Journal of Agricultural Science (2002), **139**, 455–458. © 2002 *Cambridge University Press*
DOI: 10.1017/S0021859602002691 *Printed in the United Kingdom*

Correspondence

To the Editors,
Journal of Agricultural Science

Dear Sirs,
In Volume **136**, 407–426, you published a paper entitled 'Responses of potato (*Solanum tuberosum*) to potassium fertilizers' by M. F. Allison, J. H. Fowler and E. J. Allen. We consider that the authors' conclusions were not justified and they have misinterpreted and criticized earlier published work. One of their criticisms is levelled at the use of exchangeable potassium (Kex – rapidly plant-available K) to categorize soils on the basis of the likely response of crops to an application of potassium (K) fertilizer. While Kex is not perfect, it is the best rapid method currently available (Johnston & Goulding 1990). To support their contention about Kex, the authors quote in Table 15 data from Rothamsted experiments done in the late 1950s and early 1960s. They state that despite the large amounts of K applied in fertilizers and manures the effect on Kex was relatively small. This comment fails to recognize that it is the K balance (K applied minus K removed) that must be related to Kex, not the K applied, and the inevitable transfer of part of the K balance from Kex to fixed K (less readily available K). Warren & Johnston (1962) showed that on these soil types as much as 60% of the K balance is rapidly transferred to fixed K.

To further support their contention that Kex is a poor indicator of yield response, the authors have taken their Fig. 1 from a paper by Eagle (1967) and quote the correlation coefficient given there to imply that % yield and Kex were not related. Eagle's presentation was based on Bray's idea that the effect of a nutrient should be estimated from the loss of yield between a fertilized and unfertilized plot (Bray 1948). Thus the equation given by Bray and used by Eagle gave a correlation coefficient of $-0{\cdot}23$. However, using GENSTAT to fit a similar curve to that shown by Eagle, suggests that the relation between % yield and Kex accounted for about 24% of the variance. More importantly, the critical Kex value (i.e. the level of Kex at which yield was less than 90% of the maximum) was reached at about 160 mg/kg Kex (i.e. at about Index 2).

The authors seek to reject the Rothamsted experiments by implying that the results are invalid because there was no replication and no standard errors. Earlier in their discussion they suggest that for other experiments, differences in yield of < 1 t/ha are unlikely to be significant. By inference, therefore, differences > 1 t/ha could be significant. As their Table 15 shows, in the Rothamsted experiments the average yield of potatoes on soils with least Kex was 26·3 t/ha and for a very small increase in Kex the increase in yield was 10·5 t/ha. On the basis of the authors' criterion we would suggest that this was a significant increase in yield for a small increase in Kex on soils that were in K Index 1. The response to freshly applied K fertilizer, applied on the furrow bottom or on the flat and worked into the seedbed before planting, ranged from 6·0 to 14·0 t/ha, with one exception where on the poorer soil the yield was already near the then national average. We would suggest that these increases were likely to have been statistically significant.

In summarizing results from earlier experiments in relation to current recommendations the authors note (p. 408) 'Thus, current fertilizer recommendations for application of fertilizer K in England and Wales are based on the series of experiments with comparatively small yields; use a relationship between yield response to K and soil exchangeable K that is weak; and, in many cases, recommend amounts of K far larger than those tested by earlier workers.' This criticism overlooks the fact that many farmers now achieve larger yields than previously and that current recommendations (MAFF Fertiliser Recommendations RB209) are based on replacement of K removed (with only small adjustments according to soil analysis) and not direct yield response. It is accepted that in some cases the rates for optimum yield can be lower, but in such cases if the lower 'response amounts' are used, the K balance would be negative and would result in depletion of soil K. This is not an acceptable long-term policy. For these reasons we disagree with the authors' conclusion in their summary that 'a fertilizer recommendation system based primarily on the probability of a yield response would be more than sufficient'.

In relation to the experiments described by the authors, a major concern is the method of fertilizer application which involved shallow incorporation into the ridges after planting. Because both phosphorus and potassium are so immobile, the crop would be most unlikely to see any benefit from their application. As such a method of applying phosphate and potash fertilizer is not used in commercial practice it is questionable what conclusions can be drawn using this approach.

