Wheat *(Triticum aestivum L., T. durum Desf.)*

French: Blé; Spanish: Trigo; Italian: Frumento; German: Weizen

Wheat is the world's most important cereal crop in terms of both area cultivated (232 million ha) and amount of grain produced (595 million t). It is widely grown throughout the temperate zones (in Northern Europe up to 60 °N) and in some tropical/sub-tropical areas at higher elevations. The major centres are: Europe (131 milion t grain, 27 million ha), the former USSR (108 million t grain, 48 million ha), North America (106 million t grain, 42 million ha), China (96 milion t grain, 30 million ha) and India (50 million t grain, 23 million ha). All these figures relate to 1990.

The following information is mainly for T. aestivum, though also generally valid for T. durum. Special data for durum wheat are given as an appendix to this end of chapter .

Crop data

Annual, autumn-sown (winter wheat) and spring sown types.

Harvested products: grain, straw, (occasionally) whole green plant.

Desired characteristics affecting fertilizer requirement:

In grain for milling for bread and pasta: high endosperm-protein: In grain for malting and brewing: high starch, low crude protein, absence of sprouting. For animal feed: high protein, especially lysine. For industrial starch: high starch concentration with slow starch ripening, high endosperm-protein. For alcohol production: high starch content, low crude protein.

Straw for litter and bedding: should be dry and absorbent. Straw for cellulose and for pasteboard: high starch, low lignin, low ash. Straw for constructional insulation: should be dry and of low bulk density.

Whole plant for green fodder: high protein, high energy. Whole plant for silage: high concentration of easily soluble carbohydrates

The quality of the protein in the grain depends largely on the variety. The protein/starch ratio in the grain depends both on the variety and on the way in which the crop has matured.

Preferred soils and soil conditions: Wheat (like barley) generally prefers the more fertile soils, but it can be grown on practically all types except very light sandy soils or peat soils, so long as the water requirement can be met and the nutrient demand is met by appropriate use of fertilizers.

Sowing times: winter wheat should be sown soon enough for there to be at least two leaves before the onset of the vegetative rest period. The available growth time for tillering should be ast least 21 days. Provided the ground is passable, spring wheat should be sown as soon as temperature and soil moisture permit.

Planting density: sowing rates are usually within the range of 140 - 380 grains/m2 for winter wheat (see the sample calculation page #) and 200 - 350 grains/m2 for spring wheat sown at respective row spacings of 13 - 20 cm for winter wheat or 12 -18 cm for spring wheat. But ideally the planned plant density should be based on the expected plant available precipitation, optimum ear density and number of ears per plant for the variety in question (see table below) and the intended grain yield per hectare, adjusted for the expected percentage emergence and, for winter wheat, the expected percentage winter survival.

Limits of climatic values within the development of wheat								
Development stage	**Eucarpia Scale**	**Duration dayts**		**Temperature (°C)**			**Day-length (h/d)**	**Minimum water demand (mm)**
		Winter	**Spring**	**min.**	**opt.**	**max.**		
Sowing and germination	0.1-0.9	7	7	2-4	15-25	30-32		35-40
Emergence and early growth	1.0-1.9	28	12					
Tillering, initiation of ear primordia	2.0-2.9	35*	35		6-9			
Beginning of stem elongation, forming of ear primordia	3.0-3.9	25	19		<17		>13**	72
Flag leaf, floret reduction, booting	4.0-3.9	16	10					
Ear emergence	5.0-5.9	6	5		<19.5			14
Flowering and grain initiation	6.0-6.9	11	14		20-25			22
Formation of grains	7.0-7.9	20	20		20			
Maturing	8.0-9.2	21	21					
Total growth period (sum)		169*	143*	1 900-2 500***				
*) To be added: duration of vegetative rest period, depending on location, e.g. for Northern Europe 100 days for winter wheat or 29 days for spring wheat sown late January/early February **) Some varieties < 13 h/d ***) Sum of daily temperatures above 0 °C (temperatures below 0 °C deducted)								
Source: Aigner et al., 1988, changed and supplemented								

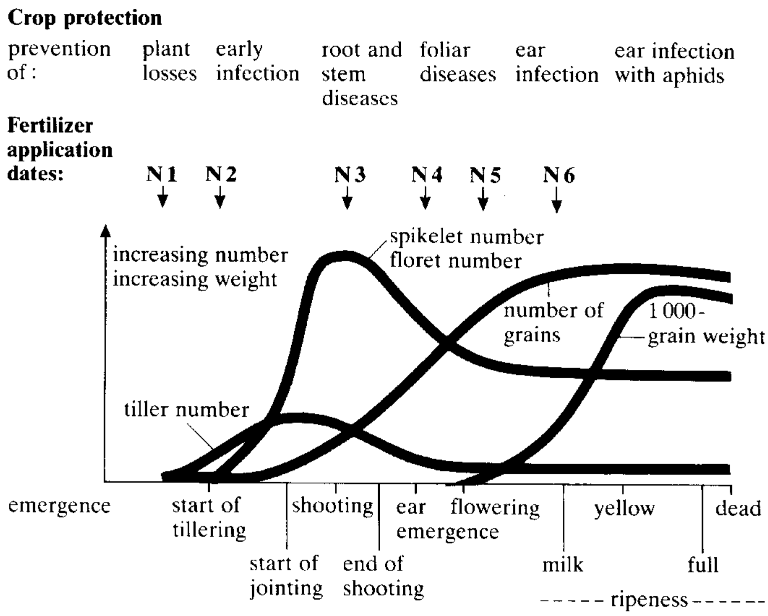
Yield structure of wheat as function of plant available precipitation*							
	Plant available precipitation (mm)						
	150	**250**	**350**	**450**	**550**	**650**	**750**
Grain yield	15	25	52	82	100 = 6.7 t/ha	116	127
Ear density	37	56	74	89	100 = 540/m2	111	120
Single ear weight	40	46	71	92	100 = 1.24 g	105	105
Relative to 550 mm available precipitation; Plant available precipitation = amount solely available for crop growth, i.e. excluding evaporation, runoff, drainage and other losses.							

