advocating increased use of organic materials (Seifritz, 1982). Proper management and use of agricultural and municipal organic wastes on land provides the best mean for protecting soils from wind and water erosion, preventing nutrient losses through runoff and leaching, and for maintaining and restoring soil productivity. Organic materials serve not only as sources of plant nutrients (i.e. as fertilizers), but also as soil conditioners by improving soil physical properties, as evidenced by increased water infiltration, water-holding capacity, water content, aeration and permeability, soil aggregation and rooting depth, and by decreased soil crusting, bulk density, and runoff and erosion (Ros et al., 2001 and 2003; Tejada et al., 2009). Application of organic materials also improves the soil chemical and microbial properties (Belay et. al., 2001).

Complementary use of organic materials and mineral fertilizers has been proved to be a sound soil fertility management strategy in many countries of the world (Lombin *et al.*, 1991). High and sustained crop yield could be obtained with judicious and balanced NPK fertilization combined with organic matter amendments (Palm et. al., 1997; Makinde *et al*., 2001; Bayu et. al., 2006).

Sometimes, organic amendments application as a substitute for the conventional mineral fertilization does not render the expected results because some crops have high nutrient needs or punctual needs throughout their growth cycle, and large quantities of OW would be necessary to satisfy the overall needs of the crop, and/or the OW would not supply sufficient quantities of nutrients at the right moment. Bazzoffi et al. (1998) found that urban refuse compost produced a lower maize grain yield than mineral fertilization, as did Businelli et al. (1990). A combination of compost application with a nitrogen mineral fertilizer meeting N needs was therefore proposed for maize, a high nutrient-demanding crop, to replace the conventional mineral fertilizer.

A system that integrates different practices of soil fertility maintenance is required. This will include the use of mineral fertilizers, organic manures and intercropping.

In this report, general recommendations for the fertilization of both cereal and horticultural crops are given, which are valid for both, open-field and green-house cultivation. The potential capability of organic wastes to supply the amount of nutrients demanded by the different crops is discussed. The combined use of organic wastes and mineral fertilizer may be the best strategy for obtaining high yields maintaining soil quality. Our proposal is that organic fertilizers are used for starting fertilization, this fertilization being complemented by topdressing N fertilization when necessary.

2. USE OF ORGANIC MATERIALS AS FERTILIZERS AND SOIL CONDITIONERS IN CROP SYSTEMS.

Depending upon the material, organic wastes can supply macronutrients (N, P, and K) and micronutrients to the soil used by crops. These materials can replace part of or all synthetic fertilizers used in a cultivation and in addition, improve soil physical (infiltration, water holding, structure, etc.), chemical (cation exchange capacity, fertility, etc.) and microbiological properties. Through agricultural utilization of organic wastes, producers can benefit from materials that otherwise may be placed into landfills or present environmental pollution problems.

Some organic materials are known to mineralize and release available plant nutrients rapidly as a result of microbial attack. In some cases this is desirable, particularly on soils that are already in a high state of fertility and productivity. On the other hand, marginal, erodible, sloping, and generally less productive soils would benefit, at least initially, from application of organic materials having a degree of microbial stability in soil. Such materials would release their plant nutrients at a relatively slower rate. A high nutrient availability index (NAI) indicates materials that would release nutrients relatively rapidly, while a high organic stability index (OSI) would be associated with more stable forms of organic matter. Materials with the high NAI value usually would be expected to have a low OSI value, and conversely.

Farmers often have the possibility to use both types of materials in their farming operations depending on whether there is a need to release nutrients rapidly, or to improve the productivity of marginal soils. However, the relative proportion of nutrients contained in some organic materials may not be in optimum balance for some crops. For example, when sewage sludge compost is applied at N fertilizer recommendations to sustain a corn crop, it is likely that P will be applied in excess of that needed by the crop. Thus, the excess P is wasted or might even become an environmental pollutant.

Certainly, the most acceptable strategy for maximizing the agronomic and economic benefits from organic wastes and residues would be to (1) determine exactly what a farmer is trying to achieve, e.g. restoration of the productivity of an eroded soil or to provide supplemental N to a high value crop, (2) determine the approximate organic stability index (OS) and nutrient availability index (NAI) of the organic materials to be used, and (3) determine what practical and workable combinations of organic materials and mineral fertilizers are most appropriate to accomplish the proposed task.

Most organic wastes and residues are low in their content of macro-and micronutrients compared with most chemical fertilizers. However, research has shown that crop yields are consistently higher when organic materials are applied in combination with chemical fertilizers than when either, -is applied alone. This would suggest that organic materials can increase the efficiency of chemical fertilizers and, if so, farmers might be able to reduce their fertilizer (and energy) inputs accordingly.

2.1. Considerations before applying organic fertilizers

Application rates should be based upon soil fertility, crop requirements, and chemical characteristics of the waste. Timing will depend upon crop needs and the weather. The application method will depend upon the physical characteristics of the waste and upon equipment availability. Generally, solid wastes can be applied with a manure spreader or common tillage equipment. Liquid wastes may be injected, broadcast, or applied through an irrigation system. Semi-solid or slurry wastes may require special equipment or may be modified so they can be handled with available or conventional equipment.

