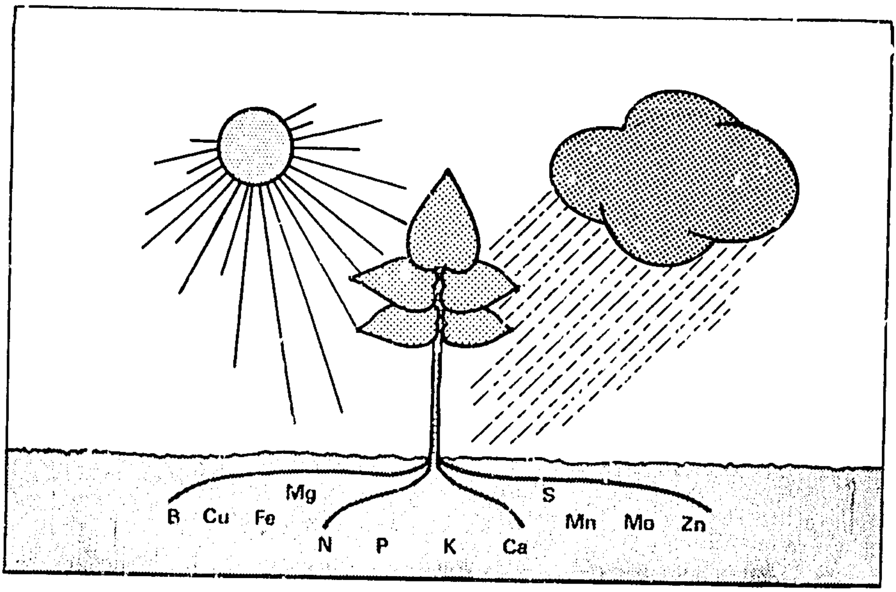
Soil Fertility Requirements for Potato Production

Peter Vander Zaag



(Adapted from Villagarcía et al., 1978)

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Soil Fertility Requirements for Potato Production

Objectives. Study of this bulletin should enable you to:

- explain the importance and nature of plant nutrients,
- describe function, requirement, sources, and deficiencies of macro- and semi-macronutrients,
- discuss the importance of micronutrients,
- discuss fertilizer application.

Study materials.

- Samples of principal fertilizers (organic and inorganic).
- Legume plants with rhizobia-infected roots.
- Slides depicting deficiency symptoms.

Practicum.

- Observe and discuss fertility status of different potato crops in the field.
- Observe in nature symbiotic relationship of roots of legumes with rhizobia.
- Calculate the nutrient (N, P, K, S, Mg) requirements for a 10; 20 and 30 ton tuber crop per hectare (assuming 1.5 t/ha haulm weight).

Questionnaire.

1. In your country what are the average yields in farmers' fields and experimental stations? Why is the difference?
2. What are the major factors limiting higher yields in your country?
3. Why is the nitrogen requirement for potatoes higher than the amount removed by the crop?
4. How can you minimize N losses?
5. What is N mineralization? At which rate does it occur?
6. Why should be P application higher than P amount removed by the crop? What is the general efficiency of P fertilizers?
7. Triple superphosphate contains 46% P_2O_5; how to calculate the concentration of P?
8. What is the general K status of tropical soils?
9. Why does new meristematic tissue suffer first from Ca deficiency?
10. How can aluminium toxicity problems be alleviated?
11. What is the importance of Mg for the plant?
12. What is the primary source of sulfur? Why is S not a problem close to industrial cities? Why is it a problem in tropical Africa?
13. What is an easy way to rectify microelement deficiencies?
14. What is the recommended time to apply N, P and K fertilizers?
15. How would you determine actual requirements of fertilizer?; for your country, for individual fields?

Technical Information Bulletin 14

Soil Fertility Requirements for Potato Production

1 Introduction.
2 Importance and nature of plant nutrients.
3 Nitrogen (N).
4 Phosphorus (P).
5 Potassium (K).
6 Calcium (Ca).
7 Magnesium (Mg).
8 Sulfur (S).
9 Microelements.
10 Fertilizer application.
11 Additional reading.

