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# RECENT RATES OF SOIL LOSS FROM AREAS OF ARABLE CULTIVATION IN THE UK

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ABSTRACT Soil erosion problems have traditionally received little attention in the UK. However, recent intensification of farming practices has led to increased erosion risk in many areas of arable cultivation. Faced with a lack of quantitative data on rates of soil loss in such areas over the past few decades, the authors have employed the $^{137}$Cs technique to estimate recent rates of soil loss from arable fields on a variety of soil types. The results obtained from the 13 sites investigated point to gross erosion rates ranging between 2.2 and 12.2 t ha$^{-1}$ year$^{-1}$ and net erosion rates in the range 0.6 - 10.5 t ha$^{-1}$ year$^{-1}$. It is estimated that rates of soil loss during the past 30-35 years in areas with significant erosion risk may have increased by an order of magnitude or more. Such increases have important implications for long-term crop productivity and increased sediment yields downstream. It is suggested that suspended sediment yields are likely to have doubled in many areas experiencing increased rates of soil loss.

## INTRODUCTION

Traditionally, the problem of soil erosion from agricultural land has received little attention in the UK (cf. Boardman, 1990). The threat from wind erosion to cultivated land in eastern England was recognized in the 1950s and 1960s (e.g. Spence, 1957; Wilkinson *et al.*, 1969), but it was generally accepted that water erosion was not a problem due to the low intensity of British rainfall (e.g. Hudson, 1967). More recently, however, there has been an increasing number of reports which have emphasized that soil erosion by water must be viewed as a significant problem in many areas of arable cultivation (cf. Evans & Cook, 1986; Boardman *et al.*, 1990). The increasing evidence of soil erosion provided by these reports is in part a reflection of the growing awareness of the problem and an upsurge in field surveys and monitoring activity which have documented what previously passed unrecorded. However, it undoubtedly also reflects a real increase in the incidence of the problem. This in turn may be related to the increasing intensification of farming over the past 30 to 40 years, which has led to the adoption of farming practices which increase the susceptibility of agricultural land to erosion. These changes in farming practices include:

(a) ploughing up of steep slopes that were formerly under grass, in order to increase the area of arable cultivation.
(b) use of larger and heavier agricultural machinery which has a tendency to increase soil compaction.
(c) removal of hedgerows and the associated increase in field size. Larger fields cause an increase in slope length with a concomitant increase in erosion risk.
(d) declining levels of organic matter resulting from intensive cultivation and reliance on chemical fertilizers, which in turn lead to reduced aggregate stability.

(e) availability of more powerful machinery which permits cultivation in the direction of maximum slope rather than along the contour. Rills often develop along tractor and implement wheelings and along drill lines.

(f) use of powered harrows in seedbed preparation and the rolling of fields after drilling.

(g) widespread introduction of autumn-sown cereals to replace spring-sown cereals. Because of their longer growing season, winter cereals produce greater yields and are therefore more profitable. The change means that seedbeds are exposed with little vegetation cover throughout the period of winter rainfall. Evans & Cook (1986) cite an increase in the area of winter-sown cereals of 3.1 times between 1969 and 1983.

The precise impact of these changes will undoubtedly have varied across the country, but Boardman (1990) identifies the widespread adoption of autumn-sown cereals as the principal cause of the upsurge of erosion in the 1970s and suggests that in some areas of the country the incidence of erosion increased by an order of magnitude. Further information on the rates of soil loss which have occurred in such areas is, however, required in order to provide a more specific assessment of the impact of these recent changes in farming practice.

Any attempt to assess current and recent rates of soil loss from agricultural land in the UK inevitably faces problems because of the general lack of quantitative data. There are very few erosion plot data, since Morgan (1985) indicated that erosion plots had been established at only seven locations and that no long-term data were available. Field surveys of rills and gullies have been undertaken by a number of workers as a means of estimating volumes of eroded soil and therefore erosion rates (e.g. Evans & Cook, 1986; Colborne & Staines, 1986; Boardman, 1990), but this approach is unable to provide precise data due to the bias towards large scale erosion features and the impossibility of including the effects of splash and sheet erosion. Furthermore, it is difficult to obtain the accurate estimates of volumes of deposited sediment necessary for calculating net erosion rates. Faced with this lack of existing quantitative data, and the need to obtain estimates of the rates of soil loss from fields at risk from soil erosion over the past few decades, the authors have employed the $^{137}$Cs technique to estimate rates of soil loss from arable fields on a variety of soil types in Britain. One particular advantage of the $^{137}$Cs technique is its ability to assess retrospectively average rates of soil erosion over the preceding 30-35 years on the basis of a single site visit (cf. Walling & Quine, 1991).

