Maize *(Zea mays L.)*

USA: Corn; French: Mais; Spanish: Maiz; Italian: Mais; German: Mais

Crop data

Annual. Harvested part: grain, used for human and livestock consumption. Lesser amounts are grown for harvest of the entire above-ground plants at physiological maturity to be made into silage for animal feed. In some areas, after the grain has been harvested the remainder is cut and used for animal feed. Yellow dent is primarily used for livestock feed, white dent is used primarily for production of meal and cereals for human consumption. Other dent lines have been bred for special purposes: e.g. waxy maize for production of amylopectin starch, high lysine maize for use in pig feed, high oil maize for production of vegetable oil for human consumption. Flint corns are grown in Central and South America, Asia and Southern Europe. Sweet corn was developed to be harvested in an immature stage for human consumption. Popcorn is used primarily for human consumption as freshly popped or other snack food items.

Adapted to a wide range of climates, the crop is mostly grown between latitudes 30° and 55°, principally in latitudes below 47°. In most areas it is sown in early spring but, due to its wide adaptation, it flowers at different times depending on the cultivar selected. Developed to take advantage of the length of growing season available, some will mature as soon as 60 days after emergence while others require over 40 weeks.

Plant densities vary considerably around the world, depending on cultivar and climate. In the more arid areas, densities as low as 15 000/ha can be found and 25 000/ha are common, but in humid or irrigated areas populations in excess of 75 000/ha give optimum production.

Spacing between rows ranges from 50 cm to 100 cm.

The crop will do well on any soil with adequate drainage to allow for the maintenance of sufficient oxygen for good root growth and activity, and enough water-holding capacity to provide adequate moisture throughout the growing season. Preferred pH 6.0-7.2. The amount of associated evapotranspiration varies with plant density, crop age, available soil water, atmospheric conditions, etc., from an estimated 0.20-0.25 cm/day for young plants to 0.48 cm/day for plants in the reproductive phase (Shaw 1977).

It is a warm weather crop, doing best when temperatures in the warm months range from 21° to 27° C. It does not do well when the mean summer temperature is below 19° C.

Nutrient removal - Macronutrients and Cl

Yield t/ha	Source	Part	kg/ha						
			N	**P_2O_5**	**K_2O**	**MgO**	**CaO**	**S**	**Cl**
9.5	Barber & Olson, 1968	Grain	129	71	47	18	2.1	12	4.5
		Stover	62	18	188	55	55	9	76.0
6.3	Aldrich et al, 1986	Grain	100	40	29	9.3	1.5	7.8	-
		Stover	63	23	92	28	15	9	-

Nutrient removal - Micronutrients								
Yield t/ha	Source	Part	g/ha					
			Fe	**Mn**	**Cu**	**Zn**	**B**	**Mo**
9.5	Barber & Olson, 1968	Grain	110	60	20	190	50	6
		Stover	2020	280	90	190	140	3
6.3	Aldrich et al, 1986	Grain	-	70	40	110	-	-
		Stover	-	940	30	200	-	-

Plant nutrient requirements of maize (yielding 11.8 t/ha) during the growing season			
Plant age (days)	Nutrients absorbed (kg/ha/day)		
	N	**P2O5**	**K2O**
20-30	1.7	0.39	1.7
30-40	6.7	1.55	9.95
40-50	8.3	2.32	11.56
50-60	5.3	2.06	4.42
Source: Spies, 1973			

Plant analytical data

Critical plant nutrient levels in leaf opposite and below the ear at tasseling										
% of dry matter						ppm dry matter				
N	**P**	**K**	**Mg**	**Ca**	**S**	**Zn**	**Fe**	**Mn**	**Cu**	**B**
2.9	0.25	1.9	0.15	0.4	0.15	15	25	15	5	10
Source: Hoeft & Peck, 1991										

Published critical values found in various maize plant tissues - Macronutrients							
Plant part	Stage of growth	Source	% of dry matter				
			N	**P**	**K**	**Mg**	**Ca**
Ear leaf	Tasseling	Melsted et al, 1969	3.0	0.25	1.9	0.25	0.4
Ear leaf	Silking	Hanway et al, 1962			2.0		
6th leaf fom base	Silking	Tyner, 1946	2.9	0.3	1.3		
Leaves	Tasseling	Gallo et al, 1968	2.9	0.23	1.7-2.7		
Lower stems	Late summer	Goodall & Gregory, 1947		0.004	0.08		
Source: Jones & Eck, 1973							

