

Concentrations of potassium in the dry matter and tissue water of field-grown spring barley and their relationships to grain yield

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SUMMARY

In 68 spring barley crops grown in five experiments at Rothamsted and Woburn between 1980 and 1982, and given adequate K fertilizer, there was a positive correlation ($r = 0.76$; $P < 0.001$) between maximum % K in dry matter of young plants and the grain yield at final harvest. In all crops changes in % K in dry matter during the growing season were directly related to changes in fresh weight to dry weight ratio (FW:DW) suggesting that differences in % K in dry matter were the result of differences in tissue hydration. Potassium concentrations expressed on the basis of tissue water were not correlated with grain yield. All crops maintained K concentrations in their tissue water of about 200 mmol/kg tissue water, except at the end of the growing season when water loss during ripening caused a steep rise.

The correlation between % K in dry matter and yield was the result of differences in FW:DW. Within each experiment there was a good correlation between FW:DW and grain yield, but because the relationship was different for each experiment the overall correlation for all crops was poor. The correlation between FW:DW and grain yield within experiments probably arises because crops with a higher FW:DW will have higher specific leaf areas and hence higher relative growth rates and yields.

INTRODUCTION

Schäfer (1977) reported that in 665 cereal crops grown in Germany between 1963 and 1965 there was a highly significant, positive correlation between % K in dry matter of the plants at stem elongation and yield. Although the crops received K fertilizer it remains uncertain whether the correlation resulted from small, but physiologically important, differences in K status or whether some other factor linked the two sets of observations. Thus to understand the relationship between % K in dry matter and yield it is important to establish whether the former does provide a good measure of the K status of cereal crops. As K has an important osmotic role in plants (Läuchli & Pfüger, 1979; Wyn Jones, Brady & Spiers, 1979) it has been suggested that its concentrations should be expressed on the basis of tissue water, not as percentage in the dry matter (Cassidy, 1970; Pitman, 1975; Ahmad & Wyn Jones, 1982). Although some authors have compared K concentrations in the dry matter and tissue water of plants grown in glasshouses or controlled environments (Cassidy, 1970; Jungk, 1970; Johansen,

1978) there have been no detailed studies with field-grown cereals nor has the relationship between grain yield and K concentrations in the tissue water been investigated. In this paper we compare the changes in K concentrations in dry matter and in tissue water during the growth of spring barley crops in the field, and examine the relationship between these K concentrations and grain yield at final harvest.

MATERIALS AND METHODS

Spring barley (*Hordeum vulgare* cv. Georgie or Triumph) was sampled from various field experiments during 1980, 1981 and 1982. The experiments (with our code letters and the number of plots studied) were: the Hoosfield Continuous Barley experiment at Rothamsted in 1980 (Expt A, 12 plots), in 1981 (Expt B, 16 plots) and in 1982 (Expt E, 12 plots), an experiment at Rothamsted in 1981 studying the effects of subsoiling and deep incorporation of P and K (Expt C, 16 plots), and a ley-arable experiment at Woburn Experimental Farm, Bedfordshire in 1981 (Expt D, 12 plots). For brevity, only data for the highest and lowest

Table 1. *Treatment received by the lowest and highest yielding crops in the four experiments sampled in 1980 and 1981*

Expt	Year	Cultivar	Seed rate (kg/ha)	Sowing date	Harvest date	Grain yields and manurial treatments on lowest and highest yielding plots				
						Grain yield (t/ha)	N*	P	K	FYM† (t/ha)
A	1980	Georgie	150	21 Feb.	18 Aug.	1.39	0	0	90	0
						7.30	144	0	0	35
B	1981	Georgie	160	17 Feb.	17 Aug.	1.02	0	0	90	0
						6.12	48	0	0	35
C	1981	Georgie	160	6 Apr.	1 Sept.	2.33	0	27	50	0
						6.61	120	27	50	0
D	1981	Triumph	160	10 Apr.	17 Aug.	1.86	0	26	50	0
						8.07	100	26	50	0

* Applied as 'Nitro-Chalk 26'.

† FYM, farmyard manure; supplied in total 235, 45 and 340 kg/ha of N, P and K, respectively.

yielding plots from Expts A–D are presented in detail, although all data are used in the correlations in Figs 2, 6 and 7. Details of the treatments applied to the highest and lowest yielding plots in Expts A–D are in Table 1. The soil at Rothamsted is a silty clay loam and that at Woburn a sandy loam. The exchangeable K in the surface soils was in excess of 120 mg/kg and 90 mg/kg at Rothamsted and Woburn, respectively, the levels below which Johnston, Warren & Penny (1970) found that spring barley responded to freshly applied K fertilizer at the two sites. Thus differences in grain yield should not have resulted from inadequate soil K.