For example, in a location with a plant-available precipitation of 550 mm and a target yield of 6.7 t/ha, the preferred plant density for a variety with an optimum ear density of 540 ears/m2 and an optimum of around 2.0 - 2.25 ears per plant would theoretically be in the range 215 to 270 plants/m2, say 240 plants/m2 (to reach the desired 540 ears/m2); but, to allow for an emergence rate of 95 % and an expected winter survival rate of 90 %, the actual sowing rate would need to be increased to 280 grains capable of germinating/m2 (i.e. 240 / 0.95 / 0.9). Similarly, with a plant-available precipitation of only 250 mm and an expected yield of 1.68 t/ha(= 25 % of 6.7), the preferred ear density would be 302 (= 56 % of 540) ears/m2, equivalent (with 2.1 ears/plant) to 144 plants/m2, and,with the same adjustments for percentage emergence and winter survival, to an actual sowing rate of 164/m2.

Where a crop is to be undersown, the intended plant density should be reduced by 10 - 15 % to protect the undersown plants.

The pattern of growth is illustrated in the next figure:

Pattern of yield formation of cereals



This model is valid only with the full plant protection programme and the indicated split dressings of N-fertilizer.

Source: Adapted from Aufhammer, 1976

Nutrient demand/uptake/removal

The amount and precise pattern of nutrient uptake will vary considerably with weather conditions. The figures given in the following table are indicative of uptake by a crop grown with 550 mm plant-available precipitation and yielding 6.7 t/ha of grain, as in the example quoted earlier.

Relative nutrient uptake in relation to plant development								
Growth stage	Winter wheat			Biomass * (dry)	Spring wheat			Biomass * (dry)
	N	**P2O5**	**K2O**		**N**	**P2O5**	**K2O**	
	Relative nutrient uptake as percentage of maximum							
Early growth	13	0	0	1	8	3	6	1
Tillering	24	9	10	4	25	17	36	2
Jointing	38	27	22	16	49	47	72	9
Booting	68	45	38	31	71	64	95	20
Ear emergence	84	75	90	58	97	100	100	36
Flowering	100	91	100	80	100	93	82	51
Grain formation	100	100	89	100	100	90	72	78
Physiological maturity -biomass* -grain	 95 70	 90 71	 77 20	 100 49	 100 78	 86 86	 68 20	 100 50
	Maximum uptake (kg/ha) of each nutrient and maximum amounts (t/ha) of biomass* and grain							
Whole plant	187	55	252	13.7	129	58	125	9.0
Grain only	130	39	51	6.7	100	50	25	4.5
Whole above-ground portion of plant								
Source: Adapted from Aigner et al., 1988								

In general, for both winter and spring types, 60 % of the expected maximum total nutrient uptake (N + P2O5 + K2O) occurs by the middle or end of shooting.

Nutrient uptake/removal - Macronutrients				
Variety	Yield t/ha	kg/ha		
		N	**P2O5**	**K2O**
Winter wheat	Biomass (DM): 13.7 Grains: 6.7	 187 130	 55 39	 252 51
Spring wheat	Biomass (DM): 9.0 Grains: 4.5	 129 100	 58 50	 125 25
* Whole above-ground part of plant				
Source: Adapted from Aigner et al., 1988				

Plant analysis data

Tentative, preliminary values:

Plant analysis data - Macronutrients (beginning of stem elongation: Eucarpia Scale 3.0; whole above-ground plant)					
Soil classification (P2O5 and K2O)	% of dry matter				
	N	**P**	**K**	**Mg**	**Ca**
Class A - very low	2.0-2.9	0.20-0.29	2.00-2.99	0.07-0.09	0.20-0.29
Class B - low	3.0-3.4	0.30-0.39	3.00-3.99	0.10-0.13	0.30-0.39
Class C - medium or normal	3.5	0.40	4.00	0.14	0.40
Source: Aigner et al., 1988					

Plant analysis data - Micronutrients (beginning of stem elongation: Eucarpia Scale 3.0; whole above-ground plant)						
Soil classification (P2O5 and K2O)	ppm dry matter					
	Fe	Mn	Zn	Cu	B	Mo
Class A - very low	20-29	20-29	15-22	3.0-3.9	3.0-4.4	0.15-0.22
Class B - low	40-59	40-59	30-49	6.0-7.9	6.0-9.9	0.30-0.49
Class C - medium or normal	40-59	40-59	30-49	6.0-7.9	6.0-9.9	0.30-0.49
Source: Aigner et al., 1988						

Tissue analysis has been repeatedly tested as a means of evaluating nutrient demand by cereal crops but generally without success, on account of large differences in the development of individual plants and tillers. For this reason it has not been widely introduced in practice. Although tissue analysis for micronutrient deficiencies has received greater attention than that for the macronutrients, reliable results can only be obtained with extreme care during sample preparation.

Soil analysis

It is possible to calculate fertilizer rates from soil analysis data, but the available informaton is usually too inexact for intensive wheat growing. Moreover, the availability of soil nutrients changes with weather dynamics, and cereals themselves vary in their ability to mobilize and take up nutrients from a soil. Data from generalized soil extraction models should therefore be used with caution. In many countries where fertilizer recommendations are based on the results of soil tests, they are generally grouped according to ranges of nutrient levels in the soil (mainly for P, K, Ca and micronutrients) rather than specific values. ***For further information*** *on soil testing procedure and interpretation, please consult on the IFA Web site in the " Publications " section, " Fertilizer and Their Efficient Use, the chapter : Diagnosis by soil testing ".*

Fertilizer recommendations

General

Cereal growth is mainly influenced by temperature and precipitation. If these fall outside the desirable limits, the resultant adverse effect cannot in general be compensated by use of fertilizers (particularly if spikelet primordia are reduced as a result of excessive temperatures at the shooting stage). However, if only isolated plants are affected - as with moderate winter kill - the adjacent plants can still be stimulated by the supply of nutrients to form more tillers, thus minimizing the overall effect, except that maturing of the plants may be uneven.

