



Predicting Carbon Sequestration under Land Management Practices for Six Periods of English Agriculture Using Century 4.0 Model

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ABSTRACT

Six periods of English agriculture namely: prehistoric, historic, agricultural revolution, post agricultural revolution, green planet and post green planet were identified. Their previous and current land management practices were reviewed with reference to East Anglian Region (EAR), the food basket of the nation. The current land management practices at EAR with Writtle College Research and Teaching Farm as case study included: grassland on permanent pasture; one on 5 y ley to stocking, the other sown with red clover a y before stocking; the third treated with N fertilizer a y before stocking; the fourth on arable crop (barley); with pristine woodland as control. By aid of CENTURY 4.0 Model, simulation of soil carbon (C) storage was generated for the past, present and future (8050 yrs). The validity of the model was tested by fitting measured with simulated C. The closeness of data fit in deciduous woodland shows the accuracy of the prediction; while the variations in other sites show the effects of management. The assumed practices during different historical and future periods led to the following predictions and conclusions. All the current land management practices including woodland do not sequester enough C. Integrated approaches like agroforestry, silviculture are required. Nevertheless, given the current land management soil C sequestration will be moderate ($0.02 \pm 0.003 \text{ t ha}^{-1} \text{ y}^{-1}$) up to 2055 before impacts that will require other sustainable options will be noticed.

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Introduction

Ever since the advent of farming some 12,000 years ago farmers have been ploughing or tilling the soil (Pretty, 2002; Pretty an Ball, 2002) while trying to maintain soil fertility. In the earliest agricultural systems dating back some 7000 years crops were grown on land for a few years after it had been cleared; when the natural fertility of the soil began to fail and crop yields began to decline the farmer moved on to a new area. For settled agriculture to develop some form of systematic rotation was necessary which allowed soil to recover its fertility. Today a lot of agricultural land management practices abound namely: arable farming, pastoral farming, agroforestry, logging/deforestation, woodland/protected areas. Each of them have sub-management practices in the form of cropping pattern/rotation, use of fertilizers (organic/inorganic), agrochemicals, tillage practices (conventional/zero/minimal), livestock stocking pattern/density and general harvesting of its resources including wildlife.

In England, UK it is believed that a simple rotation may have been practiced since around 1000 BC. The land was left fallow every year or every third year on the better soils. By the Middle Ages lowland areas had developed the variant in rotation of fallow in the second year and in the third a crop of beans (which fixes atmospheric nitrogen). In hillier areas, crop growing alternated with pastures, in the north animals were kept in temporal enclosures on the field to ensure their faeces fertilized the soil (RCEP, 1996; Briggs and Courtney, 1989; Davies *et al*, 1999; Fowler, 1983; Rackham, 1986; Dent *et al*, 1966, Simmons and Dooley, 1981).

From the 16th century onwards more advanced methods spread from the continent. The first continuous cropping system was introduced by Townsend in Norfolk in EAR of England in

1730; cereal-turnips-cereal-clover with sheep grazing turnips in winter and clover in autumn. Different rotations followed using new crops, sometimes extending over eight or even ten years. Other innovations included large scale drainage (for example in EAR) and new tools for cultivation, such as horse-drawn hoes and drills (RCEP, 1996). In addition to farm yard manure, other materials spread on soils to improve fertility included marl (a mixture of clay and calcium carbonate), river sediment, shell sand (which provided lime), rags, bones, horn, wood, ash and sea weed. In the early 19th century Humphrey Davy was the first scientist to suggest that plants derive nutrients from the soil (rather than the atmosphere). In the mid 19th century scientists in England (Lawes at Rothamsted and Germany Liebig) demonstrated the role of soil nutrients in plant growth thereby opening the way for synthetic fertilizers manufacture and use especially after the second world war (RCEP, 1996).

Over the past 150 years (a period of innovation in agriculture in Europe, otherwise known as agricultural revolution, crop and livestock production and hence land use and management have assumed different dimensions (Pretty, 2002; Pretty and Ball, 2002; Thirsk, 2000; Thirsk, 1991; Holderness and Turner, 1991; Chambers and Mingay, 1966). In the UK crop and livestock production per area have increased three to four fold as innovative technologies such as the seed drill, novel crops such as turnips and legumes, fertilization methods, rotation patterns, selective livestock breeding, drainage and irrigation were developed by farmers and then spread to local conditions by vigorous experimentation (Pretty, 2002).

Among the regions that make up England, East Anglia has a history of profound agricultural land management practices. Extensive agriculture was necessary because there was insufficient livestock (sheep) to dress the whole cultivable area.

Due to the fact that cereal growing in East Anglia required ample supplies of dung, bullock-feeding still maintained the number of cattle irrespective of the reduction in dairy farming. The EAR corn-sheep system was classified as some of the best in the country (Thirsk, 1991, 2000). The place of EAR in the agricultural history of England may have necessitated the establishment of Writtle Agricultural College. Writtle have farms developed for educational purposes including separate commercial units in agriculture and horticulture. The total land area is approximately 209.6 ha. The arable system is centered on the sturgeon farm. The farming system is designed to provide commercially convincing examples of the major enterprises to be found on the farms in the eastern counties of England (Writtle College, 2004).