In all experiments sampling began when the plants had three leaves and continued until just before harvest, except in 1982 when it stopped at anthesis. Before anthesis samples were collected every 3–5 days but less frequently thereafter. On each sampling occasion all the above-ground parts of the plants were removed from a single, randomly-selected 1 m length of row from each plot. Sequential samples were not taken adjacent to earlier sampling areas and roots of sampled plants were dug from the soil to prevent regrowth of the shoots. The top samples were sealed in moisture-proof bags and brought to the laboratory where fresh weight and dry weight were determined. Samples were dried at 80 °C overnight. Tissue water was assumed to be the difference between fresh and dry weight. Potassium was extracted from ashed tissue (450 °C, 3 h) with HCl and was measured using an atomic absorption spectrometer or an inductively coupled plasma optical emission spectrometer

(Applied Research Laboratories Ltd, Luton, Bedfordshire). Grain yields were determined by combine harvesting an area of crop measuring between 21.7 and 30.6 m², depending on the experiment.

RESULTS AND DISCUSSION

% K in dry matter and its relation to grain yield and tissue hydration

Figure 1 shows the changes in % K in dry matter during the growth of the lowest and highest yielding crops from each of Expts A–D. In all cases the K concentration increased to a maximum during tillering and then declined steadily until harvest. The early rise in % K in dry matter was small in relation to the subsequent decline. In all four experiments % K in dry matter was greater in the highest yielding crops, even though all crops received adequate K either as FYM or fertilizer (Table 1). To test whether there was a relationship between % K in dry matter of young barley crops and their subsequent grain yield, the maximum measured value of % K in dry matter was plotted as a function of grain yield (Fig. 2). The maximum value was chosen because it was readily identifiable for all crops (see Fig. 1), and it always occurred during tillering but before stem elongation began. Thus crops were compared at similar physiological ages but not at the same absolute ages, because within any experiment maximum % K in dry matter was not necessarily attained on the same day on all plots (see Fig. 1C). There was a positive and highly significant correlation between maximum % K in dry

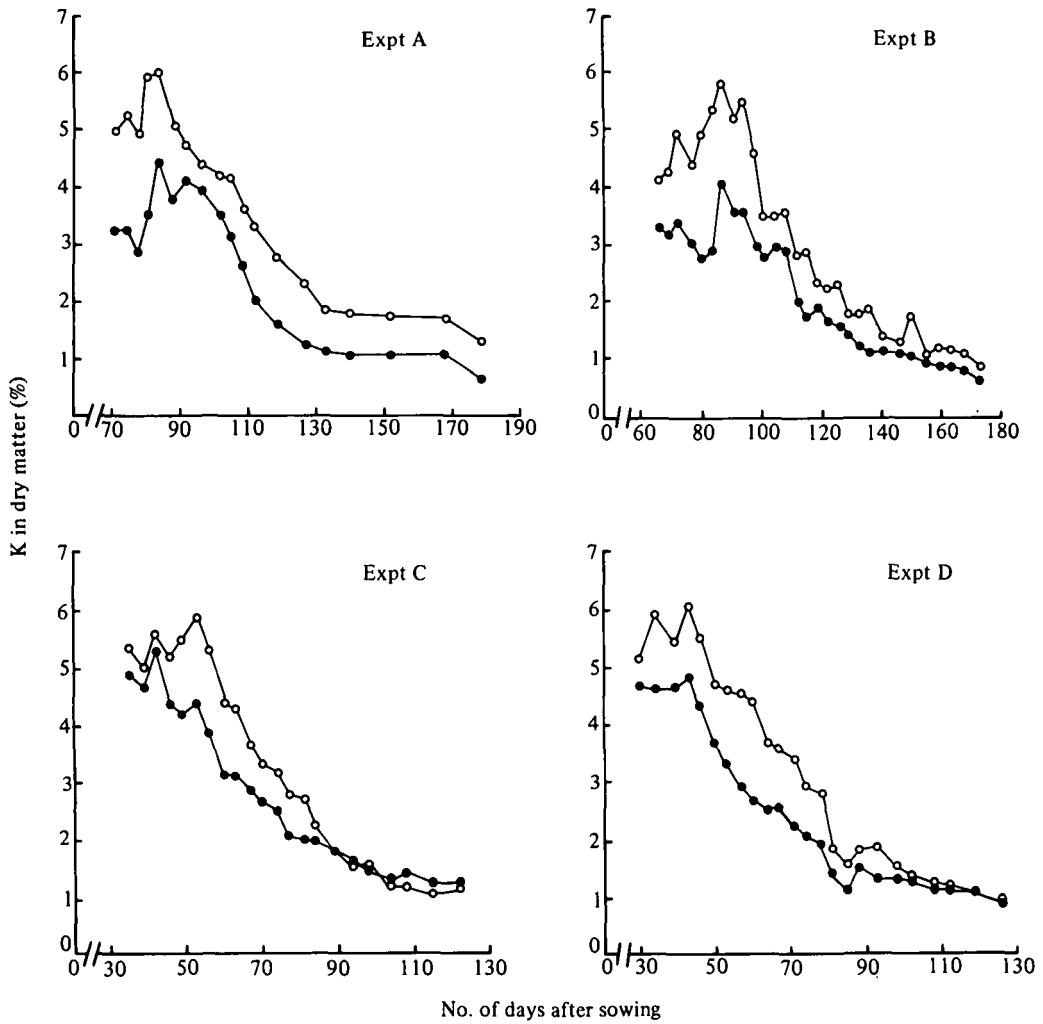


Fig. 1. Percentage K in dry matter during the growth of the lowest (●) and highest (○) yielding spring barley crops from Expts A, B, C and D.