Published critical values found in various maize plant tissues- Micronutrients								
Plant part	Stage of growth	Source	ppm dry matter					
			Fe	**Mn**	**Zn**	**Cu**	**B**	**Mo**
Ear leaf	Tasseling	Melsted et al, 1969	15	15	15	5	10	
Ear leaf	Tasseling	de L. Beyers & Coetzer, 1969			15			
Upper leaves	Not given	Berger et al, 1969					12	
Stems	Not given	Dios & Broyer, 1965						0.11
Source: Jones & Eck, 1973								

Fertilizer recommendations

Each of the following factors must be carefully integrated when determining the optimum rate for a particular field or part of a field:

- Inherent soil fertility.
Best determined by carefully calibrated and correlated soil test procedures for the particular soil type.

For N, soil sampling and analysis must be done annually, but even then the soil tests may not be reliable under high rainfall conditions, especially with sandy or very poorly drained soils. For relatively immobile nutrients like P, K and Mg, most research has shown that soil analysis conducted on samples collected every 3-4 years will be adequate. For micronutrients, the available soil test procedures have not been shown to be highly reliable and it is suggested that plant analysis should be used in conjunction with soil tests; deficiencies of many of the micronutrients are limited to soils with pH > 7.3.

- Yield potential.
Previous 5-year average yield plus 5 % is suggested as a basis for estimation, but, if fertilizer is applied post-emergence, adjustment may be made for delay in planting or inadequate stand.

- Previous crop.
Research has shown that maize will produce better when grown in rotation with another crop, especially a legume, probably as a result of diminished incidence of pests and diseases, reduction of the negative effect of continuous maize cropping, and a contribution of N from the legume. While much of the disadvantage of growing maize after maize can be overcome by applying N fertilizer, it is not possible to apply enough N to eliminate completely the yield difference between rotational and continuous maize.

- Soil reaction.
Maximum microbial activity for the release of essential nutrients from organic materials occurs at pH 6.0-7.0 and maximum availability of fertilizer nutrients is maintained. In most areas of the world, agricultural limestone is available to correct acid soils but economic means are often lacking for reducing the pH of alkaline soils.

- Timing.
Uptake of over half the N and P and 80 % of the K is accomplished before the crop reaches the reproductive stage. It is therefore imperative that an adequate supply of these major nutrients be available to the plants early and remain available throughout the growing season. Even though only small amounts are taken up early in the season, high

concentrations should be available in the root zone as the root system is small at that time and the soil is often cold.

N must be applied annually. Since it is subject to loss by leaching or denitrification, it is best applied near the time of crop need. On finer textured soils, silt loam or heavier, it is best applied as a pre-plant or side dressing; on coarse textured soils where leaching can be a problem, N is best applied as a side dressing or split application. If the crop is irrigated, 50-60 % pre-plant plus the rest through the irrigation system is an effective technique.

There is much greater flexibility in the time of application of P and K since they are relatively immobile. On many soils they may be broadcast either in the fall or spring with similar results, except on sandy soils where there is a possibility that the K might be leached out of the rooting zone (K should then be applied just before planting).

- Method of application.

On fields where the soil fertility status is at or above the desired level, there is little evidence to show any significant difference in yield associated with different methods of application. In contrast, on soils with a low nutrient status or a high P-fixing capacity, placement of the fertilizer within a concentrated band has been shown to result in higher yields, particularly at low rates of application. On higher-testing soils, although yield differences are unlikely, plant recovery of fertilizer nutrients in the year of application will usually be greater from a band placed 5 cm to the side and 5 cm below the seed than when broadcast.