Since, in intensive cereal production systems, the plant population is managed near to the risk of lodging, any mineral fertilizer applied must be distributed as evenly as possible, at the correct date, and the amount (particularly of N) must be carefully adjusted to take account of soil reserves and crop demand. Excessive N application may also increase liability to plant disease through causing too dense a plant population.

Unproductive tillering and secondary shoot formation should be avoided by restricting nutrient supply (especially of N) during early growth (stages N1 and N3 in the figure " Pattern of yield formation of cerelas ". Similarly, increasing the protein content of the grain can be achieved by increasing N supply at the appropriate period, in this instance at grain initiation and grain formation (stages N5 and especially N6). There is, however, a danger that too much N at this time can disturb the uniformity of the maturing process by delaying ripening, with the result that only the precursors of the proteins associated with the variety concerned are formed, thus lowering the quality of the protein in the grain. It is important to choose a variety which is appropriate to the intended yield and the expected weather conditions.

If there is a danger of applied nutrients becoming immobilized, especially P in alkaline or acid soils, corrective measures should be taken before application, e.g. by selection of acidifying fertilizers, or by liming, or, in arid regions, by flooding.

Because frost hardiness and resistance to drought are determined by the hydration of plant tissues, sufficient K should always be available.

Preferred nutrient forms

N - the efficiency of different types of N fertilizers in cereals is nearly identical. Differences are mainly the result of environmental influences (precipitation, temperature, denitrification). Normally they will contain nitrate and ammonium N, as ammonium nitrate, calcium ammonium nitrate, ammonium sulphate nitrate or urea-ammonium nitrate solution (UAN). Ammonia generally improves baking quality. If N fertilizers containing a nitrification inhibitor are used, they have the same effect as a depot application or concentrated band placement (see also 'Fertilizer application techniques').

P - the supply depends mainly on the availability of P in the soil. Therefore, the soil solution should be supplied with sufficient P. Especially in spring at the start of the growing period fertilizers containing water-soluble P2O5 are preferred, which can be applied advantageously together with K2O and the first N-application in form of an NPK compound fertilizer.

N-P - fertilizers containing N and P especially accelerate early growth of young plants, particularly when applied as band treatment below the seed ("starter application"). They are normally more effective than the corresponding single nutrient fertilizers. However, in contrast to nitrophosphates, diammonium phosphate or urea phosphate may injure the seedlings, especially on calcareous, dry soils, if applied at rates greater than 11 kg/ha N.

K - potassium chloride

S - on sulphur deficient crops S containing fertilizers may be used.

Mg - potassic fertilizers containing Mg. Critical Mg deficiency may also be treated by foliar application of magnesium sulphate (if necessary in combination with micronutrients, e.g. manganese).

Micronutrients - deficiencies may occur on hot, dry sites from the late shooting stage to flowering and may be treated by foliar sprays (see table at the end of chapter) (table 9).

Rates of fertilizer application

In intensive agriculture, the fertilizer application rates should primarily be based on the nutrient balance for the whole crop rotation, supported by soil analysis data and including a forecast of nutrient removal by the crop for which the fertilizer need is to be calculated.

Balance sheet for nutrients of a crop rotation: Maize - Winter Wheat - Winter Barley (example taken from practical farming)			
	Removal or supply of nutrients (kg/ha)		
	N	**P2O5**	**K2O**
1989 Crop: Wheat			
Crop residues from last year (none)	-	-	-
Legumes as previous main crop	-	-	-
Legumes as green manure	-	-	-
Farm yard manure, liquid manure	-	-	-
Fertilizer applied to crop	+180.0	+100.0	-
Yield (grains) = 5.8 t/ha*	-128.0	- 53.8	- 35.8
Straw (straw:grain = 1:0.9)	- 28.2	- 14.1	- 70.4
Losses	-	-	-
Balance 1	+ 23.8	+ 32.1	-106.2
1990 Crop: Barley			
Crop residues from last year (wheat straw 6.4 t/ha)	+ 28.2	+ 14.1	+ 70.4
Legumes as previous main crop	-	-	-
Legumes as green manure	-	-	-
Farm yard manure, liquid manure	+ 60.0	+ 30.0	+ 90.0
Fertilizer applied to crop	+180.0	-	-
Yield (grains) = 6.0 t/ha**	-120.0	- 48.0	- 24.0
Straw (straw:grain = 1:0.9)	- 33.0	- 13.9	- 79.2
Losses	-	-	-
Balance 2	+115.2***	-17.8	+ 57.2
1991 Crop: Maize			
Crop residues from last year (barley straw 6.6 t/ha)	+ 33.0	+ 13.9	+ 79.2
Legumes as previous main crop	-	-	-
Legumes as green manure	-	-	-
45 t/ha slurry from dairy cattle	+120.0	+ 90.0	+270.0
Fertilizer applied to crop	-	-	-
Yield (grains) = 8.0 t/ha	-144.0	- 51.2	- 27.2
Straw (straw:grain = 1:0.63)	- 96.0	- 70.4	-307.2
Losses	-	-	-
Balance 3	- 87.0	- 17.7	+ 14.8
Nutrient demand wheat 1992			
Grains (8.0 t/ha)	-160.0	- 67.2	- 44.8
Straw (7.2 t/ha)	- 29.0	- 14.0	- 72.0
Total nutrient demand in 1992	-189.0	- 81.2	-116.8
Difference between demand and supply (balance) from the rotation:	-137.0	- 84.6	-151.0
Nutrient amount needed for wheat in 1992 (approx.):	135 kg/ha N	85 kg/ha P2O5	150 kg/ha K2O
Unknown and unevitable losses or immissions of nutrients are not accounted for, assuming that they more or less balance each other. * When calculating the fertilizer rate, yield expectation was 9.0 t/ha ** When calculating the fertilizer rate, yield expectation was 10 t/ha *** Large N surplus due to the large difference between expected and obtained yield; a catch-crop should be introduced to prevent N losses			
Source: Aigner et al., 1988 and diverse others			

Should this nutrient balance sheet indicate a continuing substantial deficit of any particular nutrient, it is necessary to check whether the total nutrient reserves present in the soil are sufficient to sustain such a deficit and, if not, to investigate whether the production technique being used may result in too great a depletion of humus.