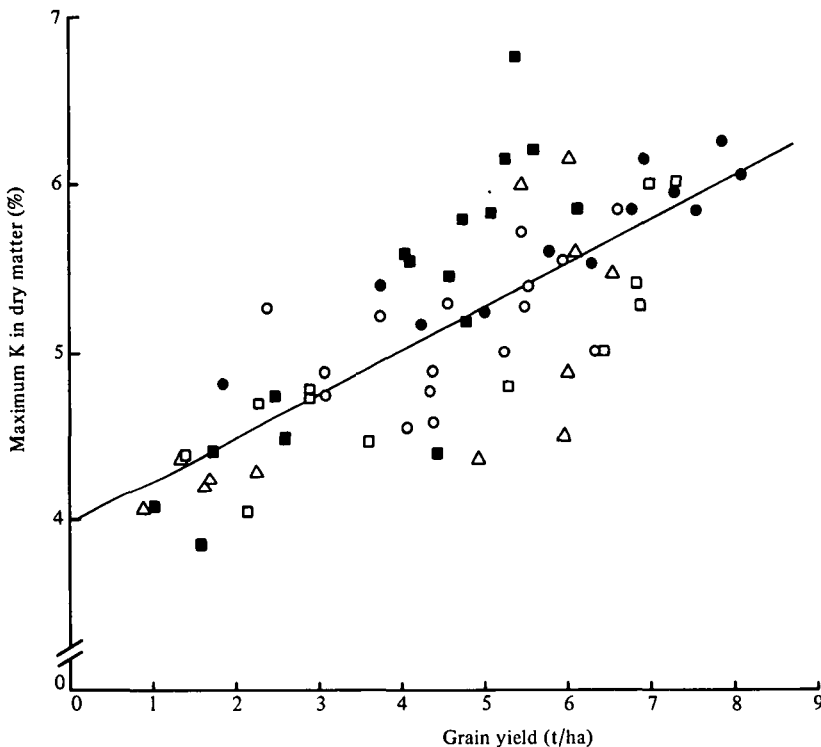


Fig. 2. Relationship between maximum measured % K in dry matter of young spring barley crops and their grain yield at harvest. □, Expt A; ■, Expt B; ○, Expt C; ●, Expt D; △, Expt E. The fitted line has the equation $y = 0.27x + 3.95$; $r = 0.76$.

matter and grain yield (Fig. 2), confirming Schäfer's (1977) findings. However, our correlation coefficient (0.76) was much greater than Schäfer's (0.39), perhaps because we used maximum % K in dry matter whereas Schäfer (1977) used % K in dry matter at the time of stem elongation. Our observations indicate that % K in dry matter is declining rapidly at this time and may be quite different in plants of only slightly different physiological ages.

Although the correlation between % K in dry matter and grain yield was highly significant this does not establish a physiological basis for the relationship because it is unclear whether differences in % K in dry matter represent real differences in K status. All our crops received K either as fertilizer or farmyard manure and the exchangeable K contents of the soils at Rothamsted and Woburn were above the levels at which spring barley responds to K fertilizer on these sites (Johnston *et al.* 1970). Thus it is unlikely that inadequate K supply was directly responsible for the observed relationship. Of particular interest in this context is the suggestion that tissue K concen-

trations should be expressed on the basis of tissue water to take account of the osmotic role of this nutrient (Cassidy, 1970; Pitman, 1975; Ahmad & Wyn Jones, 1982). To test whether the differences in % K in dry matter could result from differences in tissue hydration, the relationship between % K in dry matter and fresh weight to dry weight ratio (FW:DW) was examined. We chose FW:DW because it provides a simple, convenient measurement which is related to water content.

Changes in FW:DW during growth (Fig. 3) were qualitatively similar to those of % K in dry matter (Fig. 1). Plotting % K in the dry matter as a function of FW:DW showed the two to be closely related (Fig. 4) and within each experiment both low and high yielding crops showed similar relationships. The variations of FW:DW accounted for 90–94% of the variation in % K in dry matter. The slope of this relationship is a measure of K concentration on a fresh-weight basis and it is clear that expressing the concentrations in this way would eliminate differences between low and high yielding crops. However, because of the