2.1.1. Risk assessment

It must be kept in mind that organic wastes may prove beneficial or detrimental, depending upon how wisely they are used and upon waste characteristics. Manures and recycled organic fertilizers are derived from waste products and may contain contaminants or undesirable elements, which if not considered, may result in adverse outcomes on soils or even create a nuisance to neighbors. One waste material may provide valuable nutrients and improve soil productivity if applied appropriately, or damage soil productivity and possibly contaminate water resources if applied inappropriately.

In the application of organic amendments to soil, its agronomic quality is an aspect of crucial importance. In general, it is advisable to apply stabilized organic products and sanitized by means of a composting process or similar, in order to reduce potential risks associated with the implementation of the raw organic materials, such as nitrogen immobilization, releasing of phytotoxic compounds, the presence of pathogen microorganisms, weed seeds, etc.. Likewise, the content of heavy metals in organic amendments and organic fertilizers must be below the maximum permitted by the regulations.

2.1.2. Organic material nutrient content and availability

The quality and nutrient content of recycled organic wastes can vary considerably and is influenced by a number of factors including product type, treatment, and further processing such as composting. Therefore organic wastes should be characterized before their use.

Organic materials can be applied primarily for their nitrogen (N), phosphorus (P), or potassium (K), depending on crop requirements and available quantities. With any organic product it takes time for nutrients to become available, as microbial action is required to convert them into forms available to plants. Microbial activity is greatest in warm soils with good levels of available moisture.

The availability of N, P, K, and other nutrients from organic wastes (OW) needs to be determined so that these organic resources can be effectively utilized.

Nitrogen (N)

The application of organic wastes (OW) represents an important supply of N to the soil. This N may be immediately available to plant or need that the organic fraction of the OW is mineralized to become available. Nitrogen in OW can be divided in four fractions:

i) Inorganic N (NH_4^+ and NO_3^-), which can be used directly by plants or be lost by leaching (mainly nitrates) or volatilization (ammonium).
ii) Organic N prone to be rapidly mineralized, mainly urea, which is easily transformed to ammonium.
iii) Organic N able to be mineralized at medium-term composed of organic N compounds that are mineralized by microorganisms in few months.
iv) Organic N of slow mineralization. This fraction is constituted of organic complex resistant to microbial degradation needing years to be mineralized.

Immediately after the addition of OW to soil, mineralization and immobilization processes occur, which determine N mineralization rate and consequently N availability. It has been indicated that the addition of OW to the soil increases microbial biomass and the extracellular enzymatic activity in comparison with the addition of mineral fertilizers (Zaman et al., 1999, Tejada et al., 2010). This increase in microbial biomass and activity can lead to the immobilization of the N supply by OW, the duration and extent of this process depending on the type of organic compound, and the temperature, moisture and texture of the soil.

In general terms N mineralization from composted OW is lower than that of raw wastes. The lower N mineralization from compost is due to the fact that most of the easily convertible C and N compounds are lost during the composting process and the remaining C and N is in more stable forms. Table 1 shows estimated N mineralization for some OW.

Table 1. Estimated rates of organic N mineralization

Organic Waste	Organic N mineralization rate during the first year of application, %
Composts	25-30
Pig slurries	90-95
Poultry	55-70
Swine	40
Stabilized pig manure	40-50
Sheep manure	40-50
Pig manure	60-70

Source: Hirzel and Salazar, 2011;

The estimated fraction of organic N mineralized in the field in the first year of application ranges from 25% for composted wastes to 95% for pig slurry (Table 1), indicating different N components in each OW type. Greater N availability from pig slurry is due to the high ammonium-N concentrations in this type of manure. Nitrogen in fresh wastes is relatively volatile, and as much as 50% may be lost as ammonia or nitrogen gases during storage and after their application to land.

Phosphorus (P)

Organic waste application based on phosphorus is becoming more common in areas with high risk of P loss in runoff, since repeated application of recycled organics based on their nitrogen content, can lead to the accumulation of phosphorus in the soil, which can have adverse impacts on water quality.

Phosphorus also needs to be mineralized before it becomes available to plants. In the first year of application only 10 to 50 % of the total phosphorus applied in organics is likely to be available to the crop.

Most of the P in manure is inorganic (> 75%) indicating that P availability following application should be very high. Based on the soil test P changes and plant P uptake one year after application, it has been shown that P availability in the first year after application was 85% for beef cattle feedlot manure and 73% for composted feedlot manure (Eghball and Power 1999). Slightly lower P availability from composted manure indicates a chemical reaction of P during composting, which caused P to become less plant-available. There is substantial variability in the estimates of P availability from manure and composted manure. Motavalli et al. (1989) found that P availability from injected dairy manure ranged from 12 to 89% based on corn P uptake. The low P availability in this study was due to a small P response from applied manure P.

In a field study, Wen et al. (1997a) found that 69% of composted manure P was plant-available. Phosphorus availability from all manure types is high and can be assumed to be at least 70%. The P in manure can be used similar to P fertilizer (100% available) in areas with adequate soil P for crop production to avoid soil P accumulation. In P deficient areas, an estimation of at least 70% availability from manure should be considered. The amount of P available in the second, third, and fourth years after application is small and can be determined by testing soil for available P.