There is, however, an even greater flaw in the authors' interpretation of the data from their experiments. They were not designed as fertilizer response experiments but used a factorial design to test only a few large increments of K in combination with other nutrients and cultural practices. Although the data were analysed by standard procedures there were too few data points for K in each experiment with all other factors equal, for curve-fitting procedures to be effective and enable optimum responses to K to be derived. Of the 33 experiments reported, 10 had only two levels of K, while eight had no zero K control which would normally be regarded as desirable to define accurately a response curve from which the optimum response to K could be determined. Another conclusion, namely that neither the source nor rate of K application had any effect on crisp-fry colour, was drawn in relation to data from only two of the 33 experiments. However, as the levels of Kex in these two experiments were high (272 and 911 mg/l K) such a conclusion is not meaningful.

While the authors consider that the current recommendations for K for potatoes are over-generous, resulting in unnecessary amounts of K being applied, they have ignored the financial implications. MAFF recommendations (MAFF 2000) suggest a maximum application of 290 kg K/ha for K Index 0 soils; the authors suggest a maximum of 210 kg K/ha. The difference, 80 kg K/ha, would cost £20 at current prices of potassium chloride fertilizer. This cost would be recovered by an increase of 0·25 t tubers/ha with potatoes at £80/t. Such a small difference in yield would be within experimental error even in the most robust experiments.

The authors' claim that 'much fertilizer K is applied unnecessarily and that current recommendations require urgent revision' is, we suggest, incorrect when applied to the potassium needs of the potato crop, and must be challenged.

REFERENCES

Bray, R. H. (1948). *Diagnostic Techniques for Soils and Crops*. Washington, DC: American Potato Institute.

Eagle, D. J. (1967). Release of non-exchangeable potassium from certain soils. In *Soil Potassium and Magnesium*. Ministry of Agriculture, Fisheries and Food Technical Bulletin No. 14, pp. 49–54. London: HMSO.

Johnston, A. E. & Goulding, K. W. T. (1990). The use of plant and soil analysis to predict the potassium supplying capacity of soil. In *The Development of K-fertiliser Recommendations*. pp. 177–204. Basel: International Potash Institute.

MAFF (2000). *Fertiliser Recommendations for Agricultural and Horticultural Crops* (*RB209*). 7th Edition. Ministry of Agriculture, Fisheries and Food. London; The Stationery Office.

Warren, R. G. & Johnston, A. E. (1962). The accumulation and loss of soil potassium in long-term experiments, Rothamsted and Woburn. Proceedings No. 72, pp. 5–24. York: International Fertiliser Society.

From

J. D. Hollies, *Director General*, *Potash Development Association Brixtarw*, *Laugharne*, *Carmarthen SA33 4QP*

A. E. Johnston, *Lawes Trust Senior Fellow, IACR – Rothamsted, Harpenden AL5 2JQ*

I. R. Richards, *Agronomist*, *ECOPT*, *Dewells Farmhouse*, *Ufford Road*, *Bredfield*, *Suffolk IP13 6AR*

G. A. Wadsworth, *Soil Scientist*, *IPSS*, *Beechwood*, *South Stoke Road*, *Woodcote*, *Reading RG8 0PL*

D. Antrobus & R. Blades, *Agronomists*, *McCain Foods*, *Funthams Lane*, *Whittlesey*, *Peterborough PE7 2PG*

P. Bibby, *Senior Agronomist*, *Branston Potatoes*, *Upton Lane*, *Seavington St Michael*, *Ilminster*, *TA19 0QB*

M. F. ALLISON, J. H. FOWLER and E. J. ALLEN

Reply

The statement made in our paper in relation to the effect of large dressings of potassium (K) fertilizer over long periods of time on exchangeable K is correct and illustrates that exchangeable K is difficult to increase. Similar data for sugar beet show that withholding K fertilizers for 20 years had little effect on exchangeable K. For example, work at Broom's Barn (Last *et al.* 1985) on sandy loam textured soil showed that from an initial soil status of 65 mg K/l, a K deficit of *c.* 800 kg K/ha was associated with a decrease in exchangeable K of *c.* 10 mg K/l. Similarly, a K surplus of 800 kg K/ha was associated with an increase in soil-exchangeable K of *c.* 60 mg K/l. When the available evidence, albeit limited, is considered as a whole, there is little evidence to suggest that negative K balances result in a significant decrease in soil-exchangeable K, and should this occur, full yields may be achieved by applications of sufficient fresh K fertilizer. Exchangeable K may be the best indicator of soil K status but its limitations must be recognized. As exchangeable K is difficult to change and poorly related to response, these limitations are serious.

