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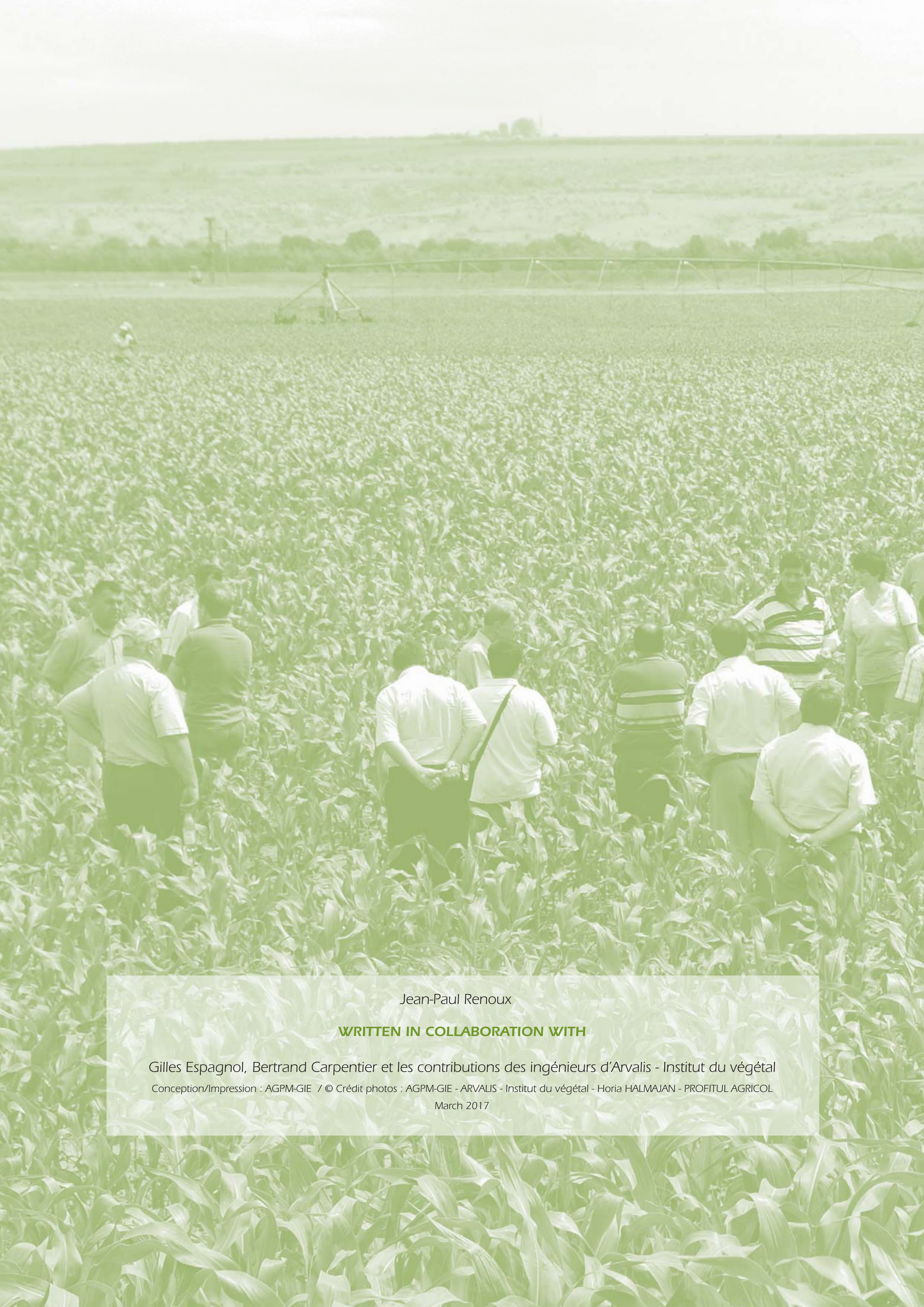
NEW EDITION

Technical Guide

Grain & Silage Maize
Central & Eastern Europe

ARVALIS
Institut du végétal



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Technical Guide

Grain & Silage Maize
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Maize has become the number one cereal grown and consumed in the world. Over the last fifteen years, maize production has seen substantial changes: production has increased from 650 million tonnes reaching one billion tonnes in 2015, keeping pace with the needs of emerging countries where eating habits have changed rapidly as more meat has become available. New markets for high biomass crops such as maize have come with the shift to renewable energy sources being used instead of fossil fuels. Globally, maize production comes from four main players: the United States which is the clear leader, China where production scarcely covers the vast needs, Latin America with a substantial increase in export capacity, and Europe. In this context, the geographical entity of Europe has seen maize production reaching a new balance between Eastern and Western Europe. Central Europe, which is now part of the European Union, and Eastern Europe (Ukraine and Russia) have become major producers and provide an ever greater proportion of maize to meet the needs of the continent. Eastern Europe has been the granary of the Mediterranean since ancient times and has both the organisations and different soil types needed for further production potential which has not been fully tapped.

The present guide to growing maize, produced by the AGPM (French maize producers' association) and ARVALIS-Plant Institute, with support from the FNPSMS (French seed maize and seed sorghum producers' federation), is designed to provide the guidance needed to make optimal use of top-performance varieties available on the market for farmers in these countries.

Luc Esprit, *Directeur F.N.P.S.M.S.*

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Throughout the guide, a distinction has been made in all presentations between two types of factors contributing to yield:

- **Input factors :** which determine the highest possible level that can be achieved when making optimal use of elements in the environment that cannot be changed (climate and land): agronomics, fertilization and the choice of varieties. A large proportion of these inputs play a role early, by the time of sowing.

- **Protection factors:** which are designed to restrict damage affecting initial genetic potential and reduce the impact of all types of attack, e.g. weeds and pests (both animal and vegetable). Minimising the impact of water stress may also be considered to be yield protection.

Chapter 1

The Physiology of Maize & the Plant Life Cycle

1. A short cycle for a plant with enormous potential

Maize is a multi-purpose plant (used as grain maize, high-moisture grain for silage, whole plant silage for animal feed, biogas, 1st and 2nd generation ethanol and more). The plant stands out for its vast production potential which is the result of thousands of years of breeding different varieties, first by farmers, then through seed research, both private and public. Seed companies devote considerable resources to breeding and improving maize varieties, doing so in particular with prospects for genetic advances possible because of the "natural" genetic variability of maize, this being a major source of hybrid vigour (heterosis) for breeding hybrids, and as maize is well suited for applications and advances through biotechnologies.

The time between the breeding of lines and developing varieties, and then having them available to maize-growers has become much shorter over the last fifteen years, and growers are not excluded from the processes leading to such advances, having been involved in the past as they still are today. This is firstly because half of the agricultural progress has come from crop-growing strategies used by the farmers themselves, and also their choices of varieties. Thus the performance achieved by the hybrid plant which has to be sown every year depends first on farmers choosing the right combination for the genotype and constraints on the farm. Their choices help contribute to genetic advances improving maize yields, as can be seen around the world.

Today, in countries where farming conditions are sufficiently good, national yields can reach or even go above 10 tonnes per hectare, i.e. approximately twice average yield globally. It even appears that there is no upper limit to such yield potential: the highest levels achieved in Europe are moving up towards 20 tonnes of dry grain harvested per hectare.

This potential is particularly extraordinary given that the development cycle of maize is so short. At the beginning of and throughout the growing cycle, different morphological and biochemical developments occurring in the plant match the development of various criteria for quality, yield, earliness and energy value.

2. An efficient system

The potential afforded by genetic advances comes initially from features inherent in the plant and in a particularly efficient biochemical system.

Maize (as is also the case for 600 grass species, sorghum and sugar cane) has a c4-type metabolism that is very efficient. C4 plants fix more CO^2 and produce more carbon biomass per hectare. A hectare of maize grown in European conditions can produce up to 30 tonnes of above-ground biomass dry matter every year. In C3 plants, when the CO^2 level goes below a certain threshold, a support process is triggered through biochemical activity to offset the decline in photosynthetic efficiency. This phenomenon, known as photorespiration, has high energy requirements and consumes not only CO^2, but also oxygen. Photorespiration can cause a 30 to 50% drop in photosynthetic efficiency. C4 plants, however, have a very low tolerance threshold for CO^2 levels, with very little or no photorespiration. This explains a number of differences, such as the efficient use of water and nitrogen inputs. C4 plants such as maize also have a higher temperature threshold, thus providing a safety margin with the prospect of global warming. But maize is a summer plant and, as such, also has to cope with more frequent and more severe drought periods. Changes to adapt farming techniques, varietal tolerance or even the use of irrigation will therefore be major issues for maize growing around the world.

The maize cycle is comprised of two consecutive stages: the first is between sowing and flowering, with the appearance of the organs that capture sunlight (leaves), water and minerals (roots), and the formation of flower heads, both male (tassels) and female (ears). The second stage is the filling of the fertilized grain through continuing photosynthesis, and the transfer of reserves to the ear. Harvesting is the concluding stage and is done at different stages according to the relevant use to be made of the plant.

With the speedy growth of the plant, its shape, size and yield components (one ear per plant), growers have little scope for action to offset the negative impact of any contingencies. The critical part of maize growing is sowing: the date and conditions are key features determining not only the crop but also most of the production costs and operating expenses: the choice of variety, basic manuring, crop density, basic weed control and crop protection to control soil-borne pests.

Starting with this initial "genetic" potential, maize yield can be calculated as an exercise in subtraction, i.e. factoring in the different variables (weather and agronomics) and any poor choices made by the farmer that will gradually reduce the potential; the final yield harvested is then the result after subtracting these. Once the seed has been sown, therefore, the goal is to minimise the impact of both biotic and abiotic stresses on the crop.

3. A two-stage vegetative growth cycle

In the first part of the cycle, farming operations are conducted, one after the other, starting with soil cultivation; all are designed for optimal establishment of the crop, to help stalks and leaves develop and keep them intact to safeguard the subsequent nutritional value for the grain (vegetative stage). The time between the stage when 50% of leaves can be seen (8-to-10-leaf stage) and tassel emergence is when the number of ovules that could potentially be fertilised is determined. As leaves develop and through to the tassel emergence stage (the number of tassels depending on the genotype), the environment, i.e. temperature, potassium and nitrogen-based nutrition and water, will have a substantial influence on plant growth.

Flowering (first the male flower, then the female) and fertilization are the "centre of gravity" in the maize growth cycle. For an average early variety (FAO earliness index of 300-400), flowering will occur mid-way (for both time and total temperature calculations) between sowing and harvesting of the grain. This is the peak of the reproductive growth stage, and is also the time of peak demand for water and the main plant nutrients (nitrogen). During flowering, temperatures above 40°C can affect the viability of pollen in hybrids, while the viability of ovules will be affected by extended water stress.

The second part of the cycle starts with fertilization and the determination of the final number of kernels. For three weeks after fertilization (250 degree-days, base 6°C for French ratings), the plant is still susceptible to water stress and nitrogen stress, although recent advances in genetics have brought considerably improved resistance to forms of stress during this stage that may cause kernel abortion. By the end of this process (end stage for kernel abortion) the final number of kernels is set.

After this, the plant devotes its energy to grain filling. The size of the sink (i.e. the kernel number per plant, KNP, and the number of kernels per square metre) determines the effort the plant body exerts for the ear, and this, in part, is done at the expense of the plant.

mid-April/late May	late April/early June	early May/early June	early June/late June	mid-June/mid-July	early July/mid-July
Sowing/Emergence	**2-3 leaves**	**4-5 leaves / Separation**	**8-10 leaves Start of tassel and ear formation**	**12-14 leaves**	**Tassel visible in whorl**
80 GDDs +/- 20 GDDs depending on date of sowing, weather and soil.			An average of 44 GDDs needed for each new leaf		220 GDDs before female flowering
• 1st leaf breaks through soil. Seedlings form row.	• First round-tipped leaf. Seedling feeds on seed reserves.	• The seedling food supply comes through the newly formed primary and crown roots	• With 50% of leaves visible, i.e. 8 leaves for early varieties and 10 for late, all leaves are differentiated and the tassel and ear have started to form. The plant moves into the fast growth stage.	• Leaves cover the inter-row space. Leaf Area Index close to 1 (1 ha leaf area/ hectare farmed)	• Tassel emerges from whorl. Silks get longer. Number of ovules per row is determined
		→ **Establishment of final plant stand**	→ **Number of ovules of main ear determined**		→ **Potential number of ears is determined** → **Number of fertilisable ovules is determined**

The crop is said to have reached a stage when 50 % of plants display the relevant characteristics.

LEAF DIFFERENTIATION & EMERGENCE
LEAF & ROOT GROWTH

FORMATION OF OVULES & FERTILISAT
GROWTH OF LEAVES, ROOTS & STA

NITROGEN: staggered application
Adjust dose to plot potential.
Divided applications aligned with plant's requirements.
TRACE ELEMENTS: during vegetative growth phase if needed (Zn & Mn)

Weeding before sowing / Weeding before emergence

1) Complementary weed control, in field targeting annual grass and annual dicotelydons.
2) Post-emergence weed control
3) First treatment of perennials

2nd (spot) treatment of perennial weeds if needed

Monitor warning signs
(e.g. slugs, cutworm and aphids)

Corn borer: monitor agricultural warnings.

Beginning of water stress susceptibility

Start up irrigation as per local warnings or tensiometer readings

Mineral supply	Pests
Weeds	Water supply
Harvest	

mid-July/mid-August	early August/early Sept.	late Aug/mid-Sept	mid-Sept/late-Sept	mid-Sept/early Oct	mid-Oct/late Oct
Female flowering	**End stage for kernel abortion**	**Appearance of the flinty spot** (flint and flint-dent varieties) **Appearance of indentation on tip of kernel** (dent varieties)	**50% grain moisture content**	**45% grain moisture content**	**32% grain moisture content**
▪ early: 825-875 GDDs ▪ semi-early flint-dent: 875-925 GDDs ▪ semi-early dent: 925-980 GDDs ▪ semi-late: 975-1000 GDDs ▪ late: 1000-1 050 GDDs	250 GDDs after female flowering	20-24 GDDs needed at end of phase for each additional percentage point of dry matter	600-675 GDDs after female flowering	▪ 640-700 GDDs after female flowering ▪ 18-22 GDDs needed to remove one grain moisture percentage point	850-950 GDDs since female flowering, depending on earliness
• Silks appear outside the ear. Tassel releases pollen. Ovules are fertilised. Leaf growth is complete. Maximum LAI.	• Albumen cells that will store starch multiply over the 3-week latency phase after fertilisation. Slight increase in kernel weight and final number of kernels is set. Plant reaches maximum height. Dry matter is stored in stalk. The vegetative part of the plant reaches maximum weight.	• Dry matter quickly forms in the kernel. The texture of the starch changes: first milky, then dough, then dent. In flint & flint-dent varieties, flinty starch begins to form in the kernel, indicating 25-27% whole plant DM content.	• Grain growth slows down. At this stage, albumen contains 1/3 milky starch • 50% grain moisture content means approx. 32% whole plant DM content	• Grain at 75-80% of maximum weight • Dry matter in stalk and leaves feeds grain growth. FAI quickly drops ➜ **Whole plant yield at maximum**	• Maize has reached physiological maturity. Grain weight is at maximum. The black layer seen at the base of the kernel means that the translocation of the assimilates has been completed. All starch is either floury or flint. The plant looks dry. ➜ **The "1000-kernel weight" is set**

TION
LK

NUMBER OF KERNELS SET
GRAIN FILLING

If fertigation, add nitrogen

Fine shredding of post-harvest residue as preventive corn borer control

Steady rate: application and frequency to suit soil and weather. Follow local warnings.

Follow local warnings for date to end irrigation. Factor in date, stage and available water capacity.

Silage harvested at 28-35% whole plant dry matter content

If possible, grain harvest after the 35% moisture content stage, or earlier for high-moisture maize

After flowering, the whole plant yield follows in line with the increase in kernel yield. Sugars produced by photosynthesis in the leaves are stored as starch in the kernel and transferred to the ear. The "stalk + leaf" part achieves maximum yield 2 to 3 weeks after flowering. Provided that the prevailing weather and the quality of the leaf surface (green and therefore efficient for photosynthesis) are adequate, the yield continues to increase. As a general rule, maximum total biomass peaks at 35% whole plant dry matter.

From late September/early October on, weather conditions limit photosynthesis and yield levels flatten out. Grain filling continues, supported by the remaining leaf surface and transfer from the "stalk + leaf" part. Maximum grain yield is reached when grain moisture content is between 32% and 28% depending on the final conditions. The decision on the right time to harvest, whether grain or silage maize, can be made simply by observing changes in the different starches in the grain (See chapter on "Harvesting").

Chapter 2

Agronomics, Soil Cultivation

1. The Site & Soil Cultivation Reviewing Basic Principles

The site will often be the decisive factor determining the level of yield. The state of the soil in the sowing horizon is therefore of crucial importance; it must be packed, but not overly compacted, with sufficient fine soil. The different ploughing and tilling operations are designed to produce the right structure for root development and emergence. There must be no breaks in the soil profile. Maize establishes roots much better in a uniform or even slightly compacted soil, rather than loose soil or a series of horizons with greatly varying degrees of porosity.

The move between the seedbed and the horizon marked out by secondary tillage tools must be done gradually as weaning (the shift from autotrophy to heterotrophism with the development of the final root system at the 4-to-5-leaf stage) is a delicate moment in the life of the young maize plant. This is where the young roots will develop. Similarly, the tillage pans or zones compacted by the initial cultivation tools or secondary tillage tools (in particular power tools) which either block or slow down main roots as they penetrate to deeper soil horizons, will reduce access to water in the soil which maize, and even irrigated maize, relies on so much in summer.

To achieve this goal, and regardless of the tools or cultivation stage, whether ploughing or secondary tillage, work is done on soil that is sufficiently drained. Seedbed preparation (early for high-clay soil and at the last minute for lighter soil) must be done with a minimum number of runs.

There is no such thing as perfect soil preparation and it often ends up as a compromise with the weather, the number of days available, the type of equipment, and the size of the farm or business. Special attention is needed to ensure that the soil does not dry out completely between runs, using different techniques and keeping an even settled profile to maintain moisture in the soil.

Any crop stubble and surface residues, while good mulch to build up silty soils, have the downside of attracting and providing shelter for various pests and plant parasites; they are also an obstacle to early weed control, which is when it is most effective.

Special Attention

Continental weather conditions mean special constraints

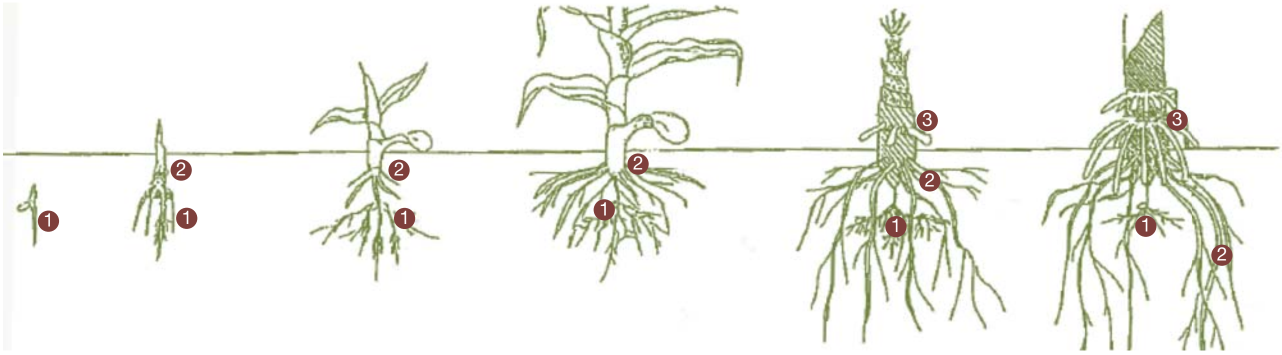
For a continental climate, the best times for cultivating the soil and sowing are in spring, and are extremely short. Logistics for sowing, in particular the width of the seed drill and the speed, are of critical importance. And in summer, when crops are often subject to severe water stress, maize is **highly dependent on the status of the root development.** Soil preparation is therefore a key exercise. For heavy soil, it is often best to cultivate the soil in autumn, before the frosts. It is often useful to plough to make sure that any maize residue is properly mulched before re-sowing maize, but this is not essential. The level of moisture in the soil is more important than the tools used.

Efforts have often been made for simpler cultivation without ploughing or tilling for financial reasons and for workflow, but this also has disadvantages. The table below compares the techniques – till and no-till – listing the pros and cons.

No-till cultivation. For or against?

For	Against
Economic Arguments	
Less expenditure through ▪ less manpower time ▪ more acreage per labour unit ▪ simplification of tool requirements (multi-purpose tools)	▪ High cost of purchasing & maintaining tools
Agronomic Arguments	
▪ Keep plant waste on surface to - reduce the risk of surface sealing (mulch effect) - reduce the risk of erosion on sloping land - concentrate organic matter in the first few centimetres of soil ▪ More even, continuous soil profile for better root development. ▪ Soil cultivation: save time in spring ; soil will not dry out between ploughing and start of growth. ▪ NB: all these benefits are cancelled if and when the field is ploughed again.	▪ Large quantities of grain maize plant debris ; fine (or double) shredding essential. ▪ Slower drying of soil profile in spring ▪ Warming the soil: thermal inertia ▪ Risk that untilled part will become compacted, probably causing the deeper soil horizons with low clay content, below 15%, to loosen. ▪ Soil cultivation: more targeted technique, and risk if soil is not sufficiently dry.
Crop establishment / Animal pests	
▪ Even sowing depth only if appropriate seed drill is used ▪ Fosters beneficial microfauna (earthworms) ▪ Helps control corn borer as shredding must be efficient	▪ Seed sown in a soft horizon with a lot of plant debris. ▪ Density may be lost if the furrow is not properly closed when sowing directly with a disc seed drill. ▪ Risk of soil drying out and plant loss at emergence. ▪ Development of soil-borne pests: click beetle, crane fly, black cutworm. ▪ Greater risk of slugs. ▪ Greater risk of borers when direct sowing without shredding harvest residue.
Weed Control	
▪ Gradual depletion of surface weed seed potential.	▪ Initial increase in weeds, particularly in single-crop farming with perennials that are difficult to control (e.g. bindweed and thistle). ▪ Risk of active ingredients binding to organic matter and recurring with following crops. ▪ Incorrect use of total weed-killer in winter.
Diseases	
	▪ Proven increase in risks with concentration of inoculum in surface horizons: fusariosis, corn blight, head smut, root die-off. ▪ Impact on mycotoxin risk for next crop.
Harvesting	
▪ Soil less subject to compacting, improved structure. ▪ Between-row mulching already done.	