A large positive surplus in the balance sheet may be the result of overgenerous forecasting of crop yields. If not, then the calculation should be re-checked. A moderate surplus, on the other hand, may be regarded as a nutrient reserve (depending on soil conditions) for the next

2 - 4 years. In the example of the maize - winter wheat - winter barley rotation considered in the foregoing table, for example, a system of P "storage application" to build up a surplus of P in the balance sheet might be used on wheat to improve the grain quality. "Storage application" of K could similarly be used on winter barley in order to improve winter hardiness and lodging resistance. Sound agricultural practices have to be used within the crop rotation to avoid built-up or depletion of soil nutrients.

Fertilizer application rates for nutrients other than nitrogen

The precise amounts and timing of P and K fertilizers are not particularly important for wheat, as the crop yield does not respond significantly to PK dresings if the soil is already moderately or well supplied with these nutrients. The respective criteria to be followed are, firstly, a balanced nutrient cycle and, secondly, the date at which application is possible.

Thus, in practice, P and K are not applied to wheat so much for the wheat itself as for the requirements of the rotation as a whole (see also: 'Timing of fertilizer application').

If growth at any stage is limited by a specific factor such as nutrient supply, water, light or temperature, then the grain yield is limited irrecoverably unless it can be compensated by modifying a yield component occuring at a later stage of development. For instance, if the number of tillers per unit area is reduced by a deficiency in nutrient supply in the early stages, then the resultant reduction in ear density can, in theory, be compensated by improving the nutrient supply in time to promote spikelet initiation and to diminish the reduction in florets. The difficulty in practice lies in estimating the true supply of nutrient from the soil and in making due allowance for any delay in availability of fertilizer nutrient in unfavourable weather conditions, as well as for location-specific variations from one part of a field to another.

Nitrogen rates

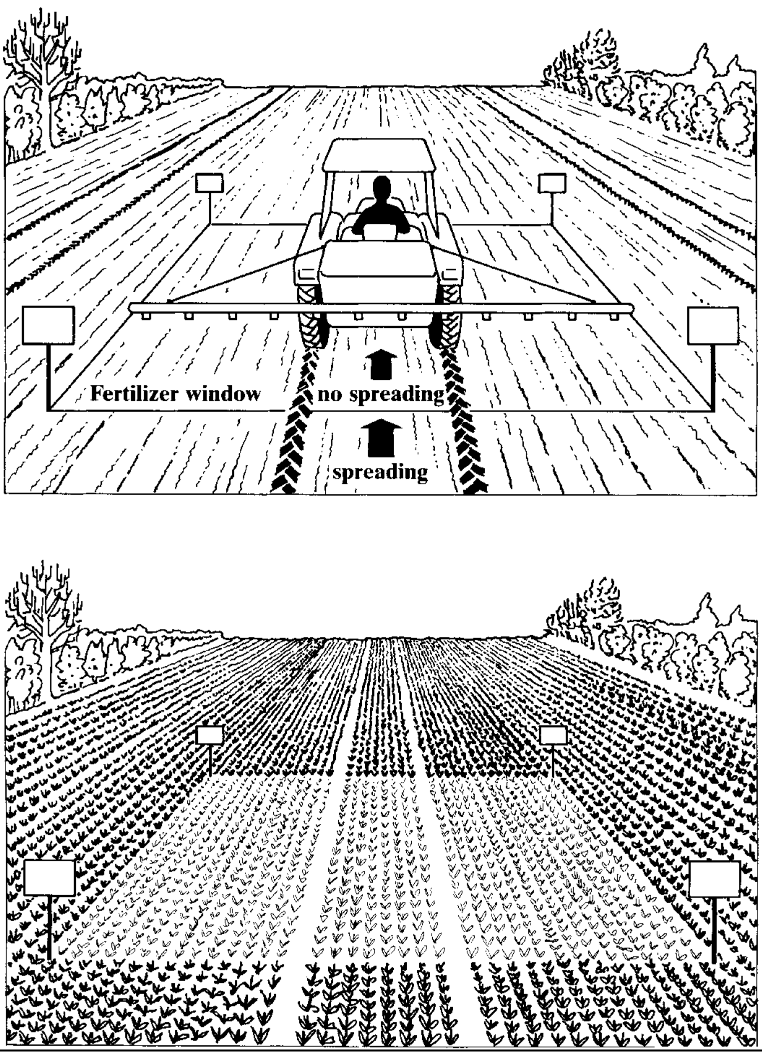
The exact calculation of the N demand for a specified yield is particularly important in intensive cereal production. A general guideline for the calculation of the N demand is given in the figure “ Model for calculating first N application (cereals) ”, but rather easier-to-use calulation 'models' are also employed. Such calculations - where undertaken - should begin, shortly before the early spring growing season, with analysis of the (probable) soil available N, based on the amount of mineralogically bound N known as N_{min}. This may relate either to nitrate plus ammonium N or, if necessary, to nitrate N alone. (For further information on use of the N_{min} technique as an indicator of the amount of mineralized and available N in the soil at the date of sampling, *please consult on the IFA Web site in the “ Publications ” section, “ Fertilizer and Their Efficient Use, the chapter : Practical Recommendations for Fertilizer Use .*

In Northern Europe, the results of experiments and observations indicate a release of about an additional 40 kg/ha N from the soil reserve of a normal fertile soil between the beginning of the early spring growing season, i.e. the date of soil sampling for N_{min} analysis, and the end of shooting. By subtracting this amount and the amount of mineral N available in the soil according to N_{min} analysis from the crop's expected requirement up to the end of shooting, one can obtain a reasonable estimate of the amount of N needed to come from fertilizers during this period. Thus, using the same example as in the table “ Relative nutrient uptake in relation to plant development ” for which the crop's total requirement up to the end of shooting was 157 kg/ha N (= 84 % of 187 kg/ha), and assuming that N_{min} analysis indicated 50 to 60 kg/ha N available in the soil at the time of sampling, then the amount to be supplied in fertilizers to provide enough N for the crop's needs up to end of shooting would be 57 to 67 kg/ha N (= 157 minus 40 minus 50 to 60 kg/ha).

