ROTHAMSTED RESEARCH

Rothamsted Experimental Station Report for 1973 Part 2


ROTHAMSTED

EXPERIMENTAL STATION

REPORT FOR 1973

PART 2

Full Table of Content

The Behaviour of K Remaining in Soils from the Agdell Experiment at Rothamsted, the Results of Intensive Cropping in Pot Experiments and Their Relation to Soil Analysis and the Results of Field Experiments

A. E. Johnston and J. D. D. Mitchell

A. E. Johnston and J. D. D. Mitchell (1974) *The Behaviour of K Remaining in Soils from the Agdell Experiment at Rothamsted, the Results of Intensive Cropping in Pot Experiments and Their Relation to Soil Analysis and the Results of Field Experiments ;* Rothamsted Experimental Station Report For 1973 Part 2, pp 74 - 97 **- DOI: https://doi.org/10.23637/ERADOC-1-34634**

The Behaviour of K Remaining in Soils from the Agdell Experiment at Rothamsted, the Results of Intensive Cropping in Pot Experiments and their Relation to Soil Analysis and the Results of Field Experiments

A. E. JOHNSTON and J. D. D. MITCHELL

Description of the soils used and the field experiment

Agdell field, Rothamsted, is on soil classified as shallow Batcombe series, a shallow flinty clay loam or very flinty loam over Clay-with-flints. Cropping and manuring on this field are known since 1848; details were given by Johnston and Penny (1971). The Classical Rotation experiment, 1848–1951, was made on six large plots which tested two four-course rotations differing only in the cropping in the third year: roots, barley, fallow or legume, winter wheat. The fallow break was on plots 1, 3 and 5; the leguminous crop was grown on plots 2, 4 and 6. Only the roots were manured; there were three treatments, unmanured (plots 5 and 6); P only, changed to PKNaMg in 1884 (plots 3 and 4); and NPKNaMg (plots 1 and 2), the N being given as a mixture of ammonium salts and rape cake, which also supplied some P and K. Because of the differences in manuring and the extra uptake of nutrients by the clover the six plots contained different amounts of soluble P and K in 1951 when the Classical experiment ended. By 1951 soils on plots 1 and 2 and parts of plots 3 and 4 had become acid whilst soils on the remaining plots still contained free $CaCO_3$. The acidity was corrected by applying varying amounts of chalk in 1954, 1959 and 1967. The experiment was fallowed in 1952 and then during 1953–57 three cereals crops and one crop each of beans and potatoes were grown without applying P or K fertilisers.

In spring 1958 P. W. Arnold took soil from each plot to study potassium release from these soils under intensive cropping in the glasshouse; the results were discussed by Arnold and Close (1961b). Also in 1958 half of each rotation experiment plot was sown to grass given N fertiliser at 100 kg N/ha for each cut taken at silage stage. This experiment was designed to find at what rate and for how long P and K would be released from the residues. Grass was grown from 1958 to 1969–70; the results were given by Johnston and Penny (1971). The half plot not sown to grass in 1958 grew arable crops during 1959–62 to test P residues, basal dressings of N and K fertilisers were applied; the results were discussed by Johnston, Warren and Penny (1970). These arable half plots were fallowed continuously from 1963 to 1970.

During 1958–63 the combined effects of the residues of P and K were measured by the yield of grass. Each harvest of grass taken from the six plots was analysed for P and K. Towards the latter part of the period decreasing concentrations of P and K in the grass suggested that P or K supplies from the soil might be limiting the uptake of K or P respectively. To measure the separate effects of P and K residues extra K or P, in addition to N, was given to sub-plots testing P and K respectively. This test started in 1964 and at the same time three amounts of fresh K fertiliser and three of fresh P fertiliser were also tested by dividing each grass half-plot into eight sub-plots. Treatments and symbols were:

Nutrients as P_2O_5 and K_2O (kg/ha) given as triple superphosphate and potassium chloride

P test sub-plots			K test sub-plots		
	P_2O_5	K_2O		P_2O_5	K_2O
P_0K_4	none	1256	P_4K_0	2008	none
P_1K_4	502	1256	P_4K_1	2008	314
P_2K_4	1004	1256	P_4K_2	2008	628
P_4K_4	2008	1256	P_4K_4	2008	1256

https://doi.org/10.23637/ERADOC-1-8

Also in 1964 the arable/fallow half-plots were similarly divided into eight sub-plots which had the eight treatments listed above.

The amounts of K fertiliser applied in 1964 would have increased the K content of the 0–23 cm depth of soil by 99, 198 and 396 ppm K for the K_1, K_2 and K_4 treatments respectively if none was leached. This calculation was based on Hall's (1905) result that a hectare of fine soil 0–23 cm deep on Agdell weighs 2632 t/ha. We have used this weight of fine soil per hectare throughout this paper. The large dressings of fresh K were intended to give four amounts of exchangeable K on the grass half plot and four on the arable half. Because the grass had removed K during 1958–63 and so decreased the exchangeable K content of the soil it was expected that the two larger amounts of exchangeable K on the grass soils would approximately correspond with the two smaller amounts on the arable/fallow soils. In an attempt to maintain the differences in the exchangeable K contents of the grass soils the K content of the grass at each harvest was determined and the total amount of K removed each year by the grass was replaced as fertiliser K in the following winter, *except* on the K_0 sub-plots where no new K was given. This experiment continued until 1970. Altogether there were 48 sub-plots which tested:

1. K release from soils not given K since 1848 and from soils enriched with K residues from manuring a four-course rotation from 1848 to 1951.
2. The more recent effect of arable/fallow or grass cropping on the K content of these soils.
3. The effect of recent very large dressings of fertiliser K.

To complement the experiment in the field a glasshouse experiment was started in 1967 to measure K release from these soils by exhaustive cropping. The soil of each sub-plot was sampled to 23 cm by taking cores with a 7-cm diameter steel cylinder; about ten cores were taken for each sample. The samples were slowly air dried on paper in the glasshouse. As they dried, grass, large roots and stones were removed where necessary and the soils were sieved in succession through 1·25, 0·62 and 0·31 cm square mesh sieves. The soils had completely air dried before they were sub-sampled for the pot experiment and for analysis. The analytical sample was ground to pass a 2-mm sieve.

We have adopted the following conventions in this paper:

1. 'Rotation experiment' plots or treatments are the six plots and the cropping or manuring treatments given during the Classical experiment, 1848–1951.
2. 'Arable/fallow soils' and 'grass soils' are soils from the half-plots growing arable crops, 1959–62, subsequently fallowed, 1963–70, and soils from the half-plots growing grass, 1958–70.
3. Ryegrass refers only to the grass grown in the pot experiment in the glasshouse and that grown in the first cropping period of seven cuts is the first crop whilst that in the second cropping period, also of seven cuts, is the second crop. Grass grown in the field experiment is referred to only as grass.
4. K uptake by the ryegrass in the pot experiment is expressed as ppm K in air-dry soil.

Pot experiments

The first pot experiment was made with four replicates of each of the 48 soils, one replicate in each of four randomised blocks. Four hundred grammes of soil (air dry, $<0·3$ mm) and 200 g of quartz (>3 mm) for each pot were moistened and well mixed. Perennial ryegrass (0·5 g of seed per pot) was sown. Basal nutrients N, P and Mg at 100, 50 and 10 mg per pot were given at the start and 25 mg P and 5 mg Mg after the fourth cut. Fifty milligram N per pot was given at intervals during the experiment,

https://doi.org/10.23637/ERADOC-1-8

usually after each cut of ryegrass had been taken. The soils were kept moist by adding demineralised water to the glass saucers in which each pot stood.

The grass was cut after 43, 71, 113, 189, 259, 335 and 540 days, dried, weighed and then analysed for K by extracting with cold 0·5*N* HCl. Little dry matter was produced at either the sixth or seventh cut and the experiment was stopped. The stubble was removed from the pots and the moist soil sampled for analysis. The soils were then allowed to air dry and as much as possible of the root residue was removed by sieving. Quartz and soil were then separated by a 2-mm sieve. The air-dry soil was sampled for analysis before the soil from each of the four replicates was bulked and stored.

It has never been possible in these 'exhaustion-type' pot experiments to decide if the grass died because of genuine lack of nutrient or because of some other factor, possibly concerned with the root environment in the pot. In a different experiment Addiscott and Johnston (1974) tested the effect of resowing pots after removing the stubble but without air drying the soil and found that the newly sown grass germinated and continued to grow for a further 734 days after a first cropping period that had lasted for 1413 days. The 'exhausted' soils from our first pot experiment were resown to test the effect of air drying the soils. The second experiment was restricted to 60 pots, one replicate of each of 36 soils and two replicates of the remaining 12 soils. Three hundred and fifty grammes of soil (air dry <2 mm) and 130 g of quartz (>3 mm) for each pot were moistened and well mixed. Perennial ryegrass (0·5 g per pot) was sown. Basal nutrients N, P and Mg at 100, 50 and 10 mg per pot were given at the start and 25 mg P and 5 mg Mg after the third cut. Fifty milligrams N per pot was given after each cut of ryegrass had been taken in the second period of cropping. The grass was cut after 41, 81, 204, 301, 405, 496 and 749 days making the total of the first and second cropping periods 1289 days. The grass was dried, weighed and analysed for K as previously. There was very little dry matter produced between the sixth and seventh cuts and the experiment was stopped. The stubble was removed, dried, weighed and analysed for K. The soils were sampled whilst still moist and were then air-dried, the quartz was separated using a 2 mm sieve and the air-dried soils sampled for analysis.