Root Development Stages



Germination Emergence	4-leaf stage	From 4 leaves to 6 to 7 leaves	Elongation 7 leaves - flowering	After flowering
Seed swells by absorbing water (imbibition). Then calls on reserves (activation)	Primary roots develop ❶ First end roots develop ❷ Terminal bud still beneath the surface.	Growth shifts from seed reserves to autonomy. End roots develop ❷.	Swift growth of final root system ❷. Brace roots appear ❸	2 weeks after flowering, root system is at maximum. Brace roots hold plant upright.
	The roots first move into surface horizons		The roots go down	
For imbibition: moisture is needed (not too much). NB Risk of oxygen shortage. ▌**For activation:** oxygen (aeration). NB Risk of compacting. Warmth: 8-12°C, moist soil.	**Needs:** water and aeration Warmth: minimum of 10-13°C	**Delicate phase,** ▌**Attention** to cold and lack of oxygen - ammonia poisoning, - red colour (poor nutrition), - zinc or manganese deficiency	**Aeration:** roots settle where water does not occupy all pores in soil. Root growth caters to needs of parts above ground	The roots must find water beyond the ploughed area. ▌**Attention** to compaction zone and/or oxygen shortage caused by poor mulching of organic matter.

Water and air are essential. Heat acts as an accelerator.

Chapter 3

Sowing, Density, Stands

1. The Choice of Variety

The choice of variety is a strategic factor in modern maize growing and must always be the prerogative of the maize-grower.

The choice, as has been stated, determines the yield potential that can be achieved within the range of weather conditions prevailing (yield potential, earliness), and also certain characteristics ensuring the target can be met within a reasonable safety margin (e.g. stress resistance and disease resistance). Modern genetics, backed by genomics, can now breed hybrids that are both productive and tough, with greater water stress tolerance. Recent hybrids have also proven to be stronger both early (initial vigour and tolerance to cold conditions) and late in the cycle (better standability and faster drying). Recent varieties have these two distinctive features which means that more productive varieties can be grown in a shorter period of time.

The "mechanical features" of a variety, i.e. lodging resistance either early in the season (vegetative growth) or later (roots, because of fusarium stalk rot), have improved so much over the last thirty years that they are now considered minimum requirements for farmers, and they have reached a point where farmers can expect to have good conditions at harvest time, or even to have a post-winter harvest, as is seen with very continental climate conditions (e.g. in Spain).

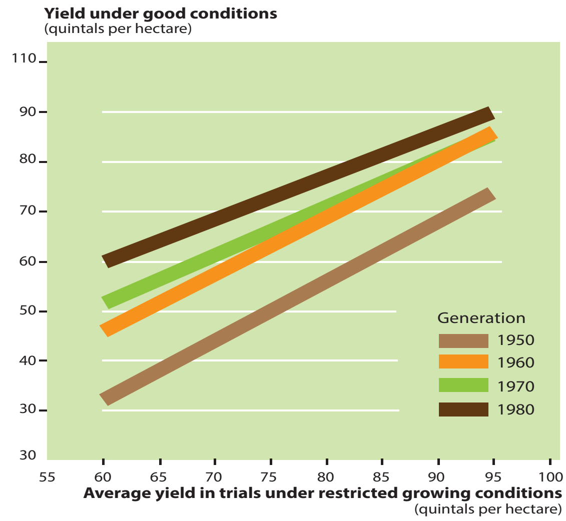
It should be noted that the size and colour of the plant at the end of the growth cycle do not necessarily correlate with the grain yield potential.

Criteria for choosing a variety

Primary Criteria	Secondary Criteria
▪ Yield potential ▪ Stable performance levels ▪ Water stress resistance ▪ Standability & lodging resistance ▪ Earliness (physiological) and contributing features: initial vigour and end-of-cycle drying rate	▪ Resistance to diseases affecting leaves (corn leaf blight) and ear (Fusarium ear rot). ▪ Feed value as silag maize.

Choosing a variety: first purchase genetic progress.

Maize is one of the few plants grown which cannot reproduce without human intervention. The plant, which developed from teosinte first domesticated in Central America 9000 years ago, has improved as farmers selected and crossed plants. Before maize conquered Europe in the 16th century, many forms of maize had adapted to all the climate conditions in North and South America, from Canada to southern Chile, and it is this "native" variability which is now the source of the genetic advances made through the heterosis (hybrid vigour) of these different genotypes that were hybridised and through their ability to adapt to most European climate conditions.



> Comparison of yields from 4 generations of hybrids with different yield levels (Derieux et al, 1987), INRA-AGPM study conducted from 1984 to 1986. The difference in yield attributable to the 1980s generation of variety is greater for the 60q/ha potential than for the higher potential ranges.

The discovery of hybridisation and the marketing of hybrid seed, starting in the United States in the 1930s and then in Europe in the 1950s, made it possible to achieve such a spectacular and steady increase in yield.

- With the development of European lines and crossing them with American lines, hybrids have become earlier and have better cold tolerance. The breeding of extra-early varieties has meant that maize can be grown in colder regions in northern Europe and silage maize has expanded into animal farming areas.
- The most striking progress has been with yield and regularity of yield. A number of studies have shown that over the last thirty years there has been an average annual increase of 1.1 to 1.6% per hectare, depending on earliness and the region.
- Improvements in standability and other mechanical features of the plants have made it possible to have higher density sowing for higher yield potential, plus security guaranteeing the harvest. This improvement did not have any negative impact on the digestibility of the

plant as feed. The energy value of silage maize as reported with the introduction of specific tests for both French and European catalogues also improved, in particular with greater digestibility of both stalks and leaves (see chapter on Silage Maize).

■ At the same time, tolerance to the main fungal diseases (corn blight and fusariums) has continued to get better.

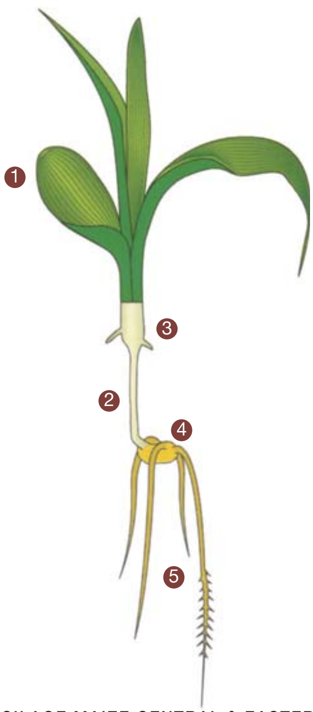
■ Contrary to common belief, better yields have also come with a steady improvement in hardiness of the varieties and better performance under water stress. This is a critical factor and should see maize continuing to adapt to climate change.

> Estimation of genetic advances, expressed in yield, in France over the past 30 years (Summary)

Period studied	Earliness	Estimates based on historical data from trials in the ARVALIS-UFS post-registration network		
		Average yield of trials over the period	Genetic advances q/ha/year or t/ha/year	Genetic advances expressed as a %ge of average yield in the trials
Grain maize 1986-2007	Very early	86	1.43	1.6%
	Early	96	1.46	1.5%
	Semi-early C1	105	1.35	1.2%
	Semi-early C2	110	1.25	1.1%
	Semi-late	116	1.14	1.0%
	Late	120	1.31	1.1%
	Very late	124	1.36	1.1%
Silage maize 1993-2007	Very early	15.0	0.183	1.2%
	Early	15.4	0.188	1.2%
	Semi-early	16.0	0.155	1.0%

2. Sowing

Sowing is the foundation for growing a crop and for yield. The date and proper sowing are the criteria that will determine the success of the crop.



1 first leaf, with rounded tip
2 mesocotyl
3 crown
4 seed
5 primary roots

2.1. Sowing date

As is the case for any crop, the sowing date must be chosen to gain benefit from all the features of the climate in the region concerned.

■ The sowing date is chosen by weighing up the need to make swift and optimal use of the full scope of weather to achieve the full potential of the variety chosen.

■ The soil must be warm, but not dried out. Maize germinates when the soil temperature is between 6 and 8°C; in the northern hemisphere, this is usually from April 1 on. It should be noted that soil temperature increases gradually and steadily throughout the spring, regardless of variations in the air temperature. The soil profile must not be allowed to dry out as the seed needs water to germinate, and when a soil surface horizon dries out, emergence will be uneven with a severely negative impact on yield.

■ Soil has a great effect on emergence: in spring, dark soil warms faster than light-coloured soil because of surface absorption of sunlight. Depending on the colour of the soil, growth stages in the same field can differ by 2 to 3 leaves, with the discrepancy continuing all the way through to harvest.

■ In soil with higher clay content, sowing must not be done with a disc seed drill with a "sculpting" effect (the furrow is not filled in and there is a risk of seed drying out). Preparation (even, for example, strip-tillage in autumn or spring) can help produce fine earth along the row and improve establishment.

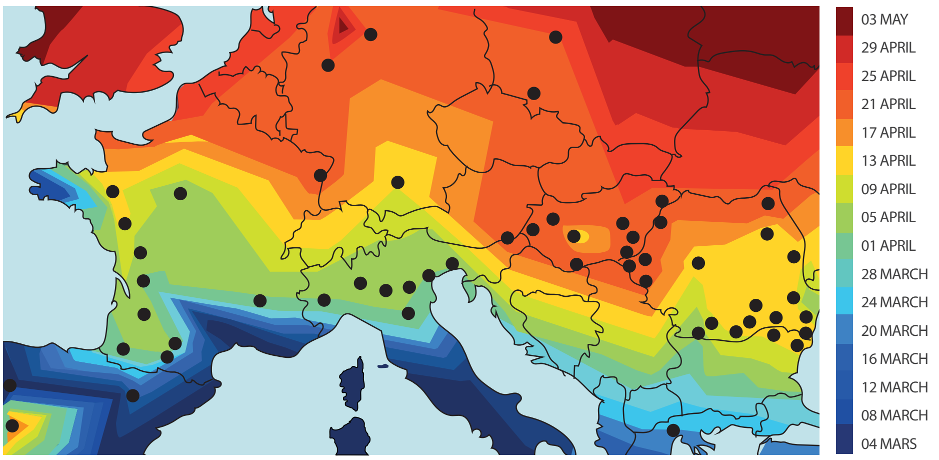
Western Europe: sowing earlier and earlier as part of a bypass strategy.

Over the past 15 years, there has been a growing trend towards much earlier sowing; this is mainly in Western and Mediterranean Europe. As the spring has become warmer and dryer, the goal is to "bypass" the water deficits encountered late in the growth cycle (in France) and attacks by multi-generation parasitic pests (corn borer in Italy), and this has led to more and more early sowing.

Over the last 20 years in France, on average, sowing dates have moved forward by 20 days, now starting in late March. The strategy, adopted by many farmers, has a large number of advantages (and a few disadvantages). It can be done in temperate regions where there is less likelihood of heavy frosts in spring. Global warming, which is behind the change, is also the reason for the swift northward expansion of maize in Europe. The shift does not appear to have any negative effect on the physiology of maize as it can now be seen flowering in late June without any negative impact on yield. In Portugal, in the right conditions, sowing can start in late February.

With a continental climate, as is the case in Central and Eastern Europe, the margin for manoeuvre is narrower because of the risk of late frosts in spring, but there is scope, as can be seen from the similar trend in the USA, although it is a narrower margin with sowing now 10 days earlier than it was 20 years ago. Under continental climate conditions, sowing too late can also have a negative impact with the greater risk of early frosts in autumn causing serious damage to maize plants still at the milky-dough stage.

> Simulation of possible dates for sowing maize in Europe according to soil temperature, rain-free periods and locations.



2.2 Sowing depth and technique

The goal is for quick, even emergence. The seed must be in contact with moisture and have sufficient air for germination to occur..

Sowing must be:

- sufficiently deep (≥ 4-5 cm) for protection from frosts, birds and any drying of the soil surface.
- not too deep (< 9-10 cm) so as to avoid depleting the seed's reserves as happens when the coleoptile is elongated, to shorten the period of emergence and to avoid parasites (both animal and plant).

Depending on the type of soil and the sowing date, the seed should be sown at a depth of 4 to 7 cm, paying special attention to ensure that:

- the soil moisture level is optimal
- there is enough fine soil around the seed for proper soil-seed contact
- in friable soil, sowing is more in surface mounds, and maize can emerge well in cloddy and stony soils
- seed is evenly covered for seedlings to emerge at the same time. **An even sowing depth is more important than even seed spacing along the row.**

KEY MESSAGE

▶ If the soil surface is dry, a realistic solution should be found (very shallow sowing in dry soil or deep sowing in cool, moist soil) rather than opting for a compromise which, in the event of extended dry conditions, would have only part of the seeds emerging.

In chernozems, when frost often turns a tilled surface into dust, the seed must be sown at a depth of 4 to 5 cm in the compacted part of the soil.

In moist soil, if there is not enough warmth for germination and emergence, the seed will keep very well. Once seed starts germinating (swelling), it must keep on expanding through to emergence.

2.3 Sowing rate and the effect

Modern hybrids offer a guarantee of quality seed which is the primary prerequisite for quick, uniform emergence. Successful emergence thus depends, first and foremost, on the farmer.

Many trials have shown that the rate and efficiency of the seed drill and the soil preparation affect the uniformity of the sowing.

- The same trials have shown that proper, even covering of the seed is the key to simultaneous emergence: a plant emerging a few days late, and two leaves in growth behind the adjacent plants may lose 30% in yield because of competition from neighbouring plants. A difference in growth between plants in the same row is more critical than a difference between two adjacent rows, although an "edge" effect was still found in the trials.
- Over 6 km/hour, sowing becomes increasingly uneven, even when using modern pneumatic seed drills in good condition. When speed is increased, the seed is sown closer to the surface, leaving it vulnerable to crows. One of the first effects of excessive speed is on the seed distribution system, and it becomes difficult to achieve the sowing density as programmed. Between 6 and 12 km/h there can be losses of up to 10% of seed sown.

Useful Tips

Second-planting – rarely a good idea

It is only rarely a good idea to do a second round of planting. First, in the event of uneven emergence, the possibility of partial re-planting, forming a patchwork alongside plants that have already emerged here and there, should be dismissed. The second round of plants would be in competition with the others that are ahead and would end up sterile.

If a second planting is to be done, it must be over the entire area where emergence was poor.

Given the cost of a second planting and, with late planting, the loss of potential for the maize plant to catch up, thresholds are set for deciding on a second planting: 55 000 emerged plants for early-maturing varieties and 45 000 plants for semi-late varieties

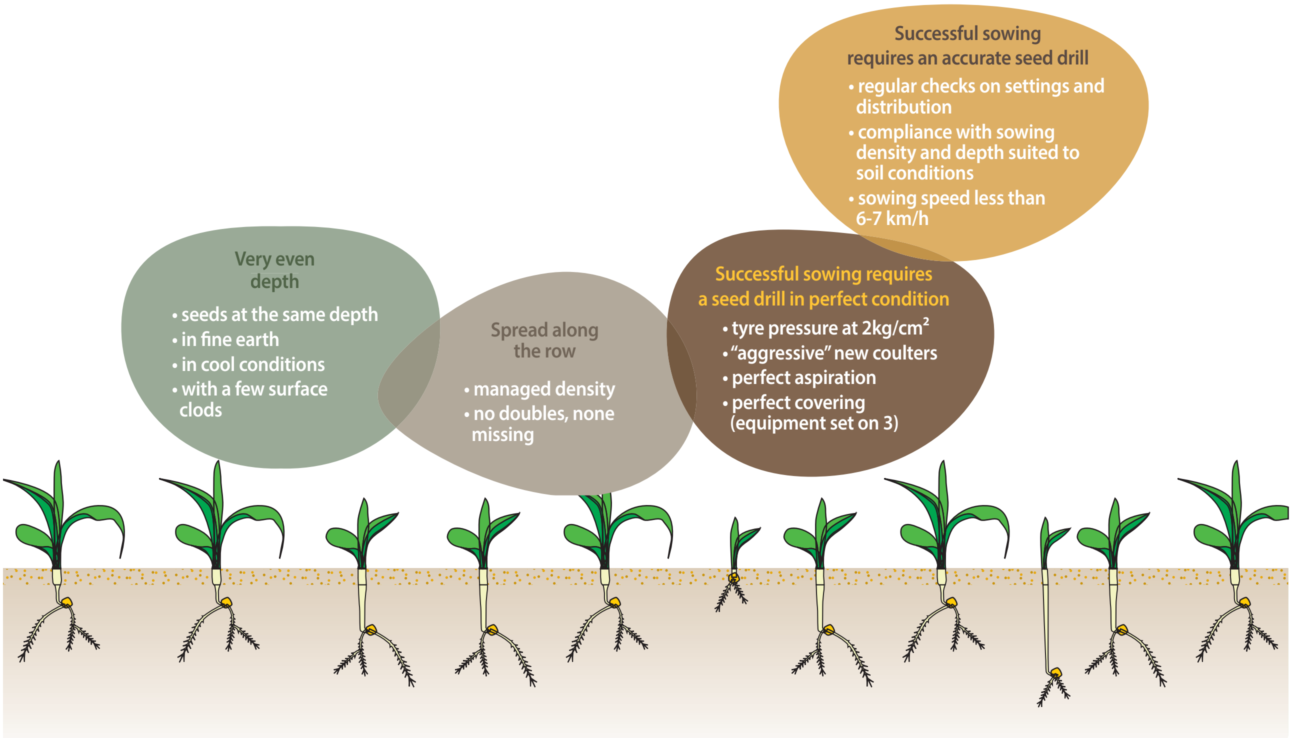
The date of the second planting must also be taken into consideration. The variety chosen must be sufficiently early for the plant to be able to reach maturity.

- A new type of seed drill is now available on the market; it has a pneumatic system for picking and sowing seed, and can operate at over 10 km/h. High-speed single-grain seed drills (Amazone EDX, Horsch Maestro, Väderstad Tempo) are on the market, so the question of maintaining optimal sowing at higher speed needs to be considered. Recent trials conducted by ARVALIS Plant Institute are encouraging and seem to be confirmed by feedback from users of these drills. An increase in speed up to 11 km/h does not appear to have a negative impact as the drills are heavy and pressure from the packer reduces the bounce of the disks which was what caused uneven results reported with conventional seed drills. However, if soil preparation has been approximate or if the soil is stony, the range of variation in seed distribution increases as the speed goes from 7 to 11 km/h.

KEY MESSAGE

In conclusion, regardless of the type of seed drill or preparation, a speed of 7 km/hour provides the assurance of good quality sowing. With high-speed seed drills and standard preparation, quality appears to be maintained up to 11 km/hour, but above that (when there is sufficient traction), the quality is likely to deteriorate.

▶ For more productive sowing (particularly in continental conditions with a limited number of days available) and without any negative impact on sowing and emergence, the only option is to have more drill rows.

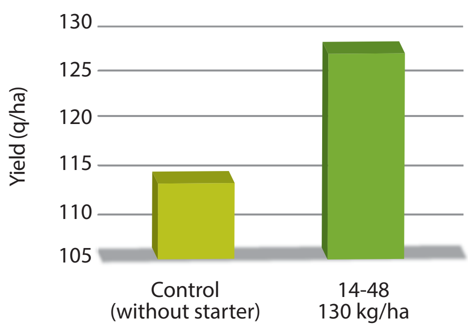


> Effect of coulters used and of preparation on sowing depth

2.4 Starter fertilizer: a useful technique for successful establishment

A starter effect is the additional vigour given at the beginning by applying a certain concentration of fertilizer near the primary roots, in particular a phosphorus-based fertilizer (130 kg of 18-46 is common practice). Phosphorus is an element that moves very little in the soil and the plant mainly needs it at the beginning of the growth cycle; the goal is therefore to position the fertilizer just a few centimetres from the roots. The seed drills are fitted with special coulters to position the fertilizer in the soil. No matter what conditions prevail in spring, starter fertilizer is useful for maize: whether conditions bring slow establishment (a long, cool spring and cold white soil that takes a long time to warm up) or whether there has been minimal preparation of the soil which then warms up more slowly, starter fertilizer has become indispensable, and all trials have shown it to be beneficial.

Impact of starter fertilizer on yield



> Tested on early sowing in silty soil, south-west France [Poucharramet 2007]

> Starter fertilizer distributor

Under the harshest conditions, differences in the final yield reported range from 4 or 5 quintals per hectare up to 14 quintals per hectare, according to the year.

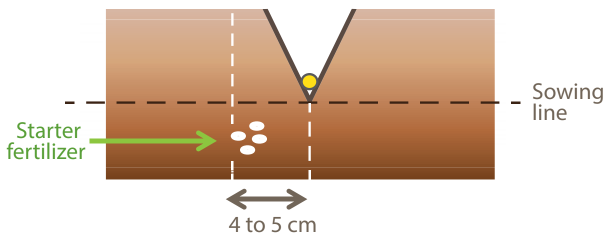
In most other situations, direct advantages are apparent:

- a faster rate of emergence and therefore more uniform emergence
- growth ahead by 1 to 2 leaves from the outset through to flowering, with a slightly earlier result, plus other indirect advantages:
  - better systemic action of insecticides and fungicides in seedlings
  - indirect protection from parasites (click beetles, nematodes and mesocotyl necrosis)

- a boost for slightly under-performing batches of seed
- less loss in the event of leaf disease developing late in the cycle.

The positioning of the starter fertilizer is crucial, firstly to achieve the "booster" effect on plants, and secondly to avoid burning that can occur with phosphoric acid. Placement must therefore be below the sowing line and 4 to 5 centimetres from the furrow. If it is too far away, the starter fertilizer will not be absorbed quickly by the young seedling. For solid starter fertilizers in particular, the dose should not be less than 100 kg, as smaller quantities could mean an uneven spread of the fertilizer and therefore uneven emergence (see Sowing Technique).