Placement of fertilizer directly with the seed is sometimes referred to as "pop-up", but this is a misnomer as the crop does not emerge any sooner and may indeed emerge 1-2 days later than without such application. If used, pop-up fertilizer should contain all three major nutrients in the proportions $N:P_2O_5:K_2O=1:4:2$. Under normal moisture conditions, the maximum safe amount of $N + K_2O$ for placement directly with the seed is 12-15 kg/ha in 100 cm rows and correspondingly more in closer rows. In excessively dry springs, even these low rates may result in reduced germination and/or damage to seedlings.

Forms of fertilizer

N: a mixture of ammonium and nitrate forms seems to be preferred, though all commonly available forms will perform well if properly applied. Within the USA Corn Belt, anhydrous ammonia is the most frequently used material; this must be injected to a depth of 15-20 cm to provide an adequate seal to prevent volatilization. Both urea and urea-AN solutions are excellent but, since the urea contained in these materials will quickly convert to ammonia, they should be incorporated in the soil within 3 days of application to prevent loss by volatilization. Although ammonium nitrate in solid form is also a satisfactory N source for maize, there is a potential for loss by leaching or denitrification if too much rain falls soon after application.

P: soluble sources including triple superphosphate or ammoniated phosphates perform well. Rock phosphate is not particularly effective since the crop grows best at $pH > 5.7$.

K: potassium chloride is the most economic source unless the soil is deficient in sulphur, in which case potassium sulphate can be used to provide both K and S.

S: precipitation carries with it not only the water essential for plant growth but also in many areas of the world a significant concentration of sulphur; values reported in the literature vary from 2 to 220 kg/ha S annually (the larger values in urban or industrial areas). Since a high-yielding maize crop removes less than 15 kg/ha, S in precipitation is often enough to meet crop need.

Micronutrients: while problems are not widespread, the most common are with Zn, Fe and Mn. These are most likely to be deficient where the pH is high; in that case, use of a chelate in a starter band or as foliar spray is the most effective treatment. Where Zn deficiency occurs on neutral to acid soils, an inorganic source such as zinc sulphate is an effective corrective.

Agricultural and industrial wastes: the value of those which are effective sources of nutrients for maize will depend on time and method of application. By-products containing free ammonia or compounds that will convert to ammonia must be incorporated into the soil soon after application to obtain maximum benefit. Since most of the nutrients will be in organic form, the amounts of the individual nutrients that will be available for the particular crop should be estimated from available data on their relative release rates. With industrial by-products, care must be taken to avoid applying excessive amounts of toxic metals.

Present fertilizer recommendations/practices

USA

N: recommendations throughout the eastern part of the Corn Belt and NE and SE USA are based on yield potential (t/ha) times 18 to 21 minus corrections for previous crop or application of organic manure. For maize after soybeans the correction is 45 kg/ha N and for maize after lucerne (alfalfa) approx. 100 kg/ha N. Procedures are being developed in the NE to modify the N recommendation according to the nitrate N concentration in the top 30 cm of soil collected at the 6th leaf stage of maize. Recommendations in the western part of the Corn Belt are based on soil nitrate levels to a depth of 60-120 cm.

P and K: recommendations are based on soil tests. If the test level is below that desired, enough is recommended to bring it up to the desired level and replace expected removal. If it is at the desired level, replacement is suggested at 7.7 kg P2O5 and 5.0 kg K2O per ton of expected yield. If the test level is above a level at which response is no longer expected, then no P or K is recommended until the field is retested 4 years later. In the eastern part of the region many producers have increased P levels in their soils to the point where additional P is not routinely needed. Soils in the western part of the region are inherently high in K, so fertilizer K is seldom recommended.

- Average fertilizer consumption on maize in the Corn Belt is, in the eastern part, 170 kg/ha N, 84 kg/ha P2O5, 78 kg/ha K2O, and in the western part 145 kg/ha N, 54 kg/ha P2O5, 56 kg/ha K2O. Farmers in NE USA use about 5-10 % less commercial fertilizer than those in the eastern part of the Corn Belt, because they have a lower yield potential and, being in a grain-deficient area which imports grain for livestock, they have more livestock waste available per unit of land area. Producers in SE USA, despite their somewhat lower yield potential, use about the same or slightly higher rates of commercial fertilizer than in the Corn Belt because their soils are more highly weathered and thus have less inherent fertility.

