The Development of Agronomic Advice on the use of Nutrients and Trace Elements for Grassland and Tillage Crops

Brian S. Coulter
Teagasc, Johnstown Castle, Wexford

Introduction

When Johnstown became a research centre of the newly emergent An Foras Taluntais in 1958, the conduct of soil analysis, fertilizer analysis and indeed fertilizer trials had been ongoing for almost ten years. Laboratory techniques, which had been developed in the USA in the early 1940s, were tested at Johnstown Castle by the staff of agronomists and chemists that had been built up in the early 1950s. From the very beginning, the research staff evaluated various soil analysis techniques by conducting field experiments to measure the response to fertilizers of different crops.

At that time, Irish soil fertility was very poor. In 1954, 77% of received soil samples had P values of 1 mg/l and a further 14% had values of 2 mg/l. Thus, 91% of samples had P status that would today be classed as Index 1. The potassium status was equally poor; 93% of soils had K status below 50 mg/l (Index 1) in 1954. Crop yields were quite low at that time and the mineral composition of grass was frequently insufficient to maintain good animal health. The botanical composition of these low fertility grasses tended towards those with poor nutrition characteristics and low digestibility.

In the light of these poor soil fertility levels, it is not surprising that soil analysis was very successful from its introduction in 1948 and that the demand for it grew very quickly. By the mid 1950s, over 100,000 samples per annum were being received by the laboratory. This had a dramatic effect on soil fertility; by 1960, the percentage of samples with P at Index 1 had reduced to 44% and the percentage of K samples at Index 1 had reduced to 29%.

In the beginning, knowledge of the concepts, units and indeed the interpretation of soil analysis results were relatively unknown outside of the Department of Agriculture and the Universities. Advice and recommendation

tables were not available; therefore, soil analysis results were accompanied by agronomic interpretation and fertilizer advice. However, knowledge of the properties of various soils in different parts of the country and the fertility needs of different crops was being built up. The information was sent to agricultural officers periodically to enable them to interpret the results of soil analysis. As the results of field experiments on different crops using fertilizers of different types and in various combinations became available, fertilizer recommendations became more and more complex and subject to a whole host of correction factors depending among other things on the soil, crop and climatic conditions.

In the late 1950s, information on soil analysis interpretation techniques were gathered together in a thirty page guide, produced on a Gestetner copier, entitled "Notes on Soil and Plant Sampling Analysis for the Guidance of Agricultural Officers". These notes were very detailed and indeed complex and were in use until the first Guide to Soil and Plant Sampling and Analysis was published in 1965 by An Foras Taluntais as a booklet for distribution to agricultural advisers. This was followed by further booklets and manuals in 1971, 1973, 1977, 1982, 1986 and 1994 and in 2001 it culminated in a comprehensive manual: Nutrient and Trace Element Advice for Grassland and Tillage Crops which will be described later in this paper.

Analysis Techniques in the Department days and An Foras Taluntais before 1965

From the earliest days in Johnstown Castle, the P and K status of soils was determined by extracting soil with Morgan's solution (Peech and English, 1944). However, the units have changed over the years. Up to 1965 the chemical composition of soils were quoted in lbs per acre. An acre of soil was assumed to contain 2,000,000 lbs; this was obtained by assuming an active soil depth of 6 inches and a specific gravity of 1.5 relative to water. In order to simplify the tables of suggested fertilizer application rates in the "Notes" (Anon, 1958), the P and K analysis was classified into 7 classes or 'symbols'. The P classes ranged from 1 lb/acre (0.5 mg/l) for Symbol 1 up to 30 lbs/ac (15 mg/l) for Symbol 7 and the K classes ranged from 50 lb/acre (25 mg/l) for Symbol 1 to 300 lb/acre (150 mg/l) for Symbol 7. For both P and K, soil values of 'symbol 3' are approximately equivalent to today's Index 1.