▶ Microgranular starters (which are not the same as starter fertilizers) are an option for farmers who do not have a fertilizer application attachment and can use the insecticide device. The effect is half-way between a starter fertilizer and the non-starter fertilizer control. The advantage is that much less is needed per hectare (20-25 kg/ha depending on the product), but they are more expensive. In-furrow application is the technique for microgranular starters.



▶ New substances are appearing all the time, claiming to accelerate germination or emergence. Extensive experiments have been conducted on these products in France, but for the moment no evidence has been found of any efficacy greater than 18-46.

3. Deciding on Density: the foundation for yield

3.1 Know the targets

The expression of the potential of a field depends on the per hectare density of the plants growing.

Yield is the direct result of the sunlight captured by the leaf cover, i.e. the leaf area index (LIA) (green leaf area/ha), multiplied by the time during which it is effective.

Therefore,

■ Density must be adjusted in accordance with earliness, i.e. perhaps use the number of plants to offset a smaller number of leaves and/or restricted sunlight.

■ Adjacent plants must be given equal opportunity to compete so that dominated plants do not become sterile.

The fertility rate (number of ears per 100 plants) is a good physiological indicator to assess the quality of a maize stand and must be above 95%.

■ The vegetative organ must be protected from parasites that might impair the capacity for photosynthesis (e.g. animal parasites such as aphids and mites, or fungi such as corn leaf blight and Fusarium stalk rot).

■ The vegetative organ must be protected from parasites that might impair the capacity for photosynthesis (e.g. animal parasites such as aphids and mites, or fungi such as corn leaf blight and Fusarium stalk rot).

The basic factors for establishing sowing density are:

- earliness of the hybrids
- achievable yield potential (water supply)
- end use (harvested as grain or whole plant)
- if applicable, soil type and genetic type

Sowing density is target harvest density minus foreseeable losses throughout the life cycle. The greatest risk of losses in a stand is between sowing and the 8 to 10-leaf stage and depends on a number of factors which are often linked to the plot itself: the date of sowing, the type of soil (hydromorphy), the quality of the seed, the level of protection, the risk of parasite attacks (e.g. from the previous crop). The farmer must assess the average level of loss with thorough scrutiny every year, monitoring the difference between the actual density of sowing in the field (digging up 2 metres) and the final crop density. Losses usually range from 5 to 10%, depending on the case in question.

3.2 Dealing with density

Yield is directly related to crop plant density, but the relationship varies according to the number of plants at the time of harvesting and the potential of the field.

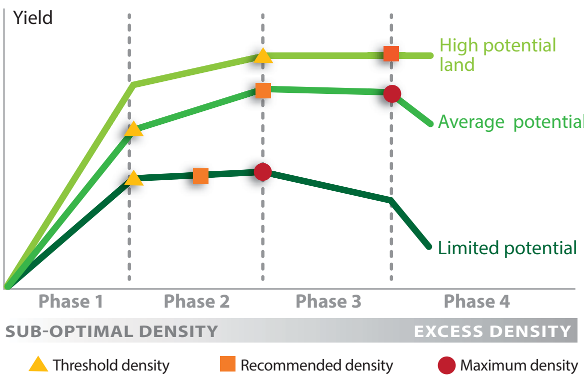
■ With very low density, the yield response is very high until the plants compete with one another and reach the minimum stand required to achieve the potential of the field, i.e. the minimum density required. During this first phase, density is probably the main factor limiting yield, regardless of the yield level.

■ Next, during the second phase, with greater density there is a lower increase in yield, but the result for the plants competing for resources is still positive. Yield depends more on achievable potential and soil type. Optimal density is reached when additional plants cannot provide any added value.

■ By the third phase, peak potential has been achieved. Any increase in the stand will only produce smaller ears on more plants, with yield remaining unchanged.

■ The fourth phase goes past the point of maximum density. An accumulation of plants can become counter-productive, with negative effects: high sterility or functional problems affecting the stalk. With modern hybrids and in good farming conditions, this stage is reached when the harvest density is well above 100 000 plants per hectare.

Yield per crop density and land potential



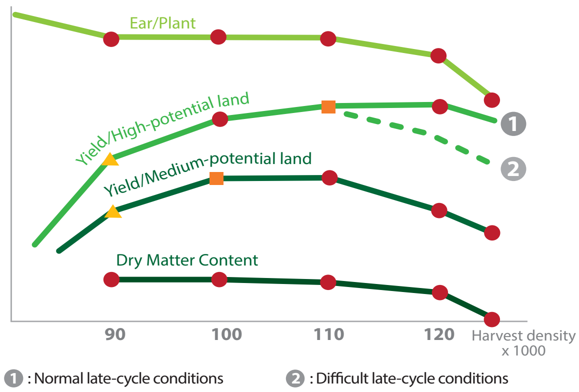
3.3 Density and susceptibility to water stress

As a general rule, optimal density is lower when there is water stress compared to situations with a good water supply. However, the difference is relatively small, and **modern hybrids have greater tolerance to water stress, so there is no point in sowing below optimal density:** the decision is therefore to target the optimal density recommended. Below a certain cut-off point, even in dry conditions, yield will be affected if there are not enough plants; e.g. for a variety rated FAO 400, if there are fewer than 6 or 7 plants per square metre, even in dry conditions, the limiting factor affecting yield will be the weather, not plants competing for resources. It is better to have the right number of medium-size ears than only a few big ones.

In a good summer and with optimal density, the full potential of the variety can be achieved, and over a number of years and a range of weather scenarios, the balance has always been in favour of the optimal density option and high-performance hybrids. For all scenarios, the goal should be to get as close as possible to a harvest-time target of 8 or 9 ears per square metre.

3.4 Impact of density on silage maize production

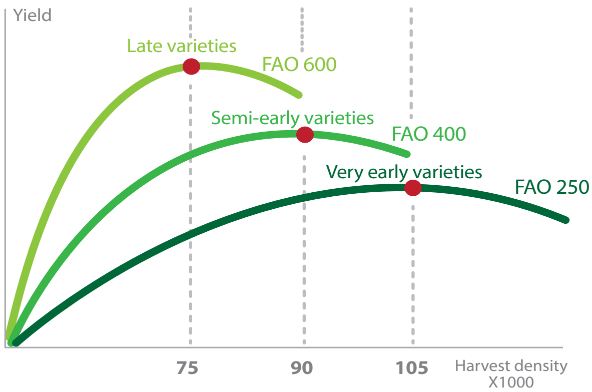
Impact of density on whole plant silage maize harvested (western France)



3.5 Other effects to consider

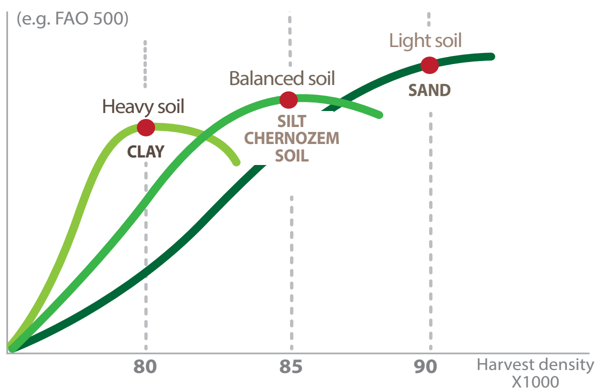
The later the plant, the more leaves it has, so fewer plants per hectare are needed for the leaf area index and therefore to capture sufficient light.

Density response in relation to earliness



Light soils have a stronger response to density and need more plants per hectare to reach the potential of heavy soils. Chernozems are in an intermediate position.

Density response in relation to soil type



Chapter 4

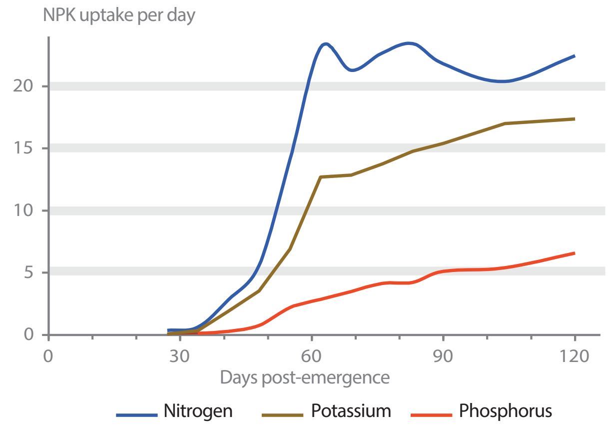
Fertilization

Fertilization of maize crops, and in particular nitrogen-based fertilization, is a major factor in crop productivity.

Optimal use of inputs to maximise both agronomic and economic efficiency of fertilizers requires thorough knowledge of the needs of the plant, the growth periods when the needs occur and the contribution made by the soil.

The requirements for the three main elements have different timing.

> **Growth kinetics and N, P and K uptake by "Roc" late maize** (Lubet et al. 1984)



The crop uses a very small amount of the phosphorus and potassium fertilizers which are applied in the year. Adjustments for doses should be made according to the fertility status of the soil (as analysed). When nitrogen is applied directly, the calculation should be based on the expected potential of the land, factoring in the contribution of the soil.

For trace elements, the most common deficiencies (e.g. zinc and manganese) often come from poor soil cultivation. Swift remedial action is needed as soon as the first symptoms appear. Leaf applications to cure the conditions produce quick results (within a few hours).

1. Nitrogen-based fertilization

1.1 Rational fertilization

No matter what cropping system is used, the soil is an essential stage in the nitrogen cycle. The farmer's duty is to add only the quantity of nitrogen that is absolutely essential for plants to develop. Any surplus is likely to end up in the soil at the end of the season and in a form that could leach into groundwater.

Every effort must be made to optimise the dose of nitrogen and optimise its use by the plants. This means:

- adjusting the dose according to the N balance method
- accurate data on the quality and quantity of organic nitrogen inputs in the field
- dividing up mineral nitrogen inputs
- incorporating nitrogen inputs
- managing long intercropping intervals
- and, in the future, setting up monitoring facilities tailored to the context.

Nitrogen-based fertilization depends on the potential of the land

In a grain-growing system, excluding organic inputs, the dose of nitrogen depends first on the yield potential expected in relation to past yield and the contribution of the soil. The right adjustment will therefore depend on the consistency of yield levels: in deep soil with good available water-holding capacity or under irrigation, the assurance of achieving the expected yield means that the proper benefit can be gained from optimal doses of nitrogen and that residue after harvesting can be minimised.

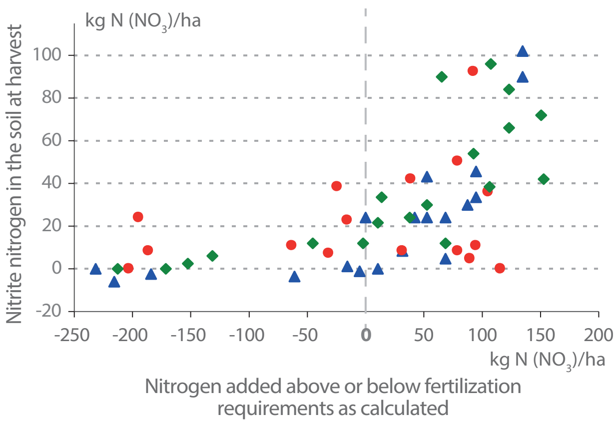
As part of a system of animal farming, regular addition of organic matter, every year or every two years, will ensure that the plant's requirements are covered to achieve an average potential of 13 to 14 tonnes of dry matter. With a small dose of nitrogen at sowing (less than 50 units), the plant can wait until it reaches the mineral content in the soil and has nitrogen provided from animal manure. For amounts above this level, any mineral nitrogen fertilization to be added to organic nitrogen will depend on the potential of the field concerned.

NB Maize makes excellent use of organic nitrogen from animal manure. For the same quantity of nitrogen, organic nitrogen is 30% more efficient than mineral nitrogen.

1.2 Nitrogen: for plant performance and environmental friendliness.

▶ ***Add only the amount of mineral nitrogen required***

> **Nitrogen dose in relation to the quantity of nitrite nitrogen in the soil at harvest.** N. Hong, JEQ 36, 2007



The N balance method can be used to calculate the quantity of nitrogen to be added for the plant.

Crop residue will then be kept to an absolute minimum. Any quantity over and above the optimal dose will produce greater amounts of residue, as shown in the diagram above.

More than one application recommended

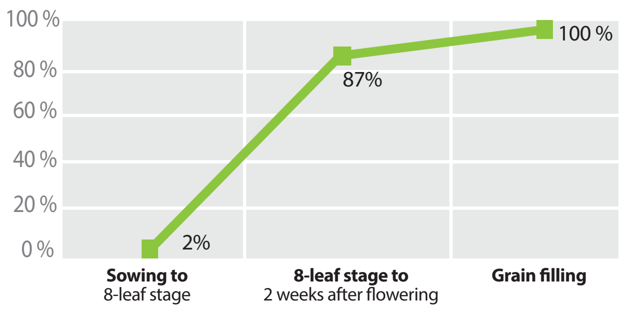
When applications are divided up, the plant absorbs the nitrogen in a more natural way:

- maize absorbs virtually no nitrogen during the first month of plant growth, so a small quantity of nitrogen applied as a starter is enough to cover the requirements of the plant in the early growth phases.
- from the 8-leaf stage on, maize needs an adequate quantity of nitrogen.

The recommendation is for fertilizer to be divided into a number of applications for light soil and when the total dose is more than 100 units. But when there is no certainty of being able to make the second application (mechanically or via irrigation), e.g. because of the threat of an early drought, it is better to apply the entire dose when sowing.

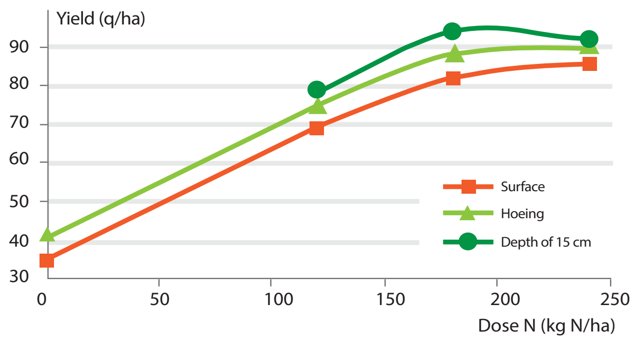
In practice, 20 to 50 units can be applied at the time of sowing, and the remainder at the 6 to 8-leaf stage to maximise the nitrogen efficiency coefficient (going from 60% before the 4-leaf stage to 80% after).

Nitrogen absorption rate per growth stage



Effect of urea application method on maize production

(silty soil, Landes France) (Inra-Cofaz-1985)



Hoeing does not stop all losses through ammonia volatilisation

The contribution to plant material at the 6 to 8-leaf stage is even more efficient when the fertilizer is well positioned. If applied as a single dose to the field, prilled urea should be used rather than ammonium nitrate as there is less burning of the leaves, although there will be greater loss through volatilisation.

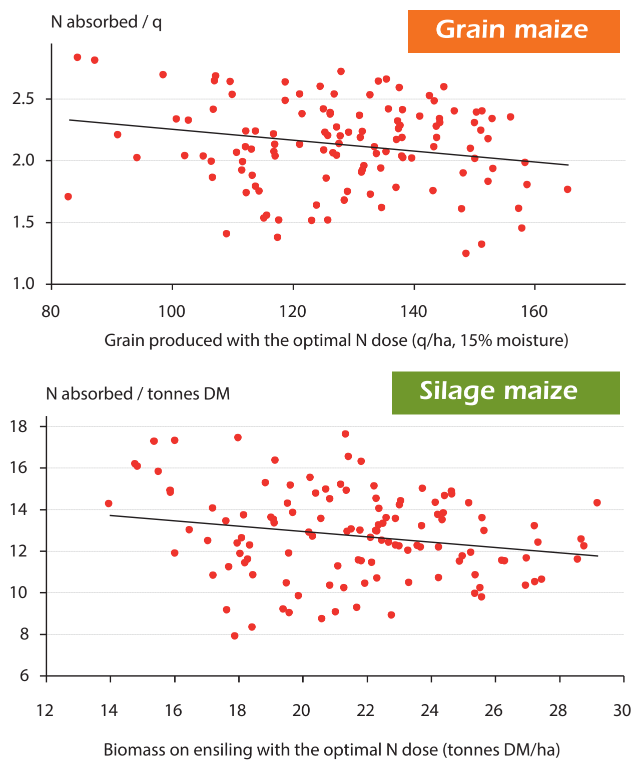
1.3 The relevant factors to understand the rational arguments

Proper use of nitrogen-based fertilization means striking the right balance between the plant's nitrogen requirements and the supply from the soil and from mineral and organic fertilizers. This is known as the "N balance method."

The yield potential of a given field is the yield that can reasonably be expected on a relatively regular basis: this is never the maximum yield achieved from the field in question, but the average of the best three yields recorded over previous years.

Total nitrogen requirements for the crop increase at the same time as the potential; however, the more productive the plants are, the less nitrogen is consumed per quintal produced.

Calculating nitrogen requirements for maize in relation to grain and whole plant yield



The soil provides a substantial part of a plant's nitrogen supply.

This can range from 60 to 130 kg of nitrogen, or even more..

Many factors are behind this variability:
- soil depth
- organic matter content
- the previous crop/grass
- grass in the rotation programme and its use
- previous nitrogen applications
- knock-on effects of farmyard manure.

Nitrogen reserves in the soil can only be optimised if the root development of the maize plant is satisfactory, which means it must not suffer from any water shortage.

To assess the nitrogen supplied in the soil, local reference data is needed over a number of years. The measurements can be estimated simply by recording the yield of the maize grown in identified sectors where no nitrogen fertilizer was applied in various parts of the field. An example of reference data in France for different soil types is given here and was used to set standards for small regions and for specific production systems.

Mineralisation of nitrogen in humus

Based on recent research on bare soil (Thesis: M.Valé, INRA Auzeville)

	Irrigated maize	Non-irrigated maize
Type of soil	(Kg N/ha)	(Kg N/ha)
Pebbly alluvium	66	30
Deep clay	75	53
Surface clay	72	35
Surface silt	81	35
Deep silt	85	57
Silt >3.5% OM	76	62
White sand	45	20
Black sand	65	30

Other factors can be used to adjust nitrogen-based fertilization, including positive effects or inputs from prior grassland.

Contribution of other nitrogen supplies for maize

- Residual effect of organic effluents. The quantity of usable nitrogen is the quantity spread x the percentage nitrogen content of organic fertilizer x the efficiency coefficient. The coefficient is higher for applications in spring than in autumn, with "fresh" fertilizer rather than dry residue. Maize makes good use of organic fertilizer: the first year, the efficiency coefficient is up to 60%, and there can be a positive delayed effect from organic fertilization the following year.
- The effect of ploughing in grassland, depending on duration and farming techniques. Previous "grassland" is good for maize crops; below is some reference data from France reporting nitrogen supplied from grassland prior to the crop, according to duration and farming techniques.

- **Effect of ploughing in grassland**

Mp (Kg N/ha)	Age of grassland		
Practice	<18 months	2-3 years	4-5 years
Always pastureland	20	60	100
Cut + pastureland	15	40	70
Cut only	10	25	40
Grass + legumes	20	60	100

1.4 Calculating the dose of nitrogen

1 - Set a realistic yield target factoring in features of the land and the technical course followed. For example, calculate the average yield for the best three of five reference years.

2 - Apply it to the requirements expressed per tonne of dry matter or per quintal of grain (see previous diagrams), i.e. 14 kg N/t of dry matter or 2 kg N per quintal of grain for the average expected yield.

3 - Factor in the quantity supplied by the soil and the efficiency coefficient of the fertilizers.

This gives
- **0.6 for an application from sowing through to the 6-leaf stage**
- **0.8 for an application after the 6-leaf stage.**

4 - When heavy doses are needed, it should be divided into two applications.
- **50 kg on sowing**
- **the remainder at the 6 to 8-leaf stage**

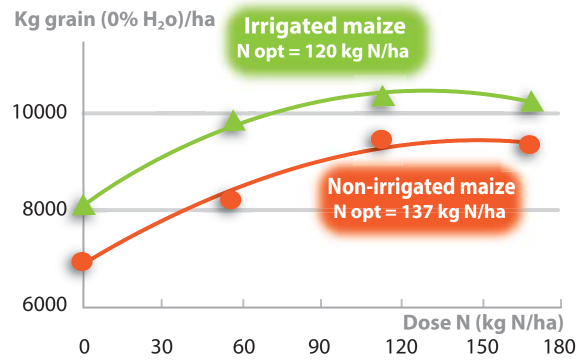
Therefore:

$$\text{Dose} = \frac{\text{yield X requirements per tonne or quintal - 50}}{0{,}8}$$

KEY MESSAGE

In a continental climate and without irrigation, nitrogen efficiency improves with yield. With good root anchorage and well cultivated soil, the root system will be able to explore the soil extensively and find available nitrogen. In addition, the plant's use of water and nitrogen are linked as fertilizers are absorbed as a solution in the soil. If conditions in summer are good for yield (sufficient rainfall and heat), mineralisation of organic matter in the soil is stimulated, boosting the growth of biomass and therefore the size of the roots, with a mechanical increase in the span of the plant to "capture" fertilizer, meaning maximum efficiency of the nitrogen input.

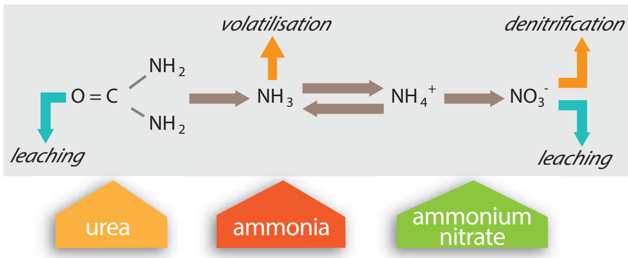
Interaction between water and nitrogen in growing maize. Experiment, South Dakota (average 2002, 2003, 2004)



1.5 Nitrogen – the form

The standard argument is that the best form for maize is the cheapest one to get to the roots, but recent studies have shown that at the optimal dose, form does have an effect. Urea, when not incorporated into the soil, is less efficient than ammonium nitrate.