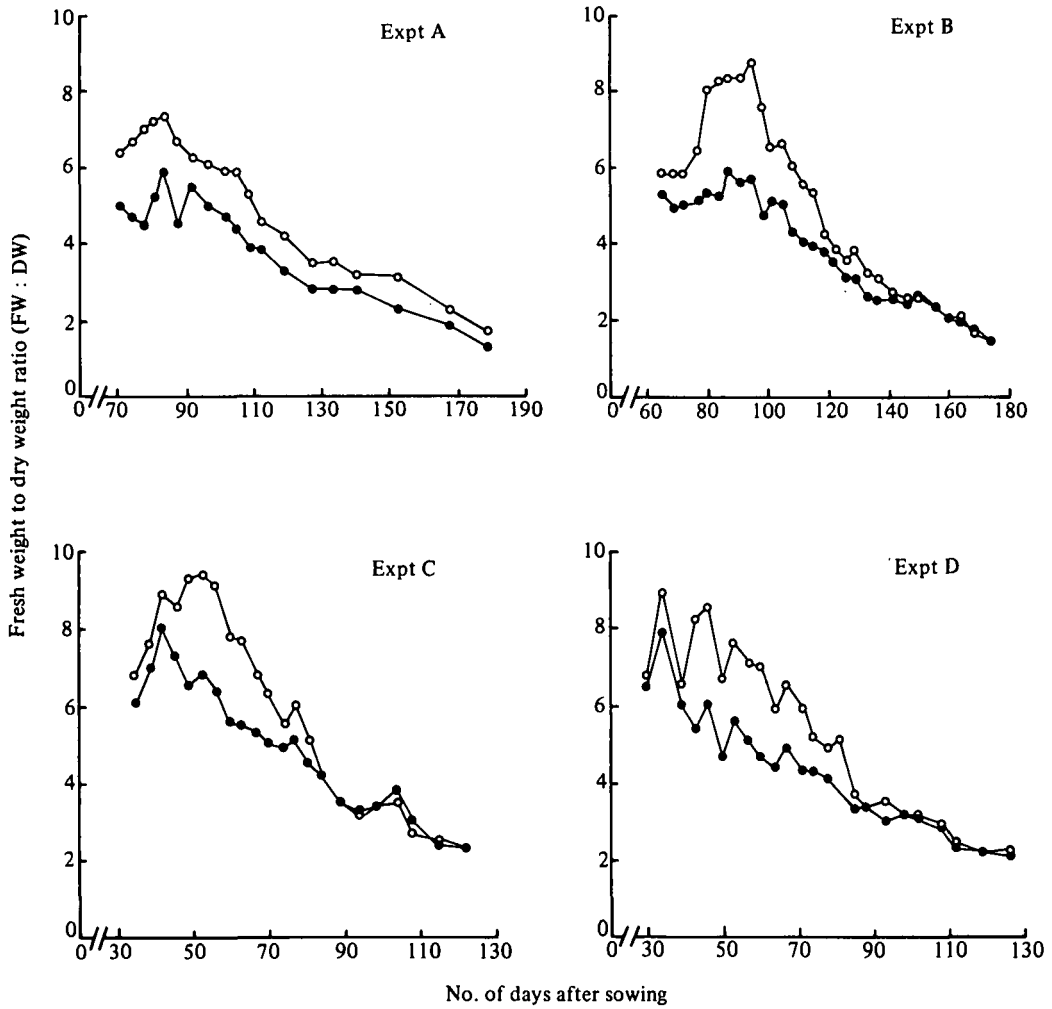


Fig. 3. Fresh weight to dry weight ratio (FW : DW) during the growth of the lowest (●) and highest (○) yielding spring barley crops from Expts A, B, C and D.