## THE $^{137}$Cs TECHNIQUE

$^{137}$Cs is an artificial radionuclide with a half life of 30.17 years, which was released into the stratosphere by past testing of thermonuclear weapons and deposited as fallout. In most agricultural environments, $^{137}$Cs reaching the soil surface as fallout is strongly and rapidly adsorbed by clay minerals (Bachhuber *et al.*, 1982; Livens & Baxter, 1988). Subsequent lateral redistribution of $^{137}$Cs occurs in association with sediment particles in response to erosion, transport and deposition processes and the degree of redistribution reflects the net effect of erosion and deposition during the period extending from the main phase of atmospheric deposition (late 1950s and early 1960s) to the time of sampling. Assessment of $^{137}$Cs redistribution is commonly based upon a comparison of the total $^{137}$Cs inventory (mBq cm$^{-2}$) of the soil profile with an equivalent estimate of atmospheric deposition to the site. Loss of $^{137}$Cs relative to this reference value is indicative of erosion, whereas an increased $^{137}$Cs inventory indicates deposition. Because direct measurements of $^{137}$Cs deposition are rarely available, the reference value is generally established for each study site by sampling nearby undisturbed, uneroded locations supporting permanent grassland. Soil erosion surveys involve the collection of samples from the study site, and comparison of the measured $^{137}$Cs inventories of these samples with the local reference inventory. The magnitude and direction of deviations provide a qualitative estimate of sediment redistribution. In order to obtain a quantitative assessment of the rates of erosion and deposition, it is necessary to establish an empirical or theoretical relationship between the magnitude of the positive and negative deviations from the reference loading and the equivalent rates of erosion and deposition. In the absence of empirical calibration data, the authors have developed a simple numerical model which represents the movement of $^{137}$Cs in association with erosion and aggradation (Quine, 1989; Walling & Quine, 1990,1991). This model can be used to predict the $^{137}$Cs inventory of soil profiles subject to a range of long-term erosion and aggradation rates and such data are then used to derive calibration relationships.

*TABLE 1 Location from Fig. 1 and soil characteristics of the study fields.*

| Farm site | | Grid Ref | Soil Type |
|---|---|---|---|
| 1 | Yendacott, Devon | SS 898 007 | Brown earth |
| 2 | Mountfield, Somerset | ST 401 168 | Brown earth |
| 3 | Higher, Dorset | SY 617 824 | Calcareous pelosol |
| 4 | Fishpool, Gwent | SO 446 100 | Argillic brown earth |
| 5 | Wootton, Herefordshire | SO 643 487 | Argillic brown earth |
| 6 | Dalicott, Shropshire | SO 773 944 | Brown sand |
| 7 | Rufford Forest, Notts. | SK 614 584 | Brown sand |
| 8a | Brook End, Beds. | TL 075 632 | Calcareous pelosol |
| 8b | Keysoe Park, Beds. | TL 063 625 | Calcareous pelosol |
| 9 | Manor House, Norfolk | TF 856 365 | Brown rendzina |
| 10 | Hole, Norfolk | TG 115 358 | Brown sand |
| 11 | West Street, Kent | TR 328 541 | Brown calcareous earth |
| 12 | Lewes, Sussex | + | Brown rendzina |

## A COUNTRYWIDE SURVEY OF SOIL EROSION

The $^{137}$Cs technique described above was used to assemble estimates of recent rates of soil loss from areas of arable cultivation in southern Britain. Fields were selected on a range of soil types representative of the range of textural classes under cultivation. The number of sites that could be studied was constrained by the within-field sampling density employed and each textural class was consequently represented by only one or two sites. In all, 13 sites were investigated (Fig. 1, Table 1). The sites were not selected randomly, but were chosen on the basis of known erosion risk and therefore to demonstrate the potential magnitude of rates of soil loss.