The Century 4.0 agroecosystem model by Parton et al (1993) describes the best understanding of the biochemistry of C, N, P, and S. The primary purpose of the model are to provide a tool for ecosystem analysis, to test the consistency of data, and to evaluate the effects of changes in management and climate on ecosystems. It was developed to deal with a wide range of cropping system rotations and tillage practices, for the systematic analysis of the effects of land management and global change on productivity and sustainability of agroecosystem (grasslands, forest, crops and savannahs). The version 4.0 integrates the effects of climate and soil driven variables including agricultural management in the simulation of management systems, including crop rotations, tillage practices, fertilization, irrigation, grazing and harvest methodologies (Parton *et al*, 1993; Metherel, 1992; Parton *et al*, 1983; Parton *et al*, 1987). Century operates on a monthly time step and is adequate for estimation of medium to long term (10>10,000 y) changes in soil total C and other ecosystem parameters in response to changes in climate, land use and management. It has additional sub-models (Parton *et al*, 1993). The CENTURY was adopted for this work in view of the numerous advantages

Materials and Methods

Site description

East Anglian Region of England (Writtle College as case study) is located approximately 68 klm east of London (51° 44', 0° 26', 32 OD). The soil belongs to Hanslope Soil Series of Chalky Boulder Clay parent material. Writtle College has total land area of 209.6 ha. The grassland area totals 44.7 ha and is either permanent grass or medium and long term leys. Of this area 21.6 ha are situated at Daws and is utilized for dairy herd. A total of 21.5 ha consists of paddocks adjacent to sturgeons grazed by young cattle and sheep. A 2 ha area of broom field is divided into 6 paddocks for forward grazing by ewes and lambs. Generally grazing is based on 4 ha paddocks which are set stocked to provide approximately 1 week's grazing at a time. About 4 ha of ancient deciduous woodland (>200 years old) is located opposite the sturgeons farms. The dominant trees include ash, common oak, double white cherry, common birch, bat willow, crack willow and field maple (Neate, 1979). A perennial stream transects the woodland and is one of the two that flows past sturgeons and lordship farms. These streams are tributaries of rivers can and wid on whose confluence the college lies (Neate, 1979; Writtle College, 2004). The rivers together with the streams flowing past sturgeons and lordship farms have been cut to form gently sloping shallow valleys so that the lowest ground is at about 30 m over datum (OD) at the eastern end of the estate and rises gradually to 50 OD on the southern boundary (Victoria field). The soils are entirely formed in recent geological (quaternary) drifts which can be placed into three lithological groups: loams (brickearth), clays and gravels.

The clays can be further subdivided into chalky and non chalky (leached) boulder clays and alluvial clay making five principal parent materials. London clay (solid geology) underlies the whole farm but only approaches the ground surface near the reservoir on daws farm. Small areas of stony loamy material originating as recent hill-wash from nearby Slopes (colluviums) are included on the soil map. Thus the soils are those of the boulder clay plateau associated drift-filled valleys soils which characterize the mixed farming district of the north-central Essex. Sampling and analysis is related to cropping policy. Grassland is sampled once every three years, fields in the six year rotation are sampled after the first cereal, that is potatoes, wheat-wheat, peas, wheat, barley (Writtle College, 2004).

Century model overall structure

The soil organic matter submodel simulates the flow of C, N, P, S through plant litter and the different inorganic pools in the soil. The model runs using the following major inputs: monthly average maximum and minimum temperature, monthly precipitation; lignin content of plant material, plant N, P, S content; soil texture, atmospheric and soil N inputs and initial soil C, N, P and S levels. The input variables are available for most natural and agricultural ecosystems and can be generally estimated from existing literature (Parton et al, 1993).

Century key model processes and assumptions

The model includes three soil organic matter pools (active, slow and passive) with different potential decomposition rates, above and belowground litter pools and a surface microbial pool which is associated with decomposing surface litter. Above and below ground residues and organic animal excreta are partitioned into structural and metabolic pools as a function of the lignin ratio in the residue. With increases in the ratio more of the residue is partitioned to the structural pools which have much slower decay rates than the metabolic pools. The structural pools contain all of the plant lignin. The decomposition of both plant residues and SOM are assumed to be microbially mediated with an associated loss of CO₂ as a result of microbial respiration. The loss of CO₂ on decomposition of the active pool increases with increasing soil sand content. Decomposition products flow into a surface microbe pool or one of the three SOM pools, each characterized by different maximum decomposition rates. The potential decomposition rate is reduced by multiplicative functions of soil moisture and soil temperature and may be increased as an effect of cultivation. Average monthly soil temperature near the soil surface is the input for the temperature function while the moisture function uses the ratio of stored soil water (0 - 30 cm depth plus current month's precipitation to potential evapotranspiration. The decomposition rate of the structural material is a function of the fraction of the structural material that is lignin. The lignin fraction of the plant material does not go through the surface microbe or active pools but is assumed to go directly to the slow pool as the structural plant material decomposes (Parton et al, 1993).