Laboratory experiments

Previous results (Johnston & Addiscott, 1971) showed a good relationship between K uptake by ryegrass in pots and the quantity of K in soil measured as exchangeable to neutral N-ammonium acetate, K_e, even though the ryegrass removed more K from the soil than that measured as exchangeable. Only K_e was determined on the soils in our pot experiment except that the equilibrium K potential, $\Delta\bar{G}_0$, was determined on the moist exhausted soils at the end of the second cropping period. Results of these K potential measurements are discussed in detail by Addiscott and Johnston (1974). Appendix Table 1 shows K_e in the soils determined at the start of the pot experiment and in the moist exhausted and subsequently air-dried soils at the end of the first and second cropping periods. The effect of air drying on the exchangeable K content of the soils is also discussed in detail by Addiscott and Johnston (1974).

Pot experiment results

Cumulative K uptake related to time. Cumulative K uptakes by ryegrass for all treatments are given in Appendix Table 2. Fig. 1 shows cumulative K uptake plotted against time for the K_0 and K_4 treatments on the grass and arable/fallow half plots of three of the Rotation experiment plots (plots 1, 3 and 5). Although the amounts of K removed by the ryegrass depended on all the previous treatments, the shapes of the curves varied

https://doi.org/10.23637/ERADOC-1-8

little suggesting that the treatments in the field experiment had little effect on the pattern of K release when the soils were cropped exhaustively in the glasshouse. The 'step-like' increment in the curves in Fig. 1 was due to K taken up at the start of the second cropping period. This extra K was made available by air drying the moist soils exhausted by the first crop of ryegrass. However the shape of the uptake curve for the later cuts of the

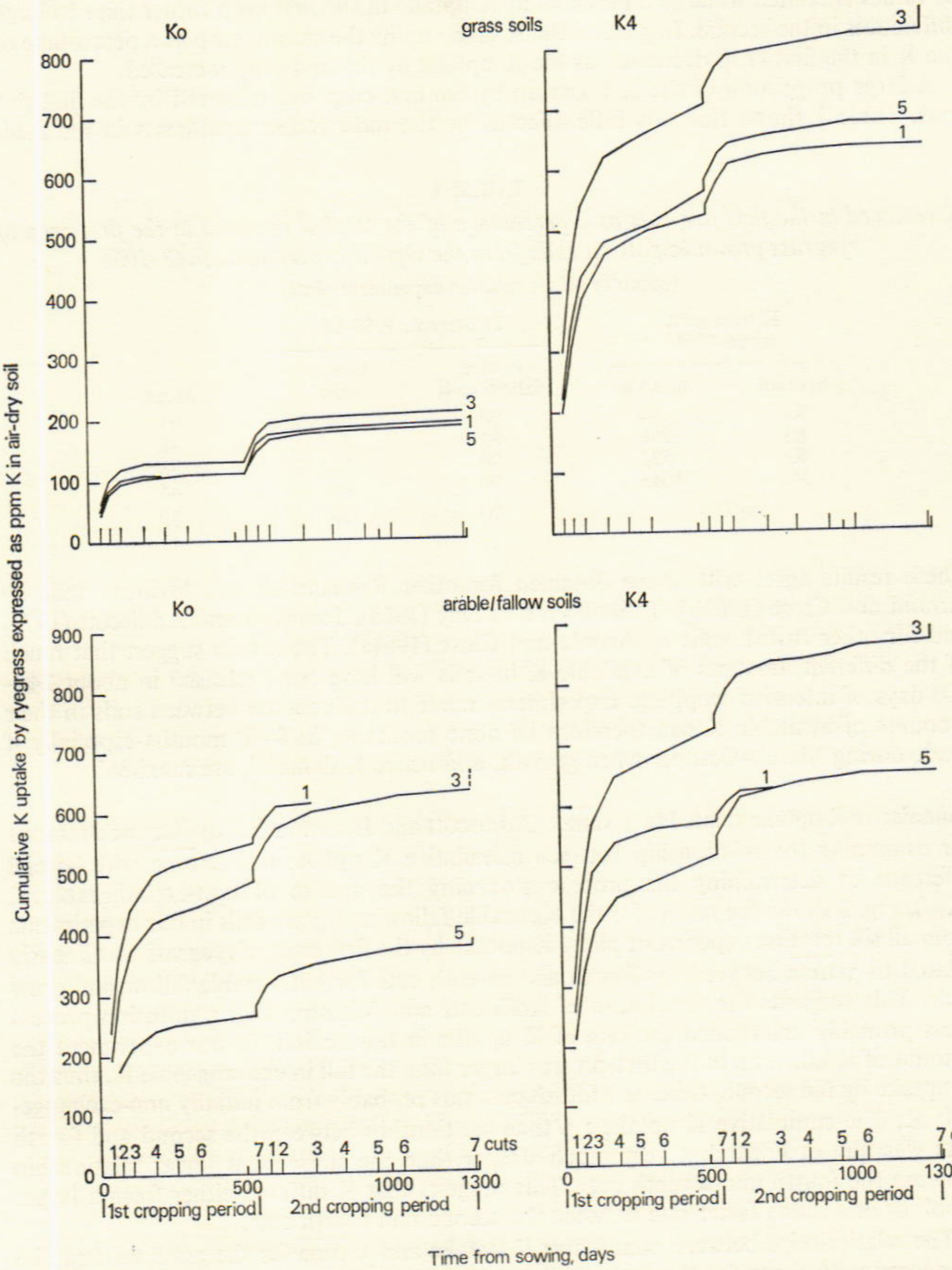

FIG. 1. Relationship between cumulative K uptake and time for soils without K (K_0) or with 1043 kg K/ha (K_4) applied in 1964 and cropped with grass or arable/fallow, 1958–67, from plots 1, 3 and 5 of the Classical Rotation experiment, 1848–1951, on Agdell.

https://doi.org/10.23637/ERADOC-1-8

second cropping period was very similar to that at the end of the first cropping period. This result agrees with that of Addiscott and Johnston (1974). In their experiment the pots were resown without air drying the soils; the step in each cumulative uptake curve was much smaller than in our experiment using air-dried soils. K uptake by the second crop varied from about 10% to more than 60% of that in the first crop. This wide range of values is related to large differences in K uptake in the first crop rather than to large differences in the second. In general the K taken up by the second crop as a percentage of the K in the first crop decreased as the K uptake by the first crop increased.

A large proportion of the K taken up by the first crop was removed by the first five cuts. Table 1 shows this was little affected by the most recent treatments in the field.

TABLE 1

K removed in the first five cuts as a percentage of the total K removed in the first crop of ryegrass grown in pots on soils from the Agdell experiment, 1848–1966

(Mean of all six rotation experiment plots)

K treatment given 1964		Treatment, 1958–66		
Symbol	kg K/ha	Arable/ fallow soils	Grass soils	Mean
K_0	0	90	96	93
K_1	261	89	86	88
K_2	522	90	85	88
K_4	1043	90	86	88
Mean		90	88	89

These results agree with those obtained for other Rothamsted and Woburn soils by Arnold and Close (1961b), Talibudeen and Dey (1968), Johnston and Addiscott (1971) and for other British soils by Arnold and Close (1961a). The results suggest that much of the different amounts of available K in soils will have been released in about 240–300 days of intensive cropping. Experiments made to differentiate between soils in their amounts of available K can therefore be done profitably in 8–10 months especially if made during March–October when growth, and hence K demand, are maximal.

Cumulative K uptake related to $\sqrt{\text{time}}$. Addiscott and Johnston (1974) discussed reasons for examining the relationship between cumulative K uptake and $\sqrt{\text{time}}$ with special reference to determining the process governing the uptake of non-exchangeable K (K_{ne}). Fig. 2 shows the results for the K_0 arable/fallow and grass soils in our experiments from all six rotation experiment plots. K uptake by the first crop of ryegrass was linearly related to $\sqrt{\text{time}}$ between the fourth and seventh cuts for both arable/fallow and grass soils. This supports the conclusion of Addiscott and Johnston that a diffusion process most probably determined the rate of K uptake in this period. In our experiment the amount of K taken up in the first cut was larger than the fall in exchangeable K, thus the K uptake by the second, third and fourth cuts was probably from initially non-exchangeable K. The cumulative K uptake : $\sqrt{\text{time}}$ relationship between the second and fourth cuts was almost linear but very much steeper than the subsequent linear relationship between the fourth and seventh cuts. This suggests that K diffused either from a larger 'pool' or at a much faster rate between the second and fourth cuts.

The relationships between cumulative K uptake and $\sqrt{\text{time}}$ for the grass soils can be compared with those for the arable/fallow soils. Much K was removed from the grass soils during 1958–66 so that in the pot experiment the average amount of K taken up in the second, third and fourth cuts of ryegrass was equal to only 70 ppm K in the air-