Transformation of nitrogen fertilizer in the soil



Guidelines for different forms of nitrogen

Fertilizer	Units N per 100 kg	Use after emergence			Equipment
		Whole field	Spot	Below surface	
Ammonium nitrate	27 or 33.5 (50% nitrate & 50% ammonia)	To be avoided after 5-leaf stage (burning)	Recommended	Particularly for very dry soil	Pneumatic spreader + hoeing or hoeing machine with fertilizer applicator
Urea	46 (100% urea)	Possible on dry leaves	Possible	Essential to avoid volatilisation losses	Centrifugal or pneumatic seed drill + hoeing or hoeing machine with applicator
Anhydrous ammonia	82 (100% ammonia)	NO	Compulsory Avoid over-dry soil (volatilisation) and soggy soil (smearing and ammonia evaporation)		Special equipment (service provider)
Blend 39	39 (25% nitrate, 25% ammonia, 50% urea)	NO	Compulsory use of application tubes	Recommended	Spray + special gear Warning: burn risk

Source Hardt eau vive

2. Phosphorus-potassium fertilization

2.1 Guidelines for phosphorus-potassium fertilization after mulching stubble from the previous crop

Grain maize	Fertilisation phosphorique (P_2O_5)		Fertilisation potassique (K_2O)	
Potentiel (q/ha)	80	110	80	110
Well supplied soil	0 or 55 units if no P205 added to field in last 2 years	0 or 85 units if no P205 added in last 2 years	0 or 40 units if no K20 added in previous year	0 or 60 units if no K20 added in previous year
Normal soil, no organic manure	55 units	85 units	50 units	70 units

Silage maize						
Potentiel (tMS/ha)	12	14	20	12	14	20
Well supplied soil	0 or 50 units if no P205 added in last 2 years	0 or 70 units if no P205 added in last 2 years	0 or 90 units if no P205 added in last 2 years	0 or 150 units if no K20 added in previous year	0 or 200 units if no K20 added in previous year	0 or 200 units if no K20 added in previous year
Normal soil, no organic manure	50 units	70 units	90 units	150 units	200 units	200 units

Source ARVALIS

2.2 Understanding the rationale

Requirements & removal rates

- **For grain maize,** moderate quantities of phosphorus are absorbed and the removal rate is approximately 50 units per 100 q of grain. If the stover is ploughed back in, most of the potassium absorbed will return to the soil. Potassium removal by the grain is moderate, some 30 units, whereas absorption can be more than 250 units depending on the potential.

- **For silage maize,** phosphorus removal is around 60 units for 14 tonnes of dry matter per hectare. Much of the potassium absorbed is removed: 162 of the 210 units absorbed for a potential yield of 14 tonnes per hectare. But the potassium then comes back to the field as farmyard manure.

Useful tips

When should P & K be added?

It is best to add phosphorus and potassium-based fertilizer before sowing, although for phosphorous, when no more than 80 units is needed, it is better to have targeted sport starter fertilization at the time of sowing. For higher requirements, the fertilizer can be hoed into the top centimetres of soil at the time of the last tilling. Soil deficient in P and K should not be fertilized before ploughing.

Is P & K fertilization optional?

In decent soil, P & K fertilization only needs to be done every second year, at the beginning of the rotation cycle, or with the most demanding crop. Soil with a poor or only average supply must be fertilized every year without fail, particularly for potassium.

Detecting phosphorus and potassium deficiencies

Any red colour on the leaves is more a sign of a transient nutrition problem related to cold spring temperatures rather than a genuine phosphorus deficiency, but symptoms of potassium deficiency (leaf blades turning brown/red around the edges) are more serious and must be dealt with promptly. A potassium deficiency affects the formation of the plant body; it can be found in fields with good yield that are under-fertilized or have not been given potassium fertilizer.

Soil analysis – a good tool for rational decisions

Soil analysis gives accurate information on the fertility status of the plot. Texture-related features are also needed to appreciate the relative value of the content levels of fertilizing ingredients.

If soil analysis is not done, and if the field has previously been given regular high levels of fertilizer, there is no need to add more than the quantity required to offset the nutrients removed by the crop.

AN EASY FORMULA
for results of soil analyses:
0.1 per thousand = 100 ppt = 0.1 g/kg = 100 mg/kg

What form?

All potassium fertilizers (chlorides, nitrates and sulphates) have the same efficiency.

Phosphate-based fertilizers have different levels of solubility depending on the form, and are therefore absorbed by the maize plant at different rates. The form chosen must be soluble in water or in neutral ammonium citrate, i.e. superphosphates, 18-46 or dicalcium phosphate. Natural phosphates are not sufficiently soluble and are therefore not recommended.

3. Maize and minor mineral elements

Part of a general approach to a fertile field is keeping calcium and magnesium at the right levels for efficient soil. Finding the right pH will help assimilate all the minerals.

Maize is particularly sensitive to magnesium, zinc and manganese.

Chemical analysis of the soil shows the potential fertility of the field and any corrective measures needed.

Proper soil maintenance and adjustments should be made to the soil rather than the plant material, except for manganese which is effective when applied to the leaves.

Adding lime, or even magnesian lime, requires longer-term planning.

Removal rates for grain maize

Grain maize	Magnesium (MgO	Zinc (Zn)	Manganese (Mn)
Removal rate for 100 q	30 kg/ha	520 g/ha	1560 g/ha

Source: INRA Bordeaux

Diagnosing deficiencies

- **Magnesium** – Magnesium deficiencies often occur in very acid soil (pH < 5.5) and must be corrected by adding magnesium to the soil. Symptoms become apparent at the 4 to 5-leaf stage, with interveinal yellowing and striped patches on the older leaves. Calcium-magnesium soil amendments are best for correcting this type of deficiency.

- **Zinc** – Zinc deficiencies occur often and are characterised by a loss of colour in the middle third of the blades of the youngest leaves on the whorl. This can be treated by applying a zinc sulphate solution, or another foliar product containing zinc, or by preventive treatment which is often more effective and is applied to the soil.

- **Manganese** – A typical manganese deficiency appears under the following conditions: high pH, open aerated soil, high organic content plus a high level of active limestone, sandy soil or with nematodes (causing the deficiency). The signs are interveinal yellowing, drooping plants and wavy edges on the leaves. In extreme cases of severe deficiency the maize does not grow or develop, or may have no ears or kernels. The deficiency can easily be corrected with two applications of manganese sulphate in the growing period, the first at the 4 to 5-leaf stage and the second two weeks later.

> A number of deficiencies caused by poor cultivation of chernozem soil (Russia)

> Magnesium deficiency

> Zinc deficiency

> Manganese deficiency

Chapter 5

Irrigation

1. Rational irrigation

In continental regions such as the plains of Eastern Europe or the United States where there are dramatic differences in climate, irrigation can be used to increase and stabilise crop performance with an impact on both quantity and quality. The technical strategy for the irrigation of maize is based on simple principles, i.e. knowledge of plant requirements, and at which development stage they are needed, knowledge of climate demand determining the plant's evapotranspiration and of the depth of the soil which is the buffer supply where inputs can be made available at set intervals. Other technological parameters need to be taken into account: water resources available, the cost of energy and the pressure provided that will determine the flow rate and therefore the choice of the most appropriate irrigation equipment. The reel sprinkler is a flexible system: it can be moved, is multi-purpose and is suitable for small plots. Centre pivot systems and booms are well suited to large flat fields with no obstacles, as is often the case with land in Ukraine. The need to avoid wasting water raises the question of low-pressure micro-irrigation such as the drip (or trickle) system which is now the latest technique being investigated in western Europe, but while it is well suited to vegetable crops and orchards, there is no firm evidence for it as a financially viable option for field crops.

Irrigation of maize, as for other crops, has always been based on reasoned arguments. Farmers have always known how precious water is, and that it must not be wasted. And water has a cost. The rational approach is two-pronged, based on sound reasoning and financial arguments.

2. The Method

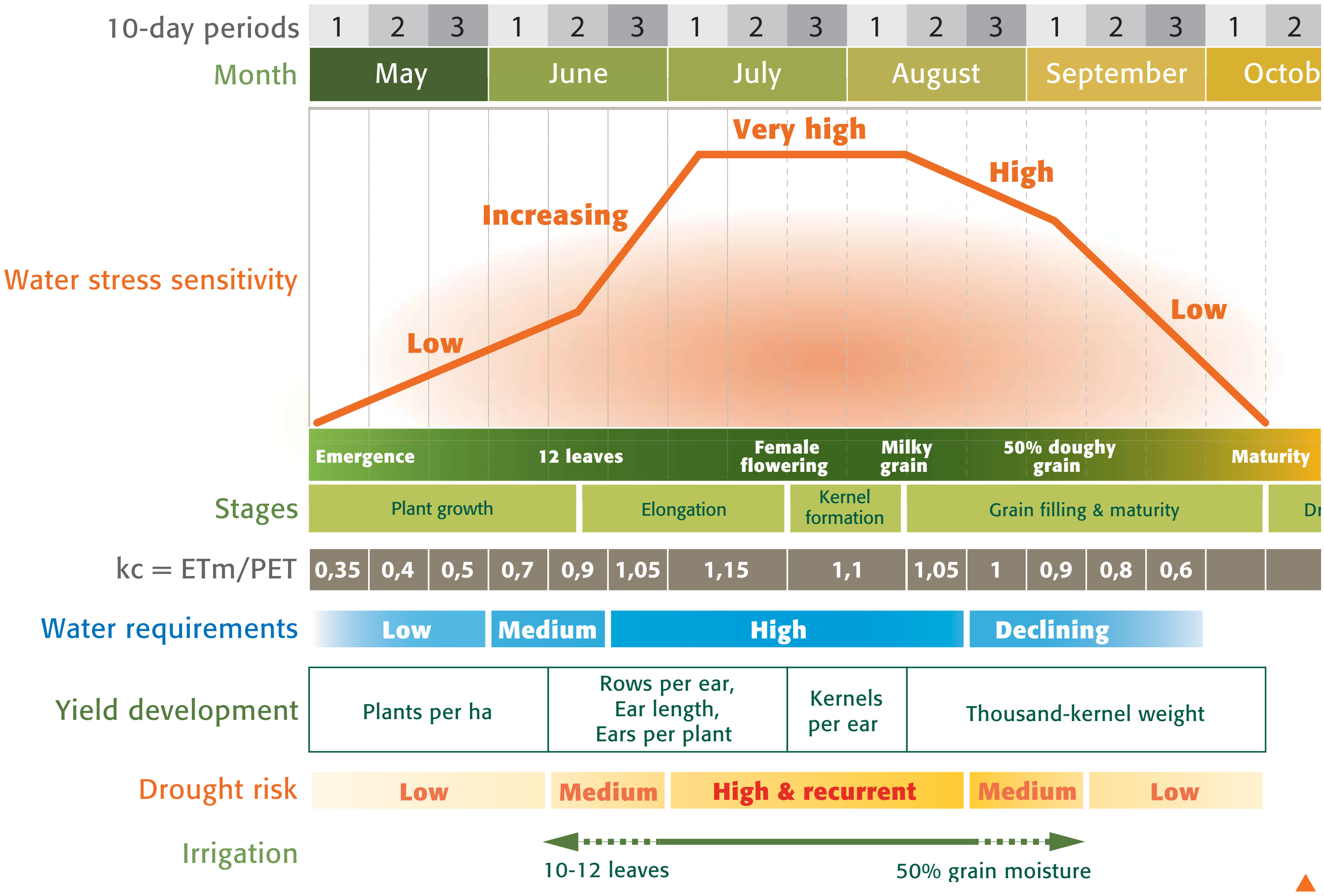
2.1 Knowing water requirements for maize

In the course of the growth cycle of maize, both water requirements and sensitivity to water shortages change according to the stages in development determining both the elements contributing to yield and overall yield.

Cumulative temperatures can provide complementary data to observations of growth stages in the field.

The following diagram summarises the key points in these developments.

- For grain maize, susceptibility to water stress is at a maximum when the kernels are being produced, and peaks during filling. The least critical period for grain yield is up to the 12-leaf stage.
- Water requirements follow water losses through soil evaporation and the evapotranspiration (ET) of the plants. Evapotranspiration changes in the course of the growth cycle as the leaf surface develops.



KEY MESSAGE

Peak demand for water and the sensitivity to water stress occur around the time of female flowering, i.e. 10 days to 3 weeks after flowering (usually July 10 to August 10). Depending on the geographical area, over a one week period demand can range from 4 to 8 mm a day, i.e. 40 to 80 cubic metres per hectare per day.

KEY MESSAGE

CALCULATION OF DAILY REQUIREMENTS

ETm requirement = kc x PET

ETm: Maximum evapotranspiration (mm/day)

Kc: crop coefficient (LIA + stage adjustment)
▶ diagram adjacent

ETP : PET: potential evapotranspiration (mm/day)
▶ national meteorological data

2.2 Irrigation water requirements and available water-holding capacity

It is clear that irrigating is designed to cover ETm (maximum evapotranspiration) for at least **eight years out of ten**.

Some of the requirements are covered by effective rainfall (which seeps in) and by any contribution from the available water-holding capacity of the soil. Irrigation therefore has to offset any shortfall.

Irrigation facilities must therefore be designed to scale so as to meet these requirements at least eight years out of every ten; the parameters are:

- flow rate (in particular to cover peak demand), expressed as millimetres per day
- total volume for the full season expressed as mm or m^3/ha (NB 1 mm = 10 m3/ha).

Regional references (weather prevalence studies, available water-holding capacities and the contribution of soil without a decline in yield) are set according to the soil and weather conditions and should be used.

Knowledge of the water resource and its irrigation capacity

It is obviously essential to know what water resources are available, with data covering the type of resource, the flow rate, volume, any administrative restrictions and the cost. The volume available per hectare (mm or m3/ha) should be set against frequency-based volume requirements..

The irrigation capacity of equipment can be calculated using the following equation:

$$\text{Irrigation capacity (mm/day)} = \frac{\text{volume per run (mm)}}{\text{Duration of run in peak period (days)*}}$$

*including the time needed to stop all parts of the same equipment

The irrigation capacity calculated then needs to be set against requirements for the flow rate available with the facilities used. Depending on the case, the capacity is said to be:

- comfortable, with at least 5 mm or more per day, thus leaving a good margin for managing irrigation.
- restricted
  - with less than 4 mm a day for soil with available water-holding capacity < 75 mm
  - with less than 3 mm a day for soil with available water-holding capacity > 75 mm, in which case irrigation management is a challenge.

Irrigation must be designed and run in different ways, according to the irrigation capacity and volume available per hectare in relation to frequency-based requirements.

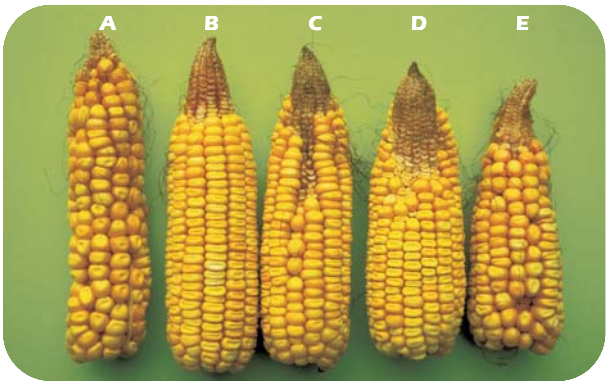
Managing and monitoring the dose of irrigation water

The choice and dose of irrigation on each round must match the type of soil and the readily available water capacities: in the range from 25 mm in fast-draining soil with low capacity to 40 mm for deeper soil, high doses are rarely suitable. Monitoring to check the average dose of irrigation provided can be done very simply with a water metre.

$$\text{Dose (mm)} = \frac{\text{Volume metered}}{\text{Surface area watered}}$$

Checks and proper adjustments must be made to irrigation equipment to have data on the input and provide the dose needed with optimal even sprinkling. The equipment is "not right" if it is not properly checked and adjusted. The flow rate, actual pressure, speed and angle of the water gun are some of the key points to check.

Depending on the stage of the maize plant, severe water stress will cause distinctive ear damage



A: Kernels missing (pre-flowering)
B: "Damaged tip" (around flowering)
C/D/E: Increasing stress after flowering

3. Managing irrigation

Irrigation management is based on strategic decisions on irrigation resources and facilities:

- with a comfortable level of resources, the goal can be aligned to requirements throughout the year, targeting a high yield. Over-irrigation must always be avoided, particularly in heavy rainfall years.
- if limited resources are available, a provisional schedule needs to be drawn up to spread the volume of water available over the key stages in the growth cycle.

Starting irrigation

With the exception of specific situations where irrigation is needed to help emergence, there is no need to irrigate maize before the 10-leaf stage. Prior to this, maize consumes very little water (estimated as evapotranspiration multiplied by 0.3 to 0.5). Measurements of the water status of soil using probes (either tensiometric or capacitive) can be an extremely useful indicator at this time, providing information in addition to the water balance as the measurement is made directly in the field with the crop. Irrigation equipment and duration also need to be factored into calculations: for example, when the irrigation run is long, more forward planning is needed for starting so that the last positions are not irrigated too late.

Resuming irrigation during the season

If the dose and frequency chosen for a period without rain proves to be too high or too low in the conditions prevailing that year, adjustments can be made either to the time interval between irrigation runs or to the dose. Relevant factors to be assessed are the water balance and monitoring of soil moisture status using tensiometric probes.

After rain, the basic rule is to wait **one day per 5 mm of rainfall** and this can be adjusted according to the soil moisture status.

The decision to stop irrigation late in the growth cycle

In deep soil, the goal is to get deeper soil horizons accessed to avoid unnecessary irrigation late in the cycle. The issues here are saving water, soil structure and the risk of leaf disease.

The decision is based on:

- identification of the stage when grain moisture content is 50%, measured by the oven drying method or by calculating total temperatures. The physiological stage can be estimated by monitoring the level of kernel starch filling, (see diagram in the chapter on harvesting).
- Estimation of the soil moisture balance. For soil with average water-holding capacity (AWC = 150 mm), a water shortage of 70 to 80 mm would be the minimum required to decide on final irrigation at the stage when grain moisture content is 50%. For shallow soils (AWC < 70 mm), the margin for manoeuvre is much narrower and a final watering could be useful when grain moisture content is between 50 and 45%.

Tools

- **One or more rain gauges on the farm and a simple water balance.**

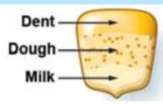
Because rainfall varies across areas, rain measurements must be taken within the area irrigated. Rain gauges must therefore be installed and readings taken on a regular basis, and data must be available on the water-holding capacity of the soil.

- **Tensiometric probes**

These probes are very useful for measuring the soil moisture balance in the field and for monitoring changes. The challenge is to find a representative site for the tensiometric measurement to be used to manage irrigation facilities.

Monitoring kernels for the decision to stop irrigation

Observations of the front of the kernel (not the germ side). Average estimates of kernels in the centre of the ear.

		Decision on last irrigation	Stop irrigation
% grain moisture		50	45
			
% DM whole plant		30 – 32	35
No. green leaves		8 à 12	7 à 11
Total temperature requirements (Base 6) after female flowering	Early	570	650
	Semi-early – semi-late	625	700
	Late & very late	650	740
No. of days to lose 1 moisture point		1.4	1.7

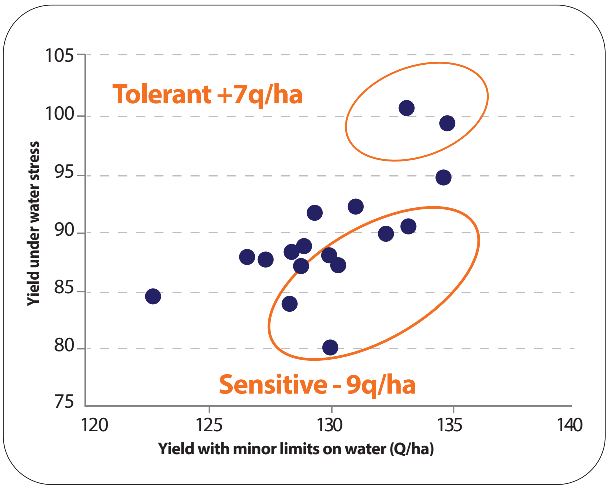
Irrigation strategies and management according to constraints

	No limit on resource	Limited flow	Limiting volume restrictive management
Constraints	▪ Flow rate of 4.5 to 6 mm/d depending on weather and AWC ▪ Volume of 200-300 mm depending on AWC	▪ Flow rate c. 3 mm/d for full cycle OR ▪ Lower flow rate in August OR ▪ Regulatory restriction on late-cycle pumping	▪ Limiting volume ≤ 180 mm (depending on AWC and weather) ▪ Supplemental watering of silage maize
Technical & financial goals	▪ Target optimal technical & financial yield on each field ▪ Maximum kernels/m² & TKW with top-potential varieties. Avoid watering in wet years	▪ Target highest possible stable average yield ▪ Guarantee kernels/m² with varieties hardy late in the cycle	▪ Target optimal financial results using all genetic options ▪ Follow provisional schedule with smaller, more frequent applications to guarantee minimum kernels/m² with limited risk on filling
Starting irrigation	▪ Be ready early, have forward planning of water cover ▪ Not before 10-leaf stage. Use tensiometer so as not to start too early when AWC>80 mm	▪ Start irrigating as soon as application can be held in soil ; start early and gradually	▪ In worst case scenario start only at 12-leaf stage or early July ; better option start gradually late June
Irrigation at highly susceptible stage	▪ No rainfall: set application & frequency to suit soil, available flow rate and per weather ; e.g. 35 mm/week when good AWC ▪ With rainfall: stop 1 day for every 5 mm rain. In wet years, water savings by using tensiometers & water balance ▪ Sprinkler settings & quality water cover can save up to 20% water for the same results	▪ Closely follow soil potential (AWC) so as to avoid water stress during critical period. Preference for smaller applications to keep right frequency, but not below 3 mm/d. ▪ Try forward planning to use AWC as late as possible. ▪ Postpone irrigation by 1 day for every 5 mm rain above 10 mm	▪ In all cases, focus around flowering: minimum of 1 application 10 days pre-, 1 at flowering and 1 10-15 days post- to ensure the number of kernels/m² ▪ Use all effective rainfall to put off irrigation towards filling time ▪ Postpone irrigation by 1 day for every 5 mm rain above 10 mm
Irrigation at grain filling	▪ Quality irrigation to be kept up during filling stage ▪ Check stage rather than date to stop irrigation ▪ In dry weather, irrigate until pasty/hard stage (45% grain moisture content)	▪ Choose hybrids with late-cycle water stress tolerance. Gradually reduce rather than suddenly stop. ▪ Try to “hold out” until fast filling stage completed (flowering + 450-650 GDDs, late August). ▪ In deep soil use tensiometers for accurate assessment of involvement of deep horizons in maize growth.	▪ Gradual reduction rather than sudden stop. If possible, keep up 2 mm/d late in cycle (until late August) ▪ Make use of varietal characteristics ▪ For silage maize, stop 10 days before 32% dry matter (24-26% DM)

The choice of variety and agronomics can also save water

Outside the specific scope of irrigation, the performance level of irrigated maize can gain significant improvements determined by the variety chosen. The most recent hybrids can tolerate longer periods of stress and have better and longer resilience, i.e. they recover better after an extended period of stress. Trials testing stress have shown differences between varieties of up to 15 quintals. It should be noted that a change to earliness does not have a substantial impact on water requirements: the choice of an earlier maturity group will only save, at the very best, 10 mm (100 m^3) over the entire cycle. Similarly, early sowing will not reduce overall requirements throughout the cycle, but will help avoid periods when there is a high risk of stress, doing so through early flowering and by maintaining the potential for kernels per m^2.