The model simulates a wide variety of crops and grassland by altering a number of crop specific parameters. Apart from barley, grassland under permanent pasture (two categories as described in materials and methods) and woodland site that was simulated, other crops that featured in the sites in the past include: wheat – *Triticum aestivum*, L; maize – *Zea mays*, L; potato – *Solanum tuberosum*, L and soybean (*Glycine max*, L). Hence, in amending the crop/tree file using File.100 CENTURY updating facility the Geescroft_Wilderness_Rothamsted_UK (succession) for woodland vegetation;

Grass_Clover_Pasture_Geescroft for the clover plot; Rothamsted_Grass for the 5 y ley plot and Brly_V₁ for the barley plot were used. The parametrization values for these crops/trees were obtained from Rothamsted data archive as described by Farage et al (2005).

The model also assumes that plant available soil N will be preferentially used by the crop. All other potential limitations to growth, including P and S supply are taken into account before calculating symbiotic N₂ fixation. This has to do with the permanent pasture sown with red clover in this work. On the other hand fertilizer addition is normally by fixed amounts or calculated automatically according to the crop requirements. The automatic option are set to maintain crop growth at a particular fraction of potential production with the minimum nutrient concentration or to maintain maximum production with plant nutrient concentrations at a nominated level between the minimum and maximum for that growth stage. Organic matter additions are specified in omad.100 file (part of Century file.100 updating facility). The fertilizer file was amended using the fert.100 file. The entire fertilizer type and rates used at writtle except potassium fertilizer that is not supported by the model were included in this amendment.

At harvest grain is removed from the system and live shoots can either be removed or transferred to standing dead and surface residue. For grain crops a harvest index is calculated based on a genetic maximum and moisture stress in the months corresponding to anthesis and grain fill. Moisture stress is calculated as the ratio of actual potential transpiration in these months. The fraction of aboveground N, P, and S portioned to the grain are crop-specific constants modified by the square root of the moisture stress term, resulting in higher grain nutrient concentrations when moisture stress reduces the harvest index. At harvest a proportion of the aboveground nitrogen is lost to volatilization. The crop harvest routine also allows for the harvest of roots, hay crops or straw removal after a grain crop. The crop may be killed at harvest as for cereal grain crops or a fraction of roots and shoots may be unaffected to harvest operations and growth may continue.

The effects of grazing on plant production are represented in the model using the data from Holland et al (1992) and Ojima et al (1990). Grazing removes vegetation, returns nutrients to the soil, alters the root to shoot ratio and increases the N content of the live shoots and roots (Holland et al, 1992). The model has three options for dealing with the impact of grazing on plant production except for the removal of vegetation and return of nutrients by the animal. Option 2 is referred to as the lightly grazed effect (Holland et al, 1992) and includes a constant root:shoot ratio (not changing with grazing) and a linear decrease in potential plant production with increasing grazing intensity. Option 3 is referred to as the heavy grazed (Holland et al, 1992) and includes a complex grazing optimization curve where aboveground plant production is increased for moderate grazing and decreased sharply for heavy grazing (>40% removed per month). The root:shoot ratio is constant for low to moderate grazing and decreases rapidly for heavy grazing. In all three options the nutrient content of new shoot will increase in relation to the residual biomass. In this work option 2 (light grazing) was in practice and was assumed up to 2055, while other options (medium to high grazing) featured in most sites in the past. These information were included in the events schedule for most of these sites.

Cultivation option allows for the transfer of defined fraction of shoots, roots, standing dead and surface litter pools as is appropriate. The model simulates a variety of conventional

cultivation methods, such as ploughing or sweep tillage, thinning operations or herbicide application. Each cultivation option also has parameters for a multiplicative effect of soil disturbance by cultivation or organic matter decomposition rates for the structural, active, slow and passive pools. The values for these parameters range from 1.0 to about 1.6 with the actual value dependent on the degree of soil stirring and disruption caused by each implement. In this work only one aspect of cultivation (ploughing or drilling) per time was chosen during events scheduling as supported by the model even when more than one cultivation activity took place on the same land per time (Parton et al, 1987)

Century inputs requirements, weather and management information

Century uses monthly precipitation and mean monthly minimum and maximum temperature. For each block in the simulation, EVENT100 allows the user to choose between four options for weather data. The first option uses the mean values for each month in every year of the block simulation. The second option uses the mean monthly temperature values in every year and stochastically generates precipitation from skewed distribution (Nicks, 1974). If skewness parameters are unavailable, a truncated normal distribution is used but this will increase the overall mean precipitation when the coefficient of variation for precipitation is high. The third option reads the monthly values for precipitation, minimum and maximum air temperature from the start of a weather data file, while the fourth will continue reading from the same file without rewinding. In this work the geographical, weather, soil information used in updating the site.100 file were based on writtle record for 35 years (Writtle, 2004). Other inputs made use of model default values.