Potassium (K)

Potassium is also an immobile nutrient and incorporating recycled organics into the soil will improve its availability and prevent run-off. Potassium in manure and compost is highly plant-available and can be used similar to K fertilizer application. In a field study, Wen et al. (1997b) found K availability of 100% from composted manure. Potassium in other manure types is also expected to be about 100% plant available and therefore, these resources can be used similar to K fertilizer.

Secondary nutrients and micronutrients

Plants require macro and micro nutrients for normal growth. Secondary nutrients required for plant growth include sulfur (S), calcium (Ca), and magnesium (Mg). Important micronutrients include boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn). Micronutrients are also important for plant growth, as plants require a proper balance of all the essential nutrients for normal growth and optimum yield.

The micronutrients zinc and copper or macronutrients such as sulfur are also found in recycled organics, particularly chicken manure and biosolids. Manure usually contains all the nutrients required for plant growth and therefore can be a good source of these plant nutrients. But not all of the secondary and micronutrients in manure are plant-available. These nutrients need to be mineralized in the soil before being absorbed by plants. Sulfur mineralization was found to range from 62 to 127% in an incubation study (Tabatabai and Chae, 1991), indicating that in some cases manure S is immobilized. Information on the mineralization of other secondary and micronutrients is limited.

2.1.3. Assessment of soil nutrient status and crop nutrient needs to be grown

Soil analysis is recommended to determine its level of available nutrients in order to establish the level of baseline of micronutrients. The concentration of available soil nutrients depends on soil properties, cropping and fertilizer history, land management and climatic conditions.

Plant nutrient requirements depend on soil fertility, the crop to be grown and the target yield of the crop. The rate of nutrients applied should be equal to or greater than the nutrients removed by the crop over time so that soil fertility can be maintained.

2.1.4. Calculation of the organic material application rate

The calculation of the application rate of organic material required to meet crop requirements should be based on dry weight of product and take into account potential nutrient losses as a result of chemical processes, particularly for nitrogen, and time required to mineralize nutrients before they become available to plants. The content of total and available N (ammonium + nitrates) in the OW is obtained by analysis of the OW.

If for example, an application of 119 kg N/ha is required using a compost containing 30% moisture, 3% total N and 0.5% inorganic N, the amount of compost to be added admitting a compost mineralization rate of 30% will be the following:

Organic N in the compost= 3%-0.5% = 2.5%;

N_{total} (kg/ha year)= initial N_{min} (kg/ha)+initial N_{org} (kg/ha) x 0.30

119 kg N/ha = A kg compost (dw) x 0.005 + A kg compost x 0.025 x 0.30= 0.005A+0.0075A =0.0125 A; A= 119/0,0125 = 9,520 kg dry compost/ha.

2.2. Economic value of organic materials as fertilizers.

When organic wastes of acceptable quality are applied to agricultural soils on a regular basis they contribute greatly to the overall maintenance of soil fertility and productivity and reduce the need for mineral fertilizers.

It is obvious that the use of OW as an alternative to the use of manufactured chemical fertilizers represents an energy saving, but in addition to help minimizing the use of energy, the use of these organic materials contributes to minimization of the pollution of air, water and soil, and maintains the productivity of the agricultural soils.

The simplest and most common means of estimating the value of organic materials is to consider them as substitutes for commercial fertilizers that would otherwise have to be purchased. This is done by assessing the current market value of the plant nutrients they contain, especially in terms of their macronutrient content, i.e., nitrogen, phosphorus, and potassium.

Many organic materials contain other components in addition to organic matter and macronutrients (N, P, K) which can contribute significantly to higher crop yields. These include secondary nutrients (S, Fe, Mg), micronutrients (Cu, B, Zn, Mn, Mo), and sometimes lime. When these constituents can be substituted for essential production inputs the value of the organic material would increase accordingly. On the other hand, some organic materials may contain such constituents as soluble salts, heavy metals, and hazardous organic chemicals that could adversely affect soils, plants, animals, and the human food chain. Some materials may have especially high C/N ratios, or unusually high levels of acidity or alkalinity. All of these would, of course, reduce the value of the material for use as fertilizers and soil conditioners.

In some cases, the organic component of a particular material may have a higher monetary value than that of its total nutrient content because of the beneficial effect of organic matter on soil physical properties and improvement of soil productivity. This is especially true when certain organic materials are used to restore the productivity of severely eroded agricultural soils, or to reclaim marginal soils (Hornick, 1982).

The economic value of an organic waste or residue to a farmer is the value of the increase in crop yield and/or crop quality that is derived from its use. The actual profitability of using organic materials will vary with the quality of the organic materials, the price of the organic materials including the cost of transportation and application, as compared with its substitutes, the value of the crop, and other variables. The rate at which organic materials decompose or mineralize in soil is highly variable. Nevertheless, they do have a greater residual effect on soil fertility than most chemical fertilizers because of the slow-release character of the nitrogen and phosphorus components. Thus, a significant portion of the economic value of organic materials as fertilizers is their capacity to elicit yield responses from succeeding crops. This response must be accounted for to assess the true value of the material. Barbarika et al. (1980) and Colacicco (1982) estimated that the cumulative economic value of some organic materials applied to agricultural soils could be as much as five times greater in succeeding years than the value realized during the application year.