1 Introduction. Potato growth depends on a supply of plant nutrients, such as nitrogen, phosphorus, potassium. Each of these nutrients has specific functions for plant growth. Lack of nutrients results in retarded growth processes and reduced yield. A potato crop removes nutrients from the soil and replacement is necessary to maintain soil fertility. Fertilizers are expensive and may not be easily available, so knowledge about the action of plant nutrients within plants and soil helps the farmer use fertilizers most efficiently.

2 Importance and nature of plant nutrients.

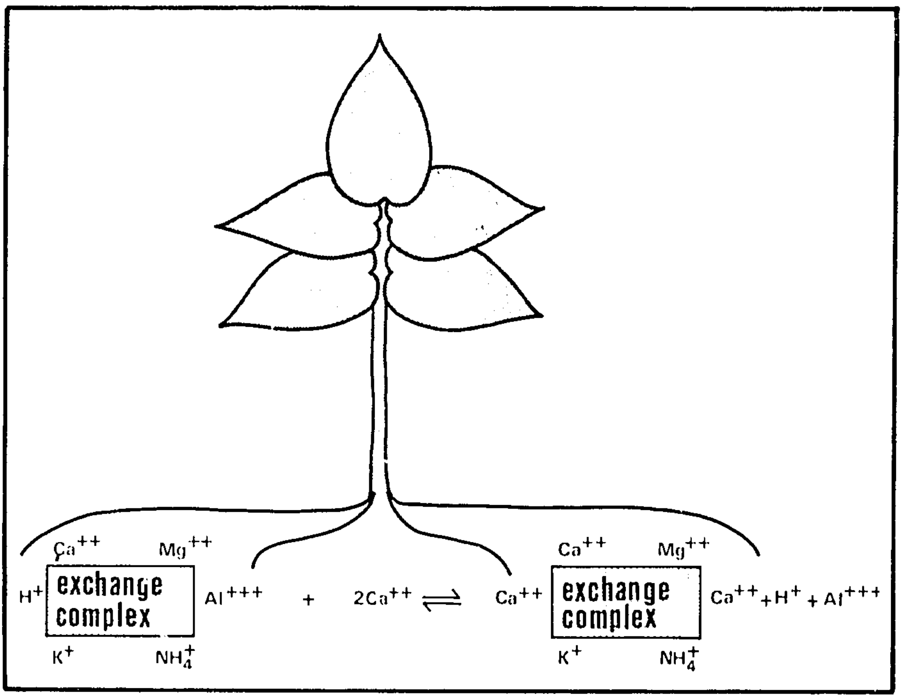
2 **Importance and nature of plant nutrients.** National average potato yields vary from less than 4 tons to more than 20 tons per hectare. Among other limiting factors for potato production, such as high temperatures, short day length, low light intensity and poor physical soil conditions, to a great proportion different levels of fertilizer application are responsible for these yield variations. In many cases, application of nutrients, increases yield. However, with increase of fertilizer application, yield increase becomes steadily smaller until cost of inputs exceeds yield benefit. Efficient use of fertilizer both meets the lant requirements and avoids excessive application.

Table 1. Grouping and average concentration of plant nutrients in leaves (60 days after planting) and in tubers (at harvest). (Vander Zaag, unpublished).

Group	Nutrient		Concentration (% dry weight) tubers	haulm
macroelements	nitrogen	N	1.6	6.5
	phosphorus	P	0.2	0.6
	potassium	K	1.6	6.0
	calcium	Ca	0.05	1.0
semi-macroelements	magnesium	Mg	0.13	0.5
	sulfur	S	0.15	0.25
microelements	boron	B	trace	trace
	cobalt	Co	"	"
	copper	Cu	"	"
	iron	Fe	"	"
	manganese	Mn	"	"
	molybdenum	Mo	"	"
	zinc	Zn	"	"

Appropriate fertilizer application requires knowledge about nature of nutrients and their action in soil and plant. Nutrients are commonly grouped as *macro*, *semi-macro*, and *micro*elements. Their average concentration in leaves and tubers may give an impression about their removal from soil by potato plants and about the necessary amount of replacement (Table 1).