Suggested application rates for N, P and K, taken from the early "Advice Notes" for several crops, are given in Table 1. The N advice was not dependent on a soil test and those for P and K assume that the soil analytical values are at a "symbol" of 3; (approximately Index 1). The figures are based on properly limed medium loam soil in an area of medium rainfall; if these are not met, the advice is subject to certain adjustments to meet a considerable number of varying conditions. For example, if the soil is a clay, the P should be increased

by 12.5%, for light loams, the P should be decreased by 15%. For tillage crops on light soils, K should be decreased by 15%. On heavy soils, K should be increased by up to 15%. For every 2000 lbs/acre Ca, a further 10 K should be added. Further corrections are applied for soils derived from non-calcareous parent material, for high fixing soils, for crops grown in high rainfall areas and for the residual effect of previous fertilizer and farm yard manure.

Table 1. Suggested 1958 fertilizer application rates (converted to kg/ha), assuming soil P and K values of symbol 3; this is approximately equivalent to today's Index 1.

Nutrient	Pasture	Cereals	Potatoes	Sugar Beet
		Suggested Fertilizer Rates (kg/ha)		
N	37	25-50	50-75	50-75
P	18	13	36	36
K	45	22	112	112

Soil acidity was long recognised as an inhibitor of growth of crops and application of lime was advised to correct acidity problems. The optimum soil pH was known to depend on the crop; cereals and potatoes were tolerant of acidity, grass and clover preferred the soil to be closer to neutrality and root crops and particularly sugar beet thrived in neutral or slightly alkaline soil. Before 1965, advice on the amount of lime to use to correct acidity problems was determined mainly by the soil pH, with exchangeable calcium, organic matter and texture used as correction factors. As with P and K, the Ca level was graded into ranges, in this case 9 ranges or Symbols.

Giving a lime recommendation based on these factors was quite complex. Thus, if the pH of a medium-loam soil of medium organic matter was 5.2 and the Ca was 800 lbs/acre (Symbol 2), 3.75 tons/acre of lime was recommended to bring the soil to pH 6.5. If the Ca was 2000 lbs/acre (Symbol 5) then only 2.75 tons/acre was advised. If the soil was sandy loam then these figures should be reduced by 1.5 tons/acre and for 'definite clays' the figure should be increased by 1.5 tons/acre. There were further corrections of 0.5 to 1 tons/acre if the organic matter was moderately high to high respectively. There was a further correction of ± 20% depending on whether the rainfall was high or low.

Guide to Soil and Plant Sampling and Analysis by An Foras Taluntais 1965-1970

The complexity of fertilizer recommendations by Department of Agriculture and the early days of An Foras Taluntais must have been very daunting. The units lbs/acre was felt to be somewhat unscientific and its classification into 7

or 9 ranges or 'Symbols' added to the complexity. Gallagher and Herlihy (1963) examined the errors associated with soil sampling and analysis and suggested that the system for P and K analysis should be simplified to just three classes. The changes were embodied in the first Foras Taluntais 'Guide to Soil and Plant Sampling and Analysis', (Anon, 1965). These P and K soil analysis classes were not numbered or named; the actual ranges were quoted on each table of recommendations. The analysis unit lb/acre was also dropped in favour of parts per million (ppm) although recommendations were still given in lbs/acre of fertilizer.

The 1965 guide was very much simpler to use than the former "Notes" (Anon, 1958) and the P and K recommendations had been modified significantly as a result of field trials carried out in the early1960s. In particular, the N recommendations were modified as a result of the Castle Field experiment which measured liveweight gains of sheep and cattle (mixed grazing) at levels of N up to 422 kg/ha (Moloney and Murphy, 1963).

Table 2 gives the Anon (1965) recommendations for a number of crops assuming that the soil P and K analyses are at a level equivalent to today's Index 1 level. The N fertilizer rates for cereals, potatoes and sugar beet were broadly in line with the 1958 "Notes" (Table 1) but N for pasture was increased dramatically from 37 to a range of 0-207 kg/ha. The use of N for grass was qualified by the need to consider the clover supply in the sward and the time of year at which the grass is required. The need for extra N for silage was indicated as clover would be unable to compete for light with tall grasses and would not supply much fixed N.

Table 2. Suggested (Anon,1965) fertilizer application rates (converted to kg/ha), assuming soil P values between 1-3 ppm and K values between 0-50 ppm; these are approximately equivalent to today's Index 1.