Summarizing, the short-term value of recycled organics as an alternative to inorganic fertilizers can be assessed by assigning an economic value per kilogram of nutrient for inorganic fertilizers. This can then be used as the basis for comparing the potential value of nutrients in recycled organics. Additional costs include transport, handling, storage and spreading costs, which will vary from site to site and product to product. Application issues will be an important consideration in deciding whether or not to use recycled organics. Fresh manures, for example, can be lumpy and difficult to apply evenly. Aged and screened products will be easier to apply but may be more expensive. The volatility of nutrients in recycled organics makes it difficult to accurately determine the effective quantities of plant-available nutrients, which can also make it difficult to determine the economic value of nutrients in a fertilizer.

The other effects of using recycled organics are also variable, depending on the product used and how it is applied. Soil biology is complex and relatively little is understood of the effects of amendments on soil biological processes and benefits may not become apparent until several years after application. The cost effectiveness will be site specific, however, potential benefits include:

- ✓ the addition of organic matter and carbon to soils;
- ✓ improved soil structure, infiltration, water-holding capacity and porosity;
- ✓ improved soil biological properties, including microbial biomass and activity, as well as macro-fauna; and
- ✓ improved yields as a result of improved soil structure.

3. FERTILIZATION OF CEREAL CROPS

3.1. Winter cereals. Wheat and barley

3.1.1. General aspects

In winter wheat growth the following main vegetative phases can be distinguished: emergence, tillering, stem elongation, spike emergence and maturation. The critical period of water needs for wheat are the phase of ears development, flowering and the initio of grain formation. The highest water needs in growing barley are given from the end of the state of booting until the spike emergence stage.

The best wheat yields are obtained in silty clay or clay soils, with good calcium supply, good absorbency and not too airy. In light soils wheat have often nutrition deficiencies and water stress in the period of grain maturation. Barley grows well in loam or slightly loamy, well-drained soils. In sandy soils, which do not store enough water it can be quickly exhausted, and the uniform growth of the crop is interrupted. Barley is more tolerant than other cereals to basic soils and less tolerant to acid soils.

As regards nutrition, nitrogen is the nutrient with the greatest influence on the cereals yield. However, each of the three major elements (nitrogen, phosphorus and potassium) does not produce its full effect if sufficient quantities of the other two are not present. The interaction between nitrogen and potassium is probably the most important. Thus, thanks to potassium, nitrogen can increase productivity by more than 50%.

Phosphorus improves earliness in cereals and promotes root development, taking an essential role in the formation of the spike and grain, and potassium is especially important in functions that ensure the growth of the plant. The cereals resistance to frost, flattening and disease is higher if they have nutrition rich in potassium.

In addition to nitrogen, phosphorous and potassium, cereals also absorb significant quantities of calcium and magnesium and especially sulfur, but never to levels as high as the three main elements.

The absorption of mineral elements by cereals is intense from tilling and stems elongation until the appearance of the spike. Typically nitrogen and potassium are absorbed more intensely and early than phosphorus.**124**

3.1.2. Nitrogen fertilization

Nitrogen fertilization (organic or inorganic) should complement in time the release of nitrogen from organic matter. The establishment of the dose of fertilizer and date of application is a complex problem which needs to be solved each year.

To make such a decision a set of knowledge (crop requirements, soil reserves, climate and previous crop residues), observations (state of the medium and culture) and rough estimates (meteorology future and potential crop yield) must be brought together.

The difference between the absorption of nitrogen for the crop and soil nitrogen availability theoretically determine the amount of fertilizer to apply. However, it will be necessary to introduce a corrective index based on the actual effectiveness of the fertilization. This index of efficiency is considered that under field conditions varies from 40 to 80%, although when there is water shortage or fertilization takes place at seeding N efficiency may be lower.

A simple way of establishing the application dose is to estimate the needs of nitrogen based on the production target, establishing that the contributions provided by the soil are balanced with the coefficient of fertilizer utilization, winter leaching and blocking of mineral nitrogen derived from the buried of the precedent crop residues (Table 2).

Table 2. Components considered for the balance of use for estimating N fertilization needs

Inputs (+)	**Extractions (-)**
Mineral N in the soil	Crop extraction for an expected production
Mineralization of soil organic matter	Losses of N by lixiviation or volatilization
Mineralization of the organic matter added with the organic fertilizers	
Mineralization of N contained in crop remains from previous cultivation	
Contribution of N by irrigation water	

Nitrogen fertilization of wheat

Wheat nitrogen needs are in average 30 kg per 1,000 kg of grain produced. These needs can vary, depending on the variety and environmental conditions, from 28 to 40 kg of nitrogen per 1,000 kg of wheat.

The overall dose of nitrogen fertilizer commonly used for wheat ranges from 120 and 200 kg N/ha, depending on the expected return, the rainfall and cultivation techniques. The distribution or fractionation of the overall dose of nitrogen fertilizer, depend on weather conditions during wheat growth and cultivation practices, especially planting time, plant density and the characteristics of the variety.