Soil cores were collected from each study field using a square grid with a 20 or 25m spacing. These samples were returned to the laboratory for determination of their $^{137}$Cs inventory by gamma spectrometry. The calibration procedure described above was used to calculate the erosion or aggradation rate at each sampling point. The resultant grid-based estimates of erosion were interpolated using the UNIRAS computer package, in order to define the pattern of erosion and deposition within the study fields. Figure 2 illustrates the result for a field on the typical brown sand of the Cuckney 1 association, at Rufford Forest Farm, Nottinghamshire (site 7, Table 1). One clear feature of the pattern represented is the large percentage of the area which is subject to erosion and the small area within which aggradation is occurring. A single measure of net erosion from the field would underestimate the severity of the erosion problem and several erosion rate indices have therefore been derived for this and the other fields investigated. The gross erosion rate is calculated by dividing the total mass of eroded sediment by the area of the field and the net erosion rate represents the amount of soil leaving the field. The mean erosion rate for the eroding zone is equal to the total mass of eroded sediment divided by the area of the field undergoing erosion. The ratio of net erosion to gross erosion provides a measure of the proportion of the eroded sediment transported out of the field and is therefore equivalent to the sediment delivery ratio.

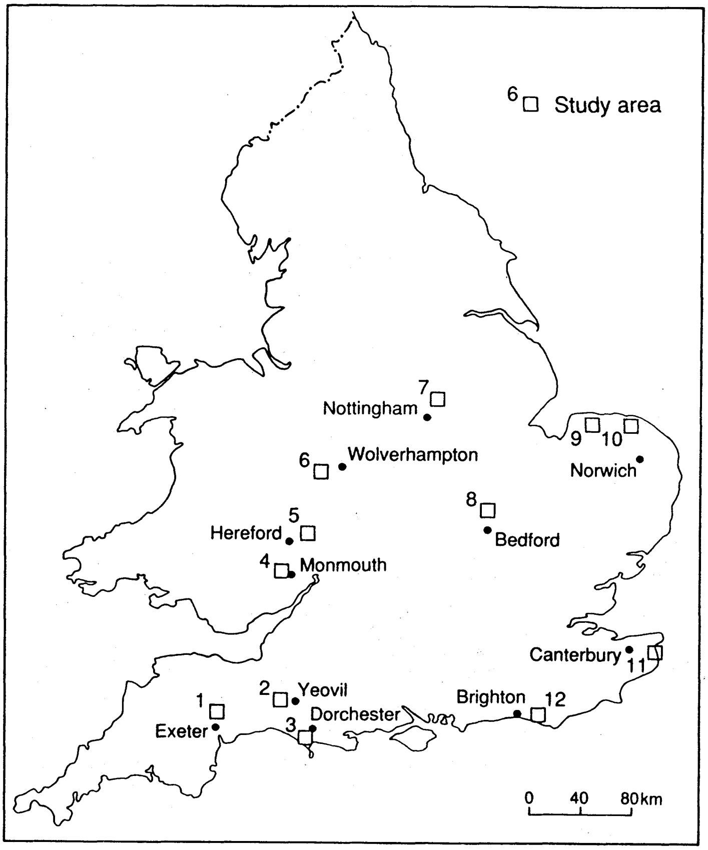

*FIG. 1 Location of the study sites. Site numbers refer to Table 1.*

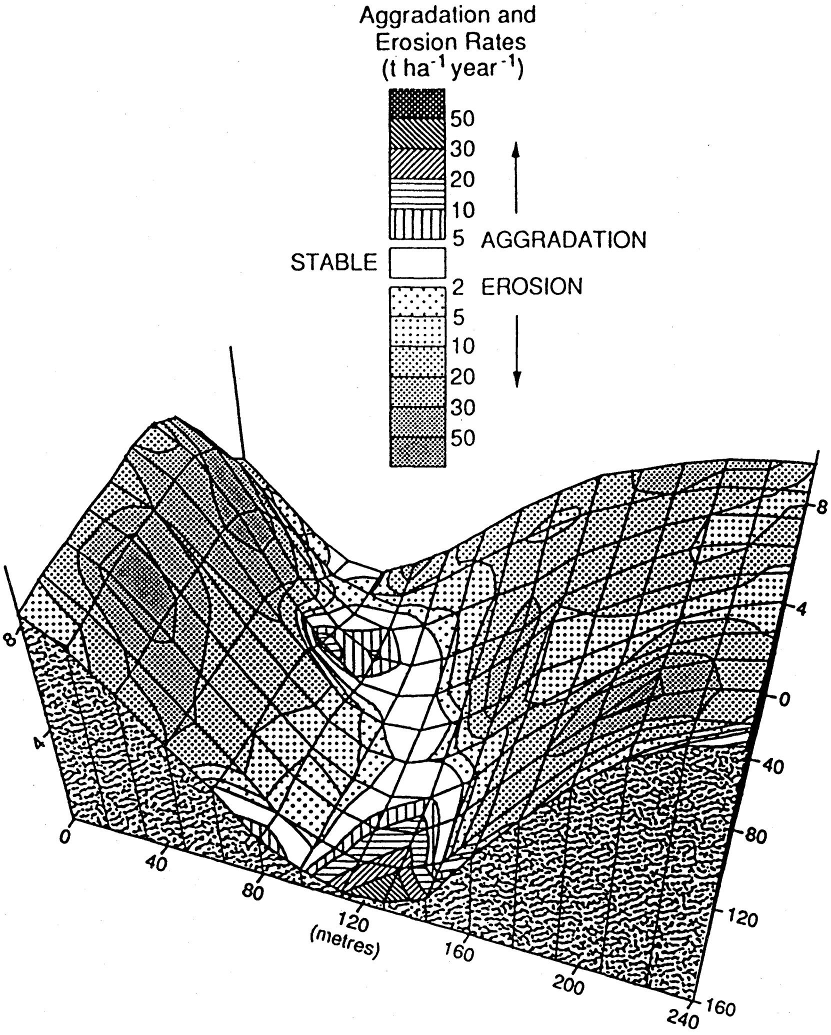

*FIG. 2 Erosion and deposition rates within the field at Rufford Forest Farm, Nottinghamshire.*

## RATES OF SOIL LOSS

The various indices of soil loss calculated for the study sites are presented in Table 2. Gross erosion rates range from 2.2 to 12.2 t $ha^{-1}$ $year^{-1}$ and average 6.1 t $ha^{-1}$ $year^{-1}$, whilst mean gross erosion rates within the eroding parts of the fields vary from 4.0 to 13.8 t $ha^{-1}$ $year^{-1}$ and average 8.2 t $ha^{-1}$ $year^{-1}$. Net erosion rates range from 0.6 to 10.5 t $ha^{-1}$ $year^{-1}$ and average 3.2 t $ha^{-1}$ $year^{-1}$. In all cases the values represent long-term average rates representative of the past 30-35 years. These data provide clear confirmation that these areas of arable cultivation in the UK are currently experiencing high rates of soil loss in response to changes in farming practices, In the absence of detailed long-term records of soil loss, it is impossible to assess the precise degree of increase that has occurred, but, based on existing

*TABLE 2 Rates of soil loss (t $ha^{-1}$ $year^{-1}$) documented at the study fields.*