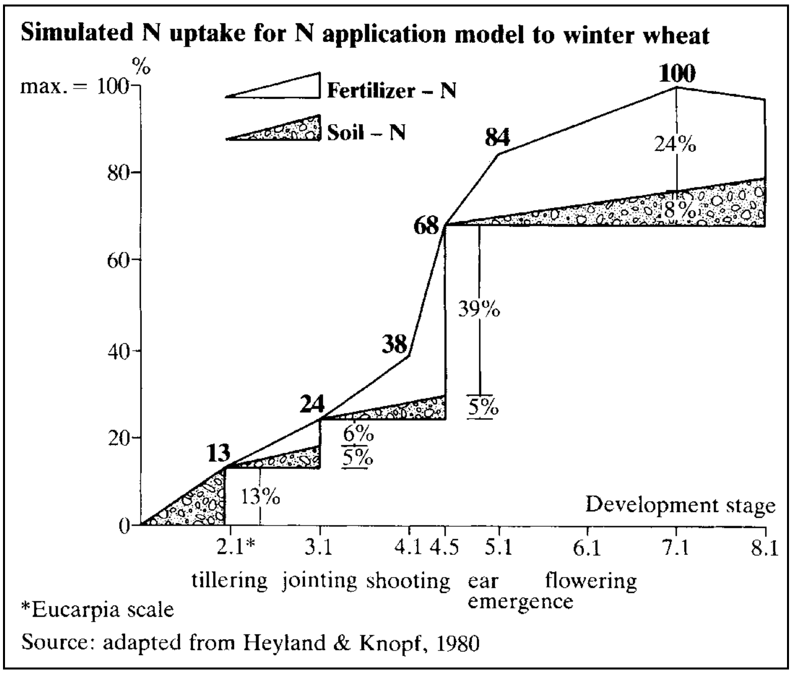
For the final "late N application", given at a stage when the yield can be estimated with a fair degree of accuracy, the amount needed can be obtained simply by subtracting the amount already supplied from the estimated maximum requirement. As a general rule of thumb, the "late N application" should be around 1 kg/ha N per 100 kg/ha expected yield of grain.

A practical system for the identification of N deficiency during growth is to leave a so-called "fertilizer window" in the field during N application. If the cereal plants within this window start to lighten in colour, then the plant-available N released by the soil has been taken up and the plants surrounding the "window" are benefiting only from the applied fertilizer N.

Method of producing a fertilizer window
(when passing the marked field area, the spreader is shut off)
Source: adapted from Rimpau, 1984



Most other methods for the calculation of N requirements make use of a model similar to that shown in the following figure, which aims to fit the N supply to the dynamics of N uptake consistent with maximum potential yield.

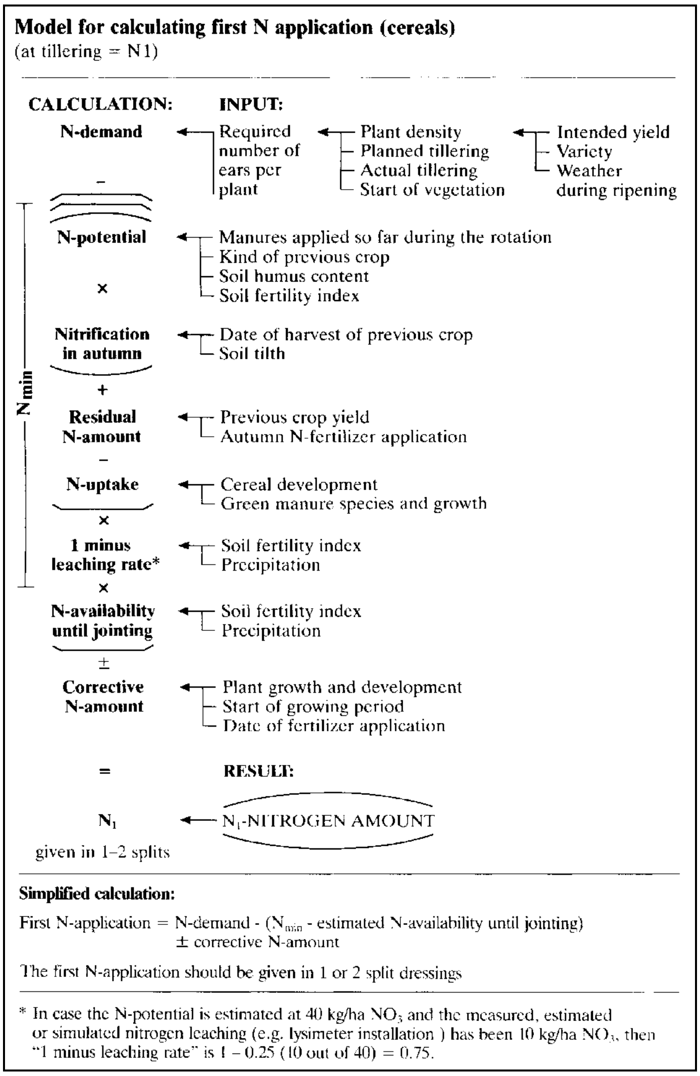


From the theoretical rate of N for each split application - to cover the crop's need only up to the next N application - there must be subtracted the estimated amount of N released from the soil during that period. If the resultant N rate is applied and the plants in an untreated "window" start to lighten, this shows, as indicated above, that N is avaible only from the applied fertilizer. For each subsequent application, the yield expectation and the amount of N available from the soil can be re-considered and the amount of fertilizer N to be applied is re-calculated. With this method it is possible to apply in each dressing as little as 30 kg/ha N; with the result that, if the calculated/estimated amounts prove to be wrong, the likely estimation error is then no more than 30 kg/ha N.