The following descriptions point out that availability of nutrients to the potato plant depends on their interrelationship and is often altered by soil conditions, especially so-called *exchange complexes*. These complexes are responsible for adsorbtion release and exchange of elements in the soil. An analysis by a soil laboratory may help to identify fertilizer requirements under specific conditions. With the results of soil analyses amount of fertilizer application can be calculated.



Exchange complexes **in soil are responsible for adsorption, release and exchange of elements.**

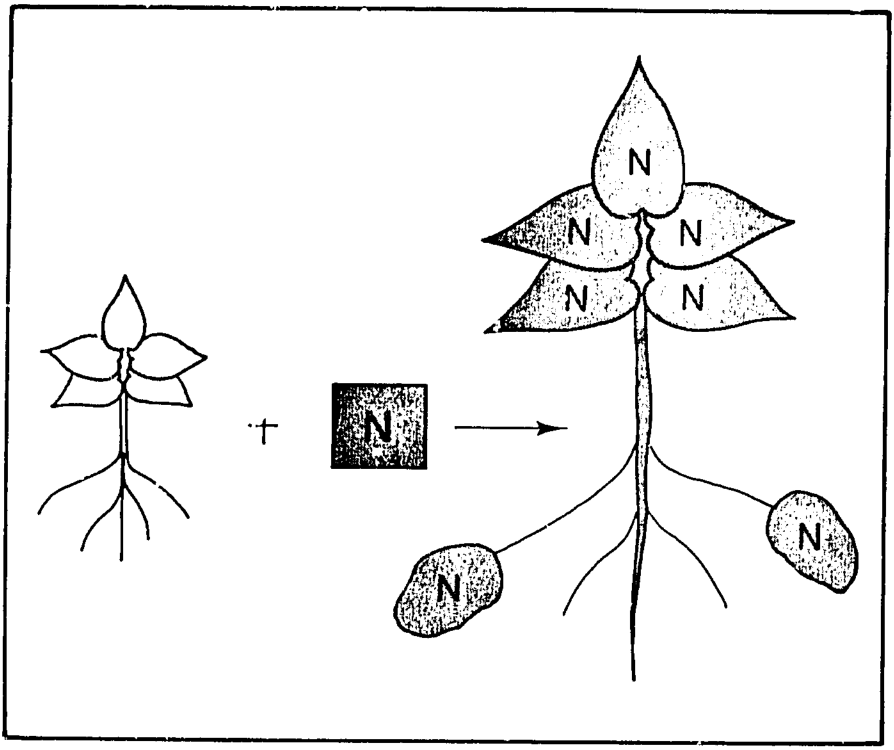
Fertilizer requirements depend also on the expected yield. To demonstrate roughly fertilizer requirements of a potato crop, in this publication averages are assumed as follows:

- tuber yield (fresh) 20 t/ha,
- tuber yield (dry; 20% dry matter) 4 t/ha,
- haulm weight (dry) 1.5 t/ha.

Table 2. Principal fertilizers, their chemical formula and nutrient content (%).

Fertilizer	Formula	Nutrient Content							
		N	P_2O_5	(=P)	K_2O	(=K)	Ca	Mg	S
anhydrous ammonia	NH_3	82							
calcium nitrate	$Ca(NO_3)_2$	16					21		
ammonium nitrate	NH_4NO_3	33							
ammonium sulfate	$(NH_4)_2SO_4$	20							24
urea	$CO(NH_2)_2$	46							
monoammonium phosphate	$NH_4H_2PO_4$	11	48	21			1,4		2,6
diammonium phosphate	$(NH_4)_2HPO_4$	20	54	24					
superphosphate	$CaSO_4 + Ca(H_2PO_4)_2 \cdot H_2O$		20	9			20		12
triple superphosphate	$Ca(H_2PO_4)_2 \cdot H_2O$		46	20			13		1
potassium chloride	KCl				60	50	0,3		
potassium sulfate	K_2SO_4				53	44			18
potassium nitrate	KNO_3	14			47	39			
potassium magnesium sulfate	$K_2SO_4 \cdot MgSO_4$				32	27		8	22
dolomite lime	$CaCO_3 \cdot MgCO_3$						22	13	
compound fertilizer	(e.g. 15-15-15)	15	15	6,6	15	12.5			

3 Nitrogen (N). Nitrogen is a component of proteins. Protein content of a plant is directly related to nitrogen concentration of plant tissues (% protein = % N x 6.25). Additionally, nitrogen is an integral part of the chlorophyll molecule, and of nucleic acids that make up the chromosomes.



