Mediaeval Cereal Yields: An Empirical Challenge

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The object of this paper is to explore the nature of the cereal yields in the Mediaeval period and to provide a comparison of actual yields between a zone in north-east Spain and central southern England. The problem essentially pivots on the widely quoted but minimally sourced documentary references for this period which indicate a ratio of seed input:output yield which varies from one:three to one:ten (Brandon, 1972 et al.). There is, of course, no value in decrying these references but there is real point in questioning their exact meaning and where the calculation of yield might be in the post-harvest cycle of grain disbursement. In order to elucidate the problem further a series of continuing empirical trials have been carried out since 1991 at the mediaeval site of L'Esquerda, Roda de Ter in the Plana de Vic (Ollich,1992). In these trials the typical cereals as determined by the archaeological data have been grown according to the accepted evidence of mediaeval agricultural practice of two and three year field rotations of fallow, cereal and beans and cereal and fallow.

At the outset it is worth considering the nature of the cereals themselves. The typical mediaeval cereals of L'Esquerda are Emmer wheat (*Triticum dicoccum*) and Barley (*Hordeum vulgare*). Indeed wheat and barley remain the typical cereals grown in the area today although they are the modern hybrids. Drawing upon pictorial representation and carbonized ears of both cereal types from pre-history to the mediaeval period, the cereals appear to have quite normal fruiting heads or ears with the expected number of spikelets, averaging some 36 - 44 seeds for both emmer and barley. In the fields it is quite normal for spring sown cereals to produce between one and five tillers or fruiting stems per plant while for autumn sown cereals, due to the effects of frost, the tillers are increased to between three and nine and, in exceptional circumstances, as many as fourteen have been recorded. If one averages these figures, for spring sown cereals there are three tillers and autumn sown cereals six tillers. Thus the product of simple multiplication would suggest from an input of one seed, spring sown cereals give an output of 120 seeds, and autumn sown an output of 240 seeds. The pursuit of this argument into the real situation of a field brings into play a host of variables: the amount of seed sown and the method of sowing whether broadcast or drilled, the germinability of the seed, crop maintenance versus weed infestation and the nature of the weed community, the soil type and its treatment and the weather experienced during the growing season.

In considering these variables in turn in the light of a projected yield there is, of course, no evidence for the quantity of seed sown. The methods of sowing, on the other hand, comprise a simple choice of two: the seed drill or broadcast. In the case of the latter the biblical parable of the sower suggests a loss rate of some seventy-five percent, a figure supported by a doggerel rhyme from the late mediaeval period:

> "One for God and one for the crow,
> One to die and one to grow."

If this is applied to the botanical figures above, spring sown cereal yields are reduced to 1:30 and autumn sown cereals to 1:60. On the other hand, if the seed is planted in seed drills, wastage is reduced to an absolute minimum. The viable seed thus planted will grow and the input:output figures need not be reduced in such a draconian fashion if at all. In practical terms, given the parsimonious attitude of farmers, it would lead to a reduced gross input for a similar if not increased output over the broadcast method.

Regarding germinability, it is reasonable to assume that seed corn was always treated specially and separately from food corn and a figure between 95 - 98% germinability would have been the norm. This level of germinability barely affects the above figures. However, this assumption is equally challenged by both parable and doggerel, suggesting that a germinability of some 75% was normal in the remote past and in the mediaeval period (i.e. that one in four seeds dies). This would arguably have been countered by the farmer sowing appropriately more to compensate for such a reduced germinability level in order that the crop should still be able to compete successfully against the inevitable arable weed infestation. Therefore, the input at one does not affect the output significantly. In this connection simple replicated controlled broadcasting trials carried out by the writer using seed with a laboratory tested germinability of 98% suffered an average loss rate of input seed over germinated seedlings of 40% " 5%. The prime cause of loss was depredation by birds, the crow of the doggerel. In adjacent control plots protected against bird attack seedling germination was in excess of 90%. Sowing seed in seed drills completely obviates this problem. Given these results, the observed 25% loss to birds and 25% loss to non-viability could well be a single 50% loss to birds. It is difficult to understand how seed grain, given its preferential treatment, can lose its natural high viability within one or two years of storage. It is extremely unlikely that seed grain was kept as seed grain for a period in excess of three years after which time its germinability does begin to deteriorate quite markedly.