Nutrient	Pasture	Cereals	Potatoes	Sugar Beet
		Suggested Fertilizer Rates (kg/ha)		
N	Up to 207	26-52	52-77	52-103
P	40	30	61	91
K	63	63	220	314

The suggested P and K fertilizer rates were greatly increased for all crops over those suggested in the earlier 'Notes' (Table1). However strict comparison is difficult as there are two levels in the 1958 'Notes' below the lowest P and K levels in the 1965. Soil levels were much lower in the1950s, and, apart from sugar beet, the suggested rates for the lowest P and K soils were broadly in line for the two tables. N rates were influenced by economic considerations; N

was expensive and the ratio of cost of N fertilizer to the value of extra product was generally unfavourable.

Modification of the above P rates was advised on soils of low total P, on acid soils where lime sensitive crops are required, on heavy textured soils and on very acid soils or soils with free carbonates. However the level of such corrections was not specified. Similarly, unspecified increases in K rates was advised on soils low in total K, on alkaline soils and on poorly drained soils where restricted rooting reduces K uptake.

There was a major change in the recommendations for liming. Statistical analysis of the results of a large number of soil analyses for pH and Ca in the early 1960s had shown that applying the Ca, texture and organic matter corrections did not improve the procedure compared to pH alone. Laboratory, greenhouse and field experiments designed to test the direct measurement of lime requirement using the SMP buffer method of Shoemaker, McLean and Pratt (1961) showed that the method was much more accurate than the former method based on soil pH. Therefore, direct measurement of lime requirement was used in the 1965 guide. However, the rates are increased by 2.5 ton/ha for sugar beet and unspecified reductions are advised for areas in which the soils are high in molybdenum.

Recommendations are given for use of N, P and K fertiliser and ground limestone on virgin and reclaimed peat. As soil analysis was stated to be of limited value in diagnosing nutrient requirements, the lime and fertilizer suggestions are dependent only on the crop and type of peat.

Fertilizer Manual 1971-1981

The Fertilizer Manual (Brogan, 1971) represented another sea change in fertilizer advice from An Foras Taluntais. The previous 23 page guide was expanded to 82 pages resulting in a very comprehensive document. The Manual was very logically laid out, the nutrient advice was divided into sections on grassland, cereals and root crops making it much more logical and easier to use. In addition, it included sections on fertilizer and lime planning, soil and plant sampling and analysis, specialist advisory services for crop failures, fertilizer efficiency, nutrient levels in soils and plants, conversion factors for imperial, Irish and metric units, scientific references and an index.

However, it can be argued that the nutrient advice tables were oversimplified. In the earlier Notes and Guide, the number of P and K classes was reduced from 7 to 3. In the Fertilizer Manual, the number of P and K classes was reduced to two. It is difficult to compare the advice in the Fertilizer Manual with the Guide because in the latter, the lowest ranges of P and K vary with the crop. For example, for grass-clover, the lowest P and K ranges are 0-3 and 0-75 ppm respectively while for root crops, the lowest ranges for P and K are 0-5 and 0-100 respectively.

The grassland section was expanded from a single page in the Guide to 15 pages in the Fertilizer Manual. This was a major advance in fertilizer advice from Johnstown Castle. It contained a valuable discussion on the stocking rates achievable using different amounts of N on various soil types from the General Soil Map. The Manual also contains many useful national maps. There is a grazing capacity map, a map showing where Mo was potentially toxic and deficient in soils, a Co distribution map showing potentially deficient areas and a map showing average summer rainfall classified into low, medium and high areas.

The section on cereals was greatly expanded also. The 10 page guide includes information on the effects of soil type, previous crop, sowing date, rotation, weather and disease on yield and fertilizer requirement. In addition, the Fertilizer Manual contains information on levels of trace elements in soils and crops and the use of foliar sprays and soil amendments to treat trace element deficiencies.

There is a 10 page section on root crops which mainly deals with the cultivation, fertilizer and trace element requirements of potatoes, sugar beet, swedes, mangels and kale.