Nitrogen (N) is necessary for vigorous vegetative growth and chlorophyll formation.

N requirement. The nitrogen requirement of potatoes is influenced by climatic conditions, soil type, soil fertility, preceding crop, variety, and practices of crop management (especially irrigation).

Table 1 indicates a N concentration of 1.6% in tubers and 6.5% in haulms. An average potato crop yields (see above):

tubers (dry)	4 t/ha
haulm (dry)	1.5 t/ha

Thus, N removal from field is:

tubers	1.6 %	x	4 t	=	64 kg/ha
haulms	6.5 %	x	1.5 t	=	97.5 kg/ha
total about				=	160 kg/ha

The nitrogen requirement is higher than the amount removed by the crop, because of losses due to leaching or vaporizing into the air. Approximately 200 kg nitrogen are required per hectare. At a tuber yield of 20 t/ha, 200 kg nitrogen requirement corresponds to:

10 kg N per each ton of tuber yield.

This figure is generally accepted as the nitrogen requirement of potatoes.

N sources. Nitrogen is provided by soil organic matter, chemical fertilizers, and nitrogen fixing legumes.

Organic matter. Soil organic matter originates from organisms living in and on the soil and from crop residues. Nitrogen is released (mineralized) slowly from this organic matter. Amount of organic matter in a soil can be determined in a laboratory by a soils analysis. Nitrogen provided by the soil can be calculated using the following factors:

- a soil may contain 3% organic matter,
- 5% of which is nitrogen,
- 2% of this N is released (mineralized) each season,
- soil weight up to an arable depth of 15 cm is 2 000 t/ha.

Thus, in one season the soil would release

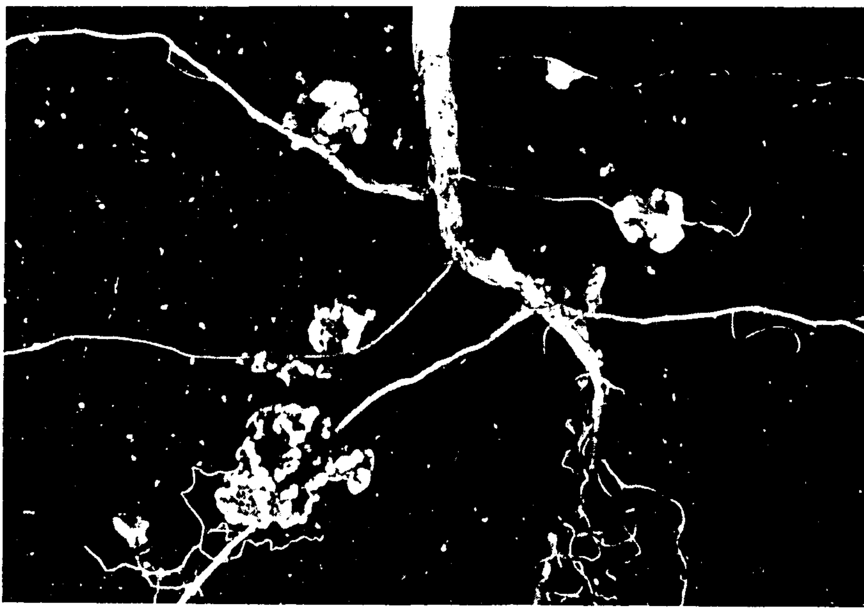
2 000 000 kg soil per ha x 3% x 5% x 2% = 60 kg N/ha.

For our example, this amount of N would satisfy about 30% of the crop requirement.

Compost is another valuable source of organic matter containing about 1% nitrogen. It may originate from crop residues, household wastes or animal manures.

