Yara’s Products

Yara manufactures and sells a large range of fertilizers. In addition the individual country operations owned by Yara may have a range of other fertilizers available for the potato grower. Check with your local agronomist to see a full range of fertilizers available.

For further information please contact:
Yara International ASA
Bygdøy allé 2,
N-0202, Oslo, Norway
www.yara.com

Disclaimer: The information contained herein is to the best of Yara’s knowledge and belief accurate. Recommendations and results stated, unless otherwise acknowledged, are based upon Yara’s experience and on field trial results.
Green tubers should not be consumed.

to sunlight they will go green in color. Often greening:
cut into long thin strips. Also known as chips.
French Fries:
page 11).
disease that rots the tuber (see photograph on
Warm weather bacterial
tyrosine to melanin.
the oxidation of phenolic substances, mainly
for significant post harvest losses. Caused by
Enzymatic Blackening (Black Spot):
ends in just one inflorescence and ‘terminates’
Plant growth in which the shoot
Determinate:
’Chips’ in some countries.
Crisps:
A thin slice of potato, which is usually
(figure 63).
A cavity of any size in the
centre of the medullary tissue (figure 63). It is not always discolored.
Haulm: Above ground organs of a potato plant – the stems and leaves.
Hollow Heart: A cavity of any size in the centre of the medullary tissue (figure 63). It is not always discolored.
Indeterminate: Where the plant keeps on producing vegetative material and growth does not ‘terminate’ with an inflorescence.
Internal Brown Spot (IBS): Any spot contained inside the vascular ring in the medullary tissue but not in the centre (figure 63).
Internal Rust Spot (IRS): also known as Internal Flack, is a physiological internal defect in which small brown spots, due to cell death, appear in the tuber.
King Tuber: the largest tuber under any individual potato plant.
Lenticel: a region of cells with intercellular spaces that permit the diffusion of oxygen into inner tissues (figure 62).
Periderm: The outermost layer of the tuber. It is composed mostly of dead cork cells which seal the surface of the root. The periderm is only a few layers of cells thick. The period when the periderm suberizes is known as the ‘skin-setting’ phase (figure 63).
Physiological Ageing: See boxed copy on page 8.
Powdery Scab: Spongospora subterranea - causes the formation of superficial pustules on tubers that release spores into the soil (see photographs on page 28).
Rhizoctonia: See black scurf.
Silver Scurf: Helminthosporium solani – a fungal infection which covers the tuber with sclerotia (see photographs on page 25).

Glossary

Black Scurf: Rhizoctonia solani – which results in the surface of the tuber becoming covered with sclerotia (see photographs on page 25).
Brown Centre: Any light brown discoloration - the stem and leaves.
Bullking: This is the swelling phase when dry matter is assimilated within the tubers.

Chips: Processed (usually fried) potato cut into long thin strips. Also known as French fries.

Common Scab: Sclerotium rolfsii – which results in the surface of the tuber becoming covered with sclerotia (see photographs on page 25).

Cortex: A layer of cells usually 1 to 2 mm thick, occurring immediately below the periderm (figure 62).

Determinate: Plant growth in which the shoot ends in just one inflorescence and ‘terminates’ growth at this.

Enzymatic Blackening (Black Spot): Internal blackening or browning of the tuber, responsible for significant post harvest losses. Caused by the oxidation of phenolic substances, mainly tyrosine to melanin.

Erwinia – Soft Rot: Warm weather bacterial disease that rots the tuber (see photograph on page 11).

French Fries: Processed (usually fried) potato cut into long thin strips. Also known as chips.

Growing: Where potato tubers are exposed to sunlight they will go green in color. Often associated with an increase in toxic alkaloids. Green tubers should not be consumed.

Growth Cracks: External cracks in tuber, usually longitudinal (see photograph on page 9).

Haulm: Above ground organs of a potato plant – the stems and leaves.

Hollow Heart: A cavity of any size in the centre of the medullary tissue (figure 63). It is not always discolored.

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Table 4 Conversion Table for Specific Gravity to Total Solids of Potatoes

<table>
<thead>
<tr>
<th>Specific Gravity</th>
<th>% Total Solids</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.072</td>
<td>19.0</td>
</tr>
<tr>
<td>1.074</td>
<td>19.4</td>
</tr>
<tr>
<td>1.076</td>
<td>19.8</td>
</tr>
<tr>
<td>1.078</td>
<td>20.3</td>
</tr>
<tr>
<td>1.080</td>
<td>20.7</td>
</tr>
<tr>
<td>1.082</td>
<td>21.1</td>
</tr>
<tr>
<td>1.084</td>
<td>21.6</td>
</tr>
<tr>
<td>1.086</td>
<td>22.0</td>
</tr>
<tr>
<td>1.088</td>
<td>22.4</td>
</tr>
<tr>
<td>1.090</td>
<td>22.8</td>
</tr>
<tr>
<td>1.092</td>
<td>23.2</td>
</tr>
<tr>
<td>1.094</td>
<td>23.7</td>
</tr>
</tbody>
</table>
There is a wide range of different types of potato with some 85 genera and nearly 3000 species worldwide. This Plantmaster Manual concentrates upon the ‘white potato’ – Solanum tuberosum – which is the most widely grown potato. Although most cultivars are white or yellow fleshed and have white skins, there are a wide range of color variations. Potatoes are largely cool season crops, produced under optimal average temperatures that range from 10-20˚C. The tubers are susceptible to freezing and need to be lifted prior to the onset of autumn or winter frosts. In most regions, yields are best when seed is planted shortly after the last frost. This ensures a long growing season. In areas with no risk of frost, potatoes can be cropped all year round. Potato varieties are either determinate or indeterminate in nature. Indeterminate varieties will carry on growing for longer and, in some growth environments, will need some form of management to stop leaf and stem growth, prior to harvesting. Desiccation or crop haulm destruction in indeterminate varieties should be timed to maximize yield and tuber quality characteristics.