In our discussion of the work by Eagle (1967), we did not imply that exchangeable potassium (K) and lost yield potential were unrelated, indeed, we stated that this relationship was reported as 'statistically significant'. Moreover, in complete agreement with Eagle, we contend that a correlation coefficient of only $-0{\cdot}23$ shows that this relationship is inherently weak and not definitive. This view is confirmed by the PDA's reworking of Eagle's data where exchangeable K explained only 24% of the variation in lost yield potential. Thus, both Eagle and the PDA show that in K response experiments *c.* 75% variation in tuber yield potential was due to factors other than soil exchangeable K. For the PDA then to state that, in the absence of K fertilizer, 90% of the maximum yield was attained at *c.* 160 mg K/kg (a larger value than in Eagle's case) is a contrivance to support their view. We would be interested to know the size of the error

https://doi.org/10.1017/S0021859602002691 Published online by Cambridge University Press

associated with this estimate since the raw data in Eagle's Figure 3 (1967) shows that once exchangeable K exceeded *c*. 140 mg K/kg, all yields exceeded 90% yield potential and in many cases 90% yield potential was achieved once exchangeable K exceeded 50 mg K/kg (Index 0).

We did not seek to reject the experiments done at Rothamsted, Woburn and Saxmundham (Table 15 in our paper), we simply indicated that given the limitations in experimental design an alternative, but equally valid, interpretation of these results may be made. Any discussion of these data is conjecture since without randomization and replication it has to be assumed that (1) yields are statistically different and (2) these differences are solely due to the effects of soil exchangeable K and fresh K fertilizers. Accepting these assumptions, we maintain these results may be interpreted to show that the increase in soil exchangeable K is small when compared with the amount applied during the build-up phase and any yield penalty resulting from small soil exchangeable K can be offset by applying relatively modest amounts of fresh K fertilizer.

The statement relating to the origins of current recommendations is correct. For the reasons given above, maintenance of neutral or positive K balances is not essential for full yields in the future. Moreover the offtake of K is itself variable, as we noted in our paper, the amount of K removed per tonne of tubers increased as soil exchangeable K increased. Similar results were also found by Milford *et al*. (2000) working with sugar beet. These workers also showed that the relationship between K removal and yield was asymptotic, not linear. Using an average K offtake value of 4·8 kg K/t (equivalent to 5·8 kg K_2O/t) will generally result in K accumulation rather than maintaining the *status quo*. A protracted negative K balance will result in a depletion of total soil K. However, it is far from clear what effect a negative (or positive) K has on exchangeable K or plant-available K and, in turn, K fertilizer requirement.

We accept that our method of fertilizer application was not representative of commercial practice. The possible confounding of results because of our methodology was also raised during the refereeing process of our draft paper and in the published paper we used yield and K uptake data to argue that confounding did not occur. If applied K were largely unavailable, it would be expected to result in small yields and restricted and shorter-lived leaf canopies. Neither occurred, and, as shown in Tables 11 and 13, K concentration and uptake were generally increased which suggests the crops had access to the K fertilizer. Subsequent to the publication of our paper, further work on a soil with low K status (89 mg K/l, Index 1) showed that neither rate nor method (before ploughing or after planting) of application of K fertilizer had any effect on tuber yield (Table 1). The discussion in our paper and these new data support our view that our methodology did not bias our results and even on soils with little exchangeable K potatoes may not be responsive to K fertilizers.