The Century environment

The century environment as described by Parton et al (1993) consists of the century model which uses the view output programmes and two utilities. The file100 programme assists the user in creating and updating any of the twelve files used by century. The event100 programme creates the scheduling file which contains the agricultural plants and events that are to occur during the simulation. The century model obtains input values through the twelve data files. Each file contains a certain subsets of variables, for example the cult.100 file contains the values related to cultivation. Within each file there may be multiple options in which the variables are defined for multiple variations of the event. For example, with the cult100 file there may be several cultivation options defined such as ploughing or rod-weeder. For each option the variables are defined to simulate that particular option. Each data input file is named a "100" extension to designate it a century file. The files can be updated and new options created through the FILE100 programme. The timing variables and schedule of when events are to occur during the simulation is maintained in the schedule file, named with a "sch" extension. The file can be created and updated through the EVENT100 programme. First the CENTURY environment must be installed on the computer to be used. Then FILE100 programme used to update values or create new options in any of the .100 data files. EVENT100 programme establishes the stimulation time and schedules events that are to occur, while the model is run as described by Parton et al (1993). The model environment runs on the following parameters: time step (one month) or ½ year or 0.083333; minimum time (year); soil organic matter (grammes C, N, P or S m⁻²); plant material (grammes C, N, P or S m⁻²); mineral pools (grammes N, P or S m⁻²); temperature (degrees

centigrade) and precipitation (centimeter per month). The above files and procedure were used in amending necessary files and creating events scenarios in this work.

Century Parametisation and events scheduling

The model includes a method for estimating steady state soil C and N levels in grassland systems which was developed for the US Great Plains. It has been parametised to simulate SOM dynamics in the top 20 cm of the soil and does not simulate OM in the deeper soil layers and increasing the soil depth parameter does not have much impact on the model. One of the most difficult parts of initializing the model is estimating the C, N, P, and S levels for the different soil fractions. The active soil fraction includes the live soil microbes and microbial products. In this work four sites were scheduled according to tillage, cropping, fertilization, pasture and general management for six periods of English agriculture namely: prehistoric, the time when predominantly all English land was regarded as pristine woodland (6000 BC to 1200 AD); the historic, this period was dominated by traditional shepherds and husbandmen whose activities included returning of wheat straw to the land during seedbed preparation and trying of certain innovations like use of red clover seeds imported from Holland to enrich soil fertility (1201 to 1699 AD); the agricultural revolution, this time was marked by the use of agricultural equipment like ploughs, harrow, chemical fertilizer and soil drainage technology, improved seeds in intensive and extensive arable and pastoral farming (1700 to 1904 AD); post agricultural revolution, this period was marked by the enclosure of open fields, common lands, meadows and wastes, conversion of land to more profitable uses, example laying of old arable land to permanent pasture or long leys, ploughing and putting under suitable rotation common and rough hills overgrown with weeds or that was bare through overgrazing (1905 to 1986); green planet, this time is marked by environmental movements, earth first, greenpeace, greenparty and national and international treaties as well as code of conduct for protection and preservation of air, water and soil resources (1987 to 2025 AD); post green planet, this is a period where some environmental problems are envisaged from higher greenhouse gases scenario and climatic change (Chambers and Mingay, 1966; Thirsk, 1991, 2000; Cantor, 1987; Holderness and Turner, 1991; Pretty, 2002; Perry, 1973; Wormel, 1999; Greenville and Grant, 1988). The sites before simulation was forest with Geescroft_Wilderness_Rothamsted_UK succession for woodland vegetation used to initialize the lignin values of the forest system (Farage et al, 2005). The output period was monthly (Jan – Dec) for all periods while the output interval were 100 years between 6000 – 5000 BC and 4998 BC to 964 AD; for the periods 965 – 1514 AD and 1515 – 1734 AD the output interval was 20 years each; for other periods up to 2055 it was a year each

Scheduling of arable land under barley

The arable land under barley was assumed under GWRS (Geescroft_Wilderness_Rothamsted_Succession for woodland vegetation from 6000 BC – 964 AD. Cropping and management activities started from 965 – 1954 AD and 1955 – 2055 respectively. Altogether 12 blocks with various types of cropping and soil management practices were scheduled.

Scheduling of grassland under permanent pasture sown with red clover a year before stocking

This site was assumed under GWRS for woodland vegetation from 6000 BC – 964 AD. Cropping and management activities started from 965 – 1954 and 1955 – 2055 respectively.

Altogether 12 blocks with various types of cropping and soil management were scheduled.

Scheduling of grassland under permanent pasture on 5 year ley before cropping

This site was assumed under GWRS for woodland vegetation from 6000 BC – 964 AD. Cropping and management activities started from 965 – 1954 and 1955 – 2055 respectively. Altogether 12 blocks with various types of cropping and soil management were scheduled.