Response to water stress by different modern varieties (Arvalis)



Another relevant factor for resource-sparing and efficient irrigation is based on the most appropriate agronomic techniques. This is particularly the case for deep soil where every effort must be made to ensure proper anchorage of the roots so that the available water holding capacity makes a "good contribution", and specifically late in the cycle (see section on Protection).

An initial conclusion to this brief presentation is that maize is a crop that gives the best value-added return on irrigation investment. But maximum capitalisation will only be achieved if there is an irrigation strategy suited to both climate and soil and combined with the right choice of variety and an optimised "agronomic environment". A healthy plant that is thriving, with a firmly anchored root system, free of competition from weeds and pests will provide a maximum return on its genetic potential.

2. Crop protection

The achievable yield potential of a field of maize depends, as we have seen, on inputs available (climate) and inputs provided (genetic potential of the variety chosen, date of sowing, fertilisation etc.) and also on the potential saved from damage by pests or weather contingencies. Such negative factors are cumulative and often interact. When ranking crop protection strategies, the first task is to estimate risks to the crop from different pests. The degree of damage caused by animal pests is generally considered to be greater than damage from weeds, but it is easier to identify and target. Damage caused by disease (fungus) can vary, sometimes killing the plant, but is partially controlled by the maize plant's natural disease tolerance which has been improved through work on varieties (leaf diseases and pathogenic fungi). Pest control is thus a combination of preventive action (varietal tolerance, agronomic practices and chemical protection, in theory before sowing or emergence) and curative action (action on weed growth and on insects present). Curative action to treat fungal disease is only done for certain special crops covered by contracts requiring strict health guarantees (sweet corn and seed maize), or is done as a last resort if previous strategies have failed (e.g. for corn blight). Crop protection strategies have been changing a great deal and are increasingly varied. More and more restrictions now apply to the use of plant protection products, but until new developments bring solutions that are genuine alternatives or devise processes able to mimic the natural protection mechanisms of plants (including biotechnology), PPPs will still have to be used. There is now sound knowledge of actions and techniques that can help minimise the impact of PPPs on the environment and these are being adopted by more and more farmers.

So that optimal action can be taken, and most importantly at the right time, an accurate diagnosis of the appearance of any anomaly must be made, reporting the presence of any pests and/or symptoms on plants. A useful reference for this is the guide to incidents affecting maize **[Guide de diagnostic des accidents du maïs publié par Arvalis].**

Chapter 1

Pests

For maize, the sole purpose of pest control is to protect yield potential by keeping the optimal number of plants per hectare, with the plants intact, in particular avoiding any early attacks. Protection of the plant and, later in the cycle, of the maize (in particular borer control), is designed to contain any mechanical losses affecting yield (plants breaking, ears falling) and to reduce any health threat to the harvested crop.

1. Observing before acting

A number of pests can cause substantial damage to a maize crop. The prevalence and severity of attacks vary according to geographical areas, agronomic conditions and soil climate.

Maize pest control requires rationally planned actions. This means:

- observing symptoms
- identifying the pest
- knowing the factors involved in the development of the different pests and recognising the damage threshold for the crop (these may change depending on the end use of the crop)
- taking action while the crop is growing, using, if possible, appropriate plant protection treatments
- taking action between crop cycles, using the most suitable preventive measures to stop conditions that would allow the pest to develop into the following season.

Source : JP Renoux

Source : JB Capdebosq

> Exemples de nuisibilité importante de ravageurs : acariens (sud de la France), diabrotica (Slovaquie)

Pest Damage Potential

The potential for pest damage is often under-estimated; damage depends on pressure from the pest itself, its modus operandi, the type of attack on the plant, the duration of the attack and the health status of both individual plants and the crop. **Pest damage potential becomes critical when sowing density options are low.**

Damage potential can have a direct, radical impact on grain and silage yield when plants are killed (e.g. through click beetles, birds, and agrotis ipsilon), or damage may be indirect and variable (stem borers causing lodging, Cirphis unipuncta and flies affecting ear formation), or by weakening the root system (millipedes, diabrotica larvae and nematodes). Indirect damage may also occur through vectors spreading viral disease (leaf-hoppers and aphids) and fungal disease (borers).

2. Maize Pests

CROWS

Period of susceptibility for maize	Sowing time to 6-7 leaves
Type of damage	Seedlings dug up by crows that feed on the seed, killing the plants attacked
Modus operandi in the field	Destroying a number of plants together in a row. Attack in rounds
Contributing factors	Presence of trees (shelter and nests) Staggered sowing
Preventive control technique	• Use seed protected with crow repellent But with large numbers of crows this protection is inadequate • Try to have the same sowing times as neighbouring fields
Curative pest control	None

CLICK BEETLE



Period of susceptibility for maize	Sowing → 10-12-leaf stage
Type of damage	Injecting at the neck, causing tillering or killing the plant
Modus operandi in the field	Doing rounds, or sometimes the entire field
Contributing factors	Deep sowing Dampness after sowing Slow growth Mulch breaking down on soil surface Previous grass or small grain crop
Preventive control technique	Chemical: Microgranules or seed treatment Agronomic: None
Curative pest control	None

FRIT FLY



Period of susceptibility for maize	Emergence – 3-4-leaf stage
Type of damage	Lays eggs on seedlings, then larvae deform the plant. Symptoms may be reversed.
Modus operandi in the field	Uneven coverage
Contributing factors	Temperature changes between mild (≥16°C) for eggs to be laid and colder temperatures with plants growing more slowly when larvae attack the plant
Preventive control technique	Chemical: • Seed treatment or microgranular neonicotinoid product Agronomic: • Choose variety with good early vigour • Starter fertilization
Curative pest control	None

SLUGS

Period of susceptibility for maize	Young plants, emergence to 10-leaf stage
Type of damage	Shredding leaves (destroying the blade, leaving only the nerves) until the plant is killed
Modus operandi in the field	Random
Contributing factors	Mild temperatures (13-18°C), relative humidity >75°, cloddy soil, previous crop (peas, oilseed rape), surface crop residues
Creventive control technique	Soil cultivation (not too coarse), with good rain-resistant molluscicide with good coverage
Curative pest control	Molluscicide, but often too late to treat

BLACK CUTWORM


Period of susceptibility for maize	Emergence to 10-leaf stage
Type of damage	Cutting off the seedling at soil level or entering the stalk, causing the plant to dry out and die
Modus operandi in the field	Outbreaks
Contributing factors	Tilling soil Staggered sowing
Preventive control technique	Agronomic: • Ploughing • Early sowing
Curative pest control	Pyrethroid treatment targeting young larvae (weak solution in water, in the evening)

MILLIPEDES



Period of susceptibility for maize	Emergence to 10-12-leaf stage, but attacks can cause damage throughout the cycle
Type of damage	Attack roots, slowing growth and weakening vegetative growth
Modus operandi in the field	Local outbreaks
Contributing factors	Damp soil Stony, light, clotty soils Loose soil with decomposing plant matter
Preventive control technique	Agronomic: • Starter fertilization • Variety with good early vigour Chemical: • Pyrethroid or organophosphate microgranules
Curative pest control	None Nitrogen + hoeing may help reduce prevalence of attacks

MILLIPEDES



Period of susceptibility for maize	Emergence to 10-12-leaf stage, but attacks can cause damage throughout the cycle
Type of damage	Attack roots, slowing growth and weakening vegetative growth
Modus operandi in the field	Local outbreaks
Contributing factors	Damp soil Stony, light, clotty soils Loose soil with decomposing plant matter
Preventive control technique	Agronomic: • Starter fertilization • Variety with good early vigour Chemical: • Pyrethroid or organophosphate microgranules
Curative pest control	None Nitrogen + hoeing may help reduce prevalence of attacks

DIABROTICA OR WESTERN CORN ROOTWORM


Subject to pest regulations according to geographical areas

Period of susceptibility for maize	Mid-May to late June
Type of damage	Larvae attack roots causing nutritional stress and lodging
Modus operandi in the field	Outbreaks, sometimes full field when heavy infestation and optimal conditions for larvae
Contributing factors	Field with previous maize crop and silt-rich and/ or clay-rich soil
Preventive control technique	Chemical: Insecticide at sowing (only partially effective for heavy infestations) Agronomic: Previous crop not maize Early sowing
Curative pest control	None

ROSE GRAIN APHID *Metopolophium dirhodum*

Period of susceptibility for maize	3-leaf to 10-leaf stage
Type of damage	Causes a toxic reaction in the plant ; whorl turns yellow, white stripes, the last leaf tears or rolls up
Modus operandi in the field	Widespread attack
Contributing factors	Relatively high temperature in late spring
Preventive control technique	Microgranules or seed treatment with a neonicotinoid product (Protection at very early stage)
Curative pest control	Insecticide treatment during plant growth if pest damage threshold is reached (10-20 aphids per plant before 6-leaf stage ; 100 aphids per plant after 8-10 leaf stage)

GREEN LEAFHOPPER *Zygidinia scutellaris*

Period of susceptibility for maize	4-leaf stage to flowering
Type of damage	Attacks leaves (starting from the base of the plant) making them dry out and go white, thus reducing the leaf area
Modus operandi in the field	Widespread
Contributing factors	Hot, dry weather
Preventive control technique	Agronomic: • Good cultivation of soil • Starter fertilization Chemical: •Microgranules or seed treatmen with a neonicotinoid product (Protection at very early stage)
Curative pest control	Pyrethroid application during plant growth

SMALL BROWN PLANTHOPPER *Laodelphax striatellus*

Vectrices du nanisme rugueux

Period of susceptibility for maize	3-leaf stage to flowering
Type of damage	Vector for maize rough dwarf virus (MRDV), spread by injecting the virus into the maize plant, causing shortened internodes above the entry point.
Modus operandi in the field	Diverse
Contributing factors	Late sowing Varietal susceptibility Plant stress
Preventive control technique	Agronomic: • Good soil cultivation • Early sowing • Starter fertilization • MRDV-resistant variety Chemical: • Minimal effect of pyrethroids during vegetative growth
Curative pest control	None

EUROPEAN CORN BORER *Ostrinia nubilalis*

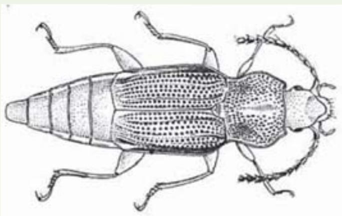
Period of susceptibility for maize	Lays eggs on plants once they reach 25cm, then generations reproduce until harvest
Type of damage	Increasingly severe damage by caterpillars as the maize cycle goes on and as generations of insects bore holes in leaf blades until flowering, tunnel into the stalk at the end of the shooting stage, then into the cob and the kernels. Subs-tantial damage. Without pest control, losses add up to dozens of quintals.
Modus operandi in the field	In target areas, relatively predictable on the basis of damage the previous year, the stage effect and appear-ance of plants at end of cycle.
Contributing factors	Staggered sowing, high infestation previous years, heat and damp
Preventive control technique	Relatively effective if widespread: fine shredding (includ-ing neck) immediately after harvest ; no piles of cobs to be left near fields. Chemical pest control for each generation in line with insect development, biological pest control (trichogramma), genetic pest control GM/Bt varieties)
Curative pest control	Difficult

HÉLIOTHIS *Heliothis armigera*

Period of susceptibility for maize	Lays eggs on silks after flowering
Type of damage	Caterpillar attacks silks and ears
Modus operandi the field	Successive generations, targeting in zones or widespread
Contributing factors	Whether sedentary or migratory, heat and humidity, as for all night moths
Preventive control technique	Difficult
Curative pest control	Long-lasting insecticide in early stage of attack

The stage of maximum susceptibility for maize is at flowering and when temperatures are particularly high. This is also the optimal stage for treating and protecting the ears of seed maize and/or sweet corn. Grain maize does not usually need specific control for this pest (as economic damage is less severe).

Tanymechus Dilaticollis, a major pest in continental Europe



The maize leaf weevil is an insect of the order Coleoptera, measuring between 5.1 mm and 9.6 mm and covered with hairs and grey scales. In the spring, 90% of adults come to the surface of the soil about three weeks after the average temperature has risen above 10°C. They start flying in mid-May when the temperatures is in the vicinity of 30°C. Adults need a substantial food supply before mat-ing, and the reproductive phase is from mid-May to mid-June. The females lay eggs in the soil at a depth of approximately 2 cm, producing 150 to 350 fertile eggs which, at a temperature of 20°C, hatch in 10 to 12 days.

The larvae live in the soil where they feed on maize roots. Larval development takes 2 to 3 months covering four stages, with the pupal stage occurring at a depth of 60 cm between mid-July and mid-September. Young adults hibernate in the soil.

Habitat: The pest is found in Slovakia, Hungary, Romania, Bulgaria, the States of the former Yugoslavia, Greece, Turkey, Syria, Iraq and Iran. It is also found in the south of Moldova, in Ukraine, in the region of Rostov in Russia, and in the Caucasus.

Ecology: The insect is univoltine, commonly found in plains, and never at an altitude above 400 metres. It is polyphagous, with its food intake increasing with the temperature once it rises above 20°C and close to the mating season.

Damage: Damage caused has increased considerably over recent decades, with adults causing more damage than the larvae. Adults attack young seedlings (or more rarely germinating seed) and kill them. They feed on the young leaves, starting on the edge of the blade, with most damage being caused before the 4-leaf stage (BBCH 14). Adults eat the leaf margins and destroy the apical meristems. Maize is needed in the rotation programme to control the damage of the polyphagous pest which also attacks other crops, e.g. small grain crops and sunflower.

Pest control: Preventive pest control targeting the weevil requires a strategy combining different approaches.

- Seed treatment with a neonicotinoid insecticide is the essential element in preventive pest control.
- Ensure seedlings develop quickly by choosing the right date for sowing and with spot starter fertilization at sowing.
- In high-risk situations, focus on optimal density for sufficient plant stand at harvest.
- Curative pest control can be done using approved pyrethroid products.

3. Pest control

3.1 Chemical pest control

In the space of just a few years, pest control has gone from a strategy of disinfecting the soil of the entire field (e.g. using Lindane) to a control strategy targeting the seed row (locally positioned microgranules), then to seedling protection (seed treatment). In terms of the impact of plant protection products on the environment, this can be seen as progress as pest control increasingly targets the plant's immediate environment and has reduced the quantities of active ingredients per hectare, but in terms of the impact on controlling the pest populations, the effect has been the opposite, with a smaller effect on insect stocks and fewer multi-purpose active ingredients.

3.2 Agronomics

Climate change (as warming affects the dynamics of insect populations, in particular cutworm), changing crop strategies and technical approaches have all had an influence on pests, both the areas of infestation and the damage caused.

- **Soil cultivation** has been greatly simplified, and with fewer tillage passes and no ploughing, these conditions can help pests spread as there is less disturbance during initial cultivation.
- As certain families of chemicals are used repeatedly, they may **degrade** faster through the effect of specific microflora. Methods should be changed as part of best agronomic practices. .
- All techniques boosting the **speed of emergence** and establishment, reducing the time of exposure to pests, are positive: proper soil cultivation and/or use of starter fertilizer, particularly when dealing with pests attacking the root system (millipedes, diabrotica larvae and nematodes). The initial choice of varieties with good early vigour, plus ways of offsetting (at least partially) any decline in density are useful. Cold conditions and soil hydromorphy can slow down the period when plants become established, thus increasing risks of pest damage.
- **Unmulched crop residues** can lead to further pest attacks by providing shelter for parasites (borers and slugs).
- **No-till sowing** or strip-till sowing can increase the risk of animal pests (and parasites: inoculum and fungus).
- **Inefficient weed control** can also indirectly increase risks as certain parasites move into a field by first attacking weeds around the edges (cutworm).
- **Rotation/Single-crop farming:** with the exception of diabrotica, single-crop farming does not cause any particular increase in pests. While extensive maize acreage in the same production area may contribute to the spread of maize pests, such as diabrotica, it will also help stop the spread of parasites from other crops, such as aphids.
- **Staggered sowing:** when there is a great difference in sowing dates within a region, air-borne pests will find crops at all the different stages, consecutively, thus increasing the time of exposure to the risk, particularly when the pest attacks or reproduces at a specific stage.

Chapter 2

Weed Control

1. Should maize be weeded and why?

The answer is definitely Yes.

Weed control means stopping weed competition and thus containing potential damage. The goal is to safeguard crop potential (for both yield and quality) and prevent the land from being invaded again by weeds and the weeds from building up seed stocks for the next crop and nearby fields. For as long as there has been farming, farmers have been working to keep crops clean. When plants are sown a wide distance apart (as is the case for maize), weeding is easier, and this is one of the reasons why maize was first adopted as a break crop in Europe in the 17th century. This advantage still applies, particularly at a time when the use of plant protection products is restricted. For maize, weed control can be chemical or mechanical, or a combination of both.

A number of objectives will determine the approach for weed control. Before a strategy is chosen, the risk first needs to be identified (presence and damage potential of possible weed growth); then the strategy for action has to be developed in relation to the acreage requiring weed control, the chemical options available and the logistics involved (remembering that it is always best to act promptly.)

2. Maize weed control and weed damage

Maize is a short cycle crop sown with wide strips between the rows and is very susceptible to competition from weeds. Weed control is complex and must be taken seriously. Just one year without strict control and the land will be invaded by weeds causing problems for years because of the seed stock replenished. Weed control must be seen as a capital asset, part of the health heritage of the land.

With thorough knowledge of mechanisms by which weeds cause damage, it is possible to have proper management of the timing and scale of weed control actions, whether chemical or mechanical.

To sum up:

- maximum competition from weeds is between the 3 and 10-leaf stage for maize and is in proportion to the duration of the weed presence x the number of weeds x the type of weed.
- declines in yield are greater when the maize seedling has become autotrophic (4-5 leaf stage). There is the initial impact on maize biomass, plus a later effect if there is stress, such as water stress, affecting weakened plants. Growing weeds compete strongly for water and nitrogen and have a significant impact on yield.

> Grass and persicaria maculosa

- losses are in proportion to the length of time the plants have been competing, calculated as an average of 0.75 quintals per hectare per day, i.e. losses comparable to the potential lost per day for late sowing after the optimal date. In situations where there is limited water and/or nitrogen, damage levels can increase very quickly. Such losses can be insignificant if the water supply is not a limiting factor. Very few references are available to assess losses with low weed levels and limited water and Nitrogen.
- pests and diseases may be spread by the microclimate created by invasive weeds or when weeds provide a reservoir or relay vector for viruses, bacteria, fungi, mites and insects.

The main purpose of weed control is to protect the crop from competition from weeds, i.e. from potential weed damage. Weed damage may seem simple to define – loss of yield attributable to competition from weeds – yet the concept is very difficult to establish in experimental conditions as it depends on the species, the density, the duration of the competition, the growth stages of both the maize crop and the weeds at the time they are competing, general climate conditions (whether resources available are restricted or not) throughout the phase, the period of the crop calendar, the height and spread of the maize plants and the angling of the leaves (upright or flat) as well as the crop density. It is rare to have such data. With the exception of certain extreme cases (see photo), it is difficult to make a visual assessment of the effects of weed competition.

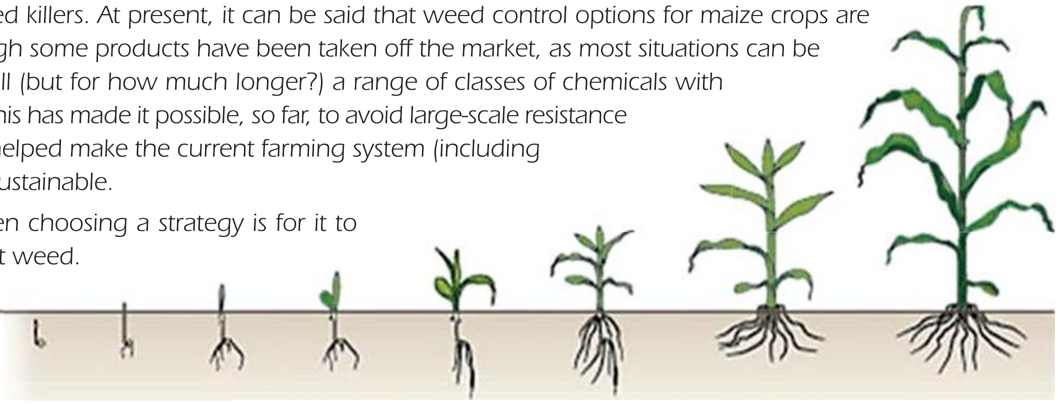
Source: JP Renoux

> Visible weed damage affecting maize growth (Chenopodioideae, France)

3. Weed control strategies

For farmers, weed control strategies must first be effective and sufficiently flexible to fit in with changes to work schedules and to weather. More consideration is now being given to environmental concerns and the protection of farmers handling weed killers. At present, it can be said that weed control options for maize crops are adequate, even though some products have been taken off the market, as most situations can be dealt with. There is still (but for how much longer?) a range of classes of chemicals with different actions and this has made it possible, so far, to avoid large-scale resistance developing and has helped make the current farming system (including single-crop farming) sustainable.