The amount of seed sown in an area directly affects the gross weight return rather than the ratio of seed input:output although the ratio must have been calculated, most probably by volume rather than by weight. However, some estimation of seed input needs to be made, an estimation which will be directly affected by subsequent crop management. If the seed is broadcast the objective is to give an even cover over the ground surface and, despite harrowing in the seed, once it germinates there is little chance of subsequent hoeing to combat weed infestation. This factor must have been well appreciated by the farmer who would probably have compensated by increasing input slightly, certainly against the quantity of seed used in seed drills.

If, therefore, one calculates an input based upon the empirical process of evenly covering an area at least to combat weed infestation, a seed input of approximately 60 kilos per hectare is obtained. Thus a harvest yielding a return of 1:3 would give 180 kilos. Given the average weight of the seed from an ear of emmer wheat at 1.25gms, such a yield would suggest 144,000 fruiting stems per hectare which equates to 14 stems per square metre or some three to five healthy plants per square metre. Such would represent the normal distribution of wild oats (*Avena sativa*) within a cereal crop rather than the cereal crop itself! These simple but real calculations underline the nonsense of the ratio returns if they refer directly to the crop from the field. It is much more likely that such figures refer to a final assessment of a harvest subsequent to subtractions and may well be the published income as opposed to the actual gross yield.

In order to test this hypothesis still further, a series of empirical trials have been put in train on land adjacent to the mediaeval site of L'Esquerda at Roda de Ter in the Plana de Vic. These trials are based directly upon the research programmes pioneered at Butser Ancient Farm in England (Reynolds, 1988 & 1992).The fundamental assumptions are that the soil is exactly similar to that used in the ninth-fourteenth centuries AD and that the weather experienced during the trials will mimic weather experienced then. In the case of the latter, the choice of the Plana de Vic is particularly felicitous in that its geophysical form attracts a particular type of climate which, given the accepted variability of weather patterns within themselves, is unlikely to have changed dramatically nor to have been affected significantly by the presence or absence of major zones of forestation as elsewhere in Spain. Similarly the concentration of mediaeval settlement in the Plana de Vic is such that to sustain it the underpinning agricultural economy must have been at least relatively successful. The soil is acidic, averaging a pH of 6.1. Modern farmers regard it as a highly fertile soil requiring a manuring input on a triennial basis. Indeed trials with rye (*Secale cereale*) and Spelt wheat (*Triticum spelta*) carried out by the author on the same site suggest manuring can actually have a deleterious effect upon cereal performance and yield. Generally the soil has a fine crumbly structure and is very easy to cultivate both manually with a hoe or with an ox-drawn ard. It derives from underlying sedimentary marga rock. On the site itself the soil depth varies considerably, ranging from 200mm down to 900mm. This variability inevitably affects the cereals, an effect which is taken into account in the crop sampling and analysis.

Within the trials, both the weather and the soil are regarded as constants in the experimental sense. Both are regularly monitored, the former with regard to its acidity, crumb structure and organic content, the latter with an automatic meterological station which records air temperature, humidity, radiation and precipitation on an hourly basis. Both soil type and seasonal weather patterns are critical to the production of cereals. Since the weather in itself is so variable, the objective is to continue the trials for a minimum of ten years in order to provide a minimum acceptable meteorological sample.

The normal weather pattern within the region, aberrations from which cause great local concern akin to the British predilection for discussing weather, comprise a humid autumn with rainfall in October and November, the winter is distinguished by heavy frosts and freezing fog, spring is humid with regular rainfall in March and April while the summer is hot and dry, occasionally interrupted by violent thunderstorms and torrential rain. In agricultural terms this weather pattern allied to the fertile soil is extremely acceptable if not ideal.