Table 3 gives recommended fertilizer N, P and K rates for a range of crops growing on soils with P and K in the 'Low' fertility range taken from the Fertilizer Manual. Low fertility for P and K is defined as 1-3 ppm P and 1-75 K for pasture and cereals and 1-5 ppm P and 1-100 ppm K for root crops.

Table 3. Recommended (Brogan,1971) fertilizer application rates (converted to kg/ha), assuming soil P and K values in the "Low" range.

Nutrient	Pasture	Cereals	Potatoes	Sugar Beet
	Suggested Fertilizer Rates (kg/ha)			
N	56	56	101	90
P	45	28	90	112
K	90	56	224	336

Several leaflets which summarised and clarified the main points from fertilizer manual were also produced for agricultural advisers (Anonymous, 1973, 1977).

Fertilizer and Lime for Grass, Cereals and Root Crops 1982-1985

In 1982, Johnstown Castle published a condensed, 12 page fertilizer advice guide for a range of crops (Conway, 1982). Major changes from the previous Manual are the changeover from lbs/acre to units/acre for fertilizer recommendations, the inclusion of sulphur recommendations for cereals and root crops on light textured soils and magnesium recommendations for soils

low in Mg. There is a full page on trace elements giving the name of the compound, the usual rate of application either as a spray or soil application and the crops usually affected.

Despite the reduced number of pages, the section on N for grazing is greatly expanded. The section begins with definitions for medium, high and very high stocking rates in terms of the cow or cattle density at different periods throughout the grazing season. Very high stocking rates were defined as 2.5 cows or 1100 kg cattle April-June, *and* 1.9 cows or 900 kg cattle/acre June-July *and* 1.3 cows per acre or 730 kg cattle.

The N advice for grazing was divided into two sections; swards 3 years and over and swards 1 and 2 years old. Detailed rates and a timetable were given for medium, high and very high stocking rates for the two ages of pasture. Recommendations were given in bags of fertilizer per acre and advice was included on when use of urea was appropriate. For swards 3 years and over, the total N for medium, high and very high stocking rates were 54, 248 and 372 kg/ha respectively.

Table 4 gives recommended fertilizer N, P and K rates for a range of crops growing on soils with P and K in the 'Low' fertility range taken from the Conway (1982). The lowest range for soil P was changed again, thus low fertility for P and K is defined as 1-4 ppm P and 1-75 ppm K for pasture and cereals and 1-5 ppm P and 1-100 ppm K for root crops.

Table 4. Recommended (Conway, 1982) fertilizer application rates assuming soil P and K values in the "Low" range (1-4 and 1-75 ppm respectively) and for pasture at low stocking rate.

Nutrient	Pasture	Winter Wheat*	Potatoes	Sugar Beet
		Suggested Fertilizer Rates (kg/ha)		
N	54	75	113	125
P	20	30	113	113
K	38	60	225	225

*Grown 3-6 years after good pasture

Soil Analysis and Fertilizer Recommendations 1986-1993

The Conway (1986) recommendations derived from a Foras Taluntais/Advisory Service commodity group discussion which suggested four changes to the soil testing procedures and fertilizer recommendations. These were:

1. To use a more detailed soil identification form with instruction on soil sampling

2. A new 1 to 4 nitrogen Index based mainly on previous cropping history
3. A 1 to 4 Index for reporting P, K and Mg soil analysis results
4. A "suggested" level of N, P and K fertilizer for the crop to be grown.

The fertilizer recommendations manual arising from these changes represented a significant improvement on the earlier advice booklets. The increase from two to four in the number of points on the P, K and Mg index scale allowed fertilizer suggestions to be more closely targeted to the needs of the crop. The N Index for tillage crops which was based on previous cropping and manurial history of the field, was completely new to An Foras Taluntais and allowed the adviser to recommend different N rates for tillage crops depending on the likely release of soil N.

The N advice for grazed swards, which the previous manual discriminated into three possible stocking rates, was widened into a 5 point "whole farm" stocking rate scale. As before, a distinction was made between swards 3 years or older and those less than 3 years established. In addition, use of clover at low stocking rates was advised and in its absence, an extra 60 kg/ha of N was recommended. The new N rates, which are close to those advised today, are given in Table 5.