In many countries, it is no longer possible to plant a potato crop and aim for a general market. Growers now have to meet tight quality criteria established by a specific end-user or face financial penalties and in the worst cases, crop rejection. As a result, the whole growing programme, from variety choice, seed spacing and agronomic management, right through to desiccation and storage, is designed to produce a high yield that fulfills the quality requirements of the marketplace.

**Fresh market potatoes**

Tuber quality in terms of appearance and cooking quality is of prime importance to the consumer. Much depends upon variety choice, but also the way the potato is grown.

For the fresh market, tubers need to be consistent in shape and size (45-85mm), with good skins that are free of any disease or blemish. Dry matter (DM) content is also important as tubers with a DM above 18-20% are more susceptible to bruising and may disintegrate when boiled during cooking. Fresh potatoes are increasingly sold in a range of ‘pre-packs’. Lower priced grades are sold loose or in ‘value packs’. 

Worldwide, approximately 310 million tonnes of potatoes are produced every year from around 20 million hectares.

China is the biggest producer with between 60 and 65 million tonnes being grown each year. Other large producers are Russia, India, Poland, USA, Ukraine, Germany, Netherlands and Belarus.

World average yields are around 17t/ha, however there is a lot of variation and many of the developed countries are producing above 40t/ha.

In the developed countries, the consumption of fresh potatoes is static, while processed potatoes continue to grow in popularity due to convenience foods.

Consumption of fresh potatoes in developing countries is increasing as human diets become more diverse.
Processing Potatoes

Processing potatoes need to be evenly shaped and of a standard size and quality from one end of the tuber to the other.

For French fries and crisps, a high DM content is needed in order to achieve a good fry color. Standard color charts are used by processors to achieve consistent fry color. In the past, contracts have stated that 18% DM is the minimum. However, industry standards now seek potatoes with a 20-25% DM.

For losses due to blemishes, bruising, pest damage, greening, growth cracks, etc. A standard contract will specify a maximum acceptable range of reducing sugars. Excessive N and high reducing sugars cause potatoes to brown when cooked. Contracts usually specify an acceptable range of reducing sugars. These values may change with processor or local standards.

Starch Production

Starch is an important ingredient in food products, particularly in the production of processed foods such as flour, pasta, and confectionery. Starch is a polysaccharide composed of glucose units, which are linked together in a linear or branching structure. Starch is produced by plants and is a major source of energy for both plants and animals.

The aim of the grower is to produce a high-yielding, quality crop that matches the needs of the intended market. Longer day lengths delay tuber initiation and favor the growth of the stolon and shoot. High temperatures also reduce tuber formation. Late varieties seem to be more sensitive to long day lengths or high temperature conditions.

Table 1 Market Needs

<table>
<thead>
<tr>
<th>Size</th>
<th>Dry Matter %</th>
<th>Reducing Sugars %</th>
<th>Sugars %</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>French Fries</td>
<td>22 - 25</td>
<td>&lt;0.25</td>
<td>&lt;5</td>
<td>USDA Chart, Fry Colour = 2</td>
</tr>
<tr>
<td>Crisping</td>
<td>23 - 25</td>
<td>0.01 - 0.1</td>
<td>&lt;5</td>
<td>Min. Storage Temp. 8°C</td>
</tr>
<tr>
<td>Canning</td>
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<td>&lt;19</td>
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Starch properties, especially its viscosity, are important in determining the final paste properties of the product. The higher the starch content, the lower the risk.

Crop Characteristics

Potatoes produce a fibrous root system. These roots are at best no more than 60cm long. Thus potatoes are shallow rooted compared to cereals for example, which can root to at least 120cm depth. As a result, potatoes are often unable to exploit nutrients and soil moisture at depth within a soil profile.

While root growth occurs when soil temperatures are between 10 to 35°C, best, most active root development is at soil temperatures of between 15 and 20°C (Figure 1).

Leaf (haulm) growth occurs at temperatures of between 7 to 30°C, but optimal growth is at around 20 to 25°C. Optimum temperatures for stolon growth are similar.

The potato tuber is an enlarged portion of the stolon. The initiation of this tuber is triggered by short day lengths (photoperiods), and involves growth hormones. The colder the soil temperature, the more rapid the initiation of tubers and the greater the number of tubers formed. The optimum soil temperature for tuber initiation is 15 to 20°C.

Under these conditions, the potato plant will have short stolons and shoots.

Agronomic Principles

Some data on the effect of N and reducing sugars on fry color. Left poor, right good.

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Physiological Ageing

By planting sprouted seed, crop growth can be advanced. The magnitude of this response and its effect on increasing crop yield is related to the physiological age of the seed at planting.

Seed storage temperature is the key to controlling physiological aging. Raising storage temperature above 4°C promotes the break in dormancy and the growth of sprouts.

The accumulation of the number of day degrees from this break of dormancy governs the physiological age of the tuber at planting.

Different varieties vary in the number of day degrees needed to age to a desired level prior to planting.

Old aged tubers are advantageous when planting early varieties or when the growing season is short.

Tubers that have been minimally aged are suited to long growing seasons where it is desirable to keep the potato growing to achieve maximum yields.

When planting sprouted seed it is necessary to control sprout numbers and length (maximum 2 cm) to ensure optimum growth according to plant spacing, and to ensure minimal sprout damage when planting.

At lower pH values potatoes can suffer from aluminum and other heavy metal ion toxicity, as well as restricted P or Mo availability.