N fertilizers. N is available in simple nitrogen fertilizers or in compound fertilizers (Table 2).

Leguminous plants. ·Legumes such as alfalfa, beans, peas and peanuts live in symbiosis with rhizobia. Rhizobia are specific bacteria that live on legume roots, but supply nitrogen from the air to the legume plant. Excess of this nitrogen can also be utilized by the potato plant when it grows in close proximity to or in crop rotation with leguminous plants.



Nitrogen fixation from the air by Rhizobia on pea roots.

N deficiency. Nitrogen is necessary for vigorous vegetative growth and chlorophyll formation. Nitrogen deficiency causes growth reduction and chlorosis. Plants become stunted and yellow. Nitrogen is mobile within the plant and is translocated to growing parts. Chlorosis and yellowing appears first on lower leaves that may eventually turn brown and die.

4 Phosphorus (P). Phosphorus is an essential element in plant chemical compounds that are responsible for energy transfer necessary for metabolic processes within the plant. Phosphorus is also included in nucleic acids. Phosphorus is especially important for seed formation and root growth.

P requirement. A potato crop removes an amount of P of 0.2% of tuber dry weight and 0.6% of haulm dry weight (Table 1). Thus, P removal of an average crop is (see section 2):

tubers	0.2 %	x 4 t	=	8 kg/ha
haulms	0.6 %	x 1.5 t	=	9 kg/ha
total			=	17 kg/ha

Total P requirement, however, is higher because of low efficiency of P uptake by the plant (see below).

P sources. Phosphorus exists in soil, compost and chemical fertilizers and as rock phosphate.

Soil phosphorus. In soil, phosphorus is in both organic and inorganic forms. Mineralization of phosphorus from organic forms depends on the activity of soil organisms (bacteria), temperature, enzymes and carbon/phosphorus ratio (C/P ratio).

The potato plant uses phosphorus available in soil solution. Virgin soils generally have sufficient amounts of phosphorus to grow subsistence level crops. Soils with high organic matter content supply adequate amounts of P. Volcanic soils contain high quantities of phosphorus; however, most of it is in a form not available for use by the plant.

Compost. Compost contains about 0.15% P.

P fertilizers. P concentration of all commercial fertilizers is given as percent P_2O_5 (Table 2). The P concentration can be calculated using the molecular weights of P (31) and O (16) and amounts to 44% of the P_2O_5 concentration *).

Efficiency of P uptake by the plant, and thus the quantity of fertilizer necessary, depends on soil type and temperature. Generally, only 10% of the P applied is available for the current crop. In the second season an additional 5% is used - and in the third season another 2.5% of the residual P may be used.

The ability of the plant to use P decreases with temperature. Thus one should apply more P when potatoes are grown in cold climates. An analysis by a soils laboratory determines actual P fertilizer requirements under specific conditions.

Example. P fertilizer application may be estimated on the basis of the following assumptions:

- a crop producing 20 t tubers removes 17 kg P/ha,
- a soil analysis reveals that 100 kg P/ha are present in the top 15 cm of arable soil,
- efficiency of P uptake is 10%,
- no loss by erosion or leaching occurs

The soil provides 100 kg P with an efficiency of 10%:

$$100 \text{ kg} \times 10\% = 10 \text{ kg/ha}$$

To supply the additional 7 kg P to replace the total removal of 17 kg, at an efficiency rate of 10%