In deriving a figure for the total N requirement during growth, the crop variety must also be taken into account. Depending on a particular variety's straw/grain ratio and protein content, total N demand can vary by about 20 kg/ha.

Timely N application is especially important for spring varieties because of their shorter growth stages. More N is needed if plant residues are incorporated into the soil, because substantial amounts will be bound up during the process of decomposition. If straw is worked in, an additional 1 kg of N per 100 kg straw needs to be applied. Where such residues are regularly incorporated on a technically sound basis, a new nutrient cycle will be established by the soil micro-organisms in which additional N will no longer be necessary. The same applies to regular use of farmyard manure, in that an equilibrium will be established after two or three crop rotations which will allow the nutrients contained in the manure to be included in the total nutrient balance. However, on poor soils where soil fertility needs to be built up, 30 - 70 % immobilization of nutrients may be expected, so the calculated nutrient application rates must be increased for about the first 10 years.

The model shown in the figure above aims to achieve optimum ear weight (for the plant-available precipitation) combined with satisfactory yield stability, which in general is only possible with reasonably low ear densities. Fertilizer application at stage N1 of the figure " Pattern of yield formation of cereals " increases the numbers of tillers, at stage N2 the spikelet primordia, at stage N3 spikelet formation, at stage N4 reduction of florets, at stage N5 grain formation and at stage N6 grain development. The yield-diminishing effect of unfavourable weather conditions at any of these stages may be compensated by stimulating the development of the appropriate later determined yield factors.



A computer-based model, "Anbauverfahren Bonn (Cropping System Bonn)" has been developed by Heyland and Kochs (BONAGRAR, 1984) designed to obtain site-specific plant populations related as closely as possible to optimum ear density and growth. With this system the necessary N-rates can be calculated for the application dates N1, N2 and N3 as shown in the figure above.

Timing of fertilizer application

Generally, for the application of P and K three methods are practized: (a) Application in autumn on the stubble of the preceding crop, or with autumn ploughing; (b) application in spring (as NPK fertilizer) with the first N. (c) For wheat following sugarbeet or maize, P and K are given to the preceding crop, the wheat receiving only N;

A number of practical points also have to be taken into account in deciding when to apply fertilizer, e.g. the availability of the necessary machinery and manpower, whether the soil is in a satisfactory condition to carry this machinery, and the actual weather conditions at the time. Particularly with N this can present a quite complex optimization problem in farm management, which can be solved more readily the higher the technical efficiency of the farm and the greater the extent to which use of the soil as a medium can be circumvented, e.g. by more foliar fertilizer applications or by reducing the intervals between applications to the soil in such a way as to reduce the risk of nutrient fixation or of loss by leaching or by emission of N2 or NOx.

The crop takes up N from the soil solution whenever it is available, so promoting initiation and formation of those plant organs which are appropriate to the plants' stage of development at that time. If the objective is to maximize production of total biomass, this is of little importance; but, if the aim is to increase only grain production, then any surplus leaves and tillers that are formed will become undesirable competitors with the grain for available supplies of nutrients and water. For this reason, accurate timing is of vital importance in a system based on split dressings of fertilizer. If, however, accurate timing is impracticable due to weather conditions or poor organization, it may be advisable to restrict the number of dressings. with a possible reduction in the targeted yield.

While a single application may, of course, be given at the beginning of the growing period or at sowing, the unknown weather factor renders an accurate assessment of the final demand much less certain and there is little possibility of taking corrective measures.

It is important that the roots reach the full rooting depth as quickly as possible. If fertilizer is not incorporated into the soil, little or none should therefore be broadcast on the soil surface, especially when urea is used, because of its liability to volatilization losses. For application before sowing, incorporation or band application is necessary, particularly in areas with a dry spring.

The richer a soil biologically, the more are nutrients biologically fixed in the soil micro-organisms, a fact which is particularly important at the start of the growing period and at the beginning of tillering. N from the previous year's crop residues is, in general, mineralized in the autumn and is liable to be leached into the deeper parts of the topsoil with the winter precipitation. In spring the surface layer warms up while the deeper parts still remain frozen; the wheat plants and the soil micro-organisms then have to feed from the effectively nitrate-free surface layer. Under such conditions there may be insufficient N left for the wheat crop, so a small amount of N should even be applied shortly before the start of the growing period. A similar situation may arise later at the beginning of shooting, when the whole depth of the topsoil has been warmed and active soil organisms are again competing with the crop for nutrients; as this is a most important stage of crop growth, fertilizers are then again needed to supply the system with plant-available nutrients. This applies particularly to wheat grown on dairy farms whose soils are very rich biologically, but these farms should at least be able to apply slurry at that time.

Fertilizer application techniques

Broadcasting

- This calls for a sufficiently dry soil to permit the use of tractors and spreaders but nevertheless enough soil moisture for adaquate nutrient uptake by the roots from the soil solution. These conflicting requirements could be overcome by the use of aircraft, but still a rather expensive method. Mostly, however, the actual date of fertilizer application fails to coincide with the optimum for nutrient uptake.

Another difficulty is that P and K - and N when applied in form of urea - should always be incorporated into the soil, normally before sowing; but such incorporation, by aerating the top soil, results in a loss of moisture and of humus.

Particular attention must be given to absolute uniformity of N fertilizer distribution, both in and across the direction of travel. Evenness of distribution depends mainly on the physical quality of the fertilizer (granule or prill size distribution, specific weight and surface characteristics), on the spreading system used (a single disc system is less accurate than a dual disc system, which in turn is less accurate than pneumatic and forced-feed precision spreaders) and on the rate and concentration of the fertilizer applied. With 120 kg/ha N applied as urea and an accuracy of spreading of $\pm$ 10 %, the overall range of error will be 24 kg/ha N. If the same total application is divided into six equal split dressings, the total overall range of error (assuming a random error distribution) is reduced theoretically to only 4 kg/ha N. However, multiple dressings not only involve more labour but also, more importantly, require spreaders capable of accurately distributing low rates of fertilizer.