Traditionally cereals are sown in both autumn and spring although greatest reliance is placed upon the autumn crops. Sowing usually takes place in October and March with harvest from mid-June to mid-July. The preferred cereal is wheat rather than barley because its growth pattern is generally slower and, therefore, more able to sustain extended periods of dry weather. Barley, however, is still grown extensively, the autumn sown crops reaching maturation in normal weather conditions in late May / early June and allowing the planting of a second crop, today commonly potatoes. This practice is particularly followed by those who rent rather than own land in order to maximise their investment. Barley planted in early March qualifies for the title of a three month cereal if the weather pattern is normal, the wheat always takes approximately three weeks longer.

For the purposes of the trials these traditional sowing times were observed. It is interesting to record that exactly these times were recommended by the earliest extant treatise on agriculture, the " Works and Days " of Hesiod in the eighth century B.C. It was decided to implement initially a three field rotation both autumn and spring sown with a fallow, a legume (*Vicia faba minor and Vicia sativa*) and both Emmer wheat (*Triticum dicoccum*) and Barley (*Hordeum vulgare*) as the cereals. In the first year instead of Emmer wheat because of seed supply difficulties Millet (*Panicum miliaceum*) was grown along with Vetch (*Vicia sativa).* The cereal and legume seed were drawn from the research programmes at Butser Ancient Farm in southern England.

The programme is designed to span a full decade thus allowing at least three complete rotations. The first year necessarily does not have the cereal crop following a legume. Plot size was restricted to adjacent quadrats of 8m x 8m which allows a sampling procedure to ignore a metre wide perimeter strip around each plot thus avoiding the edge effect and to allow full randomisation of the five metre square sampling units used for crop analysis and for weed infestation. Only the cereal plots are subject to yield analysis, the legumes being used only as nitrogen fixers. All the plots are analysed for weed infestation since different plant communities grow under the different treatments. In addition to yield analysis each cereal crop is measured for stand heights of the cereals along a random transect, the results being recorded to the nearest five mm.

Yield analysis based upon five random metre squares comprises the recording of the number of fruiting stems and the gross weight of the ears to the nearest gramme per square metre. These data are averaged and multiplied to give a gross weight per hectare and the ratio input to output is calculated by weight. Volumetric measurement was rejected because of the almost infinite variability from one region to another and, therefore, its irrelevance to an absolute measurement. In addition the cereal ears are subjected to a more detailed analysis of ear length, weight, number of seeds and actual seed weight recorded to a thousandth of a gramme.

Seed input was determined at 60 kilos per hectare and this figure is used as a constant throughout. Similarly germinability of the seed is also recorded, the results being obtained from laboratory tests rather than field tests. While there is inevitably a difference between laboratory results and field results especially with regard to emergence of seedlings over actual germination, it was decided to regard these differences as insignificant unless the field trials indicated otherwise.

The manner of sowing adopted was that of the seed drill as opposed to broadcasting primarily to maintain a known seed input. Rows are set at 300mm intervals thus in any random metre square only three rows appear. However, to accord with a broadcast regime no further management of the crop is carried out especially in terms of checking weed infestation. Weed analysis is carried out each year at the end of May, beginning of June when the weed flora is at its height and most identifiable.

This programme began in the autumn of 1991. In the autumn of 1992 a further element was added in order to simulate the two-field rotation of the high mediaeval period where a cereal crop is alternated with a fallow. Through lack of data as to actual practice concerning the fallow, whether it was a bare fallow, the ground being cultivated through the year to arrest arable weed growth or it was just left to bear whatever grew until final cultivation and seed-bed preparation, it was decided to follow the latter course. Since this field was created virtually from a fallow the results can be used from the first year.

The following tables give the results of the empirical trials from 1991 to 1994, a period which covers three agricultural cycles. For the three field rotation the results from the first season, 1991 to 1992 are strictly outside the overall experimental design since the cereal crop did not follow a legume crop.