The first criterion when choosing a strategy is for it to be suited to the target weed.



STAGES (BBCH SCALE)	5	6	9	11	13	15	17/32	19

	Strategy			Target
1	All pre-emergence			Fast-establishing or late-sowing maize. **Target :** summer grasses (low to medium pressure), common dicots (Chenopodium, Solanum, Amaranthus), Veronica
1		Post-emergence (early)		Maize for early sowing or when no pre-emergence. A second round may be needed. **Target :** common dicots, summer grasses (low to medium pressure).
2	Pre-emergence	then	Post-emergence	**Target :** summer grasses (low to high pressure) + common dicots.
3		All post-emergence (once or twice)		**Target 1 :** common dicots. **Target 2 :** summer grasses (low to medium pressure) + common and difficult dicots.
4	Mixed weed control (mechanical & chemical)			Priority to mechanical weeding with a first chemical follow-up. **Target :** annuals, mass emergence, low to medium pressure. No perennials.

CONTROLLING PERENNIAL DICOTYLEDONS often requires one or more application(s) of specific herbicide(s) and usually at stages that do not coincide with actions to control annual weeds. For plant protection products to be effective, they have to reach the reserve supply organ of the perennial plant (e.g. the rhizome for convolvulus) so the plant has to be large enough (10 to 30 cm for convolvulus) to absorb enough of the product; this is not the case for annuals which should be sprayed when young. The recommendation for convolvulus is to use a specific herbicide, first at the 5 to 6-leaf stage, then again at the 8 to 10-leaf stage.

KEY MESSAGES – IN BRIEF

WEEDING BEFORE EMERGENCE, for greater efficacy

- Post-sowing and pre-emergence applications should be done as soon as possible after sowing to gain from the condition of the prepared seed bed which should not be too rough. The dose of herbicide varies according to the organic matter content of the soil.
- Because of selective effects, shooting maize should not be treated once it has broken through the surface.
- When heavy rain is forecast, it is advisable, when possible, to wait a few hours before applying the product so as to reduce any risk of it being transferred.
- Less spray mixture can be used, depending on the range of the equipment, by using the minimum pressure required for the type of nozzle chosen (preferably using a drift-control nozzle).

WEEDING AFTER EMERGENCE, for greater efficacy

- Humidity must be in the right range when applying herbicide, above 70%, and the temperature must be between 10 and 25°C for the 48 hours after the treatment ; treatment should be avoided on maize under stress.
- Product doses must be adjusted to suit the weed flora present, and should take into account the growth stage and the most difficult weed species to control. Young weeds (less than 3 to 4 leaves) should be targeted with the dose limit for the herbicide to be more effective, particularly on tough dicotyledons.
- Treat maize before the 8 to 10-leaf stage to avoid the umbrella effect. When using less selective products on maize that has reached the 6 to 8-leaf stage, avoid, when possible, treating the entire field.
- The recommended quantity of spray mixture is 100 to 400 litres per hectare, the optimum being between 150 and 200 litres. It may be possible to use less, but for systemic products there should be a minimum of 50 l/ha, and for contact products 80 l/ha, provided that nozzles with the minimum pressure required are used (depending on the type of nozzle) and, most importantly, provided that very young weeds (no more than 2 leaves) are being treated, and at the right temperature and humidity for proper efficacy.

4. How to control weeds with less weed-killer?

In western Europe, with more and more environmental restrictions, some countries would like to reduce the quantities of active ingredients used, in particular for weed killing. For twenty years now, ARVALIS-Plant Institute has been a pioneer in developing and improving techniques to reduce these risks, e.g. grass buffer strips along watercourses have proven to be very effective. Germany has also shown that it is easier to reduce risks by dealing with one-off cases of pollution, often caused by accidents, rather than having a single goal of cutting the quantities of herbicides used or of having fewer approved compounds.

However, as part of an "all round" approach over recent years, ARVALIS-Plant Institute has stepped up research into weeding solutions requiring less use of herbicides. Mechanical weeding is, in fact, a widespread practice in many countries and is sometimes all that is needed to cope with weed flora that are simple and not too dense. This is often the case for maize grown in a crop rotation regime, and when the weather helps the maize get established very quickly, as is sometimes the case in Eastern Europe.

Three no-herbicide strategies are available for weed control for maize. Post-emergence hoeing can be done after pre-emergence use of a chemical herbicide (applied to either the entire field or along the row of maize). Hoeing can also be done after initial post-emergence chemical treatment. The third option is early mechanical weeding before emergence, using a rotary hoe or a spike harrow. Any follow-up weeding is then done with herbicide.

The advantage of post-emergence hoeing

Different trials conducted have shown that the option of hoeing after pre- or post-emergence herbicide treatment appears to be more reliable than early mechanical weeding with a harrow or a hoe. Hoeing is done between the 3-leaf and 7-leaf stages, depending on when the weed killer was applied.

Perennials

Special attention is needed to any plots severely infested with perennial weed species, in particular convolvulus, because every time mechanical weeding is done, the rhizomes are broken up and produce new plants. Mechanical weeding thus increases the number of perennial plants, defeating the purpose of weed control.

HERBICIDES + COMPLEMENTARY ALTERNATIVE TECHNIQUES

Factors for successful combined strategies of chemical weed control + hoeing	
Flora	No perennials, mass emergence, no late emergence, action on young weeds (maximum of 2 to 4 leaves)
Soil	Fine surface, no surface clods or stones, moist soil, friable soil for hilling
Weather	Drying conditions, little or no rainfall for the 3 days after hoeing to avoid any new shoots
Crop status	Maize "shooting up" and cover developing quickly
Response	Second hoeing if new weed growth emerges before the inter-row strip is covered

5. Herbicide selectivity

Herbicides are designed to be toxic to plants, the target being the weed flora, but the crop is not immune to the phytotoxic effects. Some herbicides, mainly systemic ones (i.e. transported by the sap in the plants), do have a risk of unwanted side-effects on the maize crop; this is the case of auxin derivatives.

Fusing of crown roots typically found when auxin derivatives are applied too late

Symptoms

Symptoms are not always visible immediately after the herbicide has been used. Usually a few days later anomalies can be seen on the plants: they droop and lean in every direction. Over time, the following symptoms are observed:

- at the 8-10-leaf stage, lodging in every direction
- later, the leaves of the whorl form a stiff tight roll and tear as they unfold.
- plants are brittle and break at the level of the first internodes at the bottom of the stalk
- shortly before male flowering, the whorl forms a bayonet shape enclosing the tassel.
- crown roots fuse
- plants have no ears
- ears split forming digits or have smut
- ears appear at odd heights anywhere on the plant, sometimes at soil level.

High-risk situations

The weather in the days before and after the application will determine the possible risk of phytotoxicity of auxin herbicides, so prevailing weather conditions are of critical importance. If an auxin herbicide is applied to maize under stress, there is a high risk of phytotoxicity. The plant needs at least two days to recover from any stress before a herbicide can be used. The worst situation arises with a wide temperature range after applying the product, affecting the plant's ability to break down the compound. The status of the maize to be treated is therefore an indication of potential risk.

Prevention

Auxin herbicides should not be used under adverse weather conditions and these should be assessed over a minimum of 48 hours around the scheduled date. Herbicide should not be given to maize plants under weather stress or with leaf damage caused by pests, hail, deficiencies or disease. Reducing the dose is no guarantee that the risk will disappear.

Chapter 3
Disease

Diseases of Maize: strategies in line with the level of risk

In general, maize is not greatly affected by fungal diseases, which means that there is no need for systematic use of plant protection products on the crop. This is because maize has been bred without plant protection products. There is less risk in dry continental conditions in summer, but depending on the year and the region, there can be local damage. Efficiency in choosing varieties, integrated pest control (crop residue management and borer control) will control the greatest risk which is fusariosis. If necessary, anti-fungal treatment can be used to protect from corn leaf blight. Regular checks should be made for head smut and rhizoctonia root rot which pose a moderate risk.

Review of fungi affecting crops: symptoms, risk situations and control.

1. Root necrosis

> Symptoms of rhizoctonia root rot on the radical and crown roots

Necrotic diseases are caused by the development of a number of pathogenic fungi: Rhizoctonia solani (Ag 2-2), Pythium arrhenomanes and/or Fusarium (F. graminearum and Fusarium Section Liseola) affecting the roots. These fungi often occur together, but still have distinct symptoms. Pythium mainly targets rootlets and destroys the root cortex which breaks off easily when pulled. Rhizoctonia root rot causes severe necrosis on the main roots (particularly visible on the brace roots which can even disappear entirely) with a characteristic black colour. Fusarium fungi cause brown root rot. Plants in the field display the first symptoms towards the end of the stage when reserves of starch are stored in the kernel. A few days later, the green leaves lose their colour, turning green-grey then pink before drying out completely. The plant is weak, easy to pull up, and prone to lodging because of the poor brace root system. High-risk situations occur more often in sandy soil, on irrigated land and also in all single-crop conditions when soil cultivation and irrigation management have not been optimal

Prevention & protection

It is important to follow best agronomic practices to minimise the risk of root necrosis developing, i.e. ploughing and tilling the soil in the right conditions, and secondary tillage of soil with adequate moisture. In addition to these precautions, targeted pest control with, for example, azoxystrobin from the strobilurin family of fungicides can be a good option, in particular to control rhizoctonia root rot.

2. Corn leaf blight

> Severe corn leaf blight infestation

Corn leaf blight caused by Exserohilum turcicum (the teleomorph formation of setosphaeria turcica) is an endemic leaf disease, with visible symptoms appearing after flowering, forming characteristic large spindle-shaped necrotic lesions, running in the direction of the veins, and which can cause premature drying of the leaves. In damp weather, dark brown fructifications develop, causing the disease to spread. Air-borne spore (e.g. from nearby fields and via intermediate plants relays) go directly to the top leaves. The necrosis impairs photosynthesis by the maize plant. **In the most critical cases with fast, early development of the disease, from 20 to 50% of grain yield can be lost.** The pathogen needs high temperatures to develop (18-27°C) and high relative humidity (> 95%). Heavy dew and bad light help spread the disease; under these conditions, the time between initial infection and the appearance of symptoms is quite short (5 to 12 days).

Prevention & protection

It is essential to know which situations pose risks and then implement appropriate preventive measures. The risk in the field is highest when the following conditions coincide:

- an endemic corn leaf blight area
- a severe attack the previous year
- a single maize crop or one near fields that previously had corn leaf blight infestation
- a site close to cribs and/or dryers.

La lutte contre l'helminthosporiose passe d'abord par des précautions agronomiques :

- fine shredding and mulching of maize crop residues
- choosing varieties not prone to blight.

▪ Corn leaf spot

A much rarer form of corn leaf blight caused by Bipolaris zeicola (the teleomorph formation of Cochliobolus carbonum) is spread via seed. It is therefore easy to recognise when the crop is growing as it affects isolated plants, leaving the others nearby undamaged. Cream coloured oval spots appear on the leaves, sheaths and husks, until it reaches the ear which turns black. The necrotic lesions join up and give the characteristic spotted appearance of the disease.

In hot, wet weather (28-30°C), the fungus develops fructifications inside the necrotic lesions (conidiophores bearing the conidia) giving the lesions a blackish colour.

There is much less sporulation, however, with Bipolaris zeicola than Exserohilum turcicum, which limits the spread of the disease across the crop.

This minor disease can be spread by:

- contaminated seed
- single maize crop farming with crop residue in the field
- hot, damp weather conditions.

▪ Other forms of corn leaf blight

Two other species of fungus can cause blight, but have rarely been reported in France: Bipolaris maydis (the teleomorph formation of Cochliobolus heterostrophus) and Exserohilum rostratum (the teleomorph formation of Setosphaeria rostrata). The two produce similar symptoms with small elongated necrotic lesions on the blade (1 to 2 cm long and 0.5 cm wide), sometimes with a darker purply-brown outline.

3. Rust

> Rust is rarely seen on maize

Maize, like many other plant species, has its rust – Puccinia sorghi – with characteristic symptoms. The disease very rarely causes damage to hybrids. When growing seed maize, fungicide protection may be required. The characteristic orange brown spots are found on leaves, stalks and husks exposed to the light. They then darken, looking scab-like, as the spores for the sexual reproduction of the fungus (teliospores) are produced. Onset is often late, after flowering, with warm temperatures between 16 and 25°C and high humidity (6 hours of high humidity is all that is needed for the spore to germinate).

Rust has a very short biological cycle (with spore forming approximately 7 days after infection) and therefore a number of cycles can be completed as the maize crop grows.

Prevention & protection

It is important to plough in crop residues to limit any potential for infection. With different varieties, symptoms can be different, but with low prevalence and little damage caused to hybrids there is no reason at present for any specific testing or breeding for resistance. But when symptoms do occur, between-variety comparisons of yield in trials testing varieties study the related effects.

4. Eyespot

Eyespot, caused by Kabatiella zeae, appears as a large number of small circular spots, often on leaves, and rarely more than 4 mm in diameter; these should not be confused with anthracnosis (spots with a brown necrotic centre).

> Eyespot is prevalent in the west of France

Eyespot is cream to grey coloured in the centre, and has a purple-brown edge, surrounded by a translucent halo clearly seen against the light, with spots often in clusters on the blade of the leaf. The plant may sometimes react causing the blade near the necrotic lesions to turn red. The fungus survives easily on crop residues (as stroma). Initial symptoms can appear at the seedling stage, before spreading to the leaves at the bottom of the plant. But the disease does not really become established until after flowering, when it spreads directly to the leaves above the ear. The attack spreads to all the leaves and ultimately causes the leaves to dry early, causing the kernels to shrivel. It is extremely rare for any serious damage to occur. The disease prefers low summer temperatures (10-12°C) and moisture on the leaf (needing 7 hours of surface moisture on the leaves for the infection to spread). The small spores spread easily with the wind and rain splashing.

Prevention & Protection

To date there is no cure. In single crop farming, crop residues have to be ploughed in to target the spores that keep the fungus alive.

5. Anthracnosis

> Leaf damage caused by anthracnosis, not to be confused with blight

This is another case where the leaves dry out, occurring later in the season, towards late August and early September. It is caused by the fungus Colletotrichum graminicola (teleomorph, Glomerella graminicola), producing a large number of small necrotic patches on the leaves, often before flowering. The patches are around 15 mm long and oval, with white then black fructifications in the middle which can be seen through a magnifying glass. The spots then join up and cause the entire leaf to dry out. Anthracnosis on the stalk appears as black lines on the internodes at the base of the plant. The symptoms rarely cause financial losses, except when growing seed varieties with low vegetative growth. The disease is likely to develop when temperatures are high (above 20°C) and with regular rainfall.

Prevention & Protection

The fungus survives in crop residue, in particular on the stalks. Single-crop farming and simplified techniques with no ploughing or tilling can foster the disease. In such situations, the residue from the previous maize crop should be shredded and ploughed in.

6. Common smut

> Common smut is the most common fungal pathogen affecting maize

Common smut is one of the most prevalent diseases affecting maize. It can occur at the slightest damage and develop on organs during growth stages. The disease rarely causes serious damage, but if galls (or tumours) develop extensively over a large number of plants or ears, there will be a negative impact on yield. When used as silage maize for fodder, it is grey and the colour may deter the animals from feeding.

Ustilago maydis has large numbers of volatile spores occurring naturally in the environment. Any attack on the plant can make it susceptible to infection; for example by parasites (fruit fly), chemicals (with direct or indirect phytotoxic effects, e.g. auxin weed-killers causing malformations, often together with smut), mechanical causes (broken or hail-damaged plants), or physiological causes (water stress or events affecting ear development seen with galls present).

Prevention & Protection

There are no cures. The most effective method is to control the risk factors mentioned above, but this brings no guarantee. There is a certain degree of variety-linked susceptibility, either direct or indirect (susceptibility to pests or accidents).

7. Head smut

> The soil is the main source of the inoculum

Head smut is a disease that can cause substantial yield losses. The ears and tassels are invaded by spores, taking over the zone of the kernels and stamens. The disease first appeared in France in the late 1980s and was reported in a number of maize-growing areas, often in valleys or on land prone to flooding, in sandy or silty soil, but was countered by preventive measures combining resistant varieties, seed protection and longer intervals in rotation programs before resowing maize.

The usual symptoms of head smut, caused by Sphacelotheca reiliena, are not seen until after flowering and affect the reproductive organs (tassels and ears). Affected ears are bulbous, bulging at the base (bottle-shaped), are soft and with no visible silks. The soil is the main source of the inoculum, and spores can remain viable in the soil from two to five years, although viability decreases with time and antagonistic activity can stop them developing. The fungus gets inside the seedling through the mesocotyl and roots before the maize plant reaches the 8-leaf stage; it is most susceptible at the 3-leaf stage. The attack spreads systemically, going up to the developing ear and tassel. In spring, if conditions produce a fast growth rate, prevalence will be lower. Cold temperatures slow down the rate of germination and the establishment of the pathogen which thrives in heat. The development of the disease in the plant is helped by any factors impairing or slowing early growth, e.g. early dry conditions, or compacted soil.

Prevention & Protection

Protection in high-risk situations means choosing resistant varieties and applying fungicide to the seed line or using seed protection. Strict regulations cover the disease with compulsory measures to avoid the disease being spread by seed. Breeders are continuing to work on the development and classification of maize varieties according to their resistance to head smut.

8. Fusarium head blight

> Fusarium (F. graminearum) can produce mycotoxins which are subject to EU regulations adopted in 2007

Head blight can be caused by a number of Fusarium species with fructification occurring on crop residues; the disease then spreads, developing to different degrees depending on the risk factors. Symptoms appear after female flowering and, as a general rule, later for Fusarium Section Liseola. F. graminearum infects the ear via the silks, forming a mycelium sheath starting at the apex of the ear and going downwards. The decomposing kernels and the mycelium produce the characteristic pinky-brown colour. Fusarium Section Liseola species are less aggressive and often attack opportunistically after initial infection by F. graminearum or after borer damage. Scattered areas of the ear are affected, with small clusters of kernels, sometimes purplish in colour. Fusarium Section Liseola species thrive at temperatures higher than F. graminearum (28°C and 22°C respectively), causing not only yield losses, but also Fusarium toxins which, since 2007, have been covered by European regulations. Compliance with the threshold applying to maize for human consumption and recommended levels for animal feed is now a prerequisite for market access. Research by ARVALIS-Plant Institute has shown that weather is always the key factor for each fungus and the mycotoxins produced: Fusarium graminearum for desoxynivalenol (DON) and zearalenone, and Fusarium Section Liseola (F. verticilliodes and F. proliferatum) for fumonisins.

The main factors for DON and zearalenone are, in order of importance, the harvest date and stage of maturity, varietal susceptibility and the management of crop residues from the previous season.

For fumonisins, borers attacking the stalk and/or ear (corn borer, stem borer or corn earworm) are the main vector. Fumonisin can also be associated with water stress, damage, cracks and pathogens on the ear which open the way for latent, opportunistic and competitive Fusarium (verticilloides or proliferatum). Other factors are the susceptibility of the variety and the management of crop residue from the previous season.

Maize Disease: Prevention & Protection

Risk factors can accumulate, thereby increasing the effects of disease. Such interactions need simultaneous responses with a number of technical measures to reduce the risk of Fusarium toxins:

- corn borer and stem borer **control in individual fields/plots** when the level of infestation requires such action.

- **optimal sowing and harvest dates**, and a **choice of variety with the earliness required** are some of the best practices; **no harvesting after November 1.**

  When symptoms are present, harvesting must not be deferred until after maturity so as to stop the Fusarium spreading and toxins accumulating. The temperature requirements for the varieties to reach physiological maturity must be checked and match the temperature pattern prevailing at the locality concerned and the date of sowing.

- **Choice of varieties.** It is essential to choose a variety with earliness suited to the geographical area and the target harvest date. A level of susceptibility considered as acceptable will depend on measures implemented to deal with other risk factors and all the agronomic features of the varieties concerned. The most susceptible varieties should be avoided and varieties should be chosen to suit the relevant farming practices.

- **Crop residue management and soil cultivation.** Surface residues are a potential source of contamination of the next maize crop, and this applies to the cycles for both Fusarium and borer larvae. Efficient shredding of stover immediately after harvesting and early mulching of stubble will help the organic matter break down, impacting on the hibernation of corn borers, thereby reducing borer populations.

Chapter 4

Water Stress Resistance

The main factor restricting maize is the shortage of water. Maize is mainly grown with rainwater (i.e. without irrigation); this is the case around the world and in particular in Central and Eastern Europe, and there have been steady improvements in the plant's water stress tolerance. The appearance of hybrids, and the widespread use of genomics in breeding have made for swift progress. Over the last fifteen years, and despite the effects of global warming, maize growers have seen for themselves that the plant has become more efficient in coping with water stress, and specifically around flowering time which is a critical period. Significant advances have also been made for the grain-filling stage, when maize is naturally strong.

It can be said that when farmers make their choices they are helping protect their crops from the impact of water stress. Whether there is irrigation or not, and with the prospects of global warming, it is through agronomics, soil cultivation, the farming options selected and the varieties chosen that will help increase tolerance to water stress.

1. The impact of water stress on the components of yield – a review.

Il y a stress hydrique du maïs lorsque l'état hydrique du maïs perturbe le métabolisme et a des répercussions directes et plus ou moins rapides sur la croissance des organes et leur développement. Le manque d'eau va perturber le métabolisme de la plante avec pour conséquence des modifications dans le développement, la croissance et la production de matière sèche.