Table 5. Nitrogen (kg/ha) recommended for grazed swards from Conway (1986).

Whole farm stocking rate LU/ha	Established 3 years and over	Established less than 3 years
1.5	0	0
2.1	100	150
2.4	225	280
2.8	320	375
3.0	390	490

The N recommendations for stocking rates of 2.8 and 3.0 LU/ha were significantly higher than given for high and very high stocking rates in the previous manual.

The recommended rates for a range of crops on soils at index 1 for P and K are given in Table 6.

The N rates for tillage were much greater than given in the 1982 guide (Table 4), indeed the rate for winter wheat had increased by 77%. The lowest suggested P and K rates for grassland had doubled also, although a strict comparison is not possible as the soil P and K levels in earlier table are somewhat higher.

Table 6. Recommended (Conway, 1986) fertilizer application rates assuming soil P and K values at Index 1 (1-3 and 1-50 ppm respectively).

Nutrient	Pasture	Winter Wheat*	Potatoes	Sugar Beet
		Suggested Fertilizer Rates (kg/ha)		
N	See table 5	185	220	160
P	40	35	150	80
K	75	75	290	315

*Grown 3-6 years after good pasture, straw removed

Soil Analysis and Fertilizer, Lime, Animal Manure Recommendations 1994-2000

The Gately (1994) recommendations built on the 1986 guide and gave much more information on differences between soils, the nutrient value of animal manures and silage effluent and advice on the use of trace elements Co, Cu, I and Zn for grassland and B, Cu, Mn and Zn for arable crops.

The N advice for grazed grassland was the same as those in Table 5. The rates for silage and hay were also the same as before and the P and K rates for grazed and cut swards were the same as in Conway (1986). For grassland, the main differences were the use of animal manure as a source of N, P and K for silage and hay and the tables, given earlier in the text, to enable the adviser to calculate its nutritive value for these crops.

The main advances in the 1994 booklet occur in the tillage section. Though the rates for most cereals were unchanged, new and much lower N rates were recommended for malting barley. The planting of malting barley on soils with N Index of 3 or 4 soils was not recommended.

Nutrient advice for potatoes was divided into sections for main crop, early and seed. In general, the N and P advice for potatoes was significantly lowered though the K rates were the same or slightly higher. The N rates for sugar beet were somewhat lower than given earlier but these too were refined, this time by taking account of the soil texture and the April-June rainfall in addition to the N Index in giving N application rates.

The recommended rates for a range of crops on soils at Index 1 for P and K are given in Table 7.

Table 7. Recommended (Gately, 1994) fertilizer application rates assuming soil P and K values at Index 1 (1-3 and 1-50 ppm respectively).

Nutrient	Pasture	Winter Wheat*	Main-crop Potatoes	Sugar Beet
		Suggested Fertilizer Rates (kg/ha)		
N	See table 5	185	150	140
P	40	35	125	70
K	75	75	305	360

*Grown 3-6 years after good pasture, straw removed

Nutrient and Trace Element Advice for Grassland and Tillage Crops 2001

A new nutrient advice manual was published by Teagasc in 2001 (Coulter, 2001). This manual, like all the earlier Johnstown Castle advice booklets, built on the earlier recommendations by taking account of the latest research information, changes in plant varieties and their expected yields, and improvements in management practices. In addition, new P advice for grassland, which was developed in 1996 (Carton, Ryan and Magette, 1996) was included in the manual. The publication placed major emphasis on matching crop needs and fertiliser advice, both to save money and to help protect the environment.

This document gave advice for nitrogen, phosphorus, potassium, magnesium, sulphur, lime and trace element use on grassland and tillage crops. The suggested applications were presented in a fairly simple format. However, footnotes were included with many of the tables, to modify the rates in the light of environmental or other constraints.

In general, the guidelines in the new booklet apply to the most productive soils farmed under good conditions. However, it was suggested that advisors should consider local agronomic conditions and environmental risk factors such as slope, soil type, distance from water courses and time of application etc. before giving nutrient advice.