Scheduling of deciduous woodland

This site was assumed under GWRS for woodland vegetation from 8000 BC – 2055 AD. Only three blocks were scheduled.

Statistical and data analysis

The totc (total soil carbon) was converted from g m^{-2} to t ha^{-1} by dividing by 100 (for simulated results). The carbon sequestered for each period was got by dividing by the total number of years involved to get $\text{t ha}^{-1} \text{y}^{-1}$. The measured totc were converted from g kg^{-1} to t ha^{-1} by dividing by 1000 g to get g C g^{-1} soil, which translates to t C t^{-1} soil followed by multiplication of value by 2200 t (mass of 1 ha soil at 0 – 20 cm soil depth and soil bulk density of 1.1 g cm^{-3}). This placed the measured and simulated totc in the same unit (t ha^{-1}) for comparison. Regression analysis were done on simulated and measured soil totc to determine closeness of fit and validity for testing the model (Zar, 1999).

Results and Discussions

The effects of land management practices on measured and simulated soil totc during part of the green planet era of study

A comparison was made between measured and simulated soil totc for the various land management practices. The simulated results were in agreement with the actual values as in deciduous woodland, while the differences in other sites were based on management. Further relationship was established between measured and simulated results ($\text{MSTC} = 202 + 0.6\text{SSTC g kg}^{-1}$; $R^2 = 0.68$ and $\text{MSTC} = 18.9 + 0.6\text{SSTC g kg}^{-1}$, $R^2 = 0.72$ for two years period)

Changes in simulated soil totc according to land management practices from historic agriculture to post green planet

Arable land under barley

This site was under barley during the model period but was previously under different cropping and nutrient management system for the past 40 years and was assumed to be in model time management up to 2055. The changes in simulated soil totc from 1942 – 2055 on 39 – 40 y basis is shown in Fig. 1

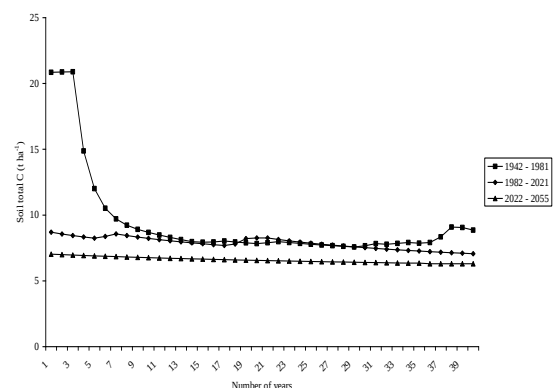


Fig 1. Changes in simulated soil totc (t ha^{-1}) in arable land under barley (1942 – 2055)

The decline in soil totc was rapid between 1942 – 1948, from 21.5 to 9.5 t ha⁻¹ arising from conventional tillage practices, crop rotation; where some crops depleted soil nutrients faster than others during the post agricultural revolution, after which it remained more stable up to the end of 1981, a period that witnessed conversion of some arable land to pasture on long leys. The rate of turnover in simulated soil totc between 1982 – 2021 was not >10 t ha⁻¹ and that between 2022 – 2055 remained at nearly 7 t ha⁻¹.

Grassland under permanent pasture sown with red clover a year before stocking

This site was sown with red clover as part of rye-grass rejuvenation before stocking during the model period but was previously under various cropping/nutrient and pasture management for the past 40 years and was assumed to be in model time management up to 2055. Fig 2 shows changes in simulated soil totc in this site from 1933 to 2055 on 39 – 40 y basis.

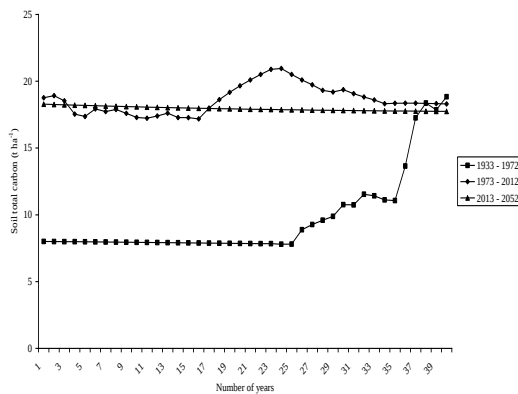


Fig 2. Changes in simulated soil totc (t ha⁻¹) in grassland under permanent pasture sown with red clover a y before stocking (1933 – 2052)

The rate of decline in soil totc was nearly uniform between 1933 – 1958 (<10 t ha⁻¹) based on the conventional tillage and fertilization practices at the agricultural revolution period. However, the amount of soil totc recorded between 1973 – 2012 was >15 t ha⁻¹ due to long leys and the greatest stability in soil totc compared to other periods was between 2013 – 2055 based on the red clover introduced as part of rye grass rejuvenation coupled with low grazing at the green and post green planet times.

Grassland under permanent pasture on 5 y ley before stocking

This site was on 5 y ley in the course of rye-grass rejuvenation before stocking during the model period but was previously under various cropping/nutrient and pasture management for the past 40 years and was assumed to be in model time management up to 2055 as in Fig 3.