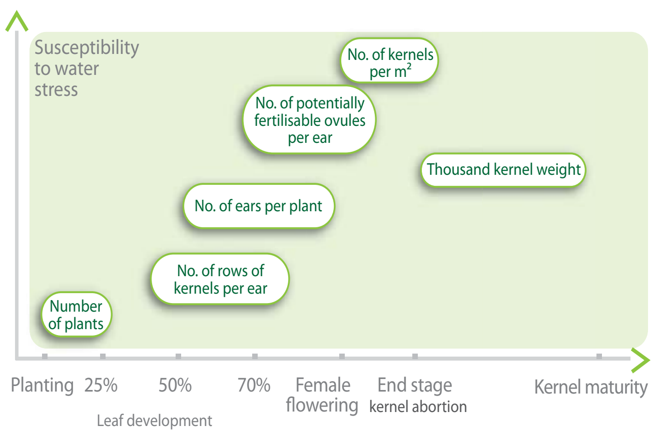
Impact on growth. The time when water stress occurs is a key factor influencing the hierarchy of organs affected, as it affects the organs growing at the time of the stress. Any water deficit around flowering time will therefore cause a significant reduction in total dry matter of the ears; but by then the dry matter in the leaves, leaf sheaths and husks, even though they are fully grown, may suffer from a background effect when the water deficit occurs early, and this will have a negative impact on potential for producing biomass later.

Impact on yield components. Depending on the period when the water stress occurs, there will be different effects on the yield components. Water stress at sowing time and during the vegetative growth stage affects first the number of plants, next the number of rows of kernels per ear and then the number of ears per plant. Water stress at the time of flowering reduces the number of ovules per ear that can be fertilized and therefore the number of kernels per ear.

Losses can be expressed in figures: for a water deficit of approximately 10 days ending around three days after silking, flowering will be delayed by around 6 days and grain yield will go down by about 25%. This type of stress makes the leaves age faster and impairs the ability to assimilate CO2, which is why there is a substantial drop in dry matter. Water stress at the time of tasselling mainly affects the number of kernels per ear and this is not offset to any great extent by the later increase in the thousand-kernel weight. The longer the period of water stress, the greater the effect on the number of kernels per ear. Water deficit occurring later, during the grain filling stage will decrease the thousand-kernel weight which may then lead to a 20 to 40% decline in yield as the filling time is shorter, although the rate of filling is not disrupted.

- **NB An important feature to consider for maize yield is that there is little compensation from one component to offset another one in the course of the growth cycle.**

Maize cycle: susceptibility to water stress and yield components affected (Lorgeou, 1977, Girardin 1999).



2. Strategies for reducing the susceptibility of maize to water shortages

A number of strategies can be used to cope with water stress.

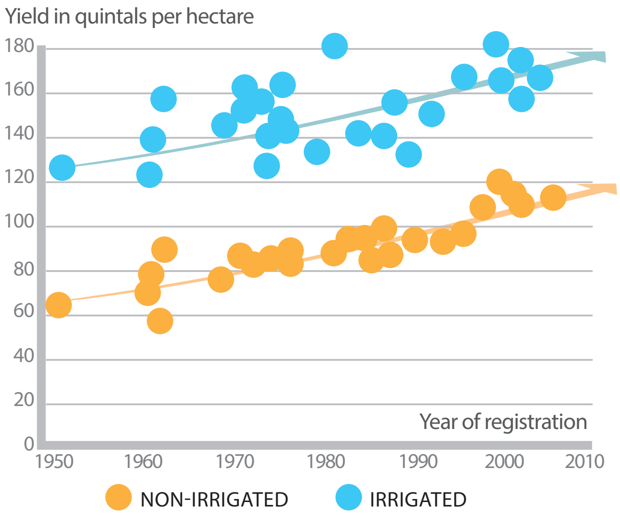
Avoidance strategies – This involves rationing plants by reducing, for example, the ratio of leaf surface area to ground surface area (via density) while maintaining nitrogen-based fertilization at a level able to increase root development, or by finding very compact plants. Such reduction strategies have often turned out to be counter-productive in the long term for, in better years, inadequate inputs (plant density and nitrogen) cannot produce plants making good use of even minimal rainfall. **Reducing inputs is the beginning of a downward spiral, depriving the farmer of better yield potential in good years, and also making sub-optimal use of advances achieved through plant breeding. To gain the most from advances in genetics, plants must be well fed and in good health.**

Resistance strategies – This entails a choice of variety with intrinsic tolerance to water deficit. By conducting experiments and comparing different hybrids under local farming conditions, varieties achieving top performance with restricted water input can be identified. After trials run over many years in different countries, including France, the “élite” varieties performing best under good growing conditions are often the same varieties that perform well under the most difficult conditions. Recent advances in plant genetics have concentrating on having steady yield levels from one year to the next.

The choice of a recent top-performance variety is therefore very likely to be a variety with greater tolerance to dry conditions. Progress has been as fast for farming under good conditions (for irrigated maize) as for non-irrigated farming.

Varietal improvement of maize is now moving ahead with the digital revolution and high-throughput genotyping in what is called “genomic breeding” and may well see faster developments with genetic advances. Water stress tolerance and adaptation to climate change will continue, and researchers consider that the rate of improvement will be between 1% and 3% per annum. The choice of varieties will therefore remain a key criterion for the performance of maize crops, particularly in countries with high temperatures and water deficits in summer.

Recent genetic advances, as reported in France (with increasing yield for varieties registered in the French catalogue), **provide confirmation that there has been swift progress when farming in good conditions (irrigated maize) and also for non-irrigated farming** (REF: Tardieu, INRA, 2010).



Evasion strategies – These strategies have the growing cycle scheduled to fit in with the water available, i.e.

- completing the growing cycle before terminal drought conditions prevail and before all water capacity in the soil is exhausted.
- avoiding high drought risks occurring at the most critical points in the cycle (flowering and grain filling).

In practice, such evasion strategies mean changing the sowing date (usually moving it forward) or changing the variety for different earliness. When weather conditions are influenced by the ocean, as in western Europe, the strategy produces good results, but it is more difficult to implement under continental climate conditions where there is less scope for adjusting the beginning and end of the growth cycle because of the risk of spring and autumn frosts.

Indirect strategies – For rainfed crops, a number of simple measures can help make plants more resistant to water stress; these are measures targeting the quality of root development, the elimination of competition from weeds and any damage to leaf surface areas. These need to be implemented on a systematic basis in particular when choosing "élite" seed.

Some examples

- Careful soil cultivation to help the roots become well established, avoiding any breaks or uneven effects in the soil caused by ploughing and tilling in damp conditions. The root system of the maize plant is less efficient than the root systems of other plants.
- Making sure there is good root development early, from the very beginning of the cycle. Phosphorus fertilization applied locally on sowing (a starter fertilizer) is very effective.
- Sowing at the right time (with a high-speed seed drill or a conventional seed drill with sufficient width) to make good use of optimal weather conditions.
- Choosing varieties with good initial vigour. Plants become established faster in dark soils.
- Avoiding early weed infestation as weeds compete with the crop for both water and nitrogen.
- Choosing compact plants that consume less water. With early sowing, plants are more compact in size but, for the same density, will have the same leaf area index.
- Maintaining the photosynthetic area in good condition for as long as possible:
  - early in the cycle: no herbicide toxicity to plants, no burning from fertilizer
  - mid-cycle: no aphids, no cutworm damage to leaves
  - late cycle: tolerant varieties to avoid leaf diseases
- Paying attention to the effect of the previous crop, timely removal of intercrop to avoid any early depletion of the available water-holding capacity in spring
- In windy areas, having hedges and windbreaks to help reduce plant cover evapotranspiration.

3 ▪ Harvesting

Chapter 1

Grain maize

1. Striking the right quality/quantity balance

The quality required for grain maize used in industry (or on the farm) depends just as much on the conditions for drying and storing the grain as it does on the actual state at harvest.

Maize growers focus on optimal financial return while keeping a close check on the health status of the plants.

In many countries, most ears are left to dry on the plant; often this is the only option as there is not enough storage capacity. The method has both advantages and disadvantages, as it eliminates the financial costs involved and improves the ecological footprint of the crop, but it also imposes the choice of certain varieties that are too early for the weather conditions in the region, thus taking away a substantial part of the yield potential (calculated as 5 to 7 quintals for every 100 FAO units). This decision then means, as already noted, that varieties have to be chosen for their mechanical strength and fast dry down rate), but not necessarily for their agronomic qualities. The right compromise is probably on harvest time, at 22% to 25% moisture content. Good use can then be made of weather potential, harvesting before losses are incurred (from lodging or disease), and with natural drying. Artificial drying can secure both the quality and quantity of the harvest and be used as an option in the event of damage to crops in the field, caused for example by storms, frost or disease (fusarium). While there is no systematic correlation between quality and kernel moisture content, the moisture of the ear has a direct impact on breakage and deseeding, and therefore on the final quantity of clean whole grain delivered.

Optimal yield is achieved once the translocation of the assimilates has been completed; the thousand-kernel weight is then at maximum level, calculated as the number of kernels per square metre. This is the stage when the "black layer" appears at the base of the kernel.

2. The best indicator: looking at the field to decide

Modern maize has made great progress, becoming much stronger and sturdier late in the growing cycle. The stage of the plants can be determined by a visual appraisal of both the kernels and the plant body. For an accurate assessment of the stage of the plants:

- make a general appraisal of the plant body to determine how the plants will perform late in the life cycle, and therefore see what margin for manoeuvre is available for harvesting after physiological maturity.
- monitor the level of grain filling up to the black layer (and/or the total temperature) to establish what stage the plants have reached.

Monitor the crop to set the harvest date

1 Watch husks yellowing and plants drying

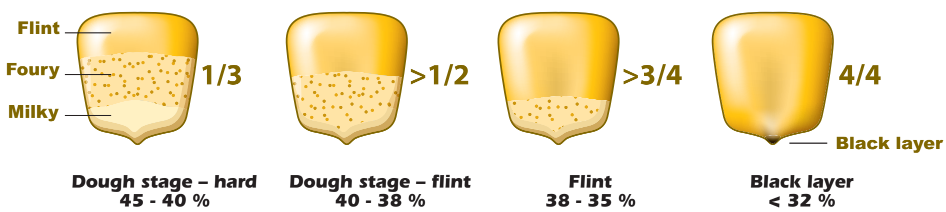
Yellow husks
> 4 green leaves below the ear

Dry husks, yellowing leaves at base of plant
> 2-3 green leaves below the ear

Dry husks, dry leaves
> The ear leaf is still green

Dry husks, dry leaves, dry stalk
> No green leaves

2 Monitor grain filling



Black Layer

The black layer marks the end of the food supply to the grain. In a warm year, with normal migrations, it can be a good indicator for the harvest date.

But… in a cold year, the food supply can stop gradually, so the indicator then is not reliable.

3 Add up temperatures since female flowering

500 GDDs	600 GDDs	700 GDDs	800 GDDs
	End of irrigation		Optimum grain harvest (physiological maturity)

Harvest: Striking the right balance

	AVANTAGES	DISADVANTAGES
Harvest too early	▪ limited losses ▪ easier harvest work ▪ soil structure maintained ▪ easier establishment of next crop	▪ more grain lost off the cob ▪ more fragile grain, more delicate settings, clogging ▪ additional cost for drying ▪ sub-maximal yield
Harvest too late	▪ easier threshing ▪ savings on drying	▪ risk of weather deteriorating ▪ greater risk of losses on the ground (ears and/or grain) ▪ slower harvest work, risk of damaging soil structure ▪ higher health risks and agronomic risks (lodging).

3. Technological quality and losses at harvesting

These last two criteria often go together.

Transactions on sales are normally made on the basis that the quality is wholesome, genuine and marketable. This approach does not take into account a number of physical parameters such as broken kernels, grain impurities, germinated grain and miscellaneous impurities. A distinction is made between grain impurities (damage caused by pests, germinated grain, non-maize grain or abnormal colouring) and miscellaneous impurities (foreign seed, inert matter or spoilt grain coloured black or green).

Maximum levels are set for maize transactions (as specified in France by the Syndicat de Paris du Commerce et des Industries des grains produits du sol et dérivés):

- moisture content: 15%
- broken kernels: 5%
- Impurities: 3.5%

3.1 Threshing and quality losses

- **Setting the spacing between the roller and the concave**

The adjustment of the concave and the speed of the roller determine the wastage rate due to damaged kernels and the quantity of incompletely threshed ears. A 30 mm clearance feeding in and 15 mm out are suitable for early varieties that thresh well. An additional 5 to 10 mm is needed for late varieties with larger ears.

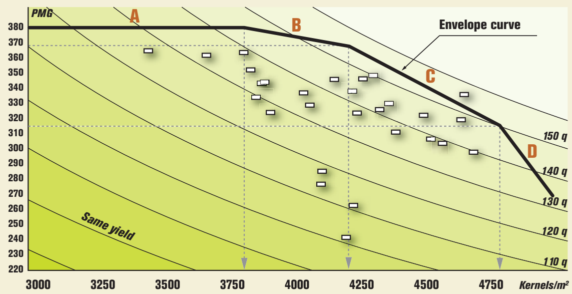
For varieties that are more difficult to thresh, the spacing can be reduced to 25 mm in and 12 mm out.

Practical Tips

ASSESS YIELD COMPONENTS: ID profile of hybrids: thousand kernel weight and kernels per square metre are linked

The assessment of yield components is a diagnostic approach after the fact designed for more rational management of a given hybrid crop in the soil-climate context of the region.

The thousand kernel weight (TKW) is not just a calculation determined by the plant at the end of the cycle, but is a "summary" of the full crop history. It is also, and perhaps most importantly, the result of the number of kernels per square metre as planted with the density of the stand and having survived all forms of stress.



A: TKW at maximum. When combined with a low number of kernels/m², this produces crop density that is slightly low in relation to the yield potential of the field.

B: TKW goes down with the number of kernels/m², but the competition balance is still positive for yield.

C: The drop in TKW is in proportion to the differences in kernels/m². The competition balance between kernels is then cancelled out. Optimum yield is achieved. There is perfect offset between density (number of kernels/m²) and grain filling. The graph shows an "isoyield" curve in line with the potential of the hybrid for a given climate context.

D: Overcrowding. TKW has declined because of the excess number of kernels/m².

Percentage of whole grain and impurities according to the concave clearance (for the same speed of rotation and moisture content of 35-37%).

Concave clearance (mm)	Impurities (%)	Whole grain (%)
30-15	0,3	90
27 – 12	0,4	88
23 – 10	0,8	85

Source: ARVALIS

3.2 Losses in the field

- **Method for estimating losses**

It is very important for maize growers to have an approximate idea of the level of losses so that they can take swift action.

To estimate ears lost, count the number of normal ears lost in a row over a length of 50 metres.

To estimate kernels lost, the distance between 2 rows is taken as a reference over a length of 1.25 metres if the distance between rows is 80 cm, giving a calculation for a square metre.

Losses	Number	q/ha (15% moisture content)
Epis complets sur 50 m et 1 rang (espacement 80 cm)	5 10 15	2 4 6
Grains sur 1 m²	100 150	3,2 4,8

Source: ARVALIS

Kernels lying along the line at the foot of the stalks are, in part, losses through deseeding due to the picker; kernels lying between the 2 lines, are losses while cleaning.

For accurate monitoring, counting needs to be done in different parts of the field, with a careful check of the piles of stalks and leaves.

4. Targeting quality – three key phases

The term quality usually refers to technological quality (physical quality and suitability for processing) and health quality (mycotoxins caused by Fusarium on the ear). The focus here is on preserving technological quality.

Demands for commercial quality and good health status have changed and are now set as new prerequisites for access to markets, with compulsory monitoring and tracing of the technical itinerary from the field to initial processing. Each step in the programme must be done carefully so that the maize that ends up on the market is wholesome, genuine and marketable.

Quality starts in the field…

Decisions made on farming techniques have an impact on quality: maturing (yield/moisture) is optimised by choosing hybrids with earliness suited to the environment, as the advantage of good dry down conditions must be put to good use in September.

- the maturity and health status of ears must be checked on every visit to the field; this helps make more accurate calculations for the harvest date, choosing the priority plots and improving crop traceability. Special attention should be given to crops sown late as they are more exposed, with challenging weather, more uneven stands and later harvesting.
- harvesting at a sufficiently early date can bring advantages and may even bring opportunities on between-season markets.
- grain filling, technological quality and health are ensured by meeting the water requirements of the plants.
- the health status of the plants and the kernels is supported by rationally structured farming programmes and techniques, from sowing to harvest, and specifically for borer control.
- the health status of the next crop will be improved by finely shredding and mulching crop residues.

…At harvesting time…

The best conditions for both quality and quantity are the result of combined and complementary efforts:

- with the farmer endeavouring to set the right harvesting date when the kernel has reached physiological maturity, with sufficiently low moisture content but without any losses in the field.
- having the right match of threshing for the variety

- proper performance and easy adjustment of the settings of the combine harvester
- for the business behind the harvest, it is a matter of harvesting quickly while meeting the requirement for the farmer to harvest without losses.

… and continues after harvesting

While harvesting at maturity is a key quality criterion for maize, the handling of high-moisture maize by the storage companies is also important:

- The recommendation is that high-moisture maize should not be stored for more than 24 hours; it can be ventilated with cool air at a high airflow rate (70-80 m3/h/per m3 of grain) to limit any heat generated while the grain is waiting to be dried. Efforts should be made to ensure that the first load in is the first load dried and that the backlog of loads is cleared every day.
- Drying conditions are then a key factor determining the quality of the grain and its value for industry; any changes are risks with an impact on the physical quality of the kernels, affecting the grain's market quality and value for use. If drying is too hot or too sudden, starch and protein can be damaged, impairing the value of the grain for use, in particular in the starch industry. The drying temperature should be set to match the target market (see Table). Promatest is an analytical method for testing starch quality and gives a good indication of the standard of drying.

Temperatures recommended for drying in relation to moisture content at harvest and end use of the grain

Moisture at harvest (%)	Maize for force-feeding	Waxy maize	Maize for starch	Maize for animal feed
20-24	90-100	100-110	130-140	130-140
25-27	90-100	100-110	130-140	130-140
28-30	80-90	90-100	120-130	130-140
31-34	70-80	80-90	110-120	120-130
35-38	60-70	70-80	100-110	110-120

TAKE HOME MESSAGES

Actions to achieve quality

Criteria	Visible alterations	Adjust thresher	Restrict prestorage time	Limit drying temperatures, avoid overdrying	Improve cooling ventilation during storage
Commercial quality	Cob fragments	✗			
Commercial quality	Kernels split, cracked and broken	✗		✗ (1)	
Commercial quality	Brown heat-stressed kernels			✗	
Commercial quality	Mould and germination		✗	✗	✗ (1)
Technological quality	Poor Promatest and sedimentation results		✗	✗	
Technological quality	Poor cornmeal and hominy results	✗		✗	
Health quality	Mycotoxins		✗		✗

(1) improved handling can help reduce grain breakage and cracking

5. Kernels with guaranteed health status

▪ Complying with European regulations

Maximum levels of deoxynivalenol (DON), zearalenone and fumonisins (B1 + B2) in cereals and derived products (e.g. milled grain and flour) apply to food for human consumption and there are recommendations for animal feed, as introduced under European regulations in 2007; these set health quality conditions for products to be marketed (see Table). While these are only recommendations for feed, there can still be marketing problems with on-farm consumption if a highly contaminated batch is used in pig farming.

Table 8.5 EC Regulation No. 1881/2006 setting maximum levels for certain contaminants in foodstuffs

µg//kg		DON	ZEA	Fumonisins (B1 + B2)
Cereals (excl. maize)	Unprocessed	1 250	100	
		Durum wheat and oats 1 750	100	
	Flour, semolina, dry pasta	750	75	
	Bread, biscuits, pastries, breakfast cereals	500	50	
	Baby food	200	20	
Maize	Unprocessed	1 750	350	4 000
	Milled <500 µm	1 250	300	2 000
	Milled >500 µm	750	200	1 400
	Breakfast cereals, snack food	500	100	800 Other foodstuffs for direct consumption: 1 000
	Baby food	200	20	200
	Starch production (wet milling process)	Derogation	Derogation	Derogation

▪ Factors influencing the appearance and development of fusarium head blight causing mycotoxins

The presence of toxins means the presence of pathogenic fungi able to produce the toxins, but these pathogens alone do not necessarily produce the toxins. Major studies have been conducted in France and Italy to classify and rank the causes making the risk occur and one of the first observations was that weather is a dominant factor involved in the infection and development of fusarium head blight and the toxins produced: i.e. rainfall at the time of female flowering and the days immediately after, humidity and temperature levels after flowering, particularly in early autumn. Water stress, heat stress and borers can all increase exposure to pathogens.

The risk factors for **DON and zearalenone,** which are secreted by Fusarium graminearum, are first the harvest date and stage of maturity, then varietal susceptibility and the management of crop residues.

Fumonisins are secreted by a Fusarium Section Liseola species (e.g. F. moniliforme), a more saprophytic fungus, so any damage caused by borers attacking ears and/or stalks (corn borer, stem borer and corn earworm) or cracks in kernels caused by water stress, or even secondary infection of the ears by pathogens (including F. graminearum) which foster the development of fumonisins. As is the case for F. graminearum, there is a certain degree of variety-related susceptibility to these fungi.

It should also be noted that in temperate regions there is a much lower risk of **aflatoxins** (which are a great source of concern for cattle feed manufacturers), but with the prospect of further global warming, the potential risk in the future cannot be dismissed. Occasional alerts on maize in both southern and eastern Europe (Italy, Romania and Ukraine) show that vigilance is needed, particularly after hot summers. Aflatoxins are mycotoxins mainly produced by three Aspergillus species: A. flavus, A. parasiticus and A. nomius. Proper drying of the grain can stop Aspergillus species from appearing as they need moisture and heat to develop.