In the fractionation it must be taken into account the influence and importance of winter leaching and that the largest wheat nitrogen requirements are in the period between tillage and stem elongation. It may be desirable, at times, smaller nitrogen inputs before seeding which have a “starting” effect, especially in late plantings to encourage tillage, and in poor soils where the previous cultivation was very impoverishing. It may also be advisable this application in heavy soils, having a high water holding capacity or when there may be difficulties in subsequent applications to the already established culture.

The following application may be performed by the initio of tillage (state 3-5 leaves). In this application, crop nitrogen needs must not be exceeded, because excessive vegetative growth can cause barley flattening.

Another application may be made at the end of the tillage phase and beginning of stem elongation and should be the last in areas where the lack of rain in spring is frequent. Undoubtedly, the dose of this contribution is the most important because of its influence on yield since it increases the force of the stems formed and the proportion of stem with ears, enhances the development of upper leaves, promotes or increases the fertility of the ears and improves grain filling.

Nitrogen fertilization of barley

Barley cultivation extracts from the soil one average of 25 kg N per 1,000 kg of grain produced. In semiarid climates, typical of barley cultivation, analysis of residual mineral nitrogen in the soil before planting has shown to be a useful data to establish barley nitrogen fertilization as there is a good correlation between that measure and yield. Soil depth recommended for sampling varies between 60 and 120 cm.

Under irrigated conditions, the content of proteins does not vary up to a dose of nitrogen over 100 kg/ha, increasing quickly after that dose. In the most humid zone with yields ranging between 3,000 and 5,300 kg/ha the optimum dose varies between 80 and 140 kg/ha.

Some studies have shown that application of nitrogen at planting can be more effective on the yield of barley than applications carried downstream of cultivation. Late applications can significantly increase the proteins grain content, so they must be used sparingly in malting barleys, in which a high level of nitrogen can be harmful. The application of nitrogen in the early vegetative stages improves growth and yield, while it does not affect yield when applied spiking emergence, though it substantially increases the protein content of the grain.

3.1.3. Fertilization of phosphorus and potassium

For phosphorus and potassium, elements that are retained in the soil, the knowledge of their content in the soil, the extraction by crop and refunds should allow estimating the quantities that is necessary to provide. The amount of phosphate and potassium fertilizer must be established on the base of crop extraction and the actual level of soil fertility that will determine the degree of response to fertilization.

One of the most challenging aspects with respect to phosphorus fertilization is its fixation in the soil, which may lead to its efficiency does not exceed 20%. To this, its low mobility and low absorption by plant under cold or drought must be added, which is frequent during the growth of winter cereals in semiarid areas. For all these reasons, it is advisable to apply higher amounts of fertilizer than that indicated by crop extraction and level in soil, in order to preserve or increase the solubility of the fertilizer.

Potassium dose will depend on the effectiveness of the fertilizer (estimated as 80% on average) and conversion levels of available form in fertilizer and vice versa. Much of potassium absorbed by cereals is restituted to the soil as crop residues.

Since both, phosphorus and potassium are retained in the soil, especially in heavy clay soils, the application of both elements must be done with the soil preparatory work, which allows burying and spread along the topsoil, facilitating the highest availability by the roots. It is not very advisable to carry out the phosphorus-potassium fertilization for several years, but it is preferable to do it annually.

Phosphorus-potassium fertilization in wheat crop

Wheat extracts as average 12 kg phosphorus pentoxide (P_2O_5) and 28 kg of potassium oxide (K_2O) per 1,000 kg of grain produced, including the corresponding vegetative organs. In soils that have sufficient reserves of phosphorus and potassium it will be only necessary to replace the amount extracted by the previous crop, performing what is called a maintaining fertilization. When the soil is poor in some of these elements, it will be necessary to make a fertilization of correction to increase stores to the optimum level.

In practice, for phosphorus and potassium fertilization the following criteria should be taken into consideration:

- To perform periodic soil analysis of available phosphorus and potassium to observe their evolution (every 3-4 years).
- To compare the results of these analyses with the established critical levels, which depend on the type of soil and cultivation techniques.
- To determine in culture, or rather in the rotation cultivation, the amounts of phosphorus and potassium absorbed by the plants, those which can be leached (especially potassium in light soils) and quantities passing to insoluble forms (in case of phosphorus in highly calcareous soils).

The coefficient of phosphorus fertilizer utilization is relatively low, only 15-20% of it is removed by the crop the first year. The application located at the planting lines improves the efficiency of fertilizer on the first year compared to broadcast application, especially in soils with low available phosphorus. In soils with a phosphorus content of medium to high differences between both application forms are minimal.

In very sandy and shallow soils special attention should be paid to the potassium fertilization due to the possible loss of the same amount by leaching. Mean doses recommended in soils with medium to low potassium content are of 100-120 kg K_2O/ha. The buried fertilizer at 10-15 cm depth improves the efficiency of its use by the plant.