https://doi.org/10.23637/ERADOC-1-8

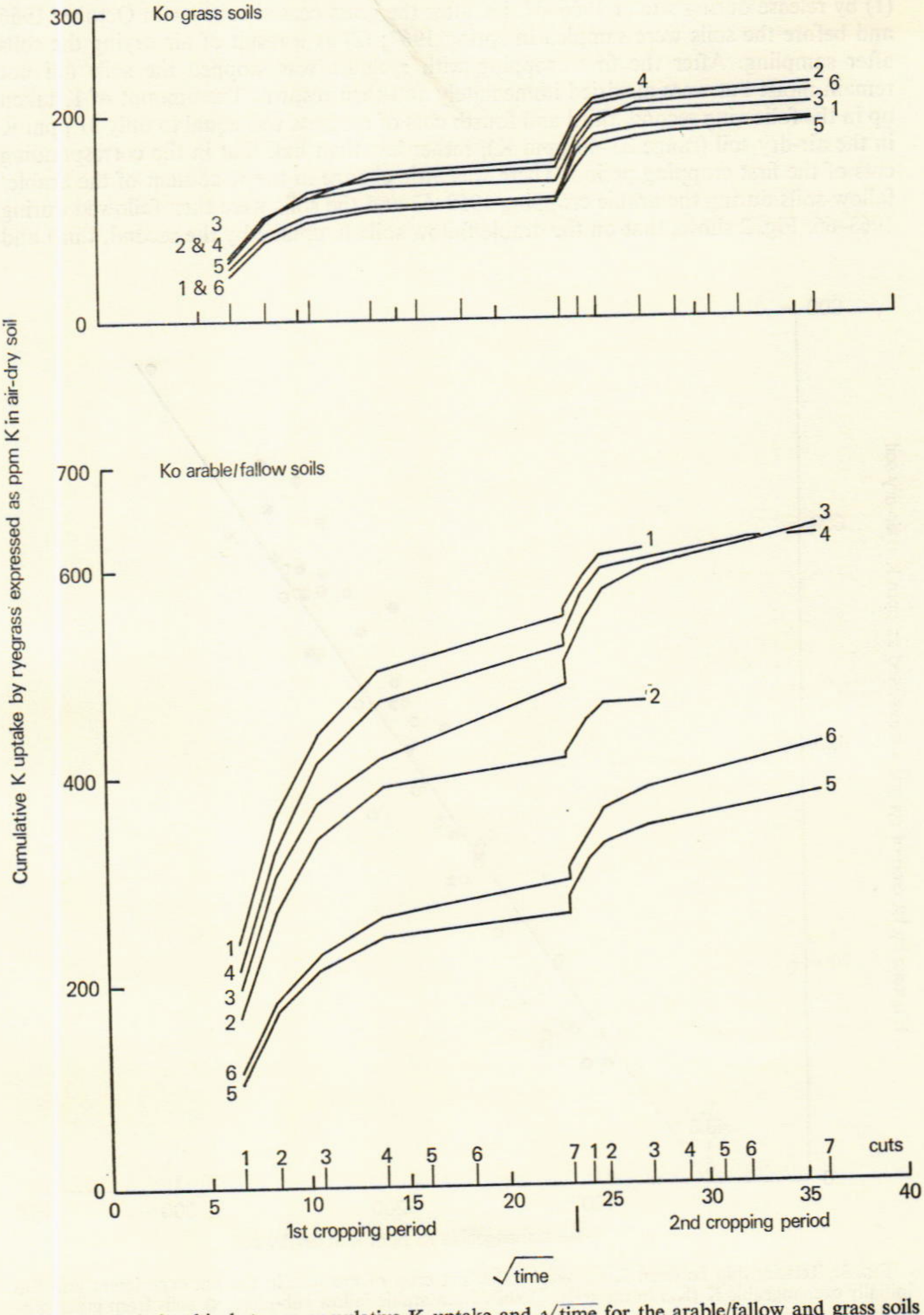

FIG. 2. Relationship between cumulative K uptake and $\sqrt{\text{time}}$ for the arable/fallow and grass soils not given K (K_0) in 1964 from all six plots of the Classical Rotation experiment, 1848–1951, on Agdell.

https://doi.org/10.23637/ERADOC-1-8

dry soil (range 59–90 ppm K). The range of values was not related to the rotation experiment treatments. Much of this K probably became available as a result of two processes: (1) by release during winter 1966–67, i.e. after the grass ceased to grow in October 1966 and before the soils were sampled in spring 1967; (2) as a result of air drying the soils after sampling. After the first cropping with ryegrass was stopped the soils did not remain moist but were air-dried immediately and then resown. The amount of K taken up in the following second, third and fourth cuts of ryegrass was equal to only 31 ppm K in the air-dry soil (range 23–46 ppm K), rather less than half that in the corresponding cuts of the first cropping period. There was little change in the K content of the arable/fallow soils during the arable cropping 1959–62 and the soils were then fallowed during 1963–66. Fig. 2 shows that on the arable/fallow soils K uptake by the second, third and

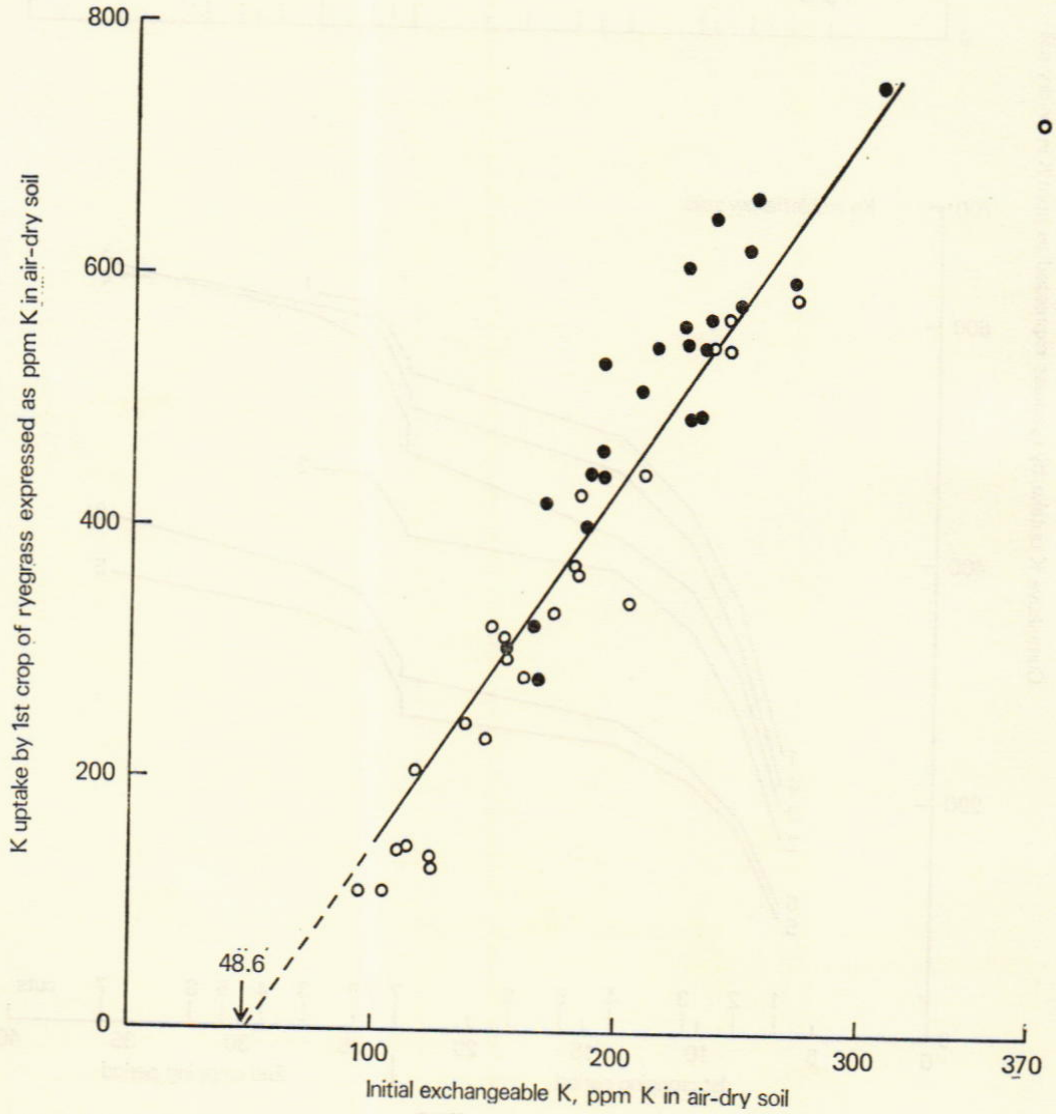

FIG. 3. Relationship between K uptake by the first crop of ryegrass in the pot experiment and the initially exchangeable K (K_e) in the soils. ○ soils from arable/fallow sub-plots, ● soils from grass sub-plots.

(slope $y = 2{\cdot}856x - 13{\cdot}88$; $r = +0{\cdot}94$)

https://doi.org/10.23637/ERADOC-1-8

fourth cuts of ryegrass was larger from soils with residues of K from the rotation experiment treatments than from soils unmanured since 1848. The slopes of the linear portions were also steeper where soils contained residues. However, in the second cropping period, the average amount of K taken up was 39 ppm K (range 20–59 ppm K) in the second, third and fourth cuts. This result was almost identical with the K uptake by the corresponding cuts of ryegrass from the grass soils. This suggests that the K residues in the arable/fallow soils were exhausted by the first crop of ryegrass and that K uptake by the second crop depended on K diffusing out from the same source on both groups of soils.

The slopes of the linear relationship between cumulative K uptake and $\sqrt{\text{time}}$ were calculated for cuts 2–4 and cuts 4–7 for the arable/fallow soils, from which the ryegrass took up much K. K uptakes from the grass soils were too small to enable the same calculations to be made reliably. When the slopes were related to the initial exchangeable K in the soils the correlation was poor ($r = + 0{\cdot}62$) for cuts 4–7 supporting Addiscott and Johnston's conclusion that little of this K fraction is in direct equilibrium with the exchangeable K. For the uptake by cuts 2–4 the slope was better correlated ($r = + 0{\cdot}77$) with the initial exchangeable K suggesting that more of this fraction of soil K was in equilibrium with the exchangeable K.