| Soil type /site | Erosion rate Gross | Erosion rate Net | Eroding area % total | Eroding area Mean rate | Eroding area % >2 | Net/gross erosion (%) |
|---|---|---|---|---|---|---|
| *Brown sand* | | | | | | |
| Hole | 6.3 | 3.0 | 79 | 8.1 | 56 | 48 |
| Dalicott | 10.2 | 6.5 | 81 | 12.6 | 75 | 64 |
| Rufford | 12.2 | 10.5 | 89 | 13.8 | 81 | 86 |
| *Brown Rendzina* | | | | | | |
| Manor House | 6.3 | 2.4 | 67 | 9.4 | 54 | 38 |
| Lewes | 4.3 | 1.4 | 68 | 6.2 | 53 | 33 |
| *Brown calcareous earth* | | | | | | |
| West Street | 7.7 | 4.3 | 70 | 11.1 | 61 | 56 |
| *Brown earth* | | | | | | |
| Mountfield | 4.6 | 2.2 | 74 | 6.1 | 49 | 48 |
| Yendacott | 5.3 | 1.9 | 73 | 7.3 | 57 | 36 |
| *Argillic brown earth* | | | | | | |
| Wootton | 6.4 | 2.8 | 78 | 8.1 | 43 | 44 |
| Fishpool | 5.1 | 1.9 | 64 | 8.1 | 47 | 37 |
| *Calcareous pelosol* | | | | | | |
| Higher | 5.2 | 3.1 | 79 | 6.7 | 61 | 60 |
| Brook End | 3.6 | 1.2 | 63 | 5.7 | 40 | 33 |
| Keysoe | 2.2 | 0.6 | 54 | 4.0 | 29 | 27 |

evidence, it seems reasonable to assume that net rates of soil loss were previously less than 1 t $ha^{-1}$ $year^{-1}$ and may well have been negligible, particularly where grassland has been converted to arable cultivation. It can therefore be suggested that rates of soil loss during the past 30-35 years from fields within study areas with significant erosion risk have increased by an order of magnitude or more. A similar level of increase can be inferred from archaeological evidence available for the chalk downland of Sussex (Bell, 1986). In this case, information on depths of colluvium on the floors of dry valleys were used to estimate long-term rates of soil loss from the surrounding slopes. Over a period of ca. 3500 years, extending from the Bronze Age to the present, mean rates of soil loss were typically in the range 0.2 - 0.75 t $ha^{-1}$ $year^{-1}$. Recent rates of gross soil loss for the chalkland site near Lewes investigated in this study were an order of magnitude greater at 4.3 t $ha^{-1}$ $year^{-1}$.

Morgan (1980) suggests that 2 t $ha^{-1}$ $year^{-1}$ should be viewed as a generous estimate of soil loss tolerance for British soils and it can be seen that gross rates of soil loss exceed this threshold on all study fields. Table 2 also indicates the proportion of the sampling points within the individual fields that evidenced erosion rates in excess of 2 t $ha^{-1}$ $year^{-1}$, and in all cases, except that at Keysoe, this exceeds 40%. In such circumstances, soil depths and crop productivity are likely to decline through time.

## The influence of soil texture

The variations in rates of soil loss between the study sites evident in Table 2 reflect contrasts in topography and cropping history and also the influence of soil texture. The magnitude of soil loss generally conforms to the expected pattern in terms of soil texture. The highest rates are found on the sandy and sandy loam soils, and the lowest rates on the clay soils. Available observations of the local distribution of soil erosion in Britain indicate that sandy soils are the most susceptible to rilling and gross rates of soil loss in excess of 10 t $ha^{-1}$ $year^{-1}$ have been recorded on the brown sands at Dalicott Farm, Shropshire and Rufford Forest Farm, Nottinghamshire. All three sites on clay soils have relatively low erosion rates and the lowest net rates were found at Keysoe Park Farm and Brook End Farm, Bedfordshire. Even here, however, the mean rates of soil loss from the eroding area of the field exceed the soil loss tolerance threshold by two and nearly three times respectively.

## Sediment delivery ratios

Recent concern for the non-point pollution of streams by land use activities has highlighted the role of sediment eroded from agricultural land. Such sediment may be viewed as a pollutant both in its own right, for example by causing increased turbidity, and because of the nutrients and contaminants transported in association with the sediment particles. Any increase in rates of soil loss from agricultural land in Britain may therefore have important off-site implications for non-point pollution as well as implications for on-site reduction of crop productivity. In the absence of a national programme of sediment load monitoring in British rivers, there is, however, no conclusive evidence of increases in sediment loads over the past 30 years. The downstream impact of increased rates of soil loss will depend upon the proportion of fields within a catchment experiencing increased erosion and the sediment delivery ratios involved. If sediment delivery ratios are low, only a small proportion of the eroded sediment may reach the watercourses and the potential impact will be reduced. Little is currently known about the likely magnitude of sediment delivery ratios associated with cultivated fields in Britain but the $^{137}Cs$ technique provides valuable evidence concerning the proportion of the eroded sediment that is transported out of the field or the sediment delivery ratio (i.e. net erosion / gross erosion). Some of this transported sediment may be deposited before reaching a watercourse, but the value provides an estimate of the upper limit for the sediment delivery ratio associated with eroding fields (cf. Walling, 1990).