At pH values above 7.5, nutrient availability, in particular of phosphorus and the micronutrients, can be reduced, even though high total amounts of these elements may be present in the soil. Liming can ameliorate undesirable, low pH values although care must be taken to ensure that the lime is applied at least 6 months before the potatoes are to be planted. Potatoes are more prone to common scab when grown in high pH soils.

When side dressing with fertilizer, the remaking of the ridge allows the incorporation of the fertilizer into the soil around the tuber.

Ridging also maximizes coverage of the developing tuber, so as to prevent greening and ensure tubers are well shaped, more evenly sized and at lower risk of damage.

Fluctuating soil moisture can cause secondary growth of tubers from the ridge. Fluctuations in soil moisture status within the ridge will lead to uneven tuber bulking, malformed tubers and growth cracks. Even a 10% variation in soil moisture status can be critical. For this reason, when using drip irrigation systems, the tape should be placed in the top of the ridge.

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Potatoes are grown on a range of soils varying from sands to clay loams, all with different water holding capacities. An ideal potato soil is well structured, with good drainage to allow proper root aeration, tuber development with minimal root disease infestation.

Potatoes prefer soils with a pH of 5.5 to 7.0 and low salinity. However, in practice potatoes are grown in soil pHs from 4.5 to 8.5 and this has a distinct impact on the availability of certain nutrients (Figure 3).

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Fluctuating soil moisture can cause secondary growth of tubers from the ridge. Fluctuations in soil moisture status within the ridge will lead to uneven tuber bulking, malformed tubers and growth cracks. Even a 10% variation in soil moisture status can be critical. For this reason, when using drip irrigation systems, the tape should be placed in the top of the ridge.

Potatoes respond to the availability of phosphorus in the soil when growing to achieve maximum yields.

By planting sprouted seed, crop growth can be advanced. The magnitude of this response and its effect on increasing crop yield is related to the physiological age of the seed at planting.

Seed storage temperature is the key to controlling physiological aging. Raising storage temperature above 4°C promotes the break in dormancy and the growth of sprouts.

The accumulation of the number of day degrees from this break of dormancy governs the physiological age of the tuber at planting.

Different varieties vary in the number of day degrees needed to age to a desired level prior to planting.

Old aged tubers are advantageous when planting early varieties or when the growing season is short.

Tubers that have been minimally aged are suited to long growing seasons where it is desirable to keep the potato growing to achieve maximum yields.

When planting sprouted seed it is necessary to control sprout numbers and length (maximum 2 cm) to ensure optimum growth according to plant spacing, and to ensure minimal sprout damage when planting.

At lower pH values potatoes can suffer from aluminum and other heavy metal ion toxicity, as well as restricted P or Mo availability.

At pH values above 7.5, nutrient availability, in particular of phosphorus and the micronutrients, can be reduced, even though high total amounts of these elements may be present in the soil. Liming can ameliorate undesirable, low pH values although care must be taken to ensure that the lime is applied at least 6 months before the potatoes are to be planted. Potatoes are more prone to common scab when grown in high pH soils.

When side dressing with fertilizer, the remaking of the ridge allows the incorporation of the fertilizer into the soil around the tuber.

Ridging also maximizes coverage of the developing tuber, so as to prevent greening and ensure tubers are well shaped, more evenly sized and at lower risk of damage.
Influencing Yield and Quality

Tuber Size

Tuber size and uniformity is critical for every market, whether it is fresh potatoes, seed or processing crops.

- Anything that the grower can do to prolong seed or processing crops.

Growers can manipulate tuber size by:

- Planting as early as possible to extend the length of the growing season in areas where daylight hours are limited.
- Planting physiologically aged potatoes that emerge quickly.
- Planting at optimum soil temperatures to ensure fast crop emergence (minimum of 12°C is desirable).
- Use of irrigation, crop nutrition and crop protection methods to ensure maximum canopy life and unlimited tuber growth.
- Desiccation at the right stage to meet market requirements.

Crop nutrition is also essential:

- Nitrogen and phosphate ensure strong leaf and tuber growth.
- Potash improves water uptake and dry matter production.
- Magnesium maximizes photosynthesis.
- Manganese and boron increase dry matter production.

Tuber Number

The numbers of tubers produced by each plant is influenced by agronomy and varietal potential. A large number of tubers per hectare will produce a crop of predominately small tubers, ideal for canning, saladdressed or seed potatoes. A relatively low tuber number provides less competition per unit area and allows the crop’s energies and resources to be used to produce larger potatoes for the fresh or processing markets.

Growers can manipulate tuber number by:

- Selecting the right variety.
- Minimizing growth checks at tuber initiation (e.g. drought, compaction).
- Irrigating to maintain a good growing environment.
- Physiologically ageing seed to produce the desired number of buds per tuber.
- Spacing seed to ensure an optimum number of stems per square meter.
- Using crop protection inputs - such as herbicides and nematocides - to ensure the crop grows relatively unhindered.

Crop nutrition is also essential:

- Phosphate that is readily available at tuber initiation ensures maximum tuber set.
- Potassium can increase the number of tubers initiated.
- High calcium supply can limit tuber numbers where large tubers are desired.

Tuber Quality

Whether it is dry matter content, internal disorders, reducing sugar levels, or cooking ability, tuber quality is critical for the end user.

Growers can influence tuber quality by:

- Selecting the right variety to meet dry matter production needs.
- Harvesting early, thereby minimizing late disease ingress or tuber deterioration.
- Ensuring blight spray programs are effective.
- Taking care during harvest and grading to reduce physical damage and bruising.

Crop nutrition is also essential:

- Nitrogen encourages leaf and tuber growth and maximizes starch production.
- Phosphate maintains leaf and tuber growth and influences starch quality and content.
- Potash maximizes water uptake and dry matter production. The source of this potassium can help reduce the level of bruising.
- Calcium minimizes internal rust spot and black spot.
- Magnesium ensures a strong photosynthetic capacity and good growth.
- Boron helps reduce internal rust spot and enzymatic blackening.