The changes in simulated soil totc in this site from 1933 to 2055 was analysed on 39 – 40 years basis. The trend reveal higher carbon level between 1973 – 2012 (5 – 7.5 t ha⁻¹) based on low grazing and intermittent ley in rye grass rejuvenation.

Deciduous woodland

This site was deciduous woodland during the model period and has been such for the past 40 years and assumed to remain so up to 2055. The changes in simulated soil totc on 39 – 40 years is shown in Fig. 4.

This site did not vary to any significant proportion in simulated soil totc from 1933 – 2055 (from 48.2 t ha⁻¹ to 48.4 t ha⁻¹) based on no tillage or nutrient management.

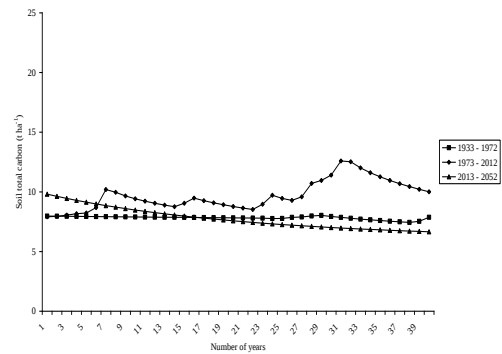


Fig 3. Changes in simulated soil totc (t ha⁻¹) in grassland under permanent pasture on 5 y ley before stocking (1933 – 2055)

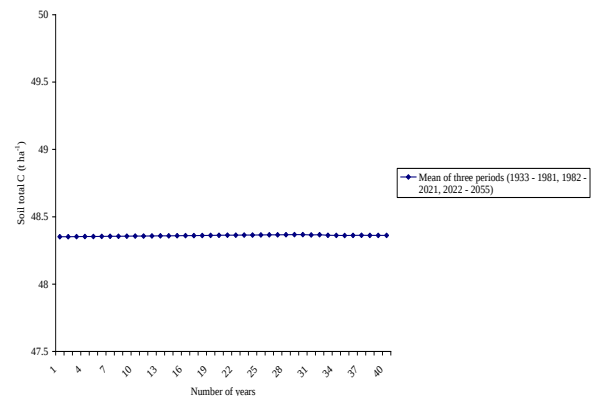


Fig 4. Changes in simulated soil totc (t ha⁻¹) in deciduous woodland from 1933 – 2055

The effects of time and land management on C sequestration

The simulated soil totc in all sites at the inception of pre-historic agriculture (6000 BC) was 61.5 t ha⁻¹. By the end of this period (1200 AD) it stood at 15 t ha⁻¹ in three sites, except woodland. The change in soil totc within this period (7200 years) across the three sites was -46.5 t ha⁻¹ with no C sequestered. It is only in deciduous woodland that soil totc ended with 47.1 t ha⁻¹ by 1200 AD, which is a change of -14.4 t ha⁻¹ with no C sequestered (Fig 5). These are effects of moderate rough grazing practiced in three out of four sites at this period, while SOM decomposition may have influenced deciduous woodland results.

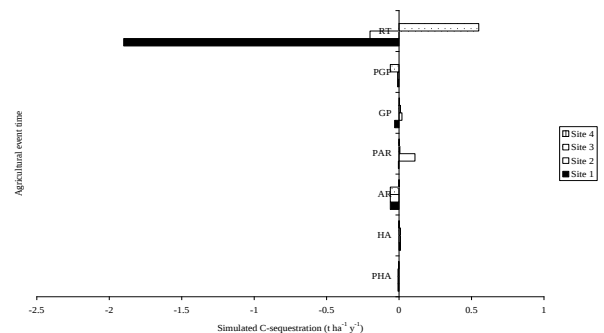


Fig 5. Simulated C-sequestration (t ha⁻¹ y⁻¹) under four types of management practices: site 1, arable land under barley; site 2, grassland under permanent pasture sown with red clover a year before stocking; site 3, grassland under permanent pasture on 5 y ley before stocking and site 4, deciduous woodland; PHA, prehistoric agriculture (7200 years), HA, historic agriculture (498 years); AR, agricultural revolution (204 years); PAR, post agricultural revolution (81 years); GP, green planet (38 years); PGP, post green planet (29 years)

During the historic agriculture (1201 – 1699) simulated soil totc started with 15 t ha⁻¹ in three sites apart from the woodland, increasing to 20.9 t ha⁻¹ in arable land under barley, 20.5 t ha⁻¹ in clover pasture and 20.6 t ha⁻¹ in ley pasture. These correspond to changes of 5.9, 5.5 and 5.6 t ha⁻¹ respectively for this 498 years and C-sequestration of 0.01 t ha⁻¹ y⁻¹ in the three sites. In deciduous woodland simulated soil totc started with 47 t ha⁻¹ in 1201 AD ending with 47.3 t ha⁻¹ by 1699, which is a change of 0.3 t ha⁻¹ and C sequestration of 0.001 t ha⁻¹ y⁻¹. This is aftermath of soil organic matter restoration, like the inclusion of wheat straw during seedbed preparation.