Values of the ratio of net erosion to gross erosion (expressed as a percentage) for the study sites are listed in Table 2 and range between 27% and 86%. In all cases, therefore, it seems likely that a significant proportion of the eroded sediment will be transported to the stream network and that the increases in rates of soil loss noted above will be reflected in increased sediment loads. In examining the range of sediment delivery ratios involved, there is some evidence of a positive relationship with gross soil loss, indicating that the proportion of the eroded sediment leaving the field is at a maximum in the fields with the highest gross erosion rates. This could be explained in terms of the increased transport capacity of the greater amounts of surface runoff occurring in those areas. However, this trend could also reflect the influence of soil texture, which has already been shown to exert an important influence on erosion rates. In this context, the highest proportions of eroded sediment leaving the field are associated with sandy soils and the smallest proportion with the clay soils. This pattern could in turn reflect the prevalence of rilling on the sandy soils and the more spatially discontinuous nature of surface runoff on the clay soils.

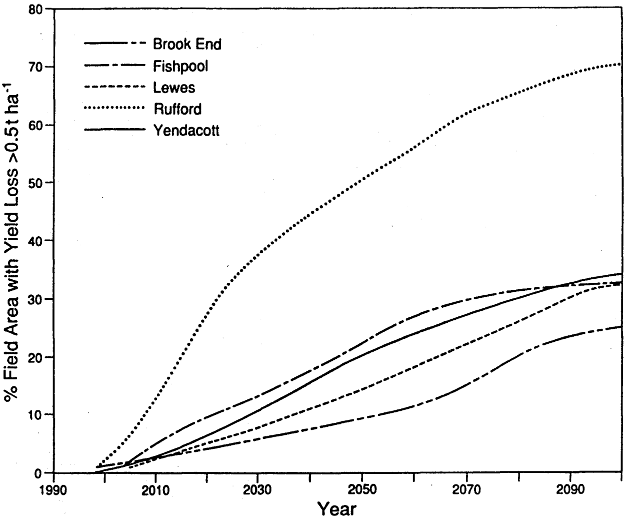

*FIG. 3 A tentative representation of the future impact of soil loss on crop productivity for five of the study sites.*

## IMPLICATIONS

The limited number of fields examined in the present study necessarily constrains the degree of generalization that is possible. Nevertheless, the evidence provided by $^{137}$Cs measurements reported above suggests that as a result of changing farming practices rates of soil loss have increased by up to an order of magnitude or more in some areas of arable cultivation with high erosion risk. These increased rates of soil loss have important implications for river water quality, because estimates of the sediment delivery ratios associated with the study fields indicate that a substantial proportion of the eroded sediment has been transported beyond the fields and towards the stream network. If it is assumed that suspended sediment yields in southern Britain under essentially 'natural' conditions (i.e. with traditional farming practices that do not promote soil erosion) are typically of the order of 50 t km$^{-2}$ year$^{-1}$, it would not be unreasonable to expect these to double in areas where recent changes in farming practices have caused increased rates of soil loss. Assuming a sediment delivery ratio to the stream network of 25% and a gross erosion rate from the eroding fields of 4 t ha$^{-1}$ year$^{-1}$, the sediment yield from a basin would double if increased soil loss occurred over only 5% of its area as a result of changing agricultural practices. A value of 5% of agricultural land subject to increased erosion is in line with the results presented by Evans (1988) who suggested that of the order of 0.1 - 15% of agricultural land in Britain is affected by erosion each year, depending on location.