The manual gives nutrient and trace element advice for grassland and all arable crops. In general, the rates are similar to those in Gately (1994) but there are changes and updates to the N, P and K rates for grazing and silage, cereals, sugar beet and forage maize. For the sake of brevity, only the nutrient rates for grassland will be discussed here.

Nitrogen for Grazing

As in the last two fertilizer manuals, the fertiliser N advised depended mainly on the stocking rate, the clover content of the sward and the age of the sward. Thus, Table 8 gives N application rates for standard dairy merit cows and cattle.

Table 8. N application rates for pasture grazed by standard dairy merit cows or cattle

		N Fertiliser Advice (kg/ha)	
Rank	Whole Farm Stocking Rate LU/ha	Pasture 3 years or older No Clover	Pasture Less than 3 years No Clover
1	Less than 1.2	45	45
2	1.2-1.5	60	75
3	1.8	80	100
4	2.1	100	125
5	2.4	225	280
6	2.8	320	390
7	3.0	390	400

Comparison of Table 8 with Table 5 shows that there are a number of significant changes in the new manual. Gately (1994) assumed that clover was present at the lower stocking rates and recommended no N while Table 8 assumes that clover is not making a worthwhile contribution. However, grassland managers are advised to encourage clover growth at lower stocking rates and then subtract its likely contribution. Table 8 also advises a small N application for stocking rates below 1.2 LU/ha unlike Table 5.

The corresponding table on N for grazed pasture in the new advice manual makes extensive use of footnotes to further modify the advice. Agricultural advisers are permitted to vary the N rates by up to 20% on less productive soils at low to medium stocking rates to suit local conditions. Nitrogen rates above 400 kg/ha are not recommended as they not felt to be economically worthwhile, and as they present a danger to the environment. On permeable soils, rates above 300 kg/ha are not advised for fear of loss of N to ground water.

There is a completely new table on N for cows of high genetic merit. There are practical definitions for dairy merit classes; cows of hig dairy merit are defined as having a milk yield of 8000 l/annum, a weight of 650 kg and fed a supplement of 750 kg/head/year of concentrates. A standard merit cow is defined as one yielding 5000 l/annum, weighing 550 kg and being fed 500 kg/head annum of concentrates.

In order to keep the new guide consistent in not using more than 400 kg/ha N on grassland, extra N is not advised for grazing for high merit cows. Instead, reduction of the stocking rate is suggested. Table 9 gives a comparison between the stocking rates suggested for standard, medium and high merit cows for the numbered N application rates in Table 8.

Table 9. Suggested stocking rates (cows/ha) for grazing by normal, medium and high merit cows at the N rates given in Table 8

	Whole Farm Stocking Rate LU/ha		
Rank	Normal Merit	Med-High Merit	High Merit
1	1.2	1.1	0.9
2	1.5	1.25	1.1
3	1.8	1.5	1.3
4	2.1	1.75	1.5
5	2.4	2.0	1.7
6	2.8	2.35	2.0
7	3.0	2.5	2.2

N for Silage

Nitrogen rates for silage are broadly the same as in Gately (1994) except that the new manual advised that all slurry produced on the dairy or cattle farm be applied to the silage ground. Thus the amounts of N assumed to be contained in such slurry is subtracted form the N advice in the published tables Nitrogen advice for silage, and indeed P and K advice, assumed that cattle slurry is applied at the rate of 33 t/ha. The assumed slurry composition depends on the date of application. All available N will have been lost from slurry applied in the summer but for spring application, the 33 t/ha of slurry is assumed to supply 30 kg/ha of N.

Phosphorus for Grazing and Silage

Phosphorus advice for grazing is based on soil analysis, and amounts are designed to achieve optimum yield of grass with efficient use of P nutrients inputs from fertilizer and organic manure. It is important that the soil sample is truly representative as soil analysis can be subject to major sampling errors. The P advice in Coulter (2001), was derived by taking a number of steps:

(1) Determining the P Index of the soil test result from Table 10.
(2) Deciding the Target Index. Indicators for such situations are given in Table 11.
(3) Determining the P required for build-up to the selected Target Index from Table 12,
(4) If the P Index is less than or equal to the Target Index, adding to that the amount of P required to maintain soil P levels by replacing the P removed by the animal production system (Table 13).