During the agricultural revolution (1700 – 1904) simulated soil totc started with 20.9, 20.5, 20.6 and 47.3 t ha⁻¹ in arable land, clover pasture, ley pasture and woodland respectively. By the end of this period (1904) simulated soil totc fell to 8.5 t ha⁻¹ in arable land, 8.3 t ha⁻¹ in clover plot; 8.2 t ha⁻¹ in ley pasture and increased to 47.5 t ha⁻¹ in woodland. This represent soil totc of -12.4, -12.2, -12.4 and 0.1 t ha⁻¹ and no C sequestered in three sites but 0.001 t ha⁻¹ y⁻¹ in woodland for the 204 years respectively. All the sites, except deciduous woodland were under different cropping and nutrient management. These practices coupled with tillage practices depleted soil C in three sites with the exception of the woodland.

During the post agricultural revolution (1905 – 1986) simulated soil totc started with 8.5, 8.3, 8.2 and 47.4 t ha⁻¹ in sites 1 – 4 respectively; decreasing to 8.2 t ha⁻¹ in arable land, but increasing to 17.3, 8.7 and 47.5 t ha⁻¹ in clover pasture, ley pasture and deciduous woodland respectively. These are changes of -0.3, 9, 0.5, 0.11 t ha⁻¹ and C sequestration of 0.11, 0.01, 0.001 t ha⁻¹ y⁻¹ in clover pasture, ley pasture and woodland for the 81 years respectively. The introduction of red clover in site 2 and ley in site 3 as part of rye grass rejuvenation led to increments in soil C. Soil totc was further depleted in arable land due to constant pulverization and crop uptake, while it increased a little in deciduous woodland.

Within the green planet (1987 – 2025) simulated soil totc started with 8.2, 17.3, 8.7 and 47.4 t ha⁻¹ in sites 1 – 4, decreasing to 6.9 and 8.2 t ha⁻¹ in sites 1 and 3, but increasing to 18 and 47.5 t ha⁻¹ in sites 2 and 4 respectively. The change in simulated soil totc over this 38 years were -1.3, 0.7, -0.5 and 0.1 t ha⁻¹ in sites 1 – 4 respectively; while the C sequestration in sites 2 and 4 were 0.02 and 0.003 t ha⁻¹ y⁻¹ respectively. The order of cropping nutrient management and tillage practices influenced these results. Nevertheless, apart from the arable and ley plots where there were depletion of soil totc arising from continuous cropping and grazing, the clover pasture and woodland retained soil C.

During the post green planet (2026 – 2055) simulated soil totc started with 6.9, 18, 8.2 and 47.5 t ha⁻¹ in sites 1 – 4 respectively decreasing to 6.5, 17.7, 6.6 t ha⁻¹ in sites 1 – 3 respectively, but remaining at 47.5 t ha⁻¹ in deciduous woodland. For this 29 years the change in soil C turnover were -0.4, -0.3, -1.6 and 0 t ha⁻¹ and no C sequestration. This will be the aftermath of retaining current land management practices without returning the arable and pasture lands to occasional leys or without the use of legumes like red clover in rye grass rejuvenation.

When two years of green planet period was simulated soil totc started with 8.3, 19.4, 11.4 and 47.4 t ha⁻¹ in sites 1 – 4 respectively, decreasing to 4.6 and 18.8 t ha⁻¹ in sites 1 and 2, but increasing to 12.5 t ha⁻¹ in site 3 and remaining at 47.4 t ha⁻¹ in woodland. The soil C turnover over this 2 y were -3.7, -0.6, 1.1 and 0 t ha⁻¹ and C sequestration of 0.55 t ha⁻¹ y⁻¹ in ley

pasture only. The long leys enhanced C turnover in the grassland under permanent pasture on 5 y ley before stocking, just as deciduous woodland remained at steady state; while arable land under barley depleted soil C. The loss in soil totc over this period in the red clover plot was regained over the green planet time, but lost again just as in the long ley as from 2026 – 2055 suggesting when the review of the current management options will be necessary.

Conclusion

There is an agreement in actual and estimated soil totc and sequestration. The validity of this model in predicting soil carbon levels is real. The broadness of its parameters made simulation of soil totc possible. The capability of grassland, arable and woodland to sequester C is low, even at relatively high soil carbon levels as in deciduous woodland. It shows that C sequestration depends on the amount of CO₂ that can be securely captured from the atmosphere and stored in the soil at a particular time. In this work both agricultural and non agricultural soil did not sequester enough C. To increase carbon sinks and reduce the effects of greenhouse gases through soil media will require complimentary agricultural and management options including silviculture, agroforestry, organic farming, zero and minimum till.