Phosphorus and potassium fertilization in barley crop

As with wheat, the response of barley to fertilizer depends on the level of these nutrients in the soil. The localized application in the seed line at low doses can be very effective when there is little phosphorus available in the soil, obtaining yields equivalent to doses applied by broadcast two or three times higher. Phosphorus increases the resistance of barley to winter, interacting crop response with temperature, especially in soils with low content of that nutrient. When the level of phosphorus in the soil is low, the applications of nitrogen reduce barley cold resistance.

3.1.4. Application of other nutrients

Sulfur deficiency can be corrected by applying fertilizers containing this element, such as complex fertilizers with sulfur, ammonium sulphate or applying superphosphate or other compounds as calcium sulfate (gypsum) or elemental sulfur, although the acidifying effect of the latter advised its use in basic soils, while its oxidation is very slow in some soils. Although wheat does not have high sulfur requirements, it is increasingly showing symptoms of deficiency in this nutrient, from tilling to the initio of stem elongation. Moderate requirements are still satisfied in most of the deep soils, insensitive to leaching of sulphates, although they are not as mobile as nitrates. However, very marked deficiencies they may appear in clayey soils with lime and in sandy and sandy-loam soils with low content of organic matter.

There may be a response to S fertilization when the soil test level in SO_4 is less than 3 mg/kg in the 0-60 cm profile, or when the nitrogen/sulfur ratio in the plant is greater than 16. In the period between tilling and stem elongation, the critical level of deficiency in leaves is 0.3 mg/kg. The direct application of sulfur must be performed between half tilling and the initio of stem elongation, utilizing 40 kg/ha of SO_3. Foliar application of ammonium sulfate or micronized elemental sulfur is more effective.

The increased needs for magnesium in winter cereals, especially wheat, occur in soils leached, sandy and containing limestone. A magnesium content in leaves and stems less than 0.14%, in the phase of “boot”, indicate a deficiency. Magnesium can be applied in the soil (18-36 kg ha) or by spray foliar with magnesium sulfate.

3.1.5. Fertilization recommendations

Table 3 shows the recommendations of fertilization for wheat and barley cultivation in Spain elaborated by ANFFE (National Association of Fertilizers Producers) taking into account crop extraction and the expected yield.

Table 3. Recommendation of fertilization for barley and wheat crops

Production (kg/ha)	Starter fertilization (kg/ha)			Topdressing, (kg N/ha)
	N	P_2O_5	K2O	
Up to 2,000	15-20	30-50	20-30	30-40
2,000-3,000	20-25	45-70	25-45	40-65
3,000-4,000	25-35	60-90	40-65	65-85
More than 4,000	35-40	80-130	60-90	85-110

3.2. Spring cereals. Maize

3.2.1. Nutritional requirements and extraction rate

The nutritional requirements of maize is similar to those of other cereals such as wheat or barley but due to the fact that its production is in general much more higher, the total amounts of nutrients demanded by maize in absolute terms are much higher. They can be established as a maximum of 28-30 kg of nitrogen (N), 10-12 kg of phosphorus (P_2O_5) and 23-25 kg of potassium (K_2O) per each 1,000 kg of grain. In addition there is a significant consume of calcium, magnesium and sulfur.

Maize begin to extract nutrients at the nascence status, the strongest extraction takes place from 4-5 weeks (8 leaves) when the vegetative growth is more intense. Potassium absorption finishes after flowering and about 47% of all required N is extracted in the period of 15 days before and after flowering.

Nutrients can proceed from different sources such as soil, irrigation water, nutrients remaining from the precedent crop, harvest debris, organic fertilizers and inorganic fertilizers. All these should be taken into consideration for establishing the amount of each nutrient that must be supplied with the organic or inorganic fertilization.

The amount of nutrients present in the soil can be established by analyzing the soil. As regards N a great pat is in the soil in organic form (not available); the determination of soil organic matter will allow a good estimation of the amount of N that will be released (Table 4). By analyzing the content of nitrates in the soil up to a depth of 60 cm, the amount of N immediately available to crop can be determined.

Table 4. Annual supply of N to the soil derived from soil organic matter

Soil organic matter, %	**Clayey soils, cold climate (kg N/ha)**	**Loam soils, moderate climate (kg N/ha)**	**Sandy soils. Hot climate (kg N/ha)**
1	15	22	30
1.5	22	33	45
2	30	45	60
3	45	65	90

Source: Fertiberia (2000)

Irrigation waters always contain some salts, which can be nutrients; this can be important in areas where maize is cultivated under irrigation because the amount of water added to this crop is high. Thus, it is also important to know the quality of the irrigation water. Harvest remains also contain an important amount of nutrients which return to the soil.

Organic fertilizers contain nutrients that are slowly released. It has been generally admitted that the lower the C/N ratio, the quicker the mineralization of the organic fertilizers. However, as already mentioned, there is controversy at this regards and some authors have not found any correlation between the amount of available N release from the organic fertilizer and its C/N ratio, suggesting the influence of the nature of the organic compounds in this process. The amount of nutrients release from these fertilizers must be calculated to close the balance between crop requirements and availability of nutrients in soil. As regard secondary nutrients and micronutrients, in general, the soil is able to provide the required amounts of them.

3.2.2. Recommendations of fertilization. Doses and fractionation

The contribution of nutrients must be calculated as a balance sheet in which input and output must remain compensated.