The PDA letter criticizes our dataset since some of our experiments tested a limited number of K application rates and, in some cases, there was no zero K control. If the sole objective of these experiments was to fit response curves then this criticism is valid but of what value? Information on the response of crops to nutrients can be gained from experiments that were not designed as classical response experiments. Many of the two level experiments were established to support the experiments testing several rates. It is our view that such experiments testing, for example, two fertilizer application rates can contribute to understanding. If there is no significant increase in yield when the larger rate was applied then it is reasonable to assume that crop was not responsive to fertilizer and the optimum application rate was no greater than the lowest rate tested. Taken overall, these results do not suggest large responses to K are as common as the PDA would imagine and the inclusion of non-response experiments in our paper is justified. For the two experiments investigating the effects of K application on fry quality done on soils containing 911 and 272 mg K/l, the paper stated the results of these two experiments but made no conclusions from them. We stated that they needed to be considered collectively with other published work. When this is done it is evident that K supply in excess of that needed for maximum yield is unlikely to improve tuber quality.

The PDA state that we have ignored the financial implications of reductions in K fertilizer recommendations and state that a 0·25 t/ha increase in yield (valued at £80/t) is needed to pay for an extra 80 kg K/ha. We believe the concept of 'economic optima' to be seriously flawed for the following reasons. First, the value of potatoes has a wide range. For example, the most recent issue of *Potato Weekly* published by the British Potato Council (24 May 2002) shows the value of ware potatoes has a 28-fold variation (from 10 to 280 £/t) and this variation is dependent on quality, variety, end use and production region. Second, and more importantly, the calculation of economic optima also ignores the fundamental principles of experimental design and interpretation. Field experiments are designed to provide observations from a sample of a population from which robust inferences may be made concerning the entire population. This objective is met by the establishment of treatment means and the unexplained variation (error) associated with those means. If there are no significant differences in yields then there is no logical basis on which to proceed to calculate economic optima. As a small increase in yield will apparently pay for extra fertilizer it is essential that great care is exercised in dealing with the data. The PDA letter is arguing that it

Table 1. *Effect of time and rate of potassium fertilizer application on total (>10 mm) tuber fresh weight yield (t/ha) of Estima grown at Ilminster, Somerset in 2001. Standard errors (S.E.) are based on 14 residual degrees of freedom*

	Rate of potassium application (kg K/ha)				Main effect of application time
	0	125	250	375	
K applied pre-ploughing	49·0	57·4	53·8	60·1	55·1
K applied post-planting	58·5	55·7	58·6	51·3	56·0
Main effect of application rate	53·7	56·6	56·2	55·7	55·5

S.E. for time of application 1·41; S.E. for rate of application 1·99; S.E. for time × rate 2·81.

is permissible to take an arithmetic but non-significant difference in yield of 2 t/ha with an S.E., for example, of 1·4 t/ha and believe it is real because it would apparently pay for the extra fertilizer. Such results can only indicate that there is no real difference in yield and to treat them otherwise is a misuse of statistics. It is also misleading to imply that the small yield increase needed to pay for extra fertilizer, will remain undetected even in robust experiments – there is no evidence that the yield difference ever existed.

This confusion in interpretation is very common and has led to excessive use of fertilizers. Consequently, this point does not challenge the conclusions of our paper but illustrates why the conclusions in our paper are critical to a more efficient use of fertilizers. We refute the accusation of misinterpretation and consider that criticisms were fair and based on an objective evaluation of historic data.

REFERENCES

EAGLE, D. J. (1967). Release of non-exchangeable potassium from certain soils. In *Soil Potassium and Magnesium*. Ministry of Agriculture Fisheries and Food, Technical Bulletin Number 14, pp. 49–54. London: HMSO.

LAST, P. J., WEBB, D. J., BUGG, R. B., BEAN, K. M. R., DURRANT, M. J. & JAGGARD, K. W. (1985). Long-term effects of fertilizers at Broom's Barn, 1965–82. *Rothamsted Annual Report for 1984*, Part 2, 231–249.

MILFORD, G. F. J., ARMSTRONG, M. J., JARVIS, P. J., HOUGHTON, B. J., BELLETT-TRAVERS, D. M., JONES, J. & LEIGH, R. A. (2000). Effects of potassium fertilizer on the yield, quality and potassium offtake of sugarbeet crops grown on soils of different potassium status. *Journal of Agricultural Science, Cambridge* **135**, 1–10.

M. F. Allison, J. H. Fowler and E. J. Allen,
Cambridge University Farm