Cumulative K uptake related to initially exchangeable K. Appendix Table 1 gives the initial exchangeable K and K_e in the moist exhausted and subsequently air-dried soils after the first and second crops of ryegrass were grown in the pots. Fig. 3 shows K uptake in the first crop of ryegrass was well correlated ($r = + 0{\cdot}94$) with initial K_e when exchangeable K ranged from 95 to 370 ppm K. Assuming that the linear relationship between K uptake and K_e continues, extrapolating the data in Fig. 3 indicates that there would be no uptake of K by the ryegrass when K_e decreased to 48 ppm K; this value agrees excellently with that of Arnold and Close (1961b) who, for soils from the same field, found about 50 ppm K_e as the value at which there would be no K uptake. The value also agrees well with the experimentally determined exchangeable K contents of the moist exhausted soils. After the first crop of ryegrass was taken K_e in the moist soils was, on average, 62 ppm K whilst after the second crop there was 37 ppm K. These small values for K_e were measured in moist soil after exhaustive cropping in the glasshouse. On air drying these soils K_e increased to 80–90 ppm K but these values were still smaller that those found in comparable soils in the field experiment. Johnston and Penny (1971) showed that although grass had removed 860 kg K/ha during 1958–70 from soils without K manuring since 1848, K_e in air-dry soil in 1969 had decreased only to 107 ppm K.

K uptake in the first three cuts (113 days) was only slightly less well correlated ($r = + 0{\cdot}93$) with initial K_e. This result agrees with that of Arnold (1962) who found K uptake in 36 days cropping was well correlated ($r = + 0{\cdot}88$) with initial K_e (range 30–380 ppm K) for 64 soils taken from 50 sites in England. The total K uptake in both crops of ryegrass was also well correlated ($r = + 0{\cdot}93$) with K_e. However, K uptake in the second crop of ryegrass was poorly correlated ($r = + 0{\cdot}68$) with K_e in the air-dry soil at the start of the second cropping period. This, presumably, was because K uptake by the second crop depended much more on the amount and type of K releasing minerals in the soil.

Arnold and Close's (1961b) results for the Agdell soils showed that K uptake was linearly correlated with initial K_e. The results we report are not quite so good. The reason for this is not known but the following explanation is suggested. When sampled in 1958 the soils had had ten years without K manuring or intensive cropping. Ample time had elapsed therefore for equilibrium between exchangeable and non-exchangeable K to be established. The 1967 samples were taken from soils with and without recent large dressings of fresh K and some of the soils had been intensively cropped whilst others

https://doi.org/10.23637/ERADOC-1-8

were fallowed. It is probable therefore that equilibrium between exchangeable and non-exchangeable K had not been re-established and the relationship between K uptake and K_e was less good than when equilibrium had been established. This is supported by the following observation. When *differences* in K_e between arable/fallow and grass soils (differences due only to cropping and manuring since 1958) were correlated with *differences* in K uptake by ryegrass from the two groups of soils, a linear regression accounted for 78% of the variance. This was less than the variance accounted for (87%) by the linear regression of K uptake on K_e in Fig. 3 where the values for K_e depended on the history of cropping and manuring since 1848.

Uptake of non-exchangeable (K_{ne}) or initially non-available K by ryegrass

Determination of non-exchangeable K; effect of air-drying soils. Many workers have tried to relate release of K_{ne} to the decrease in K_e on cropping. Both depend on the measurement of K_e in the cropped soil,

$$\text{decrease in } K_e = \text{initial } K_e \text{ minus } K_e \text{ in cropped soils}$$
$$\text{release of } K_{ne} = \text{total K uptake minus decrease in } K_e$$

The amount of K_e in moist exhausted soil, expressed on an air-dry basis, is not readily determined because allowance must be made for the amount of quartz in the soil–quartz mixture extracted with ammonium acetate and the amount of air-dry soil must be determined. It is easier to determine K_e after air-drying especially if the quartz can be sieved out.

In our experiment K_e increased on air drying the soils, the increase varied from 30 to 160% of the K_e in the moist soil. The second crop of ryegrass decreased K_e to smaller values than did the first crop. However, after both crops K_e returned to the same value in the air-dry soil so that apparently more K was released on air drying after the second crop. The amounts of K_e in the moist and air-dry soils and the increases due to air drying were:

	Arable/fallow soils			Grass soil		
	Moist soil	Air-dry soil	Increase due to air drying	Moist soil	Air-dry soil	Increase due to air drying
	Exchangeable K, ppm in air-dry soil					
After the						
1st crop	60	83	23	65	89	24
2nd crop	38	80	42	36	91	55

The Rotation experiment treatments apparently had a large effect on the increase in K_e on air drying. The amounts of K_e in the moist and air-dry soil after the second crop of ryegrass and the increases due to air drying were:

Classical Rotation experiment treatments

	NPK	PK	Unmanued
	Exchangeable K, ppm in air-dry soil		
Moist soil	34	34	43
Air-dry soil	67	84	105
Increase due to air drying	33	50	62

Exhaustive cropping decreased K_e in moist soil to about 40 ppm K. Soils without K manuring during 1848–1964 gained more exchangeable K on air-drying than soils with K residues. However, this result is probably related to the clay content of the soils, those

https://doi.org/10.23637/ERADOC-1-8

which were unmanured in the Rotation experiment contained most clay because of their position in the field. Neither arable/fallow or grass cropping, 1958–66, nor K treatments applied in 1964 had any effect on the increase in K_e on air-drying the moist soils.

Uptake of K, decrease in K_e. K uptake by the first crop of ryegrass and decrease in exchangeable K in soils, using the K_e contents of the moist soils, were well correlated ($r = +0{\cdot}95$). The linear regression, which had a slope $y = 2{\cdot}887x + 3{\cdot}558$, accounted for 90% of the variance. Neither the Rotation experiment treatments nor the K applied in 1964 affected the ratio of the K uptake to decrease in K_e. There was little consistent effect of previous cropping:

Ratio of K uptake by ryegrass in pots to decrease in K_e in soil

(mean of six Rotation experiment plots)

K treatment given 1964	Arable/ fallow soils	Grass soils
K_0	3·45 : 1	2·73 : 1
K_1	3·26 : 1	3·05 : 1
K_2	3·24 : 1	3·31 : 1
K_4	3·15 : 1	2·87 : 1
Mean	3·28 : 1	2·99 : 1

K taken up by ryegrass in pots was, on average, three times larger than the fall in exchangeable K in the soil.

Release of non-exchangeable K and decrease in K_e. Because the release of K_{ne} is derived from K uptake it would be expected that release of K_{ne} and the decrease in K_e would be related as K uptake was to decrease in K_e. The correlation coefficient for the release of K_{ne} and decrease in K_e was $r = +0{\cdot}90$ whilst that for K uptake and decrease in K_e was $r = +0{\cdot}95$. Fig. 4 shows the relationship between release of K_{ne} and the

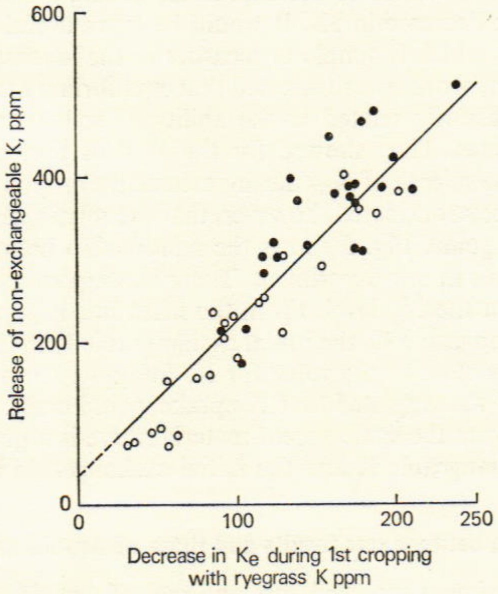

FIG. 4. Relationship between release of initially non-exchangeable K and the decrease in exchangeable K during the first cropping period by ryegrass ○ soils from arable/fallow sub-plots, ● soils from grass sub-plots.

(slope $y = 1{\cdot}887x + 3{\cdot}558$; $r = +0{\cdot}90$)

https://doi.org/10.23637/ERADOC-1-8

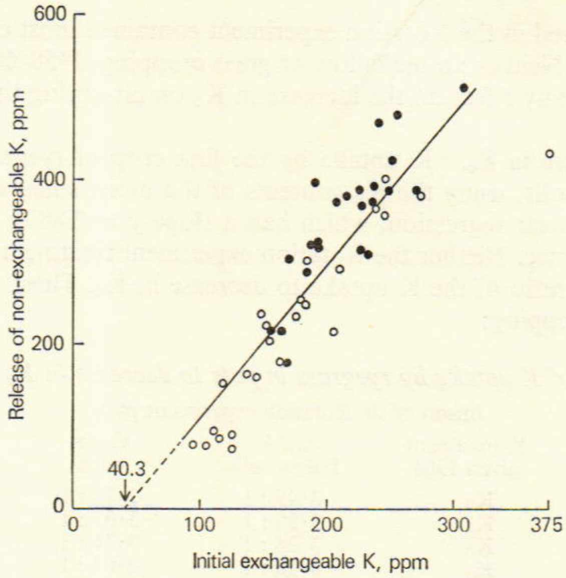

FIG. 5. Relationship between release of initially non-exchangeable K and the initial exchangeable K in the soil. ○ soils from arable/fallow sub-plots, ● soils from grass sub-plots.
(slope $y = 1{\cdot}833x - 7{\cdot}378$; $r = +0{\cdot}87$)

decrease in K_e. The fitted line did not quite pass through the origin but over the range of values tested the release of non-exchangeable K was about twice as large as the fall in K_e.

Release of non-exchangeable K and initial K_e. It is valuable to know how much non-exchangeable K might be released to growing crops. In the previous section release of K_{ne} was shown to be well related to decrease in K_e in soil. However, this required a pot experiment to measure decrease in K_e. It would be more useful if release of K_{ne} could be related to initial K_e which is simple to measure in the laboratory. Arnold and Close (1961b) stated that many workers had stressed that equilibrium amounts of K_e in different soil types are not necessarily related to the ability of soils to release potassium from non-exchangeable sources. They showed for the 19 soils they examined from various parts of Britain that the release of K_{ne} during exhaustive cropping tended to increase as initial K_e increased. They considered, however, that the relationship was not well enough defined to be a useful guide. Fig. 5 shows the relationship between release of K_{ne} and initial K_e for the 48 soils in our experiment. There was a good correlation ($r = +0{\cdot}87$) which was significant at the 1% level. From the fitted line it appears that when there is no release of non-exchangeable K, the initial exchangeable K in the air-dry soil would be 40 ppm K. This is very close to the value for K_e (48 ppm K) at which the relationship between K uptake and K_e suggested that K uptake would cease. Our experiment shows that for soils derived from the same parent material there is a good correlation between the release of non-exchangeable K and the initial exchangeable K in the air-dry soil.