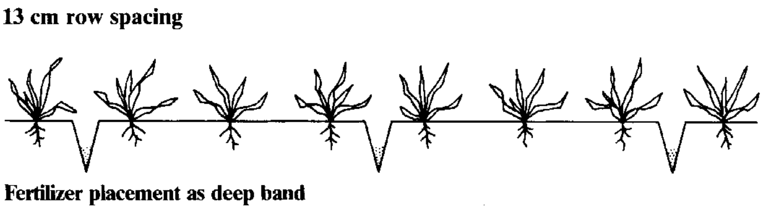
Again, because of soil heterogeneity in large fields, the rate of application ought theoretically to be continously adjusted to take account of the varying nutrient requirements, particularly in intensive agriculture where the cropping system is operated near to the risk of lodging; but there are considerable practical difficulties in changing the rate during spreading. Some flexibility could, however, be achieved by using fertilizer solutions or foliar sprays. Where the crop is irrigated, crystalline fertilizers may be dissolved in the irrigation water or liquid fertilizer added, thus permitting accurate distribution at the optimum time.

Band or storage application

- If it is desired to make fertilizer nutrients available only in those parts of the field which are actually covered by the wheat plants at tillering, band application is recomended. High nutrient concentration will then prevail in those particular areas, which may be used as long-lasting "fertilizer depots" because neither the roots nor the soil organisms will penetrate to the centre of the high concentrated zones and only their outer surfaces are exploited. This method is especially suited to nutrient-deficient and strongly nutrient fixing soils.

Possible technical solution for placement of deep band-application of fertilizer for cereals

Source: adapted from Halvorson, 1987



The greater efficiency of deep placement pre-plant urea ammonium nitrate solution compared with surface application is shown in the following table:

Effect of deep placed pre-plant UAN solution (Stafford County, KS; USA) Grain yield (t/ha)				
Application date	**8 July**		**15 August**	
	deep placed	broadcast	deep placed	broadcast
33 kg/ha N	1.99	1.89	2.24	2.3
67 kg/ha N	2.8	2.24	2.96	2.18
100 kg/ha N	3.3	2.99	3.33	2.66
Source: Gallagher et al., 1976				

However, injecting or "knifing-in" the fertilizer with coulters causes rupture of the soil surface parallel to the rows, so increasing the risk of greater germination of weed seeds. In already established cereal crops, the method is only applicable if the "depots" can be spaced widely enough and the plant density is low, both factors restricting the potential grain yield. If injection nozzles are used, then it is necessary to have expensive technical systems and a stone-free soil.

The following conditions must be fulfilled in all cases where the "fertilizer depot" method is to be used:

- the amount of nutrient stored must supply the crop's total demand;

- the outer surface areas of the depots must be of an appropriate size to minimize both immobilization and leaching loss;

- placement should be at least 4 cm beside the seed or, even better, about 2.5 cm beside and 2.5 cm below the seed;

- in dry areas, placement can be up to 15 cm deep;

- the depots shold not be spaced more than 39 cm apart;

- the amount of nutrient stored should not exceed 100 kg/ha.

The fertilizers generally used are anhydrous ammonia, aquaeous ammonia and easily soluble P- or NP/NPK-fertilizers. Anhydrous ammonia should only be used where nitrification is low and where the winter precipitation is almost equal to the waterholding-capacity of the soil; a nitrification inhibitor should be added.

When non-pressure N solutions are used (e.g. urea ammonium nitrate), no more than 30 kg/ha N should be given at a time, preferably in conjunction with a pesticide spray (in which case the pesticide rate should be reduced - depending on droplet size - by up to 20 %, due to the reduced rate of evaporation of the spray solution and increased uptake through the leaves). N solutions are best applied in spring, to healthy, timely developed and dry leaf canopies. They should not be applied during flowering, nor if frost is expected. Minor leaf damage from leaf burn will have no effect on the final grain yield; any leaf burn of the flag leaf (which is important for grain filling) must, however, be avoided by using drag hoses attached to the nozzles of the spraying boom when giving a late N-application.

Foliar application

- The advantage of foliar application is the direct uptake of nutrients into the metabolism of the plant tissues. Thus, with a very low consumption of energy for transportation within the plant, the uptake is virtually independent of environmental factors such as soil moisture. The disadvantage is the limited amount that can be applied at one time, due to the risk of leaf burn; but this is of less concern provided proper attention is paid to the relevant limits of concentration, especially when there are a number of split dressings. Another advantage is the opportunity to combine fertilizer application with that of pesticides and growth regulators, in many cases with beneficial synergistic effects. In arid conditions the high concentration of combined sprays reduces evaporation, and so reduces vaporization of the active ingredients, thus permitting a reduction in pesticide usage with resultant benefit to the ecosystem.

Foliar application of dissolved granular fertilizer to cereals (assuming an application rate of 400 litres/ha)				
Fertilizer type	**Chemical formula**	**Concentration of fertilizer in the spray solution kg/100 l**	**Amount of fertilizer kg/ha**	**Amount of nutrients kg/ha**
Urea	CO(NH2)2	8-16	32-65	15-30 N
"Liquid nitrogen" (Non-pressure nitrogen solutions)	NH4NO3 + CO(NH2)2	0.5-1	2-4	1-1.8 N
Triple superphosphate	Ca(H2PO4)2	2	8	4.8 P2O5 2.0 CaO
Potassium sulphate	K2SO4	2	4	2.2 K2O 0.7 S
Magnesium sulphate	MgSO4.7H2O	2	8	1.3 MgO 1.5 S
Manganese sulphate	MnSO4.4H2O	1-2	4-8	1-2 Mn 0.6-1.25 S
Zinc sulphate	ZnSO4.7H2O	0.5	2	0.5 Zn 0.2 S
Copper sulphate	CuSO4.5H2O	0.5	2	0.5 Cu 0.3 S
Commercial foliar fertilizer		0.5-1	1-4	
Source: adapted from Finck, 1979				

Slurry

- Application of slurry to cereals causes great problems. Autumn application without added nitrification inhibitors may result in a large loss of nitrate by leaching, due to the limited uptake by the young crop. Application on frozen ground, while not harming the crop, may cause environmental problems. Spreaders with oversized tyres (to reduce pressure on the soil), applying the slurry through drag hoses, may be used for spring top dressing, provided "tramlines" have been laid down at sowing.