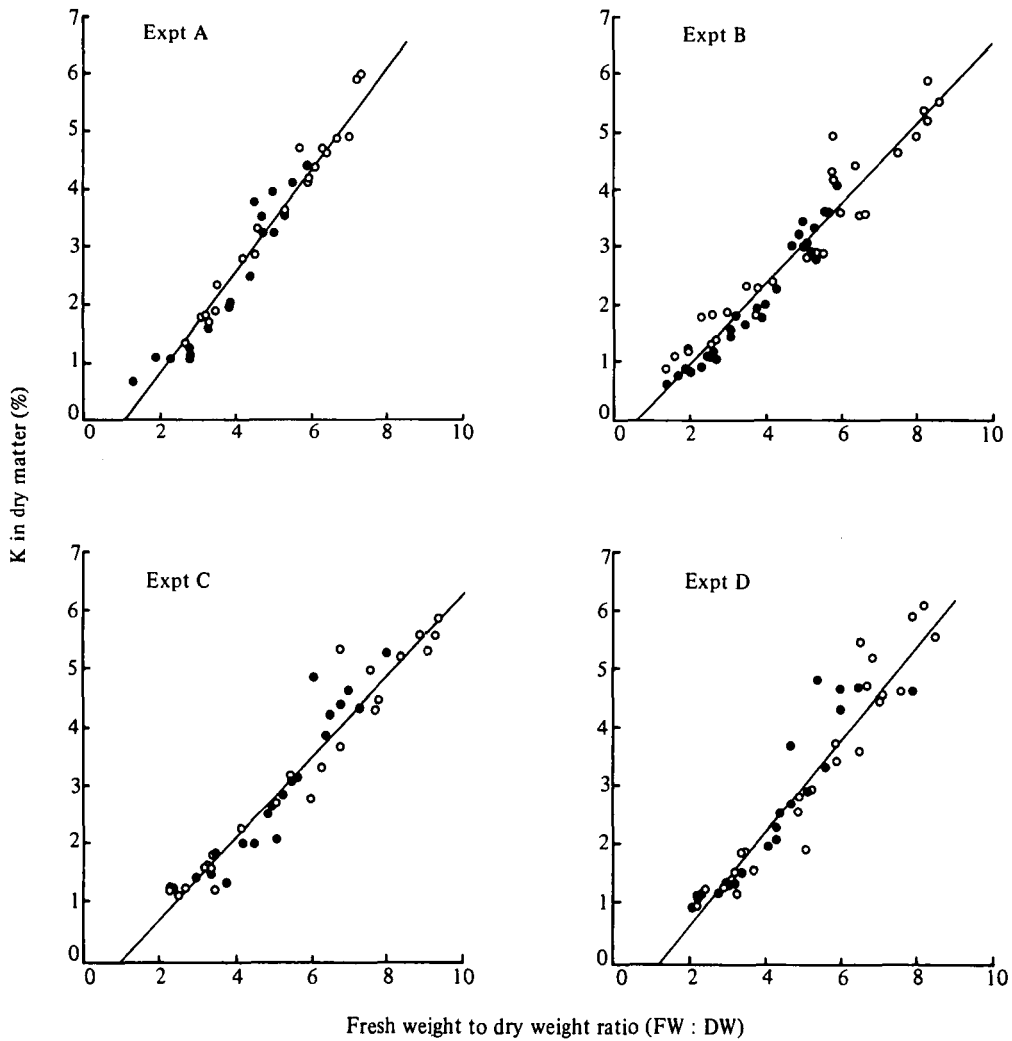


Fig. 4. Relationship between % K in dry matter and fresh weight to dry weight ratio during the growth of the lowest (●) and highest (○) yielding spring barley crops from Expts A, B, C and D. Values for % K in dry matter and FW:DW were from the corresponding points in Figs 1 and 3. The equations of the fitted lines and values of the correlation coefficient are: Expt A, $y = 0.88x - 0.91$, $r = 0.97$; Expt B, $y = 0.70x - 0.45$, $r = 0.97$; Expt C, $y = 0.70x - 0.71$, $r = 0.96$; Expt D, $y = 0.80x - 0.95$, $r = 0.95$.