The long-term implications also are important for declining crop productivity, because at all the sites examined the gross rates of soil loss exceed the nominal soil loss tolerance threshold and substantial areas of the study fields are suffering erosion many times greater than the tolerance level. Mean rates of soil loss from the eroding areas of fields on brown sands, brown calcareous earths and argillic brown earths, are greater than 8 t ha$^{-1}$ year$^{-1}$. It is difficult to convert these rates into an estimate of yield reduction, but data presented by

Evans (1981) suggests that for soils less than 0.4 m deep, a loss of 0.05 m from the soil depth may decrease cereal yields by 0.5 t $ha^{-1}$. Therefore, cereal yields on 20-50% of the area of most of the fields investigated in this study may decrease by 0.5 t $ha^{-1}$ by the middle of the next century. Those zones within the fields with much greater local erosion rates will clearly suffer yield loss much earlier. Figure 3 illustrates the temporal increase in the percentage area of five of the fields investigated that could be expected to suffer a loss of cereal yield in excess of 0.5 t $ha^{-1}$, assuming the relationship cited above, an initial soil depth of 0.4m, optimum productivity at present and continuation of the measured erosion rates into the future. These are necessarily very tentative estimates, but they serve to emphasize the potential economic significance of the increased rates of soil loss reported.

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## REFERENCES

Bachhuber, H., Bunzl, K., Schimmack, W. & Gans, I. (1982) The migration of $^{137}$Cs and $^{90}$Sr in multilayered soils: results from batch, column, and fallout investigations. *Nuclear Tech.* **59**:291-301.

Bell, M.G. (1986) Archaeological evidence for the date, cause and extent of soil erosion on the chalk. *SEESOIL* **3**:72-83.

Boardman, J. (1990) *Soil Erosion in Britain: costs, attitudes and policies.* Education Network for Environment and Development, University of Sussex.

Boardman, J., Foster, I.D.L., & Dearing, J.A. (eds.) (1990) *Soil Erosion of Agricultural Land.* Wiley, Chichester.

Colborne, G.J.N. & Staines, S.J. (1986) Soil erosion in Somerset and Dorset. *SEESOIL* **3**:62-71.

Evans, R. (1988) Water erosion in England Wales 1982-1984. Report for Soil Survey and Land Research Centre, Silsoe.

Evans, R. & Cook, S. (1986) Soil erosion in Britain. *SEESOIL* **3**:28-59.

Hudson, N.W. (1967) Why don't we have soil erosion in England? In: Gibb, J.A.C. (ed.) *Proceedings of Agricultural Engineering Symposium,* Institute of Agricultural Engineers Paper 5/B/42

Livens, F.R. & Baxter, M.S. (1988) Chemical associations of artificial radionuclides in Cumbrian soils. *J. Env. Radioactivity* **7**:75-86.

Morgan, R.P.C. (1980) Soil erosion and conservation in Britain*Prog.in Phys.Geog.* **4**:24-47.

Morgan, R.P.C. (1985) Soil erosion measurement and soil conservation research in cultivated areas of the UK. *Geog. J.* **151**:11-20.

Quine, T.A. (1989) Use of a simple model to estimate rates of soil erosion from $^{137}$Cs data. *J. Water Resources* **8**:54-81.

Spence, M.T. (1957) Soil blowing in the Fens in 1956. *Meteorological Magazine* **86**:21-22.

Walling, D.E. (1990) Linking the field to the river: sediment delivery from agricultural land. In: Boardman, J., Foster, I.D.L. & Dearing, J.A. (eds.) *Soil Erosion on Agricultural Land,* Wiley, Chichester, pp. 129-152.

Walling, D.E. & Quine, T.A. (1990) Use of $^{137}$Cs to investigate patterns and rates of soil erosion on arable fields. In: Boardman J., Foster, I.D.L. & Dearing, J.A. (eds.) *Soil Erosion on Agricultural Land,* Wiley, Chichester, pp. 33-53.

Walling, D.E. & Quine, T.A. (1991) Use of caesium-137 measurements to investigate soil erosion on arable fields in the UK: potential applications and limitations. *J. Soil Sci.* **42**:147-165.

Wilkinson, B., Broughton, W. & Parker-Sutton, J. (1969) Survey of wind erosion on sandy soils in the East Midlands. *Exp. Husbandry* **18**:53-59.