Skin Finish

Consumers increasingly demand potatoes with clean, attractive skins, particularly during storage.

Growers can influence skin quality by:

- Avoid selecting fields, where adverse factors such as disease, poor drainage or low water holding capabilities are present.

Storage and Cooking Quality

Once the crop has been harvested the story does not end. In many countries potatoes have to be stored to provide continuity of supply throughout the year.

Damaged or infected potatoes going into store will produce significant losses during storage.

- Adequate ventilation is important to dry the tubers after harvest and evacuate heat, water and CO₂ released by tuber respiration during storage.
- The appropriate storage temperature depends on the potato market.

Growers can influence storage and cooking quality by:

- Selecting the right variety with the right cooking quality for the market.
- Irrigation scheduling to maximize quality characteristics.
- Minimizing damage during harvesting.
- Using in-store treatments (e.g. fungicides) to reduce tuber disease build-up.
- Controlling temperatures in storage.

Crop nutrition is also essential:

- Potash affects bruising, enzymatic blackening and after-cooking blackening.
- Calcium helps prevent storage rots caused by Erwinia spp and also skin diseases.
- Boron and magnesium may reduce enzymatic blackening.
Nutritional Summary

Macronutrients
Nutrient uptake varies with the growth stage of the crop (Figures 4 & 5).

Potassium is the element most widely utilised by the potato crop.
While removal differs from field to field and depends on yield, potato crops can utilise 50% more potassium than nitrogen. A 35 t/ha crop can remove over 200 kg/ha of potassium and 115 kg/ha of nitrogen. (Figure 6).

Both potassium and nitrogen are needed throughout vegetative growth, tuber formation and bulking (Figure 4 & 5).

Potassium is particularly important for high yields but also for maintaining tuber integrity. “Luxury uptake” of potassium is typical in potatoes.

Nitrogen is important for leaf and tuber growth. Like potassium, a lot of nitrogen is recycled from the leaf to the tuber during bulking.

Phosphate is also needed in relatively large quantities, particularly during early growth, to encourage rooting and tuber set, and then again during late season for bulking.

Micronutrients
While much lower amounts of micronutrients are needed, the correct balance is essential for quality crop production (Figure 7).

Boron is needed in greatest quantities in order to ensure several key growth processes proceed unchecked. It is also important in optimizing calcium utilization.

Manganese and zinc are important for yield. Zinc plays a key role in N-assimilation and metabolism and starch formation.

While significant quantities of copper are used, deficiencies are rarely seen, with most soils providing adequate long-term supplies.

Molybdenum can be important in low pH soils.
Soil and Plant Analysis

Soil tests prior to planting can be used to predict responses to applied phosphorus, potassium, calcium, magnesium and sulfur fertilizer.

Tissue analysis (either petiole or whole leaf) taken during the growing season provides a more accurate guide to a crop’s nutrient status and the likelihood of nutrient disorders or deficiencies, particularly of micronutrients. See tables 2 & 3.

Standard practice is to sample the youngest mature compound leaf (leaflet and petiole) early in the season from 30 plants. This corresponds to the fourth or fifth leaf from the top of the plant.

In mid-season, the 30 – 40 petioles are collected from the first fully expanded new leaf. The petioles should be bulked together from a range of locations in any field.

Take care when sampling for copper, zinc and manganese to avoid sampling leaves that have recently been sprayed with fungicides as they may be formulated with these elements and so give misleading analysis results.

Tuber peel analysis is a useful means of assessing calcium levels in tubers – calcium tends to concentrate in or just under the potato peel. However, as yet no standards for peel nutrient concentrations have been established.

---

**Table 2**

Petiole Analysis Standards for Varying Tuber Sizes

<table>
<thead>
<tr>
<th>NO3</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>000 ppm</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>10</td>
<td>20 - 25</td>
<td>0.5 - 0.6</td>
<td>10.1-13.0</td>
<td>0.6 - 2.5</td>
<td>0.25 - 0.9</td>
</tr>
<tr>
<td>50</td>
<td>18 - 22</td>
<td>0.45 - 0.54</td>
<td>9.4 - 12.5</td>
<td>0.6 - 2.5</td>
<td>0.25 - 0.9</td>
</tr>
<tr>
<td>100</td>
<td>12 - 16</td>
<td>0.29 - 0.44</td>
<td>8.5 - 10.5</td>
<td>0.6 - 2.5</td>
<td>0.25 - 0.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ppm</th>
<th>B</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
<th>Mo</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 - 100</td>
<td>25 - 100</td>
<td>4 - 20</td>
<td>50 - 100</td>
<td>40 - 100</td>
<td>0.2 - 0.5</td>
<td>20 - 100</td>
</tr>
</tbody>
</table>

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**Table 3**

Leaf Analysis Standards, Potatoes

Leaves collected are from youngest fully mature leaf from healthy potato plants

<table>
<thead>
<tr>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deficiency</td>
<td>&lt;4.5</td>
<td>&lt;0.29</td>
<td>&lt;9.2</td>
<td>&lt;0.75</td>
</tr>
<tr>
<td>Optimum Level</td>
<td>4.5 - 6</td>
<td>0.3 - 0.5</td>
<td>9.2 - 11.5</td>
<td>0.75 - 1.0</td>
</tr>
<tr>
<td>Excess</td>
<td>&gt;6</td>
<td>&gt;0.5</td>
<td>&gt;11.5</td>
<td>&gt;1.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deficiency</td>
<td>&gt;25</td>
<td>&gt;6</td>
<td>&gt;50</td>
<td>&gt;30</td>
</tr>
<tr>
<td>Optimum Level</td>
<td>15 - 50</td>
<td>7 - 20</td>
<td>50 - 100</td>
<td>30 - 250</td>
</tr>
<tr>
<td>Excess</td>
<td>&gt;50</td>
<td>&gt;20</td>
<td>&gt;100</td>
<td>&gt;250</td>
</tr>
</tbody>
</table>

---

For petiole samples - collect 30 leaves (fourth leaf from the top) and strip the leaves from the petioles.