The output is the demand of the culture that is obtained by multiplying the needs of nutrients (in kg/t of grain) by the expected production. The input must be calculated for every source of nutrients, as indicated for wheat and barley crops. The nutrients that are retained by the soil can be supplied at a single? time in the starting fertilization, but this must not be done for the nitrogen since it is a mobile element. The total dose of nitrogen must be divided between the starting fertilization and at least one topdressing fertilization. In soils with little capacity of water storage and nutrients one must resort to two topdressing fertilizations.

It is advisable to apply about 1/3 of the total nitrogen in the starting fertilization, along with phosphorus and potassium, and the rest in a topdressing fertilization, when the maize is 40 cm tall (8 leaves). If two topdressing fertilizations are provided, the second one will be with the maize to 1m of height, dividing into two parts the nitrogen that is contributed in the topdressing fertilization. Topdressing fertilization must serve to fit the dose of nitrogen, since in this moment the expectations of crop are known better.

4. HORTICULTURAL CROPS

4.1. General Aspects

The production and quality of horticultural crops is affected by the level of soil available macro and micronutrients. Nitrogen is the nutrient that most often limits production, but in other cases the limiting factor may be the availability of phosphorus and potassium or of a particular micronutrient. The influence that each nutrient can have on the quality of a horticultural product much depends of each crop. For example, an excess of nitrogen increases the nitrate content in lettuce and spinach and this increase may affect their commercial value. There is evidence that a N increase in the soil produces a decrease in the vitamin C content in some vegetable.

Nutrient requirements vary by crop and production. For establishing the nutrient amount to be added to the soil with the organic or inorganic fertilizer it is necessary to take into account, apart from crop nutrient requirements, the inputs (nutrients existing in the soil proceeding from previous crops, or from soil organic matter mineralization) and extraction (lixiviation, soil and microbial fixation, volatilization) of nutrients that may occur in the soil (see Table 2).

The rate of nutrient absorption throughout the crop cycle follows a pattern similar to that of growth, for example, there is a slow initial phase, followed by a rapid stage of absorption in which the highest accumulation of dry matter and nutrients in the plant is produced. In some cases there is a third phase in which both, the absorption of nutrients and growth is clearly reduced whereas in other crops, crop harvesting is done before it reaches the third phase.

Nutrient deficiencies produce a decrease in crop production and quality, which manifest, when they are pronounced in some visual symptoms. Nitrogen deficiency usually produces a decreased growth and pale or yellowed color leaves. Phosphorus deficiency normally produces purple shades in older leaves. Potassium deficiency is manifested, in some cases, by necrosis in the edges of the leaves and a sickling upwards thereof. The lack of calcium tends to produce an edge necrosis of the youngest leaves (which is known as “apical necrosis”), and the lack of magnesium causes yellowing between leaves nerves.

4.2. Fertilizer recommendations

4.2.1. Calculation of doses

As earlier indicated for grain crops, the dose of nutrients to be applied in each case depends crucially on the crop extractions, the nutrient content in the soil and utilization efficiency of the crop. The level and rate of nutrient mineralization from the organic material added as fertilizer must be taken into account as well as the level of nutrients remaining in the soil derived from the organic fertilization carried out in the previous year. The extraction of nutrients depends mainly on the production, while the use efficiency, especially in the case of nitrogen, depends fundamentally on crop root system, fertilizer management and the efficiency of irrigation.

Some basic ideas for the calculation of the fertilization dose for the three main nutrients (N, P and P) are given below:

Nitrogen

The needs of N can be calculated by a simplified balance in the soil layer in which most of the roots develop which generally covers the first 60 cm. To simplify, N losses by lixiviation or immobilization are not considered in this balance, in which, it must be taken into consideration that for avoiding production reduction due to lack of N, it is necessary that the content of mineral N in the ground at the end of the culture is not less than a minimum value. This minimum value can therefore be considered as a requirement when performing the balance.

The amount of nitrogen fertilizer applied in culture would be:

Fertilizer dose = (Extraction of N by plant + minimum content of mineral N on the soil at the end of the crop) - (Contribution from crop residues + N mineral content in the soil at planting + mineralization of soil organic matter + mineralization of organic amendments + Contribution of irrigation water).

Since in this simplified balance the losses by immobilization, lixiviation and volatilization are ignored, it is advisable to increase the calculated fertilizer dose by 10-20%.

The following describes how to determine each of the terms of the simplified balance sheet:

- <u>*The extraction of N by the plant*</u> for the expected production can be estimated on the base of the data existing in the literature.
- <u>*The minimum content of mineral N in the soil*</u> at the end of the crop in most crops ranges between 30 and 60 kg N/ha (0-60 cm layer). In the case of early broccoli, cauliflower, leek, onion and spinach, N values range between 60 and 90 kg /ha.
- <u>*The contribution of N by crop residues*</u> can be estimated using existing published data on the nutrient content in crop residues, taking into account that N in these residues must be mineralized (converted to ammonium and nitrate) before being available to plants. Between 40-80% this N may be available for cultivation after 2-3 months, if these residues are incorporated into the soil.
- <u>The content of mineral N in the soil</u> at the starting of the culture is usually high and, therefore, its determination is important. This determination is made by measuring ammonium and nitrate content in soil samples.
- <u>*The contribution of N by the mineralization of soil humus*</u> can be estimated using existing published data based on the content of soil organic matter and texture.