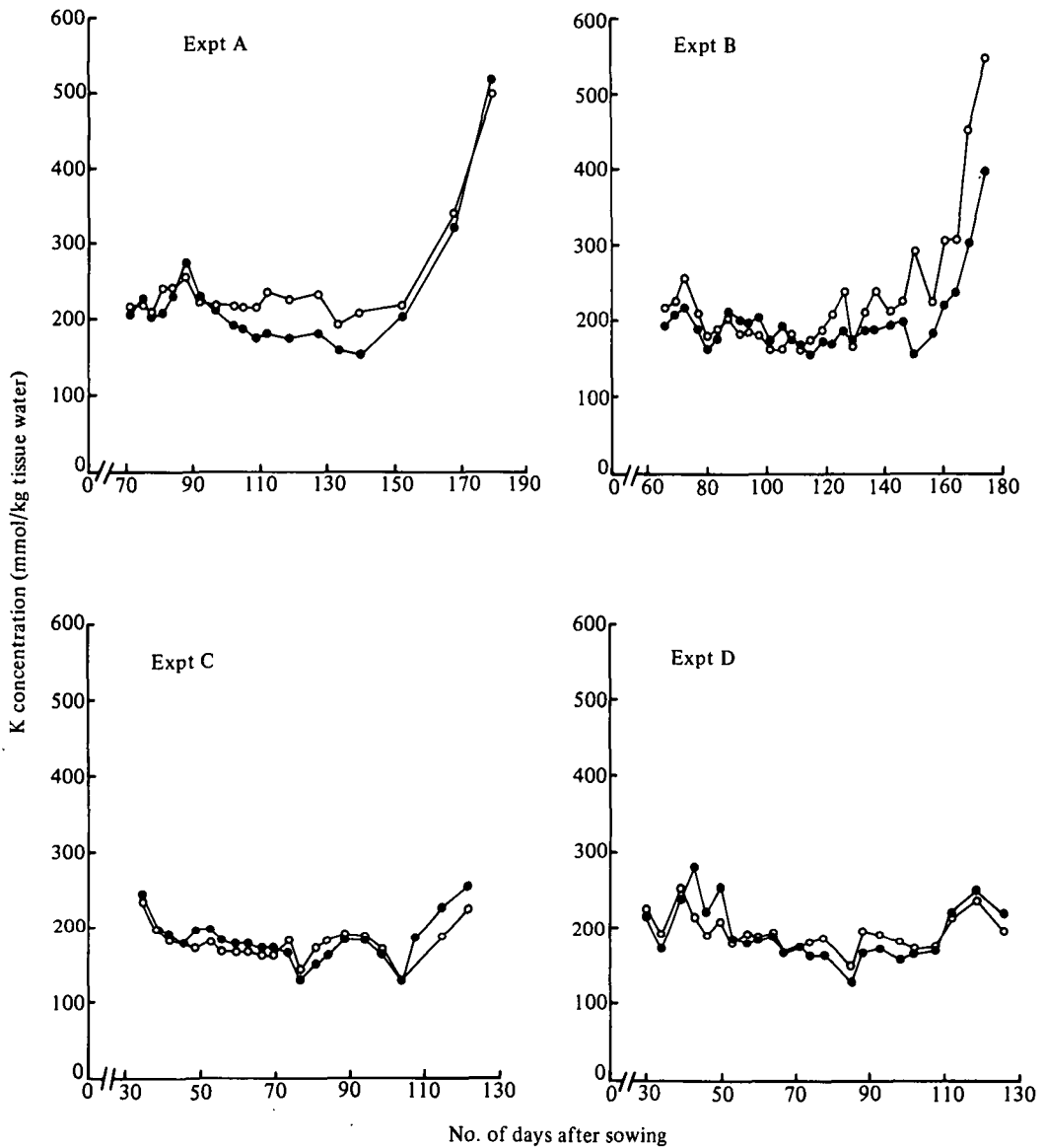


Fig. 5. Concentrations of K in the tissue water during the growth of the lowest (●) and highest (○) yielding spring barley crops from Expts A, B, C and D.

Table 2. Mean K concentrations maintained in the tissue water of the lowest and highest yielding crops from Expts A, B, C and D, measured between the 3-leaf stage and the cessation of dry-matter accumulation

Experiment	Mean \pm s.e. K concentration (mmol/kg tissue water)	
	Lowest yielding crop	Highest yielding crop
A	202 \pm 7	225 \pm 4
B	188 \pm 4	205 \pm 7
C	176 \pm 6	174 \pm 5
D	182 \pm 10	187 \pm 6

important osmotic role of K in plants (Läuchli & Pflüger, 1979; Wyn Jones *et al.* 1979), tissue water is a more appropriate basis on which to recalculate the concentrations.

Concentrations of K in the tissue water of growing barley crops and their relation to grain yield

As expected from Fig. 4, calculating K concentrations on the basis of tissue water substantially decreased differences between the low and high yielding crops from each experiment (Fig. 5). On all plots the K concentration was maintained at about 200 mmol/kg tissue water from the 3-leaf stage until the cessation of dry-matter accumulation. The rapid increase in concentration at the end

of the growing season coincided with water loss during ripening (Figs 5A and B). There were some day-to-day variations in K concentration in the tissue water which probably resulted from variations in the amount of water associated with the crops rather than from real fluctuations in crop K status.

During the period when K concentrations were relatively constant the average K concentrations maintained in the tissue water of the low and high yielding crops ranged from 174 to 225 mmol/kg tissue water (Table 2). Crops from Expts C and D had slightly lower mean concentrations than those from Expts A and B. These differences may indicate small differences in K status, but they did not influence grain yield (see Table 1). Potassium concentrations in the tissue water at the time of maximum % K in dry matter showed no relationship to grain yield (Fig. 6). Thus in these crops, which were well supplied with K, the correlation between % K in dry matter and grain yield (Fig. 2) does not result from differences in K status. Nonetheless, the relationship between % K in dry matter and yield may have some predictive value. On any given site, % K in dry matter of young cereals is likely to be related to maximum potential yield for a particular set of treatments, though this yield may subsequently be reduced by other factors such as disease, water stress or lodging. To improve the predictive value of the relationship the influence of these factors will need to be decreased.

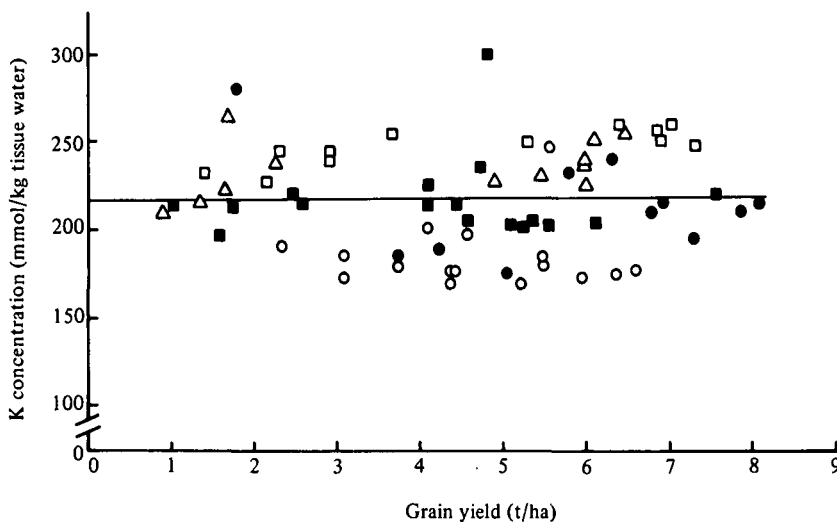


Fig. 6. Relationship between K concentration in the tissue water (at the time of maximum % K in dry matter) and harvested grain yield. \square , Expt A; \blacksquare , Expt B; \circ , Expt C; \bullet , Expt D; \triangle , Expt E. The fitted line has the equation $y = 0.16x + 217.0$; $r = 0.01$.