For peel analysis take a layer of tissue immediately under the peel.

Sample: Most recently developed leaf = collect 25 leaves.

REF: DIAGNOSTIC TECHNIQUES FOR IMPROVING CROP PRODUCTION, B WOLF - 1997
Fertilizer Application

Nutrients need to be applied as accurately as possible to the zone of uptake, before or at the time that the crop needs them. Failure to ensure that each plant gets the right balance of nutrients can spoil crop quality and reduce yield.

Preplant fertilizers are either broadcast or banded. Generally, banded fertilizers give the best results.

When broadcasting fertilizer it is essential to ensure that it is evenly distributed. Small variations in distribution of plus or minus 10% will result in yield losses of up to 3 t/ha (Figure 8).

When banding fertilizers it is important to keep the fertilizer away from the seed pieces. On low Cation Exchange Capacity (CEC) soils the band should be 10 cm below and 10 cm to the side of the seed piece. On higher CEC soils the fertilizer band can be placed closer to the seed piece. (e.g. 7 cm to the side and below the seed). Fertilizer must not be banded beside the seed piece, as germination will be reduced (Figure 9).

Figure 8
Yield Loss as a Result of Poor Spreading

Figure 9
Fertilizer Placement on High CEC Soils

Nutrients need to be accurately timed to coincide with critical growth stages; for example calcium at tuber initiation. Because different varieties initiate tubers at different times, it is important to visually check when the first tubers are being formed in order to ensure maximum nutrient efficiency.

With drip irrigation small quantities of nutrients are fed throughout the growing season. The irrigation tape must be placed near the top of the ridge to ensure good soil water and nutrient management in the potato root zone.

Overhead systems such as centre pivots, allow growers to feed soluble fertilizers constantly throughout the watering period.

Foliar nutrient applications need to be applied with sufficient water to give good canopy coverage and penetration, but not to the point of run off.

The Role of Specific Nutrients

<table>
<thead>
<tr>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>S</th>
<th>B</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
<th>Mo</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A</td>
<td>A</td>
<td>0</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td></td>
</tr>
</tbody>
</table>

YIELD

TUBER SIZE

TUBER NUMBER

SPECIFIC WEIGHT & DRY MATTER

TUBER - INTERNAL BLEMISHES

TUBER - SKIN FINISH

CROP STRESS

BRUISING & HANDLING RESISTANCE

STORAGE ROTS

COOKING QUALITY

PAGE NO. 18-19 20-21 22-24 25-27 28 29 30 31 32 33

INCREASE A REDUCTION V NEUTRAL ◊

© Yara
Nitrogen

Crop Needs

Nitrogen is important in fueling growth and providing high yields.

It is largely needed during leaf formation and then for tuber growth and yield, when it ensures optimal photosynthesis production in the leaves (Figures 10 and 11).

Nitrogen fed at an early stage of crop development will help build the overall size of the leaf canopy.

At later stages of growth, nitrogen use helps maintain the greenness of the canopy and maximize yield.

Figure 10

Nitrogen - Effect on Tuber Size

England

<table>
<thead>
<tr>
<th>Grade Sizes</th>
<th>Yield t/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;40mm</td>
<td>0</td>
</tr>
<tr>
<td>40-60mm</td>
<td>60</td>
</tr>
<tr>
<td>60-80mm</td>
<td>265</td>
</tr>
<tr>
<td>&gt;80mm</td>
<td>328</td>
</tr>
</tbody>
</table>

Application Rates

The total amount of nitrogen supplied will vary according to the length of time the canopy needs to be maintained and any potential losses such as leaching. Optimum total N rates vary with soil type and previous cropping history.

Where there are apparent yield responses to very high applications (>300 kg/ha), checks should be made for losses due to leaching.

Potatoes are very responsive to NPK at planting. Balancing nutrition in such a manner – often with magnesium and sulfur applied at the same time - ensures a good start for the potato crop.

Over-use of early N can lead to excessive vegetative growth at the expense of tuber formation.

In temperate climates, an excess supply of nitrogen at later stages of growth will keep the crop growing, preventing it from reaching maturity. It may also, reduce stalk and dry matter content, reducing processing potato crop quality (Figure 12 and 13).

Figure 12

Nitrogen - Effect on Starch Content

Belgium

<table>
<thead>
<tr>
<th>Grade Sizes</th>
<th>Yield t/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;60mm</td>
<td>0</td>
</tr>
<tr>
<td>40-60mm</td>
<td>80</td>
</tr>
<tr>
<td>60-80mm</td>
<td>150</td>
</tr>
<tr>
<td>80-120mm</td>
<td>245</td>
</tr>
</tbody>
</table>

Split Applications

High rates of N can cause internal cracking.

Where high levels of nitrogen are needed, advantages can be obtained from splitting N applications. Trials with a three way split increased yields by 12% compared to where all the nitrogen was applied in one go (Figure 14).

Figure 13

Nitrogen - Effect on Dry Matter

Norway - 12 varieties

Nitrogen form

A balance of ammonium and nitrate is best used at planting, and can be supplied from a quality NPK fertilizer.

Too much ammonium nitrogen is a disadvantage as it reduces root zone pH and thereby promotes rhizoctonia.

For side dressing from tuber initiation onwards, nitrate nitrogen has distinct advantages.