$$\frac{7 \text{ kg}}{10\%} = 70 \text{ kg/ha}$$

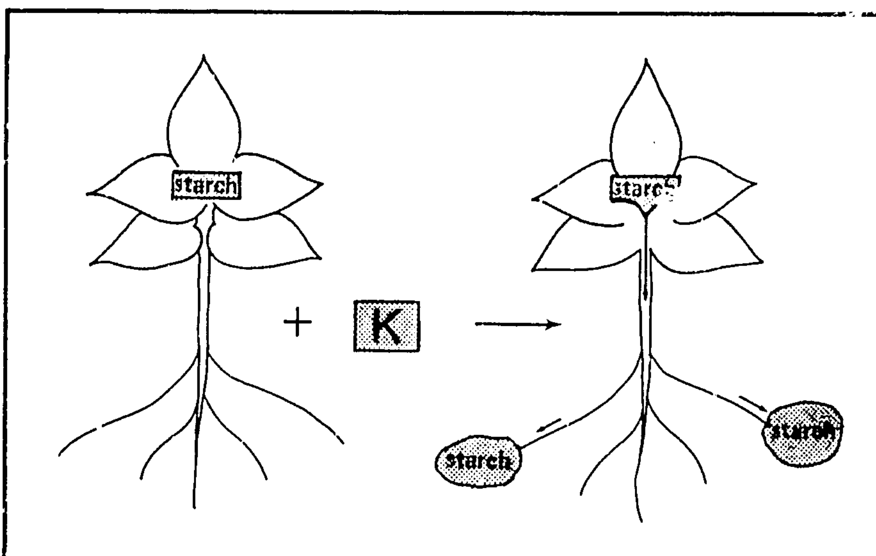
must be applied. These 70 kg P correspond to 160 kg P_2O_5.

*) P: $P_2O_5 = (2 \times 31)/(2 \times 31 + 5 \times 16) = 0.44$

Application of P fertilizer can be reduced in subsequent years because of residual effect of previous P applications. If 70 kg of P was applied in the first season, 5% = 3.5 kg P are still available in the second season.

P deficiency. Phosphorus is especially important for root growth and seed formation. A deficiency of P may cause poor development of the root system.

5 Potassium (K). Potassium is not included in plant chemical substances directly. It acts in carbohydrate formation and the transformation and movement of starch from potato leaves to tubers. Potassium is also important in controlling stomatal movement and water status of the plant.



Potassium (K) acts in movement of starch from potato leaves to tubers.

K requirement. Potassium is the most abundant element in the plant. Tubers contain around 1.6% K and leaves about 6% K (Table 1). Thus the amount of K removed by an average potato crop is (see section 2):

tubers	1.6 %	x 4 t	=	64 kg/ha
haulms	6 %	x 1.5 t	=	90 kg/ha
total			=	154 kg/ha

K sources. Potassium is present in the soil, compost and fertilizers.

Soil potassium. Potassium occurs in soil minerals such as feldspars, micas and biotite (primary minerals). On clay minerals (secondary minerals) K may be adsorbed and exchangeable. Exchangeable K is available for plant growth. K may be lost due to leaching. In tropical soils, K content may be low because K-containing minerals may not be present, high precipitation may lead to leaching, and high temperatures may hasten release and loss of adsorbed K.

Compost. Compost contains about 0.5% K.

K fertilizers. K-content of commercial fertilizers is given in percent K_2O (Table 2). K content is 83% of K_2O content *). The quantity of K fertilizer required can be determined by soil analysis.

K deficiency. K deficiency becomes evident by yellow to brown discoloration of lower leaves, combined with necrosis of leaf margins.

*) $K: K_2O = (2 \times 39)/(2 \times 39 + 16) = 0.83$ (Molecular weight of $K = 39$).

6 Calcium (Ca). Calcium is related to protein synthesis, cell division and growth, and development of meristematic tissue.

Ca requirement. Ca concentration in potato tubers and haulm is relatively low (Table 1), thus the potato requires little of this element.

Ca sources. Ca is available in soil and fertilizers.

Soil calcium. Calcium is in minerals such as calcite, dolomite, and apatite. Calcium availability to the plant depends on soil factors such as the exchange capacity of the soil, Ca saturation on exchange complexes, and relationship to other elements of the exchange complex. In many warm humid areas Ca saturation is low, while interfering aluminium (Al) leads to Al toxicity. Excess Ca may reduce potassium and iron metabolism in the plant.

Ca fertilizers. Common phosphorus fertilizers contain considerable quantities of calcium (Table 2). Liming materials such as calcium oxide (unslaked lime, CaO), calcium hydroxide (slaked lime, $Ca(OH)_2$), calcium carbonate (calcite, $CaCO_3$), and calcium silicate (slags) are good sources of Ca, and are able to increase pH of acid soils. Generally, a pH of 5.3 is sufficient to solve aluminium toxicity problems in tropical, acid soils.