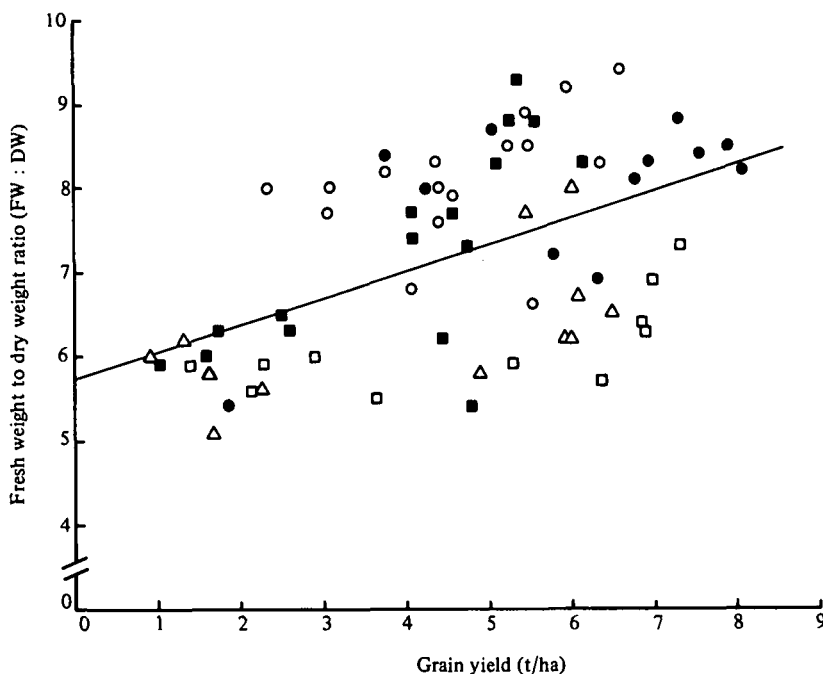


Fig. 7. Overall relationship between fresh weight: dry weight ratio (at the time of maximum % K in dry matter) and grain yield. \square , Expt A; \blacksquare , Expt B; \circ , Expt C; \bullet , Expt D; \triangle , Expt E. The fitted line has the equation $y = 0.32x + 5.74$; $r = 0.51$.

The relationship between grain yield and FW:DW of young barley plants

Figure 7 shows the relationship obtained when FW:DW, measured at the time of maximum % K in dry matter, was plotted as a function of grain yield. Although the correlation coefficient was highly significant ($P < 0.001$) it was less than that obtained when % K in dry matter was plotted against yield (Fig. 2) even though FW:DW and % K in dry matter were closely related (Fig. 4). This poorer correlation resulted both from the inter-experiment variation in the relationship between % K in dry matter and FW:DW (compare slopes in Fig. 4) and because within experiments crops on different plots attained maximum % K in dry matter on different days (e.g. Fig. 1C). Differences in weather and soil conditions between these days may have caused differences in FW:DW which also helped to mask any underlying relationships. It is not possible to allow for inter-experiment variation in FW:DW but environmental influences can be minimized within an experiment by using FW:DW

for samples collected on the same day. When this was done FW:DW and grain yield were well correlated, but the slopes of the regression lines varied from experiment to experiment (Fig. 8). The FW:DW values used in Fig. 8 were for single sampling dates close to the time when % K in dry matter was at a maximum, so crops were at a similar physiological age to those in Figs 2, 6 and 7.

The correlations between FW:DW and grain yield probably result from differences in specific leaf area between crops. Plants with a high FW:DW have a higher water content per unit dry matter and must produce larger cells to accommodate the increased volume of tissue water. At the whole plant level this will be reflected as the production of large and thicker leaves per unit of dry matter which will result in higher relative growth rates and hence increased yield (see Hunt, 1978). Because FW:DW varies between similarly yielding crops grown under different conditions or at different times (Fig. 3) it is unlikely to be as useful as % K in dry matter as a general predictor of yield, even though yield differences probably result from variations of FW:DW.