Figure 16

Nitrate Nitrogen - Effect on Specific Gravity

South Africa

Relative Yield

Total N

Total N

Total N

20 Ammonium

40 Ammonium

80% NH _4 / 20% NO _3

20% NH _4 / 80% NO _3

30% NH _4 / 70% NO _3

50% NH _4 / 50% NO _3

100% NO _3

Deficiency Symptoms

When nitrogen is deficient, potato leaves are a pale yellow/green, small in size and drop prematurely. The plant is stunted in growth with only a few thin stems. Yields are low as few tubers are formed.

Nitrates nitorgen enhances the uptake of cations such as calcium, potassium and magnesium. This results in increased specific gravity (Figure 16).

Nutrient uptake is at its greatest during tuber bulking. At this time, nitrate nitrogen is the preferred source and vital for high yields and quality crops (Figure 17).

Figure 17

Nitrate Nitrogen - Effect on Yield

South Africa

Specific Gravity

Relative Yield

Total N

Total N

Total N

Nitrate nitrogen enhances the uptake of cations such as calcium, potassium and magnesium. This results in increased specific gravity (Figure 16).

Too much ammonium nitrogen is a disadvantage as it reduces root zone pH and thereby promotes rhizoctonia.

For side dressing from tuber initiation onwards, nitrate nitrogen has distinct advantages.

Figure 15

Foliar Nitrogen - Effect on Yield

South Africa

Relative Yield

Total N

Total N

Total N

20% NH _4 / 80% NO _3

50% NH _4 / 50% NO _3

100% NO _3

© Yara
Phosphorus

Crop Needs
Phosphorus is important for early root and shoot development, providing energy for plant processes such as ion uptake and transport.

At tuber initiation, an adequate supply of phosphorus ensures supplies of optimum numbers of tubers are formed (Figure 18).

Figure 18
Phosphorus and Yield
Wales - Desiree

Following tuber initiation, phosphorus is an essential component for starch synthesis, transport and storage.

Under situations of high phosphorus lock-up e.g. volcanic soils or low organic matter, low P, sandy soils, it is important that fertilizer-P is placed close to the tuber. Because phosphorus is relatively immobile in the soil, banding the fertilizer usually works better than broadcasting.

While potatoes are very responsive to fresh soil phosphate, the economic optimum rate is often very difficult to define (Figure 18). Rates will depend on soil type and soil test results.

In trials, tuber yield is increased by 0.6 t/ha for every extra day during which leaf tissue phosphorus is maintained above 0.22% (Figure 19).

Tuber Numbers
It is particularly important that phosphorus is available at tuber initiation, especially if tuber number needs to be increased in varieties producing few tubers, or where the market demands a large number of smaller tubers (e.g. seed production).

Where sufficient soil phosphorus is not available for growth, foliar phosphate ensures rapid availability. Applied just before tuber initiation, foliar phosphate increases total tuber number (Figure 20).

In addition, foliar phosphate, applied after tuber initiation, has been shown to have a positive effect on tuber yields by increasing tuber size (Figure 21 and 22).

Figure 21
Foliar Phosphorus - Effect on Yield
England

Deficiency Symptoms
The older leaves curl upwards and may develop necrotic spots on the margins. The tubers may have rust-brown colored blotches and plants are shorter with thinner stems.

Phosphorus fertilizer use can influence starch quality. By increasing the tuber P content, the viscosity of the gelatinised starch is also increased and the gelatinisation temperature decreased (Figure 23). As starch is commonly used as a thickening agent in food and other products, good phosphate nutrition can be of significant benefit.

Figure 22
Foliar Phosphorus - Effect on Yield
Australia

However, foliar phosphate is not a substitute for soil applied phosphate. Without adequate soil phosphate early season growth is sub-optimal.
Potassium

Crop Needs
Potato plants absorb large quantities of potassium throughout the growing season. Potassium has an important role in the control of the plant water status and ionic concentrations inside plant tissues, including stomata. As a result of the improved cell strength that potassium provides, stress such as frost can be better tolerated (Figure 24).

Figure 24
Potassium and Frost
India
Similar responses have also been found in South African and Indian research (Figures 26 and 27).

Figure 26
Potassium and Yield
South Africa
In comparison, the chloride in potassium chloride can have a negative effect on tuber dry matter and skin quality.

Figure 27
Potassium and Yield
India

Potassium also influences the transport of nutrients and the movement of sucrose from the leaf to the tuber.

Figure 28
Potassium Form - Effect on Yield
Bulgaria
It is important that potassium availability is not limiting. Trials show that potassium nitrate is a particularly effective formulation, providing readily soluble and quickly absorbed potassium and nitrate nitrogen in comparison with other potassium forms (Figures 26 & 28). This makes potassium nitrate particularly effective in sidedressing applications during the bulking stage.

In trials, use of potassium nitrate in conjunction with calcium nitrate, ensures fast uptake of all three important elements enhancing yield over and above other products (Figure 30).

Figure 29
Potassium Form and Tuber Number
England - Maris Piper
Sulfate of potash (SOP) in comparison, can lead to greater bruising than muriate of potash (MOP) when tubers with a high dry matter content are produced (Figure 33).

Figure 30
Potassium Form and Yield
South Africa

Quality Characteristics
Potash reduces the level of tuber bruising. (Figure 31 & 32).

Figure 31
Potassium and Bruising
England
Low levels of potassium can also increase the incidence of after-cooking blackening. Potassium influences the concentration of organic anions such as citric acid or ascorbic acid (i.e. vitamin C within the tuber). These 2 molecules have an antioxidative function, which decreases the incidence of enzymatic and non enzymatic discoloration by slowing down the oxidation processes (Figure 34).