Table 10 P and K Index system for soils

Soil P or K Index	Soil P Level (mg/l)	Soil K Level (mg/l)
1	0 – 3	0 – 50
2	3.1 – 6	51 – 100
3	6.1 – 10	101 – 150
4	> 10	> 150

Table 11: Indicators for determining Target P Index for grazing

Soil P Target Index 2	Soil P Target Index 3
Any one of the following • Stocking rate below stock carrying capacity • Grazing before May-cut silage not required • Grass supply usually in excess of demand • Peat soil	*Any one of the following* • Stocking rate at or above stock carrying capacity • Grazing before May-cut silage practiced • Grass supply fully utilised by grazing animals

Table 12 Grazing and silage - P required to build-up P content of soils (kg/ha)

Soil P Index	Soil P Target Index 2	Soil P Target Index 3
1	20	20
2	0	10
3	0	0
4[2]	none	None

1. For peats, apply P nutrients only in the growing season, as P applied in the autumn or later could be washed down below the rooting zone over the winter.
2. The distinction between 0 at Index 3 and 'none' at Index 4 is to show that neither build-up nor maintenance P should be applied at Index 4.

Table 13: Grazing: Soil P maintenance requirement to replace offtakes (kg/ha)

	Stocking Rate (LU/ha)			
System	1.0 – 1.5	1.6 – 2.0	2.1 – 2.5	2.6 – 3.0
Dairying	6	9	13	16
Drystock	3	5	7	9

Following the review of P rates for grazing and silage reported by Carton et al (1996), P advice had been considerably reduced below the levels in recommended by Gately (1994) and this has been reflected in reduced sales of

P and K fertilizer and reductions in P and K fertilizer usage on grassland crops (Coulter, 2002).

Under normal circumstances, there is adequate P in the grazing sward to satisfy the needs of the animals. However, there is a possibility of inadequate P content in grass to meet the animal nutrition requirements of high yielding cows. In these circumstances, the agricultural advisor should look to other sources of P supplementation to ensure a balanced mineral diet. There may not be adequate P in silage alone to meet the nutritional requirements of high yielding animals. Dietary P supplementation may be necessary to meet this need.

The four-step approach that was used for grazing was also applied silage. The first three steps (Tables 10-12) were used for silage; however the P maintenance requirement to replace the P removed by the animal was assumed to be zero assuming that:

(1) all the slurry produced by the animals from silage and concentrates during over-wintering was applied to the silage ground and
(2) that concentrate was fed at the rate of 500 kg/LU per year.

Potassium for Grazing and Silage

Regular soil analysis was recommended to monitor the soil K levels because the K status can drop quite rapidly in some soils. Only regular monitoring, at least every five years, ensures that the K Index (Table 10) is correct. For K fixing soils such as the Athy soil series, K application was recommended in the spring and/or throughout the growing season. Potassium fixation is more likely to occur in conditions when organic matter content is low and during reseeding.

Table 14 gives the K advice for a grazed sward. Unless the soil is at K Index 1, fertilizer K was advised in autumn to reduce the risk of hypomagnesaemia i.e. to avoid Mg deficiency in animals arising from luxury uptake of K by grass in the spring.

Table 14: K for grazing at stocking rate of 2.5 LU/ha.

	K Advice (kg/ha)	
Soil K Index	Dairy	Drystock
1	90	75
2	60	45
3	30	15
4	none	none

Table 15 presents N, P and K advice from Coulter (2001) for pasture and a range of tillage crops. This table is broadly comparable to the suggested rates

and recommendations from earlier fertilizer notes and manuals. Comparison with Table 1 shows that for pasture, nutrient advice has at least doubled since 1958. For cereals, rates have increased 4 or 5 fold, for potatoes, the increase is 3-4 fold and for sugar beet, the ratio is 2-3.

Table 15. Advised (Coulter, 2001) fertilizer application rates assuming soil P and K values at Index 1 (1-3 and 1-50 ppm respectively).