Ca deficiency. Calcium is an immobile element, thus if a deficiency of Ca exists the new meristematic tissue does not have access to the amount required for proper development. Deficiency becomes apparent by the failure of terminar buds to develop.

7 Magnesium (Mg). Magnesium is the only mineral constituent of the chlorophyll molecule. Magnesium is also necessary for activation of carbohydrate metabolism and cell respiration.

Mg requirement. The amount of Mg removed by an average potato crop is substantial (see Table 1, and yield assumptions in section 2):

0.13% of tuber dry weight	=	5.2 kg Mg,
0.5 % of haulm dry weight	=	22.5 kg Mg,
total of average potato crop	=	27.7 kg Mg.

Thus, about 28 kg Mg/ha are removed by an average crop.

Mg sources. Soil magnesium levels may be adequate for subsistence potato production; however, for more intensive agriculture these levels do not suffice. In many countries with intensive farming, Mg is applied to each potato crop.

Dolomitic limestone supplies not only Mg, but also Ca for adjusting soil acidity (pH). Basic slag, potassium magnesium sulfate, and magnesia are also good sources of Mg.

Mg deficiency. Mg deficiency results in interveinal chlorosis of leaves, with only veins remaining green. Lower leaves show deficiency symptoms first, because Mg is easily translocated to the growing parts.

8 Sulfur (S). Sulfur is required for the synthesis of S-containing amino acids (cystine, cysteine, methionine), and protein. S-containing amino acids are important for humans; they cannot be synthesized by the human body. Their content makes the potato valuable for human nutrition.

S requirement. On dry weight basis, potato tubers contain 0.15% S and leaves 0.25% S (Table 1). Thus, the quantities removed by a crop are substantial (about 10 kg S per hectare).

S sources. Amount of sulfur containing amino acids in plants can be increased by sulfur application to the soil. Sulfur in most fields is located in organic matter or adsorbed to the soil complex. Modern industry emits considerable S quantities into the atmosphere. From there it returns to the soil with precipitation. But only between 1 to 3 kg sulfur is supplied per hectare by rainfall in tropical Africa. The sulfur content of soil plus sulfur originating from precipitation may be sufficient in subsistence agriculture, but is not sufficient for intensive potato production.

Sulfur may be supplied with triple super phosphate, ammonium sulphate. gypsum, basic slag, super phosphate, or potassium sulphate.

S deficiency. S deficiency retards plant growth. Plants may be uniformly chlorotic, stunted, and spindly with thin stems.

9 Microelements. Microelements, such as boron (B), cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), molydbenum (Mo) and zinc (Zn), in minor quantities are important for plant growth. Occasionally, they may be either limiting or exceed toxic proportions (especially Fe and Mn under humid conditions). One of the easiest way to rectify microelement deficiency is to apply ashes from household fires. Ashes commonly contain small amounts of all of these microelements.

10 Fertilizer application. Form, quantity and time of fertilizer application depend on local conditions.

Organic fertilizers are generally applied at the time of land preparation prior to planting. Inorganic phosphorus and potassium are applied at planting time. Because nitrogen is easily leached by rain or irrigation, it is often recommended to apply one half at planting and the other half at hilling (after 4 to 5 weeks).

Fertilizer quantity depends on the yield desired, soil conditions, and economic consideration (fertilizer prices). Local research should be conducted to determine actual recommendations. Experiments should compare soil and plant tissue analysis with crop response.

11 Additional reading.

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Correct Reference. Vander Zaag, P. 1981. Soil fertility requirements for potato production. Technical Information Bulletin 14. International Potato Center, Lima, Peru. 20 pp.

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a) to support individualized study,
b) to support application of known and new technology,
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d) to support formal courses,
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To facilitate additions and changes the bulletins are commonly delivered in loose-leaf form or with binding rings. The objectives, study aids, practicum and questionnaire attached in front of most bulletins may be useful when th information is applied to support the objectives (a) and (d).

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