Figure 32
Potassium - Reduces Tuber Damage
Germany
Sulfate of potash (SOP) in comparison, can lead to greater bruising than muriate of potash (MOP) when tubers with a high dry matter content are produced (Figure 33).

Figure 33
Potassium Form and Bruising
UK

Deficiency Symptoms
Leaves turn a dark to bluish-green color with a bronzed metal sheen. Small brown necrotic spots appear first in the margins and grow rapidly to spread across the leaf area. The leaves bend downwards and the leaf tip has a waxy appearance. The foliage wilts and dies as the deficiency progresses. The tubers will have black spots and, when cut, will blacken rapidly.

Figure 34
Potassium and Tuber Discoloration
USA
Sulfate of potash (SOP) in comparison, can lead to greater bruising than muriate of potash (MOP) when tubers with a high dry matter content are produced (Figure 33) and therefore is frequently the preferred form for processing potatoes.
Crop Needs
Calcium is a key component of cell walls, helping to build a strong structure and ensuring cell stability. Calcium enriched cell walls are more resistant to bacterial or fungal attack.

It is critical during cell division and expansion, and is therefore essential prior to, and during, the rapid growth phase of tubers.

Calcium also helps the plant adapt to stress by influencing the signal chain reaction when stress occurs. It also has a key role in regulating the active transport of potassium for stomatal opening.

Calcium Movement
The vast majority of calcium taken up by the plant is through the main root system. It is then transported through the xylem vessels upwards to the leaves, by water-flow through the plant. Once in the leaf, calcium is immobile and unlike other nutrients such as N, P and K, doesn’t move to other leaves or down to the tubers at a later stage (Figure 38). For example, calcium is immobile and unlike other nutrients such as N, P and K, doesn’t move to other leaves or down to the tubers at a later stage (Figure 38).

Calcium movement into the tubers is via the stolon and tuber root hairs, and through the tuber skin.

A large number of research papers show that readily available calcium supplied in the soil close to the stolons and tubers is the most effective way to increase tuber calcium levels. This can be best achieved by top-dressing with Yara calcium nitrate at tuber initiation. Where fertigation is an option, calcium nitrate should also be applied throughout tuber bulking.

Foliar applied calcium specially applied at tuber initiation may also have a small role in increasing calcium content of the tubers (Figure 39). However, soil applied calcium remains the most efficient way of increasing tuber calcium levels. (Figures 40 to 42).

Calcium Movement in Potatoes
Calcium movement into the tubers is via the stolon and tuber root hairs, and through the tuber skin.

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Crop Stress
Russett Burbank

Calcium and Crop Stress

Figure 36
Calcium and Crop Stress
Russett Burbank

Crop Needs
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Figure 37
Calcium and Heat Stress

Calcium movement into the tubers is via the stolon and tuber root hairs, and through the tuber skin.

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Foliar applied calcium specially applied at tuber initiation may also have a small role in increasing calcium content of the tubers (Figure 39). However, soil applied calcium remains the most efficient way of increasing tuber calcium levels. (Figures 40 to 42).

Calcium Movement in Potatoes
Calcium movement into the tubers is via the stolon and tuber root hairs, and through the tuber skin.

A large number of research papers show that readily available calcium supplied in the soil close to the stolons and tubers is the most effective way to increase tuber calcium levels. This can be best achieved by top-dressing with Yara calcium nitrate at tuber initiation. Where fertigation is an option, calcium nitrate should also be applied throughout tuber bulking.

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High levels of calcium in the tuber also reduce bruising risks at harvest and subsequent transportation. Varieties vary in their calcium uptake (Figure 44). However, using calcium nitrate rather than ammonium nitrate minimizes bruising damage (Figure 45). In some varieties, damage can be halved.

The use of calcium in crops grown for seed boosts the following crop's performance. A mother tuber enriched with calcium is faster growing and in better condition, thereby boosting yield per plant (Figure 46).

Severe symptoms in the field will show in the leaves. The youngest leaves are pale green and small, and curl downwards at the ends of the leaves. Brown blotches may appear on the leaf margins. When potatoes are grown in hydroponic solutions with no calcium, the leaf stalks and growing points will collapse and the developing tubers may show severe cracking of the skin (See photo).

For processing potatoes e.g. Russet Burbank high levels of calcium (165 kg/ha) have increased individual tuber size and weight, through decreasing tuber set (Figures 47 and 48). There is no loss in total crop yield, but a more marketable tuber is produced for the french fries and crisping industry.

Adequate magnesium is needed during tuber bulking. If dry soil conditions restrict uptake, then foliar sprays can be very effective. Uptake of magnesium is dependent upon the cation exchange capacity of the soil and its balance with the other cations, especially potassium. High concentrations of potassium in the soil can induce magnesium deficiency. In such cases, foliar applications of magnesium are beneficial.

Low magnesium levels can increase susceptibility to enzymatic discoloration (Figure 53). Trials confirm the positive benefits of magnesium on tuber dry matter and specific gravity (Figures 50 and 52).
**Sulfur**

**Crop Needs**
The potato crop has a demand for sulfur in similar quantities to magnesium.

Where potassium sulfate is commonly used, supplies are usually adequate.

Sulfur helps to reduce the level of common and powdery scab. This effect may be due to a reduction in the soil pH where elemental sulfur is used.

**Deficiency Symptoms**
Sulfur deficiencies in potatoes appear similar to nitrogen deficiencies. All leaves are pale yellow and are smaller in size than normal. The youngest leaves are a brighter yellow. This should not be confused with iron deficiency, which looks similar but the veins stay green.

**B Boron**

**Crop Needs**
Boron influences root and shoot growth, plant development and pollination.

Boron also affects calcium absorption (Figure 55), so supplies are important to ensure a balanced nutrition.