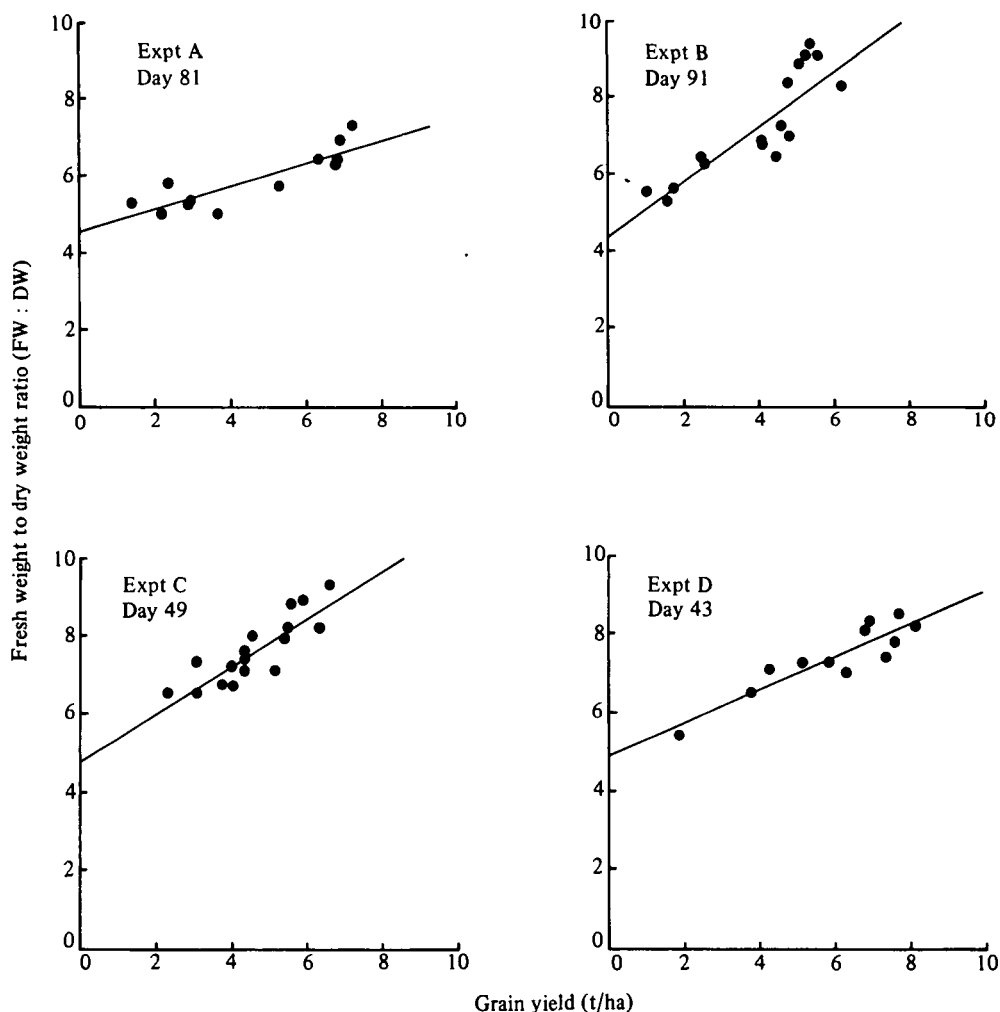


Fig. 8. Relationship between fresh weight to dry weight ratio (measured on the day after sowing indicated) and grain yield for Expts A, B, C and D. The equations for the fitted lines and values for the correlation coefficients are: Expt A, $y = 0.29x + 4.55$, $r = 0.86$; Expt B, $y = 0.72x + 4.39$, $r = 0.87$; Expt C, $y = 0.61x + 4.78$, $r = 0.85$; Expt D, $y = 0.42x + 4.92$, $r = 0.91$.

The benefit of expressing K concentrations on a tissue water basis

Expressing K concentrations on the basis of tissue water eliminated differences between low and high yielding crops and also revealed a different pattern of behaviour of this nutrient during the growth of barley. Whereas % K in dry matter generally declined during growth (Fig. 1), K concentrations in the tissue water remained reasonably constant at about 200 mmol/kg tissue water (Fig. 5; Table 2). Barley seedlings grown in K-sufficient nutrient solution in controlled environ-

ments also maintain K concentrations about 200 mmol/kg tissue water (Asher & Ozanne, 1967; Pitman, 1972; Ahmad & Wyn Jones, 1982), suggesting that this is the level to which adequately K-supplied barley plants accumulate this nutrient. The maintenance of a constant concentration despite falling FW:DW (Fig. 3) suggests that the decline of the latter results from the addition of structural material (e.g. cell walls) rather than a decline in intracellular water content. In contrast, during crop ripening the change in FW:DW results from loss of cell water leading to increased K concentrations. Because K concentration in the

tissue water stays relatively constant during most of the growth of the crop it should prove a more useful measure of K status than % K in dry matter and may provide an age-independent method for assessing tissue K status. In

another paper (Leigh & Johnston, 1983) we further investigate the usefulness of K concentrations in tissue water by examining the effect of fertilizers and drought on these and on % K in dry matter.

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