Table 1 **Three Field Rotation System Autumn Sown**

Year of Harvest	Cereal	Yield Weight	Yield Ratio
1992	Emmer	2.4 tonnes	1 : 34
	Barley	3.76 tonnes	1 : 53
1993	Emmer	3.58 tonnes	1 : 51
	Barley	2.18 tonnes	1 : 31
1994	Emmer	1.56 tonnes	1 : 22
	Barley	1.15 tonnes	1 : 16

Three Field Rotation System Spring Sown

Year of Harvest	Cereal	Yield Weight	Yield Ratio
1992	Millet	3.82 tonnes	1 : 54
	Barley	2.47 tonnes	1 : 35
1993	Emmer	2.45 tonnes	1 : 35
	Barley	2.4 tonnes	1 : 34
1994	Emmer	Crop Failure	
	Barley	Crop Failure	

Table 3 **Two Field Rotation System Autumn Sown**

Year of Harvest	Cereal	Yield Weight	Yield Ratio
1993	Emmer	2.66 tonnes	1 : 38
	Barley	2.06 tonnes	1 : 29
1994	Emmer	1.18 tonnes	1 : 17
	Barley	1.05 tonnes	1 : 15

The results so far are dreadfully skewed by the 1993 - 1994 season when quite exceptional weather conditions were experienced from March to May 1994. During these months when rainfall is critical to the success of the spring sown cereals and extremely important for the enhancement of autumn sown cereals, there was virtually no rainfall of any significance. During March a total of 17mm were recorded half of which fell in one day, in April 40mm, 26.6mm falling in one day and May 29.8mm, 17.4mm of which fell in one day. While the totals themselves might just have been adequate, the fact that more than 50% of the rainfall each month fell at one time in the form of short lived storms, water run-off precluded any real benefit to the cereals. The contrast is underlined by the normal rainfall for these months recorded in 1993 with 75.6mm in March, 60.6mm in April and 24mm in May. The direct result of this unusual weather pattern in 1994 led to complete crop failure of the spring sown cereals and a severe effect upon the autumn sown cereals. In a sense it is unfortunate that such an extreme set of weather conditions has occurred so early in the experimental programme obviating the establishment of any kind of norm.

However, discounting the failure of the spring sown crops of 1994 for which there is a clear cause, the results from all the other significant trials uniformly exceeded a ratio of 1 : 10. The results from 1993 are arguably what one would expect certainly as a farmer. Visually the crops of 1994 were extremely poor and caused increasing concern as the season progressed both from the point of view of the stand heights of the cereals and the size of the ears. In the event the yields were less than half the preceding year. At present the data base is far too small to allow any further manipulation of the figures but the reason for what can only be seen as an agricultural disaster can be directly attributed to the weather pattern. Once the full cycle of three rotations have been completed with a range of weather conditions experienced it may prove possible to provide an average figure for yield expectation by treatment.

In order to provide a source of comparison for these data, the results from similar experiments carried out at Butser Ancient Farm are quoted below. The Ancient Farm is located on the chalk downs of central southern England some 15 kilometres north of the city of Portsmouth. There trials into the yielding characteristics of the early cereals have been carried out in different bio-climatic zones and on different soil types for the past twenty five years. The subject cereals are respectively

Emmer wheat (*Triticum dicoccum*), Spelt wheat (*Tr. spelta*), Einkorn (*Tr. monococcum*), Rivet wheat (*Tr. turgidum turgidum*), and Barley (*Hordeum vulgare*). Rotation trials have also been conducted using the legumes of Vetch (*Vicia sativa*) and Celtic beans (*Vicia faba minor*) as well as fallow rotation. While the overall purpose of these trials has been to explore the potential yields of the late Iron Age (c.200 B.C.) the experimental process is exactly similar to the trials described above. A greater number of different treatments are built into these trials including manuring and non-manuring autumn and spring sown, continuous cropping, fallow rotation, legume rotation, interrowing cereals and legumes and mixed cropping.

To provide a direct comparison, only those treatments and crops which broadly equate to the mediaeval practice described above are cited in the following tables. The major differences are the soil and the weather. The soil is alkali with a pH of 7.1 and the weather is considerably more humid though for the year quoted (1994) the spring months were drier than the norm. The specific treatments of a fallow rotation, the two field system of the mediaeval practice are presently spring sown rather than autumn sown as is the legume rotation of cereal following beans or vetch. The cereals used in these trials are both Emmer wheat (*Tr. dicoccum*) and Spelt wheat (*Tr. spelta*) although only the Emmer results are given here.