**Quality Effects**
Boron stabilizes calcium in the cell wall and acts in synergy with calcium to improve plant resistance to disease, pest and environmental stresses. In this respect, it can help minimize apical necrosis of sprouts (Figure 56).

**Deficiency Symptoms**
The stems of potato plants are short and as a result of sprouting from the lateral buds, the plants look bushy. The youngest leaves become chlorotic, develop necrotic spots and die. The chlorosis of the leaves may progress from yellow to brown to a reddish dark brown.

In tubers, the rings of vascular bundles turn brown, particularly near the hilum. The tuber skin is often rough and cracked with necrotic flesh underneath.

Boron reduces the oxidation of phenols that are responsible for enzymatic discoloration. Thus, a good supply of boron reduces the occurrence of enzymatic discoloration in potato tubers. (Figure 57).
Deficiency Symptoms
Copper deficiency is rare, although it can occur on extremely acid soils below pH 4.0.

When it occurs the youngest leaves are permanently wilted and curled up. There is no chlorosis of the leaves.

When flower buds develop, the terminal buds are missing.

Crop Needs
Copper behaves in a similar manner to magnesium in the potato plant, supporting a number of biochemical processes. However, unlike magnesium, copper is extremely immobile in the plant and moves only upwards via the xylem to the leaves. Once in the leaves, there is no transference to other parts of the plant.

Severe copper deficiency can significantly reduce yield (Figure 58), and dry matter content (Figure 59).

Deficiency Symptoms
The visual expression of molybdenum deficiency in potatoes depends on the level of the micronutrient within the seed tuber. If the seed tubers are taken from a soil lacking in molybdenum (e.g. low pH soils), then the young developing leaves remain pale green and develop golden yellow chlorotic blotches.

Deficiencies can be corrected with foliar applications of molybdenum.

Crop Needs
Zinc resembles manganese and magnesium in that it acts as a binding agent in enzymatic reactions. In this way it is important in protecting proteins from denaturing.

Therefore, zinc has a major role to play in nitrogen metabolism and deficient crops will have lower levels of protein. Starch content is also affected by zinc.

Yield responses to zinc can be expected in crops grown on soils with a low or high pH if the zinc levels are low (Figure 60).

Deficiency Symptoms
In potatoes, zinc deficiency symptoms are variable. In general the leaves are smaller and the plants are stunted in growth. The leaves fold inwards giving a ‘fern-like’ appearance. Grayish brown to bronze colored blotches appear first on the middle leaves and later on all leaves.

Quality Effects
Zinc is commonly used to suppress powdery scab where the innoculum is at low levels. Only soil applications are likely to provide sufficient zinc to have an effect on powdery scab (Figure 61).
Nutritional Programme

Showing nutrient requirements at key growth stages

- **Planting**
  - **Nutrient Effects**
  - Nitrogen and Potassium - early growth and dry matter
  - Phosphate - more tubers, growth and dry matter
  - Magnesium - for plant development
  - Zinc and Manganese - Powdery and Common Scab control
  - Sulfur - Common and Powdery Scab and tuber numbers
  - Trace elements - for balanced nutrition

- **Post Planting**
  - **Nutrient Effects**
  - Nitrogen - split applications to reduce losses
  - Potassium - growth and dry matter
  - Trace elements - for balanced nutrition

- **Ridging and Hilling**
  - **Nutrient Effects**
  - Nitrogen - second split application
  - Calcium (+/- Boron)
  - good skin quality
  - internal rust spot reduction,
  - stress tolerance – drought/heat.

- **Before Tuber Initiation**
  - **Hook Stage**
    - **Nutrient Effects**
    - Phosphate - more tubers
    - stronger growth

- **Tuber Initiation**
  - **Nutrient Effects**
  - Phosphate and Magnesium - bigger tubers
  - Zinc and Manganese - skin finish
  - Calcium (+/- Boron) - good skin quality, internal rust spot reduction, stress tolerance – drought/heat

- **Flowering and Bulking**
  - **Nutrient Effects**
  - Nitrogen, Phosphate and Magnesium - maintain tuber growth
  - Calcium - improves skin finish and reduces disease impact
Potato Plantmaster™

Yara is a leading supplier of specialist crop nutrition advice and fertilizers to farmers throughout the world.

As part of its commitment to the agricultural industry, the company has developed a comprehensive series of Nutrition Management Programmes for a wide range of crops under the Plantmaster™ brand.

They bring together the results of research and development activities and the practical experiences of the company’s agronomists from around the world, to provide comprehensive baseline fertilizer management strategies. This Potato Plantmaster™ summarizes the quality requirements for the fresh and processing markets and outlines the nutritional principles required to achieve a top-performing potato crop.

More information on potato growing is available through Yara, or its alliance partners, SQM or Phosyn, including the detailed trials upon which this manual is based; scientific papers, local country recommendations, as well as detailed product and application guidelines.

Yara recognize that there is no universal blueprint for potato production. However, by working with your local Yara, SQM or Phosyn agronomist you can be sure of top potato crop performance backed by one of the most comprehensive Nutrition Management Programmes available, developed and supported by the world’s leading fertilizer specialists.

Units

The units used within this manual are largely those quoted by the authors or the source in their country of origin. Where applicable metric equivalents have been used.

Thus a yield expressed as Tonnes relates to Metric Tonnes (1000kg), unless the country of origin is the USA when this figure is an American Ton, which is equivalent to 907kg.

1 lb/acre = 1.12kg/ha  1kg/ha = 0.89lbs/acre

Converting Oxides to Elemental Form

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Growing Your Potential

For a potato fertilizer programme to meet your local needs, contact your nearest Yara Agronomist.

Inserted here are local Yara fertilizer recommendations. If this sheet has been removed, please contact your local distributor.