- About 47 % of total N supplied is in the form of anhydrous ammonia, 27 % as urea-AN solutions and urea 20 %. Well over 80 % of the total P is applied as an ammoniated material and virtually all the K is in the form of muriate.

- Where fall tillage is practised, P and K are broadcast before tillage; where tillage is in spring, fertilizer application is usually in late winter or early spring. In many areas, particularly where maize is sown in cool soil or where inherent fertility is low, some of the P and K is applied at sowing as a band application below and to the side of the seed. N is applied pre-plant in spring to a very high proportion of the area but is applied post-emergence where loss potential is high. Under irrigation, producers often apply 60 % of N pre-plant and the remainder in successive applications of 20-25 kg/ha N through the irrigation system, so that all the N will have been applied by 2 weeks after pollination.

France

N: Rate of application (X) is determined as a function of predicted yield (Y) and the availability of N from the soil (FS), all as kg/ha, according to the equation:

$X = 0.23\ Y - FS.$

In southern France the rate of application is set at 0.18 times the expected yield; in other regions the rate, when FS is not known, should not exceed 0.2 Y. The rate recommended for fields which regularly receive organic manure, as in the west and northeast parts of the country, is 50 kg/ha N. In Lorraine and Poitou-Charentes the recommended rate depends on soil type, previous crop and previous N content of the soil.

In southern France, one third of the N is applied at sowing and the rest at the 6-8 leaves stage. In the north, N is usually applied pre-plant.

P and K: Recommendations are based on soil test results. When these are not available, 100 kg/ha of each is usually adequate for high yield.

Both P and K are usually applied before sowing. In some areas, 100 kg/ha 18-46-0 starter is applied at sowing.

Zn and Cu: Applied before sowing to deficient soils at 10 kg/ha Zn and/or 6 kg/ha Cu.

Brazil

N: 50-90 kg/ha, mostly post-emergence.

P: 50-80 kg/ha P_2O_5, all at sowing.

K: 30-60 kg/ha K_2O, all at sowing.

Preferred forms of primary nutrients: urea, ammoniated phosphates, potassium chloride.

S: 20 kg/ha S.

Zn: 5 kg/ha Zn.

S.E.Asia

Nutrient rates vary substantially between and within countries (see table). The higher rates are for hybrids and the lower for local varieties. Urea, ammoniated phosphates and potassium chloride are the preferred forms.

Country	kg/ha					
	Hybrids			**Local varieties**		
	N	P_2O_5	K_2O	N	P_2O_5	K
Indonesia	120-180	45-60	30-60	45-90	30-45	0-30
Philippines	90-140	45-60	0-60	45-90	30	0
Thailand	45-120	45-60	0-60	30-45	30	0-30

India

N: 100-125 kg/ha N as urea, split into three applications.

P: 60 kg/ha P2O5, as processed phosphates applied mostly at sowing.

K: 30 kg/ha K2O, as potassium chloride applied mostly at sowing.

South Africa

N: Rates are calculated according to yield potential. 170 kg/ha, 45 kg/ha and 20 kg/ha N are recommended for yield levels of 8 t/ha, 3 t/ha and 2 t/ha respectively. N is applied within 8 weeks after planting, depending on rainfall distribution.

P: Rates are based on soil analysis (Bray 1, Bray 2, or Ambic 1) and yield potential (up to 300 kg/ha, 100 kg/ha or 45 kg/ha P2O5 for yields of 8 t/ha, 3t/ha or 2 t/ha respectively). At least a minimum of fresh P is applied each year (cold springs, P-fixing soils).

K: Rates are based on soil analysis (NH4OAc, Ambic 1), sub-soil K and clay content of the soil (up to 120 kg/ha, 45 kg/ha or 30 kg/ha for yields of 8 t/ha, 3 t/ha and 2 t/ha respectively).

Liming: Exchangeable acidity is reduced by liming to approx. 10 %.

Micronutrients: To prevent zinc deficiency, Zn-containing fertilizer mixtures are used on soils with < 1.5-2 ppm Zn. Because of acidic soils boron and molybdenum deficiency are common. Seed is usually treated with Mo; B-containing fertilizers or B-foliar sprays are used.

Further reading

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