Relation between our results and those of Arnold and Close

The results of the experiment reported here and that of Arnold and Close (1961b) offer one of the few opportunities to assess the reproducibility of the results obtained in this type of experiment. For the comparison of K uptakes by ryegrass only the results for our arable/fallow soils not given K in 1964 (K_0) can be used. Table 2 shows that in our

https://doi.org/10.23637/ERADOC-1-8

TABLE 2

Comparison between the results in the pot experiment, 1967–72, and those obtained by Arnold and Close (1961b)

Results in the 1967–72 experiment from K_0 arable/fallow soils only
K ppm in air-dry soil

Rotation experiment plot and treatment	K uptake by ryegrass in pots			Exchangeable K in soil		
	Johnston & Mitchell 1	Arnold & Close 2	Difference 1 minus 2	1967	1958	1967 minus 1958
1 NPK fallow	560	484	76	227	154	73
2 NPK clover	419	337	82	170	172	−2
3 PK fallow	511	549	−38	208	178	30
4 PK clover	531	396	135	193	134	59
5 None fallow	280	256	24	168	102	66
6 None clover	308	258	50	154	105	49
Mean	435	380	55			46

experiment average K uptake by ryegrass was equal to 435 ppm K in air-dry soil whilst in that of Arnold and Close K uptake was, on average, 380 ppm K. The difference in uptake, equal to 55 ppm K in air-dry soil is only 15% of the average uptake, 380 ppm K, in Arnold and Close's experiment. This is a satisfactory result. Agreement between the results of the two experiments is improved if compensation is made for known changes in K_e of the arable/fallow soils during 1958–67. Table 2 shows K_e in 1958 and 1967 and the increase in K_e during ten years. This increase in K_e probably came from non-exchangeable K reserves; on average, the increase was 46 ppm K. Assuming that gain in K from rainfall was about equal to loss of K by leaching the average increase in K_e (46 ppm K) in the soil during 1958–67 was almost equal to the extra 55 ppm K taken up by the ryegrass in our experiment. (Sampling note: the K_e results for 1958 given here differ slightly from those of Arnold and Close. Their samples were taken to represent the whole of one Rotation experiment plot. Our samples were taken by quarter plots and there were small differences in K_e between quarter plots. The results given here were from quarter plots sampled in 1958 and again in 1967.)

Relation between results of the pot experiment and the histories of the soils in the field

Because the histories of these soils are known so well the results of the pot and field experiments can be compared to see how well pot experiments can predict the release of K under field conditions and whether pot and field experiments measure the release of the same categories of soil K. After the Rotation experiment plots were halved in 1958 the change in soil K content on each half-plot is well known. Changes in arable/fallow soils were small due to arable cropping during 1959–62 but much K was removed by the grass during 1958–66. Thus, for corresponding arable/fallow and grass soils, differences in K content in 1967, when the soils were sampled for the pot experiment, can be calculated. In 1958 there were small differences, both plus and minus, in K_e of the quarter plots used in 1964 for the test of fresh fertiliser K. The average difference was equal to about 10 kg K/ha and is ignored in the subsequent calculations. During 1959–62 there were differences between the K applied to and K removed by the arable crops grown on the arable/fallow half plots. When K applied minus K removed was calculated there was the following K balance:

Rotation plot	1	2	3	4	5	6
K applied minus K removed (kg/ha)	−22	−34	−56	−45	+100	+112
Equivalent loss or gain in soil (ppm K)	−8	−12	−21	−17	+38	+42

These differences are allowed for in the following calculations. During 1958–63 grass removed K from the grass half-plots and during 1964–66 from the K_0 sub-plots, none of this K was replaced. During 1964–66 K taken up by the grass on the K_1, K_2 and K_4 sub-plots was replaced as fertiliser K. The total amounts of K removed from K_0 sub-plots during 1958–66 and the amounts of K replaced on K_1, K_2 and K_4 sub-plots during 1964–66 are given in Table 3.

TABLE 3

K uptake by grass in the field experiment, Agdell, 1958–66

(K kg/ha)

Rotation experiment plot and treatment	K removed: from whole plot 1958–63	K removed: from K_0 sub-plot 1964–66	K removed: total from K_0 sub-plot 1958–66	K uptake by grass 1964–66 (replaced by equivalent K as fertiliser) Sub-plot: K_1	K_2	K_4
1 NPK fallow	970	391	1361	619	636	780
2 NPK clover	725	258	983	538	632	797
3 PK fallow	818	318	1136	605	652	715
4 PK clover	698	360	1058	572	638	751
5 None fallow	372	225	597	516	584	735
6 None clover	308	233	541	560	547	698

Comparison of the K uptake from K_0 arable/fallow soils in pots and K removed by the grass in the field during 1958–66. K uptake by ryegrass in pots from K_0 arable/fallow soils should be related to the K taken up by the grass during 1958–66 from the K_0 grass soils in the field. Table 4 shows the amount of K (kg/ha) removed by the first crop of

TABLE 4

Comparison of K uptake from K_0 arable/fallow soils in the pot experiment and K removed by grass in the field during 1958–70, the Agdell experiment

Rotation experiment plot	K, kg/ha, taken up from soils not given K in 1964 — K in arable/fallow soils in 1958 calculated from pot experiment results: K uptake by ryegrass in pots	K in soil corrected for changes in 1959–62	K removed by grass in the field experiment from K_0 grass soils	K removed by grass in the field minus estimate of available K
	1967–70 (1st crop)		1958–66	
1	1474	1496	1361	−135
2	1103	1137	983	−154
3	1345	1401	1136	−265
4	1398	1443	1058	−385
5	736	636	597	−39
6	810	698	541	−157
Mean		1135	946	−189
	1967–72 (both crops)		1958–70	
1	1621	1643	1659	+16
2	1234	1268	1218	−50
3	1752	1808	1430	−378
4	1652	1697	1405	−292
5	1015	915	858	−57
6	1148	1036	757	−279
Mean		1394	1221	−173

https://doi.org/10.23637/ERADOC-1-8

ryegrass from the K_0 arable/fallow soils. This was not the amount of K in the arable/fallow soils in 1958 because of the changes in the K content during 1959–62. These changes are known so Table 4 shows the corrected amounts of available K in the arable/fallow soils, derived from the pot experiment results, and compares it with the K uptake by grass in the field during 1958–66. The amounts of K taken up by the grass in the field are all slightly smaller than the pot experiment estimates of the total K available to the grass. The average difference, 189 kg K/ha is only 20% of the average amount of K removed in the field. Table 4 also shows the total uptake in the field during 1958–70 and compares it with the amount of available K derived from the total K uptake in both crops of ryegrass in pots. In this second comparison individual plot differences are rather more variable but on average the ryegrass in pots took up 15% more K than did grass in the field. However, the K taken up from the soil in both pot and field experiments are sufficiently close for confidence in the pot technique as a method of estimating total amounts of K likely to be available to crops over periods as long as ten years.

Differences in K uptake between arable/fallow and grass soils in the pot experiment compared to estimated differences in K content of the soils in 1967. The differences in K contents of corresponding arable/fallow and grass soils in the field at the time of sampling in 1967 can be calculated and compared with the differences in the amounts of K taken up by ryegrass in the pot experiment. Table 5 shows the difference in the amount of K

TABLE 5

Differences in K uptake between arable/fallow and grass soils in the pot experiment compared to estimated differences in K content of the soils in 1967, the Agdell experiment

K, kg/ha, taken up from soils not given K in 1964

Rotation experiment plot	Difference in the amount of K taken up by ryegrass in pots arable/fallow minus grass	Estimated difference in the K content of the arable/fallow and grass soils	Difference measured by the pot experiment minus estimated difference
	K in 1st crop of ryegrass	K uptake by grass 1958–66	
1	1174	1339	−165
2	718	949	−231
3	1000	1081	−81
4	1008	1013	−5
5	442	697	−255
6	450	653	−203
Mean	799	955	−156
	K in both crops ryegrass	K uptake by grass 1958–70	
1	1116	1637	−521
2	637	1184	−547
3	1189	1374	−185
4	1076	1360	−284
5	518	958	−440
6	568	869	−301
Mean	851	1230	−379

(kg/ha) taken up by the ryegrass from the K_0 arable/fallow and K_0 grass soils in the pot experiment. Table 5 also shows the estimated differences in the K content of the K_0 arable/fallow and grass soils calculated from the known K uptake by the grass in the field and the change in K content of the arable/fallow soils during arable cropping in 1959–62. Table 5 shows that the estimated difference in the amounts of K in the arable/fallow and grass soils in 1967, was, on average, 955 kg K/ha. The difference in K uptake

https://doi.org/10.23637/ERADOC-1-8

by the ryegrass was, on average, 799 kg K/ha, about 85% of the estimated difference. If the results in the preceding section are correct, namely that ryegrass in pots takes up most of the available K, then our results which show that the differences in K uptake between arable/fallow and grass soils were larger when measured by grass in the field experiment than when measured by ryegrass in pots suggests that some K in the field experiment came from other sources. Amounts of K in rainfall are too small to account for the discrepancy but K could have come from the sub-soil. The amount of K derived from this source was, on average, about a sixth of the total K taken up by the grass in the field.