Present fertilizer practices

Germany

Fertilizer application rates Germany, Hesse (P, K, Mg) and Weser-Ems (micronutrients) based on an expected yield of 5 t/ha grain*								
Supply class	kg/ha							
	N**	**P2O5**	**K2O**	**MgO**	**Cu**	**Mn*****	**Zn**	**Mo**
A-very low	120	120	240	80	1.5	2 x 2	10	2
B-low	90	90	180					
C-medium or normal	60	60	120	40	0.5-1	2	5	1
D-high	30	30	60		1			
E-very high	-	-	-	-	-	-	-	-
* With other yield expectations the rates have to be adapted accordingly. ** N rates see: Calculation of fertilizer rates. *** As foliar spray; 2 x 2 = two foliar sprays with 2 kg/ha Mn each.								
Source: Aigner et al., 1988								

The table gives the recommended rates of nutrients for a wheat crop producing a yield of 5 t/ha grain. The ratios do not change much even with different water supply levels. This is also true of the maximum uptake and the demand at each developmental stage. On the other hand, if any factor such as nutrient supply, moisture, light or temperature is inadequate at any stage, the kernel yield could be limited irreparably. The only chance of compensating for the resultant yield loss is by modifying a yield component associated with a later stage of development. For example, a poor supply of nutrients early in growth reduces the number of tillers per unit area, but the consequent reduction in ear density could in theory be compensated without difficulty by promoting the initiation of spikelets at EC stage 3.1 - 4.0 and diminishing the floret reduction at EC stage 4.1 - 5.1. In practice, however, it is not so easy to estimate accurately the available nutrient supply coming from the soil, or the magnitude of losses, e.g. by denitrification. The time interval elapsing between the application of fertilizer and nutrient uptake by the crop presents an additional and greater problem, particularly under unfavourable weather conditions, because the plant organs which are formed at the later stages of development are those which have less influence on yield production. In order to maximize the efficiency of fertilizer use, techniques will therefore need to be used which can quantify the various factors involved, by means of intensive site-specific crop observations, analysis, fertilizer management methods and/or computer-based simulation models.

China

(North China, winter wheat)

- Irrigated, expected grain yield 6 t/ha
  Basal application
  113 kg/ha N
  113 kg/ha P_2O_5
  broadcast and incorporated (15-20 cm)

  Topdressing (15-20 days after emergence)
  113 kg/ha N
  followed immediately by irrigation

- Rainfed, expected grain yield 4.5 t/ha
  Basal application
  150 kg/ha N
  90 kg/ha P_2O_5
  broadcast and incorporated (15-20 cm)

  No topdressing

Available organic manures are to be applied and incorporated well before sowing.

India

Irrigated timely-sown crop

- under assured irrigation
  N: 80-120 kg/ha N, depending on previous crop
  P: 40-60 kg/ha P_2O_5
  K: Based on soil test result

- under limited irrigation
  N: 60 kg/ha N
  P: 30 kg/ha P_2O_5
  K: Based on soil test result

Half the N and all the P and K are applied at or before sowing; P should be placed 5 cm below the seed. The remaining half of the N is topdressed at the first irrigation. N and P rates are adjusted according to soil test results.

Irrigated late-sown crop

N:	60-80 kg/ha N
P:	40-50 kg/ha P2O5
K:	Based on soil test results

All N, P and K are applied at sowing; rates are adjusted according to soil test results.

Durum wheat *(Triticum durum Desf.)*

French: Blé dur; Spanish: Trigo duro; Italian: Frumento duro; German: Durumweizen, Hartweizen

Durum wheat has been grown traditionally in semi-arid regions (e.g. in the Mediterranean, Turkey, North Africa) but is now found increasingly in other countries too (France, Germany, Austria, UK, Russia, Argentina and North America).

Crop data

Annual, autumn-sown types (winter durum), spring-sown types and types with dual sowing time.

Harvested product: grain - with special properties for the production of semolina for pasta (noodles) and couscous; in the UK also for puffed wheat and sugar puffs.

Quality: grains of durum wheat are richer in gluten, glassier and harder than grains of ordinary wheat (T. aestivum); their concentration of enzymes is also higher. Spring-sown durum types often give the best quality.

Yield level: about 10 % lower than that of wheat (T. aestivum), although the individual grains are about 7 - 10 % larger and 10 - 12 % heavier. Yields of autumn-sown durum wheat are normally greater than those of spring-sown types.

Preferred soils and climate: the crop prefers a fertile wheat soil with sufficient humidity up to the grain filling phase, mild winters (autumn-sown), cool springs and warm summers dry at harvest time. Vernalization is not necessary.

Seed density: 350 - 450 grains/m^2 depending on variety, sowing time and region; the seedbed should be dry and of very fine structure, and the depth of sowing not more than 3 cm because of the low germination power of durum wheat. The sowing time in Europe for autumn-sown types is October and for spring-sown types mid-February to mid-March.

Harvest: mid-July to early August

Fertilizer use

Rates and timing of fertilizer application are similar to those for T. aestivum. The recommendations given on the previous pages therefore also apply to this crop, including those for the calculation of N rates. To obtain the desired glassy grains, late N topdressings of about 60 kg/ha N before ear emergence are necessary.

Further reading

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