SUMMARY

Preventive measures to control health quality

It has been seen that the management of residues from previous crops can play a role in prevention, making it more difficult for the inoculum to survive, which means that there are key risk factors that can be targeted. With interactions between climate, the technical itinerary and varietal susceptibility, action must involve simultaneous use of a number of technical levers:

- Crop residue management and soil cultivation as soon as the previous maize crop has been harvested: surface residues are a potential source of contamination of the next maize crop, and this applies to both Fusarium and borers. Efficient shredding of stover immediately after harvesting and early mulching of stubble will help the organic matter that fosters the pathogens break down. By shredding and removing any stumps there will be a positive impact on the conditions required for corn borers and stem borers to hibernate. These recommendations, however, also depend on climate and harvesting and will be easier to implement when harvesting dates are not too late.
- sowing dates for early maize varieties together plus the right choice of variety with the earliness required can produce earlier maturing, making it possible to avoid exposure to fusarioses causingμ head blight which prevail when the autumn is mild and damp. Early sowing, moving the cycle forward, can achieve lower kernel moisture levels when the humidity in autumn is conducive to the spread of the fungi. As harvesting after November 1 increases the risk of toxins, it is recommended that the earliness of varieties bee reviewed for any sowing after May 10 to 15.
- choice of varieties. The most important measure is to choose a variety with earliness suited to the geographical area and to an early target harvest date. When sowing in uncultivated soil, the most susceptible varieties should be avoided. Observations in the field by the farmer monitoring the plots over the month prior to harvesting will help identify and eliminate the most susceptible cases.
- corn borer and stem borer control in individual fields/plots must be done whenever the level of infestation requires such action. The strategy is to control and contain pest populations, in particular any second generation caterpillars.
- harvesting dates in relation to the health status of the kernels. When symptoms are established, the harvest must not wait for maturity so as to contain any spread of fusarioses and the accumulation of toxins.
- Avoid the cumulative effect of the different factors

Chapter 2

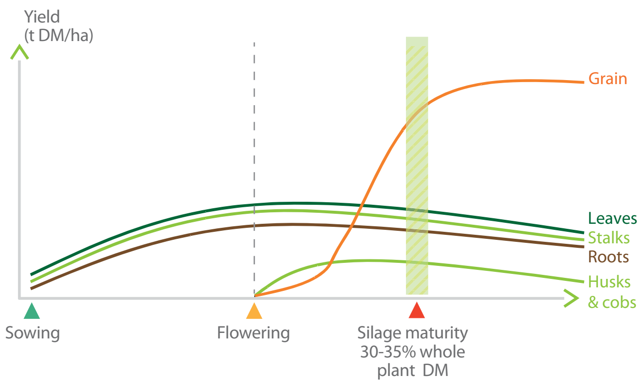
Silage maize

As silage maize is used as fodder, the value of whole plant silage maize is highly dependent on silage preparation. For successful silage, a few simple rules must be followed..

1. Efficient ensiling for successful storage of maize

Silage maize is ideal livestock fodder to use as winter feed for beef cattle. Silo storage is a natural method for keeping fodder on the farm, making use of lactic bacteria which, in an environment that is moist and anaerobic (without oxygen), can turn soluble carbohydrates into lactic acid. Low pH levels can stop other microorganisms from causing damage, as long as the anaerobic conditions are maintained. Once the silo is stabilised it can be kept for more than a year. With the content and structure of maize, it is ideal for successful silage, which is why it has become such a popular choice as stored fodder.

Silage maize: yield of different components of the plant



The goal of grain farming is to have maximum yield by harvest time, meaning a high number of well-filled kernels/grains, harvested at maturity and ready to be harvested. For fodder crops, all of the plant above the ground contributes to the yield and the quality of the produce harvested (percentage dry matter and feed value), for storage and as feed. But yield is not the only criterion; the percentage of dry matter at harvesting is an important factor for storage, and the chemical composition is a factor in the feed value of the fodder. The choice of the stage and date of harvesting is therefore important for gaining optimal value for the livestock. The plant, whether it is to be harvested for grain or silage, still behaves the same way. The only change is the date of harvesting.

Five golden rules

1.1 Monitor grain filling to decide on the harvesting date

Under "normal" growing conditions, the optimal stage for harvesting is with a whole plant dry matter (DM) yield of 32 to 33%. An animal farmer can monitor grain filling in the field to identify the right stage and choose the right date to harvest. Starch is present in the kernel in one of three forms, first milk, then dough and finally dent which is bright yellow and difficult to scratch with a fingernail. As the plant matures the proportions of these three types of starch in the kernel change, with the milk declining and more dent appearing. It is easy to make an accurate diagnosis in the field. The ideal stage has all three starch types (milk, dough and dent) in equal thirds in the kernels in the central crown. (See diagram on last page.)

The average proportion of dry matter in the whole plant needs to be adjusted in relation to the development of both ears and stalks, and the condition of the vegetative organ. Depending on the ear to plant ratio, the percentage of dry matter will be lower or higher (ranging from 29 or 30% up to to 35%). A vegetative organ with high water content will reduce dry matter content, and a dried "stalk + leaf" section will increase dry matter by one to three percentage points.

When harvested too early, yield is lower with fewer kernels in the whole plant; when maize is harvested with less starch, and therefore less energy, there is the risk that silos might lose sugar in liquid silage run-off.

When harvested too late, there is the risk of less efficient storage (a problem of packing with more time needed for the fermentation process to be initiated as there is more air and less soluble carbohydrate). The ingestion of the silage is in fact determined by its energy content and proper storage.

1.2 Efficient, fine chopping for storage and consumption

Chopping is done for two apparently contradictory reasons: fine chopping helps the silo settle, but also leaves pieces long enough for cows to chew. Over-large pieces (>20 mm) are not wanted as they hinder compaction and will be rejected at the trough: large bits must not account for any more than 1% of the total (i.e. one cupful per 10 litre bucket).

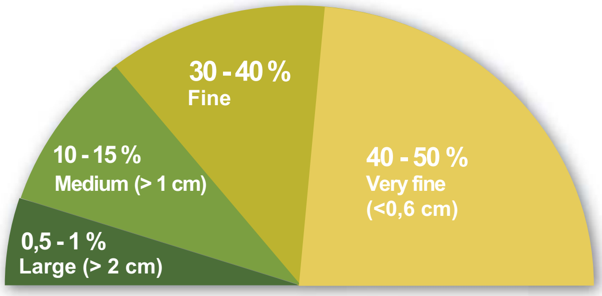
For medium-size pieces (10-20 mm), 10% is the target for feed in the trough. The fewer there are, the better the compaction and storage of the silo, in particular when the dry matter content of the maize is above 35%; but medium-size pieces are needed for rumination. Warning: silo unloaders and mixers make the pieces smaller; in 5 minutes of mixing, maize silage can lose one-third of the medium-size pieces.

Shredding must match the level of maturity. Flinty starch in maize with more than 32% whole plant dry matter needs to be broken up for optimal digestion; this is done by grain busters that can be fitted to most silo fillers.

Chopping texture : not too fine, not too coarse.
The texture will affect:

- ***silage storage quality***
- ***the quantity of fodder eaten***

Recommended grain size:



1.3 Setting a sufficiently fast rate on the silo front

In a silo filled with silage maize, losses occur on the front when the silage is being used. One prerequisite to avoid heat being generated is to keep the front of the silo moving ahead faster than the fermentation recurrence rate. The minimum usually set for the front is an average of 10 cm per day in winter and an average of 20 cm per day in summer.

1.4 Keeping earth out of the silo

Earth that comes in on tractor wheels and trailers brings butyric acid spores endangering the efficient storage of the silo. To avoid this, silos should have concrete floors and the access ways around should be on stable ground.

1.5 Settling to trap as little air as possible in the silo

The fermentation process which provides stable fodder happens in an anaerobic environment. For fermentation to occur properly, there must be no oxygen. This is why it is important to remove a maximum amount of air from the silo through efficient settling. New developments with high flow rate silo fillers mean the compacting tractor no longer has the time to do a proper job, particularly when there is a high level of dry matter. In such cases, the whole rationale of the work plan must be reviewed, either by going back to less efficient machinery, or by setting up two silos simultaneously, with compacting tractors.

On harvest day, the silo must be hermetically sealed, insofar as possible, using a well positioned, well protected sheet of plastic. When the silo is opened, the incoming oxygen revives the heat being generated in the grain. When removing silage, be careful not to upset the overall mass of the silo as this would bring in air and rekindle fermentation.

2. Knowing the feed value of the maize

Livestock farmers can use the analysis of a sample of maize taken from the harvest to calculate the feed value of the silage maize, and then to make adjustments as needed with feed supplements incorporated in the ration given to the animals. But laboratory data are the findings of tests run on a sample brought in by the animal farmer. The conditions for taking and storing the sample are therefore of critical importance and can mean that the findings are representative or not.

2.1 Values measured by sample analysis

- **Dry matter content of the silage (percentage of dry matter).**

Silage maize is usually harvested with whole plant dry matter at around 30 to 35%. Livestock farmers seeing higher measurements should see it as a warning of the risk of the silo heating during storage and, when opened, the risk of developing microorganisms (yeast and mould) in silage that is too dry. The risk increases when the silage has been harvested with dry matter content above 35%, particularly when shredding is inadequate, with pieces that are too long and poorly compacted.

- **Mineral content (or "ashes")**

On average, mineral matter accounts for 4% of the dry matter in silage maize. For anything over 6%, the suspicion would be that earth (e.g. dust or mud) is in the sample analysed and that there would therefore be a risk of butyric acid bacteria spreading.

- **Total nitrogenous matter or "raw" protein**

Maize has a relatively low level of total nitrogenous matter (6-7% of DM) when seen in relation to the needs of stock. And the nitrogen content is diluted as the crop yield increases (e.g. with maturity). Low nitrogen content may therefore be due to high yield! Information on the level of total nitrogenous matter in the maize being used is needed to achieve the right nitrogen balance for feed for ruminants.

- **Soluble Carbohydrates (SC)**

These are components produced directly by photosynthesis and which circulate in the plant (in the sap) and the cells. Soluble carbohydrate content varies depending on the stage when the maize is harvested and/or the handling of the samples: the average figure and the range go down in line with the percentage of dry matter. For 30% dry matter, an average of 6% of it (in a range from 0 to 15%) is soluble carbohydrate, which ensures that it will keep well. Soluble carbohydrates are needed for the silage fermentation process; when bacteria are not in contact with air, they turn into organic acids, in particular lactic acid. There are virtually no soluble carbohydrates left in the fermented fodder fed to the animals. If low levels are found in green fodder, this probably means that the sample has not been handled properly (e.g. faulty cold chain compliance or dried too slowly); it may also mean that the plant itself was too dry.

- **Starch**

Starch in its final form is carbohydrate stored in the kernel of which it is the main component. The whole plant contains 30% starch on average, but this can range from 0 to more than 40%. There is a strong correlation between starch content and the number of kernels. Starch content increases with maturity.

For nutrition, starch is completely digestible and thus makes a major contribution to the energy value of maize. For feed for dairy cows or fast-growing livestock, starch is a prime ingredient because of its high energy content, but if the starch content is too high, the stock may not be able to extract all the value from the fodder ingested (losses due to swift digestion and a risk of acidosis). High-starch maize coming from a late harvest and/or exceptional plant growth requires appropriate feed complements so that dairy cows are not fed a ration of more than 28% starch.

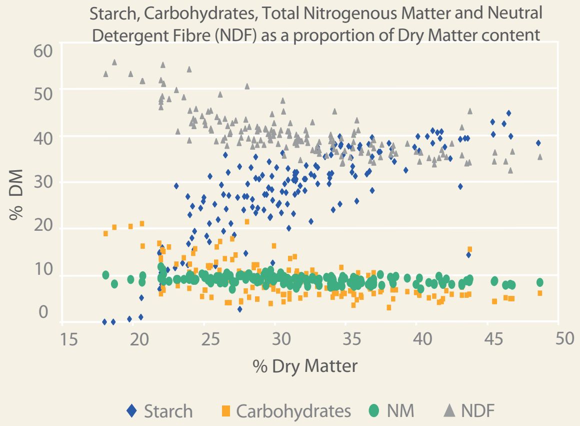
- **Fibre**

Fibre makes up the wall of the plant cells and contains a percentage of completely indigestible matter (lignin), plus potentially digestible carbohydrates (cellulose and hemicellulose); these are bound up in the components of lignin, thus making them partially indigestible.

Composition of the whole maize plant

The starch content does not indicate whole plant digestibility. **Digestibility depends on the proportion of non-digested fibre.**

Chemical composition and energy value per plant growth stage



Plant growth stage	Flowering	25 %	30 %	32 %	35 %	40 %
Approximate date	1er août		25 sept.	1er oct.	10 oct.	(*)
Chemical composition (% de la MS) Starch Soluble sugars N matter NDFs		20 >15 8,5 47	30 8-10 7,5 44	32 7-9 7 42	34 6-8 7 41	>35 <6 7 41
Energy Value						
Organic matter% FUM (/kgDM)		70 0,90	72 0,92	72 0,92	72 0,92	71 0,91
Dinag						

2.2 Using tests to calculate feed value

Silage maize is primarily used for its energy value which is high and remains stable in the silo. In relative terms, the protein, vitamin and mineral content of silage maize is not high, which is why feed supplements are added. Energy value and the nitrogen value of silage maize are calculated using data on the chemical composition. The calculation models used have been devised and improved by researchers after conducting trials on animals being raised for dairy/meat production. Each country has its methods and units for these calculations.

The expression "feed value" covers both the possibility for an animal to ingest the feed and the "nutritional" value of one kilo of dry matter, i.e. the energy, protein, mineral and vitamin content. It is therefore expressed as a number of parameters, the main ones being energy value and protein value.

Energy value expresses the energy supplied by the feed for dairy cattle (UFL – unité fourragère lait in French) or beef cattle (UFV - unité fourragère viande). Information on the energy value of fodder and the nutritional additives in the feed ration show that the energy provided covers the animals' needs. Energy value and the digestibility of fodder are closely linked, basically being the same parameter expressed as different units.

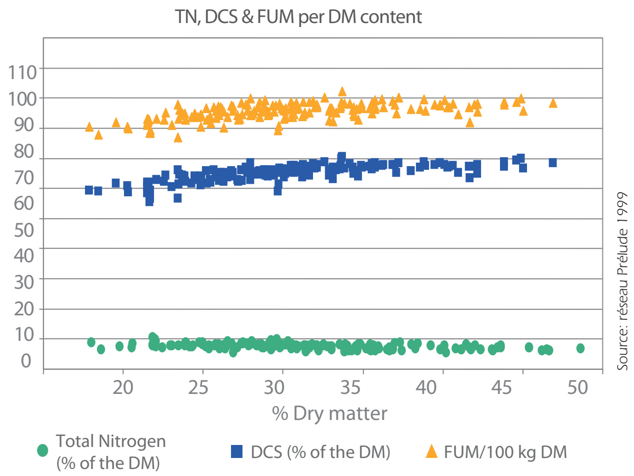
An example is the case of standard silage maize, with 30% starch and a target dairy value unit of 0.91 (ad libitum intake); it is balanced with a nitrogen supplement (approx. 3.1 kilos) and a mineral supplement, mainly calcium carbonate (300 g). The dry matter content of the maize ingested is approximately 15 kg, and this ration is sufficient to produce 22 kilos of milk with 42 grams fat content and 33 grams protein content.

The same applies to protein requirements for livestock. The protein value of fodder is calculated on the basis of the total nitrogenous matter contained in it. When mixing a ration, the goal is to cover the needs of the livestock with what is supplied in the fodder.

The rate of intake is the ad libitum consumption of fodder by an animal of standard weight and for standard production (e.g. an adult dairy cow weighing 600 kg and producing 25 kg of milk). The rate of intake depends on the fodder. Intake, i.e. the quantity ingested, depends on relevant characteristics of the animal (e.g. species, size and level of production).

The bulk value of the fodder is calculated by comparing the rate of intake to the rate for standard fodder. The bulk of average silage maize is around 1.03, i.e. in theory a cow would consume 3% less than it would standard fodder.

Chemical composition of silage maize per growth stage



High moisture maize – uses & development

A more widespread technique

Use of the technique of storing maize with high moisture content has been developing and has become more widespread in France. The technique takes grain harvested with a high moisture content, storing it either whole or ground. It has been used as pig feed ever since the 1950s, but today, with improved storage techniques, the practice has increased and is now used as feed for other animals, such as ruminants. The first reason for livestock farmers to choose the option of storing moist grain maize as silage is financial: it is concentrated feed grown and consumed on the farm, making the farmer self-sufficient and offering security to offset fluctuations in feed prices. There is the guarantee of a steady price throughout the year, in line with the price at harvest and with no additional costs for drying or handling and shipping. High-moisture maize is therefore a solution with a short, energy-efficient circuit.

High-moisture maize can be stored whole (inertised) or ground and ensiled (silage). The key features when growing high-moisture maize are primarily the harvest date and method: 34-38% kernel moisture content for high-moisture ground maize stored as silage, and 26 to 32% for whole maize stored after inerting. Quality, as is the case for whole plant silage maize, is first managed in the field when deciding on the right harvest date. It should be noted that the earlier the harvest, particularly for the ground form, the lower the risk of mycotoxins, which is an important safeguard for pig farming. The basic principle for storage is silage, i.e. lactic fermentation in anaerobic conditions.

Many technical advantages

- Direct use and value on the farm.
- Harvest date earlier than for grain maize, i.e. freeing the land earlier: harvesting and soil cultivation under the best conditions if preparing the next crop, a lower risk of harvest losses and better maintenance of good health status.
- Grain maize, either inertized or as silage, is a raw material that is easy to store because of the high levels of fermentable sugars, the relatively low levels of nitrogenous matter and the high moisture level.
- Lactic bacteria act as natural preservatives and ensure the stability of the silo.
- It is multi-purpose feed for different types of animals, and with storage options readily adaptable to any type of stock farm.
- Simple processing to produce feed.

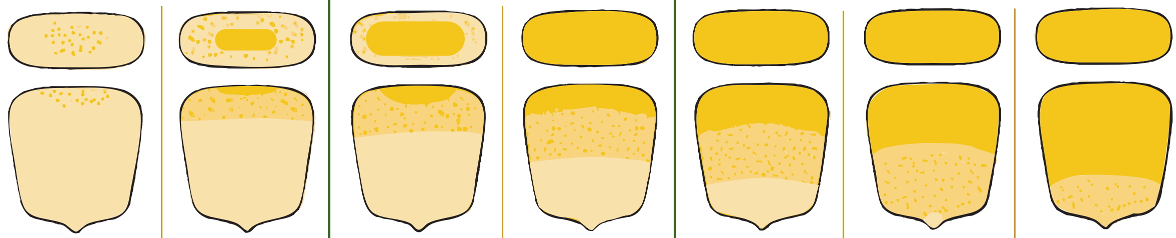
And great advantages for animal husbandry

- High-moisture grain maize has consistent feed value, making it easier to adjust daily allowances and helping meet requirements for high growth rates.
- There is the same high energy value as for grain maize, plus a better fatty acid profile as silo storage which produces a small degree of acidification, helps the livestock digest the feed, and in particular has a positive effect on phosphorus digestion.
- When maize is stored with high moisture levels, the digestibility of the energy from the high-moisture maize silage is significantly greater than for dry grain maize (88.4% and 85.2% respectively), with digestible energy values of 4,019 and 3,854 kcal per kilo of dry matter. For amino acids, the chemical profiles are similar: 9.8 ± 0.1% MS.

SILAGE MAIZE

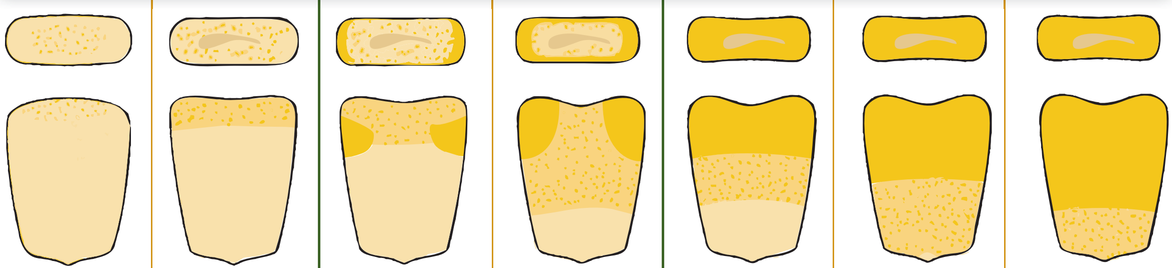
MONITORING KERNELS TO ASSESS WHOLE PLANT DRY MATTER CONTENT

FLINT-DENT



First Observations		Reference Stages		Harvest Periods		
Start filling: flowering + 250-300 GDDs	1st flinty spot on tip of kernel in central crown	Flinty spot visible on tip of most kernels	Flinty starch at tip of all kernels ; flinty starch = 15% of kernel volume	Flowering + 600-650 GDDs, 3 starches in 3 thirds of kernel	Kernel 50% flint, milky at tip	Grain 2/3 flint, no milky starch at tip
STEADY WATER SUPPLY – LARGE SIZE, GREEN LEAVES						
< 22 % DM	**23-24 % DM**	**25-26 % DM**	**27-29 % DM**	**31-32 % DM**	**33-34 % DM**	**35-37 % DM**
	Possible to forecast harvest date	Possible to forecast harvest date	If necessary, harvest may start at 29% DM (not recommended)	Start of optimal harvest period	Optimal harvest period	Past optimal harvest period
LIMITED WATER SUPPLY – MEDIUM SIZE, ± DRY LEAVES						
< 23 % DM	**26-27 % DM**	**28-29 % DM**	**31-32 % DM**	**33-34 % DM**	**36-37 % DM**	**> 39 % DM**
	Possible to forecast harvest date	Harvest may start at 29% DM, if necessary	Start of optimal harvest period	Optimal harvest period	Past optimal harvest period, stalk & leaves drying	Harvest too late

DENT



First Observations		Reference Stages		Harvest Periods		
Rounded kernel	Initial indentation of tip	. Flinty ring . Dented kernel	Flinty tip	The 3 starches in 3 thirds	Kernel 50% flint	Kernel 2/3 flint
20 % DM	**25-26 % DM**	**26-27 % DM**	**29 % DM**	**32-33 % DM**	**35 % DM**	**38 % DM**

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