Nutrient	Pasture*	Winter Wheat†	Main-crop Potatoes	Sugar Beet‡
		Suggested Fertilizer Rates (kg/ha)		
N	See tables 8,9	190	150	150
P	30	45	125	70
K	70-85	95	305	320

* Assuming a stocking rate of 2 LU/ha
† Grown 3-6 years after good pasture, straw removed
‡ Assuming 200 mm summer rainfall

Conclusion

Reflecting on the changes in advice since the early 1950s; it is clear that developments in crop husbandry use of weed killers and growth modifiers and improvement in plant varieties account for major increases in yield potential. In addition, great changes have occurred in the ratio of cost of fertilizer to the value of produce for tillage crops as well as milk and meat. These have greatly influenced fertilizer advice, especially N application rates. Formerly, there was more of a tendency to advise lime, P and K levels that would enable the soil to produce economic crop yields, these in turn often depended on the level of N used. As a result, the economic efficiency of the N fertilizer influenced the amounts of P and K advised to maintain soil fertility since moderate crop yields extracted less P and K when the price of N was unfavorable.

Fertilizer advice from Johnstown Castle has always been based on a combination of agronomic and economic factors. Environmental protection, which has been given increased prominence in recent fertilizer manuals is advocated by adherence with codes of good agricultural practice (Anonymous, 2001), and in particular by taking account of nutrients in organic manures and by applying no more nutrients than were necessary to achieve optimum yields of crops.

Nutrient advice tends to be self correcting when accompanied by frequent soil testing. Thus if higher than necessary nutrient applications are made, this will tend to be corrected following the next soil test. Since soil nutrient levels tend to change slowly under most cropping systems, it is usually safe to base

fertiliser advice on soil tests for four to five years from the date of sampling except on very light soils where it is prudent to have soil analysis carried out every three years.

REFERENCES

Anonomous (1950) Notes on soil and plant sampling analysis for the guidance of Agricultural Officers. Department of Agriculture, Johnstown Castle, Wexford.

Anonomous (1965) Guide to soil and plant sampling and analysis, An Foras Taluntais, Johnstown Castle, Wexford.

Anonomous, (1973). Fertilisers for grass, cereals and roots. An Foras Taluntais, Johnstown Castle, Wexford.

Anonomous, (1977). Fertilisers for grass, cereals and roots. An Foras Taluntais, Johnstown Castle, Wexford.

Anonomous, (1982). Fertilisers for grass, cereals and root crops. An Foras Taluntais, Johnstown Castle, Wexford.

Anonymous (2001) Good Farming Practice (GFP). Department of Agriculture, Food and Rural Development, Kildare Street, Dublin 2.

Brogan, (1971). Fertiliser Manual. An Foras Taluntais, Johnstown Castle, Wexford.

Carton, O.T., Ryan, M. and Magette, W.L. (eds) (1996). Phosphorus recommendations for grassland. Good agronomic practice. Teagasc, Johnstown Castle, Wexford. pp 99.

Conway, A. (1986). Soil analysis and fertiliser recommendations. An Foras Taluntais, Johnstown Castle, Wexford.

Coulter, B. S. (ed) (2001) Nutrient and trace element advice for grassland and tillage soils. Teagasc, Johnstown Castle, Wexford. ISBN 1-84170-246-3, pp 67.

Gallagher, P. and Herlihy, M (1963). An evaluation of errors associated with soil testing. Ir. J. Agric. Res. 2: 149-167.

Gately, T. F. (1994) Soil Analysis & Fertiliser, Lime, Animal Manure & Trace Element Recommendations, Teagasc, Dublin, pp 36.

Moloney, D. and Murphy, W.E. (1963) The effect of different levels of N on a grass clover sward under grazing conditions. 1: Animal outputs. Irish J. Ag Research 2: (1) 1-15.

Peech, M. and English, L. (1944) Rapid microchemical soil tests. Soil Science, 57: 167-175.

Shoemaker, H. E., McLean, E. O. and Pratt, P. F. (1961) Buffer methods for determining lime requirement of soils with appreciable amounts of extractable aluminium. Soil Sci. Soc. Am. Proc. 25: 274-277.