- The contribution of N by mineralization of organic amendments is calculated by taking into account the richness in N of the organic amendment and its mineralization rate.
- The contribution of N with irrigation water is calculated from the water applied and its concentration in nitrate, taking into account that nitrate has 22.6% N.

Phosphorus and Potassium

The strategy for potassium and phosphate fertilization must consider the contribution of an amount of phosphorus and potassium that is sufficient to cover crop needs for these elements and at the same time maintaining the soil with satisfactory levels of available phosphorus and potassium.

The calculation of the needs of potassium and phosphate fertilizer may be performed by a simplified balance of these nutrients in the soil that include the main inputs and outputs in the soil-plant system.

The amount of potassium and phosphorus to be added can be calculated as follows:

• **Dose of fertilizer** = Extraction of phosphorus or potassium by the crop - (contribution of the soil reserve in available nutrients + contribution of crop residues + contribution from amendments and organic fertilizers + contribution from the irrigation water).

The determination of each of these terms is performed as follows:

- *The extraction of phosphorus and potassium by crop* for the expected production can be estimated on the base of the data existing in the literature.
- *The available P or K existing in the soil* is estimated by determining the content of these elements in soil samples.
- *The contribution of P and K in crop residues* from the precedent cultivation can be estimated from existing published data on the nutrient content in crop residues. For practical purposes of calculation it may be considered that 100% of this P and K will be available to the following crops in assuming that such wastes are incorporated to the soil.
- The contribution of P and K in the amendments and organic fertilizers can be obtained knowing the dose, type of product applied and the physical-chemical characteristics of these organic materials.
- The contribution of K with irrigation water can be calculated from the amount of water applied and its potassium concentration.

4.3. Time of fertilizer application

The main advantage of the fractionated application of the required nutrients, mainly in the case of N, allows an increase of the fertilizer efficiency by better encompassing nutrient supply with nutrient uptake by the culture.

In the case of traditional irrigation, the distribution time should be approximately:

Starting fertilization:

• Nitrogen: 20-40% of the total.

• Phosphorus: 100% of the total.

• Potassium: 100% of the total.

Topdressing fertilization:

• Nitrogen: 60-80% of the total, spread over one or more applications, depending on the culture duration, avoiding the application in the last part of the crop cycle.

In the case of fertirrigation the distribution of N, P and K is more fractional and, generally, 20-30% should be applied in the first third of the growing season, a 50-60% in the second third, and 10-30% in the last third cycle.

Some basic rules that should be taken into account are:

• In the initial stage of cultivation, nutrient demand is low, but if it occurs a deficit of nitrogen effects on growth may be irreversible.

• During phenologic periods such as flowering, fruit set and bulb formation, excessive nitrogen applications must be avoided.

• In the final stage of the crop, the application of N should be small or zero, as it can affect negatively on quality and can cause high levels of mineral N in the soil that subsequently could leach.

5. CONCLUSION

In conclusion, all crops need macro (N, P and K) and microelements for growing although the amount of nutrient requirements depends on the type of vegetal specie, and, in general terms, nitrogen is the most growth limiting factor. Organic Wastes can provide these nutrients to crops covering, at least in part, crop nutrient needs. Most organic wastes and residues are low in their content of macro-and micronutrients compared with most chemical fertilizers. However, different studies have shown that higher crop yields are obtained when organic materials are applied in combination with chemical fertilizers than when either is applied alone, suggesting that organic materials can increase the efficiency of chemical fertilizers. Therefore, farmers might be able to reduce their fertilizer (and energy) inputs accordingly.

Due to the slow release of nutrients from organic wastes it is difficult to ascertain if nutrients will be available just at the moment they are required by crops. Consequently, a good practice is to add with the organic waste the amount of nutrient required by crop taken into consideration, as indicate before the OW mineralization rate, and at the same time, to complement nutrient supply by inorganic fertilizer addition in some vegetative phases of the crop when necessary. The rate of mineralization is the key to the rate of application of any given material. The yearly rates of mineralization are expressed as a series of fractional mineralization of any given application, or the residual of that application. These are referred as a *decay series.* For example, the decay series, 0.30, 0.10, .05, means that for any given application, 30% is mineralized the first year, 10% of the residual (that which was not previously mineralized) is mineralized the second year, and 5% of the residual is mineralized the third and all subsequent years.

Research is needed to evaluate crop yield response to various combinations of organic and chemical fertilizers and to improve the efficient and effective use of organic materials in cropping systems as well as to establish the proper rate and time of application, best sequence of crops to be grown, and the rate of nutrients release. A better understanding of the interaction of these factors would provide more reliable basis for a developing effective utilization strategies for organic waste in agriculture.

Because organic wastes represent a potential source of considerable agronomic, energy and economic value, their proper and efficient use as fertilizers should be emphasized by national governments in developing strategies for increasing agricultural productivity and stability

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