Table 5 also shows that when total K uptake by both crops of ryegrass was compared with total K uptake by grass in the field during 1958–70, apparent K recovery by ryegrass in pots was less; only 70% was recovered compared to 85% in the preceding calculation. There are two possible explanations for this result. The first is that grass in the field took up more K from the surface soil than ryegrass was able to get in pots. This would be possible if firmly held non-exchangeable K continued to become available during the winter when there was no crop uptake; in the pot experiment the soil did not have this 'rest and frost period'. This in turn suggests that the rate of release of this category of soil K is quite slow. The second explanation is that as the surface soil was exhausted of K the grass took up more K from the soil below 23 cm. In practice both mechanisms could work together.

TABLE 6

Estimates of the recovery of fertiliser K as extra K_e in soil and as extra K taken up by ryegrass in pots

K added in 1964 to sub-plots in the Agdell experiment
(mean of six Rotation experiment plots)
K, ppm, in air-dry soil

K treatment		K recovered									K recovered as a percentage of K added					
		as K_e in soil			by ryegrass in pots						as K_e in soil		by ryegrass in pots			
					1st crop			1st and 2nd crop					1st crop		1st and 2nd crop	
			increase over			increase over			increase over		increase over		increase over		increase over	
Symbol	Amount	Amount	K_0	K_1	Amount	K_0	K_1	Amount	K_0	K_0	K_0	K_1	K_0	K_1	K_0	K_1
								Arable/fallow soils								
K_0	0	187			435			534								
K_1	99	202	15		470	35		562	28		15		35		28	
K_2	198	225	38	23	535	100	65	626	92	64	19	23	50	66	46	65
K_4	396	256	69	54	614	179	144	708	174	146	17	18	45	48	44	49
Mean % recoveries											17	20	43	57	39	57
								Grass soils								
K_0	0	112			131			210								
K_1	99	157	45		281	150		411	201		45		152		203	
K_2	198	167	55	10	341	210	60	470	260	59	28	10	106	61	131	60
K_4	396	264	152	107	568	437	287	678	468	267	38	36	110	96	118	90
Mean % recoveries											37	23	123	78	151	75
Grass soils but with the K_0 results for uptake by ryegrass adjusted for K uptake by grass in the field																
K_0	0				244			323								
K_1	99				281	37		411	88				37		89	
K_2	198				341	97	60	470	147	59			49	61	74	60
K_4	396				568	324	287	678	355	267			82	96	90	90
Mean % recoveries													56	78	84	75

https://doi.org/10.23637/ERADOC-1-8

Recovery of fertiliser K added in 1964

As an increase in exchangeable K (K_e) in soil. K_e in the top 0–23 cm of soil would have increased by 99, 198 and 396 ppm K for the K_1, K_2 and K_4 treatments respectively if all the fertiliser K added in 1964 had remained both in the surface soil and in an exchangeable form. Previous laboratory studies on K fixation by Rothamsted soils (Warren & Johnston, 1962) had suggested that, at best, only about 50% of the K added to the Agdell soils would remain exchangeable. Increases in K_e due to individual treatments can be calculated from the results in Appendix Table 1. Table 6 shows the increases in K_e by each of the three K treatments applied in 1964 averaged over the six Rotation experiment treatments and the percentage K recovered as extra K_e. Results are also given for the effect of the K_2 and K_4 treatments compared to K_1. On soils which were fallowed for three years after K was applied the percentage recovery of added K, either as an increase over K_0 or over K_1, was reasonably consistent. About 20% of the added K was recovered as extra K_e in the top 23 cm of soil; recovery appeared to be independent of the amount of K added. On soils cropped with grass during 1964–66, K taken up by the grass from the K_0 sub-plots was not replaced and the K content of the soil decreased, but on the sub-plots with the other K treatments K was replaced each year. Therefore, when measured as an increase over K_0, recovery of added K was larger on grass soils than on arable soils. However, when extra K_e in K_2 and K_4 treated soils was calculated from K_e in K_1 soils the recovery was about the same (20–23%) for both grass and arable soils.

As K taken up by ryegrass in pots. Table 6 also shows the amount of extra K taken up by ryegrass in pots and the percentage recoveries both for the first crop and the first and second crops combined. From soils fallowed during 1964–66 the ryegrass recovered about 40% of the added K as an increase over K_0 and rather more (57%) as an increase over K_1. Percentage recovery changed little when extra K in the first crop was compared with extra K in both crops together suggesting that most of the recently applied K that was available to the ryegrass was taken up by the first crop. For the grass soils Table 6 shows that when the recoveries of added K were measured as increases over K_0 apparent recoveries were larger than 100% in all comparisons. This was because K removed by grass from the K_0 sub-plots during 1964–66 was not replaced. When recoveries from the K_2 and K_4 treatments were measured as increases over K_1, about 75% of the added K was recovered either by the first crop of ryegrass alone or by both crops. This value was larger than the corresponding recovery from the arable soils because fresh K, equal to the amount removed by the grass in the field, was added to the soil each year. More of this very recently added K was available to the ryegrass compared to the K added in 1964.

Apparent recovery of added K exceeded 100% on the grass soils when measured as an increase over K_0 because K removed by the grass from the K_1, K_2 and K_4 sub-plots was replaced whilst the K taken from K_0 sub-plots was not put back. However, the K uptake by grass from K_0 sub-plots in the field during 1964–66 is known; on average it was equal to 113 ppm K in air-dry soil. If it is assumed that all this K would have been available to the ryegrass in the pots, if it had not been removed by the grass in the field, the K uptake by ryegrass for K_0 grass sub-plots can be increased by this amount. The last section of Table 6 shows the effect of adding 113 ppm K to the K uptake (131 ppm K) by the first crop of ryegrass and the total K uptake (210 ppm K) by both crops of ryegrass and using these corrected values, 244 and 323 ppm K respectively, to calculate recoveries of added K. The percentage recoveries of K added in the K_2 and K_4 treatments when compared to K_0 or K_1 are now much closer, all about 75%. As with other results the fact that this correction can be made suggests that both field and pot experiments were measuring much the same amounts of K from the same categories of soil K.

https://doi.org/10.23637/ERADOC-1-8

Comparison of soil and pot experiment measurements for the recovery of added K. Table 6 shows that the recovery of added K, measured as an increase in K_e, was much smaller than the amount of extra K recovered by ryegrass in pots. The increase in K_e was only about half that expected from the results of laboratory tests on fixation of K by soil, probably because it is difficult to simulate in a laboratory experiment conditions which occur in the field during a period of three years. There are too few comparisons to tell whether arable/fallow or grass crops differed in their effect on the recovery of added K. The ryegrass recovered much more of the K added in 1964 then remained as extra K_e in the soil. The percentage recoveries were larger on the grass soils than on the arable/fallow soils, 78 and 57% respectively, when the increases were measured relative to the K_1 treatment. The percentage recovery by ryegrass was 2·8–3·3 times as large as the percentage recovery measured as extra K_e in the soil. The extra K in the ryegrass from the K applied in 1964 was well correlated ($r = +\,0{\cdot}92$) with the extra exchangeable K in the soil.

TABLE 7

Amounts of K taken up by the first crop of ryegrass from exchangeable (K_e) and non-exchangeable (K_{ne}) sources from soils in the Agdell experiment

K, ppm, in air-dry soil

K treatment given 1964		Rotation experiment plot													
		1		2		3		4		5		6		Mean	
Symbol	Amount	K_e	K_{ne}	K_e	K_{ne}	K_e	K_{ne}	K_e	K_{ne}	K_e	K_{ne}	K_e	K_{ne}	K_e	K_{ne}
		Arable/fallow soils													
K_0	0	172	388	116	303	139	372	133	398	103	177	91	217	126	309
K_1	99	145	316	175	312	159	449	163	379	105	218	117	282	144	326
K_2	198	200	422	180	309	186	479	177	369	126	320	123	320	165	370
K_4	396	192	386	211	385	239	511	180	467	173	372	174	391	195	419
		Grass soils													
K_0	0	36	78	52	94	57	74	62	86	34	78	47	90	48	83
K_1	99	83	161	56	153	114	248	92	204	75	159	129	211	92	189
K_2	198	85	238	101	179	117	251	127	301	92	223	98	232	103	237
K_4	396	177	364	154	291	297	432	187	356	203	380	168	400	198	370

Recovery of added K from exchangeable and non-exchangeable sources. Table 7 shows K uptake by the first crop of ryegrass apportioned between K from K_e and K_{ne} fractions in the soil. K_e results were derived from initial K_e minus K_e in moist exhausted soil, K_{ne} results from total K uptake minus K_e. For all amounts of new K added in 1964, i.e. 0, 261, 522, 1043 kg K/ha, the ratios of K uptake from K_{ne} and K_e were very consistent:

Ratio K_{ne} to K_e

	Treatments given in 1964			
	K_0	K_1	K_2	K_4
Arable/fallow soils	2·45	2·26	2·24	2·15
Grass soils	1·73	2·05	2·30	1·87

Less K tended to come from K_{ne} on grass soils which received very recent dressings of fertiliser K. The ratios of the *extra* K taken up from K_2 and K_4 treatments compared to K_1 were:

Ratio K_{ne} to K_e

	K_2 minus K_1	K_4 minus K_1
Arable/fallow soils	2·1	2·2
Grass soils	4·4	1·7

https://doi.org/10.23637/ERADOC-1-8

On average about 2·5 times as much of the extra K taken up came from the non-exchangeable K fraction.

Table 7 also shows two further interesting results. First, from soils which had most K in 1964 (K_4 sub-plots) K uptake was about the same from both K_e and K_{ne} irrespective of the preceding cropping and even though the K_4 grass soils had had dressings of K fertiliser more recently than the arable/fallow soils. This suggests that these results may be maximum values for these two categories of K in this soil. Second, on the arable/fallow K_0 sub-plots, natural weathering during fallowing increased the amounts of K_{ne} and K_e taken up by ryegrass to near the values on the K_4 sub-plots. This increase in plant available K during weathering must depend on the type and amount of clay minerals in the soil and on the ability of the soil to retain this K against loss by leaching.