References

- Briggs, D. J., Courtney, F. M., 1989. Agriculture and Environment: The physical geography of temperate agricultural systems. Longman Scientific and Technical.
- Cantor, L.; 1987. The Changing English Countryside (1400 – 1700). Routledge and Kegan Paul Ltd, London: 190 pp.
- Chambers, J. D and G. E. Mingay. 1966. The Agricultural Revolution (1750 – 1880). B. T Batsford Ltd, London: 222 pp.
- Davis, B., Walter, B., Ball, N., Fitter, A.; 1992. The soil: The new naturalistic survey of British Natural History, Harper Collins
- Dent, J. M., Russell, E. J., 1966. A history of agricultural science in Great Britain. George Allen and Unwin
- Farage, P. ; Pretty, J. ; Ball, A. ; 2005. Carbon sequestration in tropical dryland agroecosystems. Carbon sequestration in dryland tropics modelling report. Centre for Environment and Society/Department of Biological Sciences, University of Essex, UK, 51 pp.
- Fowler, P. J., 1983. The farming of prehistoric Britain. Cambridge University Press.
- Grenville, A., and Grant, A.; 1988. The Countryside of Medieval England. Basil Blackwell Ltd, Oxford: 282 pp.
- Holderness, B. A. and M. Turner.; 1991. Land, Labour and Agriculture (1700 – 1920). Hambledon London: 262 pp.
- Holland, E. A., Parton, W. J., Detling, J. K., Coppock, D. L., 1992. Physiological responses of plant populations to herbivory and their consequences for ecosystem nutrient flows. Am. Nat. 140 (4): 685 – 706.
- Metherell, A. K.; 1992. Simulation of soil organic matter dynamics and nutrient cycling in microbial assimilation of nitrogen. Biol. Fertil. Soils 12: 261 – 264.
- Neate, D., 1979. Writtle agricultural college wildlife and landscape survey: Report and recommendations, Sept., 78 pp.
- Nicks, A. D., 1974. Stochastic generation of the occurrence, pattern, location of maximum amount of daily rainfall. In: Proceedings symposium on statistical hydrology. United States Department of Agriculture Misc. Pub. N. 1275: 154 – 171.
- Ojima, D. S., Parton, W. J., Schimel, D. S., Owensby, C. E., 1990. Simulated impacts of annual burning on prairie ecosystems. In: S. L. Collins and Wallance, L (Eds.). Fire in

- North American Prairies. University of Oklahoma, Norman, Oklahoma.
- Parton, W. J., Anderson, D. W., Cole, C. V., Stewart, J. W. B.; 1983. Simulation of soil organic matter formation and mineralization in semi-arid agroecosystems. In: Lowrance, R. R., Todd, R. L., Asmussen, L. E., Leonard, R. A., (Eds.). Nutrient cycling in agricultural ecosystem. The University of Georgia, College of Agriculture Experiment Stations, Special Publ. No. 23, Athens, Georgia.
- Parton, W. J., Metherell, A. K., Harding, L. A., Cole, C. V.; 1993. CENTURY: Soil organic matter model environment. Technical documentation, agroecosystem version 4.0. Great Plains System Research Unit, Technical Report No. 4, USDA-ARS, Fort Collins, Colorado.
- Parton, W. J., Schimel, D. S., Cole, C. V., Ojima, D. S., 1987. Analysis of factors controlling soil organic levels of grasslands in the Great Plains. *Soil Sci. Soc. Am. J.* 51: 1173 – 1179.
- Perry, P. J. 1973. *British Agriculture (1875 – 1914)*. Methuen and Co. Ltd, London: 180 pp.
- Pretty, J., Ball, A. S.; 2002. Soil health and sustainability. In Pretty, J. (Ed.). *Guide to Green Planet*. University of Essex, Colchester, Essex, UK, p. 105 – 106.
- Pretty, J.; 2002. *Agriculture: Reconnecting people, land and nature*. 1st Edition. Earthscan Publishers Ltd, London, UK, pp. 261
- Rackham, O., 1986. *The history of the countryside*. London, Dent: 445 pp. + xvi
- Royal Commission on Environmental Pollution – RCEP. ; 1996. Sustainable use of soil. In: Houghton, J. (Chairman). 19th Report presented to Parliament by Command of Her Majesty, HMSO Royal Commission on Environmental Pollution (RCEP).
- Simmons, I., Tooley, M. 1981. *The environment in British prehistory*.
- Thirsk, J.; 2000. *The Agrarian History of England and Wales (1850 – 1914)*. Vol. vii (part 1). Cambridge Univ. Press: 944 pp.
- Thirsk, J.; 1991. *The agrarian history of England and Wales*, vol. 111. Thirsk, J., (Ed.), Cambridge University Press, New-York.
- Wormel, P. 1999. *Essex Farming (1900 – 2000)*. Alberton Books, Colchester, UK, pp. 342
- Writtle College, 2004. *Crop production handbook: Farm data and general information (2003 – 2004)*, 93 pp.
- Zar, J. H.; 1999. *Biostatistical analysis*. 4th Edition. Prentice Hall, New Jersey, pp. 663 + xii