Recovery of the K residues accumulated during the Rotation experiment, 1848–1951

Johnston and Penny (1971) estimated the amounts of K added to and removed from each plot of the Rotation experiment during 1848–1957. The amount of K applied in manures was known as was the yield of the crops, where % K in these crops had not been determined the % K in crops grown under very similar conditions was used to estimate K removals. They found that grass did not recover all the estimated K residues during 12 years cropping in the field; the larger the amount of the residue the smaller was the percentage recovered. This was not because cropping was stopped too soon; during the later years of the period K uptake was about the same on all K_0 sub-plots. This result was disappointing as there was a good correlation between the estimated amount of the residues and K_e in the soil in 1958.

TABLE 8

Comparisons of various estimates of the K residues accumulated during the Agdell Rotation experiment, 1848–1951

(K kg/ha)

			K uptake by grass in field experiment			K uptake by ryegrass in our experiment arable/fallow soils only				K uptake by ryegrass in Arnold and Close's experiment			
	Rotation experiment plot and treatment	Estimate of K residues[1]	K uptake	K from residues	% recovery of estimated residue	K uptake	K from residues	% recovery of estimated residue	% of field estimate	K uptake	K from residues	% recovery of estimated residue	% of field estimate
	Uptake of K by grass in the field during 1958–66 and by 1st crop of ryegrass in the pot experiment												
1	NPK fallow	+1445	1361	764	53	1496	861	60	107	1273	600	42	75
2	NPK clover	+788	983	442	56	1137	439	56	95	887	208	26	45
3	PK fallow	+1576	1136	539	34	1401	765	48	134	1445	772	49	136
4	PK clover	+595	1058	517	87	1443	745	125	115	1042	363	61	56
5	None fallow	(−1199)[2]	597			636				673			
6	None clover	(−1454)[2]	541			698				679			
	Mean				58			72	113			44	78
	Uptake of K by grass in the field during 1958–70 and by both crops of ryegrass in the pot experiment												
1	NPK fallow		1659	801	55	1643	728	50	91				
2	NPK clover		1218	461	59	1268	232	29	50				
3	PK fallow		1430	572	36	1808	893	57	156				
4	PK clover		1405	648	109	1697	661	111	102				
5	None fallow		858			915							
6	None clover		757			1036							
	Mean				65			62	100				

[1] Johnston and Penny (1971)
[2] K removed from plots given no K during the Rotation experiment, 1848–1951

Table 8 shows (1) the amount of the estimated K residues; (2) K uptake by grass in the field during 1958–66 and 1958–70 and the percentage recovery of the estimated K residues; (3) the amount of K residues calculated from (a) our pot experiment and

https://doi.org/10.23637/ERADOC-1-8

(b) the pot experiment of Arnold and Close. (The results of Arnold and Close have been recalculated using the weight of soil per hectare given at the beginning of this paper.) Table 8 shows that where crops were grown without manure from 1848 to 1957 large amounts of K were removed from the soil. There is no way of telling if fertiliser K applied to the other plots prevented the release, and presumably loss, of this amount of K from those soils. We have calculated the amount of the residues as K applied minus K removed without attempting to allow for K which may have been released from soil minerals To calculate K uptake from the residues on plots 1 and 3, K uptake on the unmanured plot 5 was used, and similarly for plots 2 and 4, which grew clover in the Rotation experiment, K uptake from the residues was calculated using K uptake on plot 6. From the results of our pot experiment only K uptake from arable/fallow soils were used, and these were corrected for the small changes in K content during the arable cropping, 1959–62.

Table 8 shows K uptake by grass in the field on K_0 sub-plots during 1958–66 and 1958–70. Percentage recovery changed little with the longer period of cropping except on plot 4, 58% and 65% of the calculated residues were recovered during 1958–66 and 1958–70 respectively.

Table 8 also shows that the amounts of residual K taken up by the first crop of ryegrass in our pot experiment was about equal to that taken up by grass in the field during 1958–70 for plots 1 and 2 and rather more for plots 3 and 4. The first crop of ryegrass recovered, on average, 72% of the estimated K residues, the grass in the field experiment recovered 65%. Table 8 shows that apparently less residual K (62%) was recovered when the uptakes by both crops of ryegrass were considered. This was because proportionately more K was taken up from the starved soils (plots 5 and 6) which contained most clay. In Arnold and Close's experiment the recovery of the estimated K residues was rather less, 44%.

All the pot experiment results, and especially that for the first crop of ryegrass in our experiment, support the results of the experiment made in the field. On average only about 70% of the estimated K residues were recovered. Unfortunately the experiments failed to show whether the incomplete recovery of residual K was due to it being very firmly fixed within the clay minerals or because it had been leached out of the surface soils and below root range in the field.

Summary

1. A pot experiment was made in the glasshouse to measure K release from soils taken in 1967 from the Agdell experiment at Rothamsted. The amounts of K in the soil depended on cropping and manuring in the Classical Rotation experiment, 1848–51, on arable/fallow or grass cropping during 1958–66, and on large dressings of K fertiliser, 261, 522 and 1043 kg K/ha, given in 1964. When the ryegrass in the pots ceased to grow the soils were air-dried and resown for a second crop of ryegrass.

2. K uptake was measured in each of the seven cuts of the first crop of ryegrass and again in seven cuts of the second crop. Exchangeable K was measured in the soils at the start of the experiment and in the moist and air-dried soils after both crops of ryegrass had been grown. Air-drying the moist exhausted soils increased the exchangeable K content by as little as 30% to as much as 160% of the exchangeable K in the moist soil.

3. The shape of the curves relating cumulative K uptake in the pot experiment and time was not affected by any of the treatments in the field experiment except in so far as the treatments affected total available K. Air-drying the soil after the first crop of ryegrass

https://doi.org/10.23637/ERADOC-1-8

made more K available and there was a step-like increment in each curve. About 90% of the K taken up by the first crop of ryegrass was removed by the first five cuts. The fifth cut was taken after 259 days; the first cropping period lasted for 540 days.

4. The relationship between cumulative K uptake and $\sqrt{\text{time}}$ distinguished two categories of non-exchangeable K; the first category was released rapidly and was better correlated with exchangeable K than the second which was released much more slowly. It was this 'slow-release' K which was taken up by the fourth to seventh cuts of both crops of ryegrass.

5. K uptake by the first crop of ryegrass suggested that the 'readily available' pool of non-exchangeable K was related to Rotation experiment residues and cropping during 1958–66. K uptake by the second crop of ryegrass was independent of all previous treatments. The K taken up in the first four cuts of the second crop was from the readily available pool of non-exchangeable K which had been replenished by air-drying the soils.

6. Cumulative K uptake by the first crop of ryegrass was linearly related with initial exchangeable K, correlation coefficient $r = +0{\cdot}94$. Extrapolation of the data suggested that no K would be taken up when the exchangeable K decreased to 48 ppm K, a value similar to the exchangeable K, 62 ppm K, in the moist exhausted soils. Variability from the linear relationship was because recent large additions of K fertiliser and intensive cropping prevented the establishment of the equilibrium between non-exchangeable and exchangeable K.

7. Both K uptake and release of non-exchangeable K were well correlated with the decrease in exchangeable K in the soil on cropping. Release of non-exchangeable K was about twice the decrease in exchangeable K.

8. Release of non-exchangeable K and initial exchangeable K were well correlated ($r = +0{\cdot}87$). Possibly this was because the experiment was made with soils derived from the same parent material.

9. Where comparisons could be made there was good agreement between the results obtained in this experiment and in an earlier one made in 1958. This suggests that the pot experiment results are reproducible.

10. The pot experiment estimates of the amount of available K in the soils differed by only 15% from the K uptake by grass in the field experiment during nine years.

11. K added as fertiliser in 1964 increased exchangeable K in the soil by only 20% and this increase was independent of the amount added.

12. Recovery of added K by ryegrass in pots depended on previous cropping, only 40–50% of the added K was recovered where the soils were fallowed for three years after the K was applied. More K was recovered where K was added each year before sampling.

13. K recovered by ryegrass was three times as much as the increase in exchangeable K in the soils. Recovery of added K from non-exchangeable sources was twice as large as from the exchangeable K.

https://doi.org/10.23637/ERADOC-1-8

14. Of the estimated K residues remaining in the soil from the Rotation experiment, 1848–1951, only 70% was recovered by ryegrass in pots. This result was in good agreement with that obtained in a field experiment lasting nine years.

15. Release of K by weathering of soil minerals increased the amounts of exchangeable and non-exchangeable K in the soil that were available to plants in the same ratio that residues of applied K fertiliser increased plant available exchangeable and non-exchangeable K.

16. Results from both pot and field experiments confirm that the crops grown in both experiments were measuring the same amounts and categories of soil K.

References

Addiscott, T. M. & Johnston, A. E. (1974) Potassium in soils under different cropping systems. 3. Non-exchangeable potassium in soils from long-term experiments at Rothamsted and Woburn. *Journal of Agricultural Science, Cambridge*. (In the press.)

Arnold, P. W. (1962) The potassium status of some English soils considered as a problem of energy relationships. *Proceedings of the Fertiliser Society* **72**, 25–43.

Arnold, P. W. & Close, B. M. (1961a) Release of non-exchangeable potassium from some British soils cropped in the glasshouse. *Journal of Agricultural Science, Cambridge* **57**, 295–304.

Arnold, P. W. & Close, B. M. (1961b) Potassium releasing power of soil from the Agdell rotation experiment assessed by glasshouse cropping. *Journal of Agricultural Science, Cambridge* **57**, 381–386.

Hall, A. D. (1905) *The book of the Rothamsted experiments*, 1st edition. London: John Murray. 294 pp.

Johnston, A. E. & Addiscott, T. M. (1971) Potassium in soils under different cropping systems. I. Behaviour of K remaining in soils from classical and rotation experiments at Rothamsted and Woburn and evaluation of methods of measuring soil potassium. *Journal of Agricultural Science, Cambridge* **76**, 539–552.

Johnston, A. E. & Penny, A. (1971) The Agdell Experiment, 1848–1970. Estimates of the P and K accumulated from fertiliser dressings given between 1848 and 1951, their recovery by grass between 1958 and 1970, and their effect on the response by grass to new dressings of P and K. *Rothamsted Experimental Station. Report for 1970*, Part 2, 36–68.

Johnston, A. E., Warren, R. G. & Penny, A. (1970) The value of residues from long-period manuring at Rothamsted and Woburn. V. The value to arable crops of residues accumulated from K fertilisers. *Rothamsted Experimental Station. Report for 1969*, Part 2, 69–90.

Talibudeen, O. & Dey, S. K. (1968) Potassium reserves in British soils. I. The Rothamsted classical experiments. *Journal of Agricultural Science, Cambridge* **71**, 95–104.

Warren, R. G. & Johnston, A. E. (1962) The accumulation and loss of soil potassium in long-term experiments, Rothamsted and Woburn. *Proceedings of the Fertiliser Society* **72**, 5–24.

https://doi.org/10.23637/ERADOC-1-8

APPENDIX TABLE 1

Exchangeable K in the soils from the Agdell experiment at the start of the pot experiment in 1967 and in the moist and air-dried soils after the first and second crops of ryegrass had been grown

K_e, ppm, in air-dry soil

Rotation experiment plot and treatment 1848–1951	K treatment given 1964	Arable/fallow soils, 1958–67: 1st cropping cycle at start	1st cropping cycle at the end: moist soil	1st cropping cycle at the end: air-dry soil	2nd cropping cycle at start	2nd cropping cycle at the end: moist soil	2nd cropping cycle at the end: air-dry soil	Grass soils, 1958–67: 1st cropping cycle at start	1st cropping cycle at the end: moist soil	1st cropping cycle at the end: air-dry soil	2nd cropping cycle at start	2nd cropping cycle at the end: moist soil	2nd cropping cycle at the end: air-dry soil
1 NPK fallow	K_0	227	55	74	74	53	57	95	59	74	74	31	75
	K_1	193	48	62	62	47	47	138	55	74	74	27	71
	K_2	252	52	67	67	53	52	148	63	79	79	27	74
	K_4	249	57	72	72	36	64	238	61	84	84	29	74
2 NPK clover	K_0	170	54	69	69	32	65	111	59	82	82	31	80
	K_1	229	54	74	74	39	68	117	61	79	79	29	78
	K_2	233	53	72	72	22	54	163	62	80	80	24	80
	K_4	271	60	75	75	33	64	210	56	75	75	26	69
3 PK fallow	K_0	208	69	95	95	43	93	125	68	92	92	50	93
	K_1	227	68	91	91	47	101	183	69	95	95	48	96
	K_2	256	70	95	95	41	95	181	64	93	93	39	100
	K_4	307	68	96	96	45	100	373	76	94	94	36	103
4 PK clover	K_0	193	60	80	80	19	72	114	52	64	64	32	67
	K_1	215	52	73	73	36	64	154	62	91	91	26	78
	K_2	227	50	75	75	20	57	184	57	80	80	26	78
	K_4	238	58	80	80	18	66	245	58	85	85	26	81
5 Unmanured fallow	K_0	168	65	100	100	35	106	104	70	94	94	57	105
	K_1	165	60	82	82	48	90	146	71	95	95	42	104
	K_2	188	62	87	87	30	88	152	60	88	88	36	94
	K_4	236	63	91	91	45	101	272	69	97	97	44	106
6 Unmanured clover	K_0	154	63	92	92	44	95	124	77	107	107	53	116
	K_1	186	69	104	104	54	114	205	76	115	115	50	131
	K_2	193	70	98	98	32	95	174	76	113	113	42	111
	K_4	237	63	96	96	42	102	244	76	115	115	38	126

https://doi.org/10.23637/ERADOC-1-8

APPENDIX TABLE 2

Cumulative K uptake by both crops of ryegrass in the pot experiments made on soils from the Agdell experiment

K uptake by ryegrass expressed as ppm K in air-dry soil

Rotation experiment plot and treatment	Cropping 1958–67	K treatment given 1964	1st crop of ryegrass, cut number								2nd crop of ryegrass, cut number								2nd crop only
			1	2	3	4	5	6	7	stubble	1	2	3	4	5	6	7	stubble	
1 NPK fallow	Arable/fallow	K_0	238	358	442	499	514	526	548	560	588	609	616	616	616	616	616	617	57
		K_1	190	299	373	418	431	439	452	461	490	507	514	515	516	516	516	517	56
		K_2	281	393	490	561	577	589	610	622	660	677	684	684	684	684	684	686	64
		K_4	261	391	489	537	549	559	570	578	603	618	621	622	622	622	622	623	45
	Grass	K_0	46	78	95	105	107	109	111	114	159	176	183	185	186	191	191	192	78
		K_1	94	154	182	205	211	216	234	244	277	298	310	320	329	342	346	378	134
		K_2	102	169	211	247	260	272	306	323	358	378	391	401	407	416	420	437	114
		K_4	202	310	392	464	482	496	526	541	583	607	622	629	632	637	637	638	97
2 NPK clover	Arable/fallow	K_0	166	270	340	382	394	402	412	419	451	466	468	468	468	468	468	469	50
		K_1	211	319	400	450	462	470	479	487	517	533	536	536	536	536	536	538	51
		K_2	231	345	421	465	475	481	485	489	514	526	539	542	544	548	548	550	61
		K_4	276	402	484	550	564	574	587	596	626	648	656	658	658	658	658	659	63
	Grass	K_0	58	100	123	137	140	142	144	146	188	207	214	217	219	226	226	227	81
		K_1	66	116	149	174	182	188	200	209	249	281	304	312	316	322	323	329	120
		K_2	106	174	218	253	254	262	271	280	320	340	353	358	361	367	367	369	89
		K_4	174	264	327	375	389	400	431	445	475	492	502	507	511	515	515	516	71
3 PK fallow	Arable/fallow	K_0	196	302	374	418	433	445	487	511	547	576	598	607	614	626	631	666	155
		K_1	221	337	432	501	519	536	580	608	645	678	701	709	715	729	741	775	167
		K_2	271	401	497	569	586	601	643	665	705	731	749	756	763	773	775	787	122
		K_4	307	455	567	646	663	679	725	750	790	813	833	841	847	858	866	887	137
	Grass	K_0	62	103	121	129	129	129	129	131	173	194	201	202	203	206	207	214	83
		K_1	134	213	267	307	317	326	351	362	399	421	437	448	459	470	481	506	144
		K_2	120	195	247	289	302	313	350	368	406	425	442	451	458	472	498	523	155
		K_4	298	434	541	621	643	659	707	729	767	786	800	808	813	823	828	862	133

4 PK clover	Arable/fallow	K_0	212	326	413	471	486	497	519	531	573	595	606	612	618	625	625	628	97
		K_1	231	339	424	483	497	507	528	542	577	595	602	605	608	612	612	613	71
		K_2	227	345	439	493	506	516	534	546	582	595	604	610	612	616	616	617	71
		K_4	253	378	483	563	582	598	630	647	689	715	726	731	734	740	740	743	96
	Grass	K_0	52	100	121	139	141	144	145	148	193	211	218	218	218	218	218	219	71
		K_1	84	150	194	228	241	252	283	296	334	354	369	376	381	391	392	395	99
		K_2	144	239	303	354	370	383	411	428	467	490	506	516	520	526	528	537	109
		K_4	199	309	391	452	468	482	522	543	579	605	623	630	633	641	642	648	105
5 Unmanured fallow	Arable/fallow	K_0	102	174	213	242	251	255	265	280	315	331	347	355	363	372	374	386	106
		K_1	115	181	225	258	269	277	303	323	357	377	392	399	405	422	423	426	103
		K_2	170	268	328	368	381	393	429	446	479	502	519	528	535	544	546	566	120
		K_4	214	321	395	447	460	473	515	545	579	609	626	634	640	647	647	648	103
	Grass	K_0	50	83	101	109	110	110	110	112	149	167	176	179	181	186	187	189	77
		K_1	79	137	172	198	205	211	225	234	277	308	332	341	349	355	365	387	153
		K_2	122	196	241	276	285	291	301	315	341	361	372	380	387	395	403	453	138
		K_4	222	338	422	480	495	509	563	583	623	641	654	661	667	675	675	678	95
6 Unmanured clover	Arable/fallow	K_0	114	182	228	262	271	278	296	308	340	365	383	391	398	414	419	435	127
		K_1	141	228	288	328	341	351	383	399	441	463	481	489	493	499	499	500	101
		K_2	168	268	328	366	378	388	419	443	468	494	512	520	527	547	548	549	106
		K_4	222	333	409	470	485	499	542	565	599	623	642	649	654	663	668	685	120
	Grass	K_0	52	92	113	128	130	132	135	137	166	192	208	212	213	218	219	220	83
		K_1	120	202	255	292	302	310	330	340	392	423	445	453	459	467	467	471	131
		K_2	100	178	226	262	273	283	311	330	368	402	421	431	438	453	460	502	172
		K_4	195	317	406	466	482	499	542	568	618	648	673	686	695	710	712	724	156

D

https://doi.org/10.23637/ERADOC-1-8