Table 4 **Fallowing Treatment** **Spring Sown**

Year of Harvest	Cereal	Yield Weight	Yield Ratio
1994	Emmer	2.57 tonnes	1 : 43

Table 5 **Legume Rotation** **Spring Sown**

Year of Harvest	Cereal	Yield Weight	Yield Ratio
1994	Emmer	3.13 tonnes	1 : 52

These figures, arrived at in exactly the same way as those for the trials at L´Esquerda, are significantly greater and reflect the fundamental differences in climate between the two zones in question. Furthermore they are typical of results covering a number of seasons and weather patterns.

A major part of the research trials at the Ancient Farm is devoted to examining the differences between autumn and spring sown cereals on manured and non-manured soil under a continuous cropping regime. As far as the mediaeval period is concerned there is every likelihood that manuring regimes were practised especially on poor soils. Continuous cropping, however, seems slightly less likely. It is interesting to reflect that rotation of crops either with a simple fallow followed by a cereal or the more complex fallow, beans, cereal system where the cereal benefits from the nitrogen fixing qualities of the legume, a benefit recognized if not scientifically by Theophrastus in the fourth century B.C., was probably brought about by the observational experience of a disease called 'Take-all' (*Ophiobolus graminis*). This disease is endemic in most soils and tends to attack the root stock of cereals in the second and/or third years of a continuous cropping regime. The effect is a cereal with perfectly formed but empty or blind ears. However, if one persists in growing cereals the following season, the effects of the disease are dramatically reduced if not eradicated. In subsequent seasons it has no significant effect. If the cropping cycle is broken the disease re-asserts itself and again attacks the cereal in the second or third year. Rotation naturally obviates the activities of this disease. At the Ancient Farm it was decided to break through the Take-all barrier because the archaeological evidence of the prehistoric field systems seemed to indicate permanent cereal production rather than elaborate rotational treatments. Thus for the season of 1994, three years after the initial crops were sown and after the mild effects of Take-all experienced in the second year, the yield data are quite remarkable but certainly not untypical.

Table 6 **Manuring Treatment Autumn Sown**

Year of Harvest	Cereal	Yield Weight	Yield Ratio
1994	Emmer	4.18 tonnes	1 : 70
	Barley	3.15 tonnes	1 : 53

Non-Manuring Treatment Autumn Sown

Year of Harvest	Cereal	Yield Weight	Yield Ratio
1994	Emmer	3.16 tonnes	1 : 52
	Barley	2.38 tonnes	1 : 40

Table 7 **Manuring Treatment Spring Sown**

Year of Harvest	Cereal	Yield Weight	Yield Ratio
1994	Emmer	2.46 tonnes	1 : 41
	Barley	1.93 tonnes	1 : 32

Non-Manuring Treatment Spring Sown

Year of Harvest	Cereal	Yield Weight	Yield Ratio
1994	Emmer	1.77 tonnes	1 : 30
	Barley	1.38 tonnes	1 : 23

Within the remit of this paper it is not possible to publish the further data of stand heights, stem frequency or ear analysis nor the nature or intensity of arable weed infestation. These data will be the subject of further papers (Reynolds, forthcoming). With regard to the former the analyses reflect quite accurately the nature of the weather during the growing season demonstrating the plants' strategy for its own survival in extreme conditions. The findings will, in due course, be invaluable for providing paradigms for palaeobotanical analysis of carbonised seed. In the case of the latter the arable weed flora similarly reflect extremes of climate both by presence and absence and by abundance/dominance. One general observation that can be drawn is that on average in a crop within any square metre a third of the surface area is occupied by the crop, a third by arable weeds and a third remains bare earth.

From all these trials which are based upon minimum input, minimal management and minimal interference the results presented in Tables 1 to 7 all exceed the maximum ratio of 1 : 10 recorded in the documentary evidence from the mediaeval period. Indeed, where the empirical ratios approach this figure the harvest has usually suffered from an extreme of either climate, disaster or disease. In addition the appearance of such a crop engenders alarm and despondency. A yield of 1 : 3 would visually indicate utter failure. For these ratios to be significant they are most unlikely to refer to a harvest as it leaves the field and much more likely to be a final calculation subsequent to disbursements of the harvest. Further, were such ratios, in fact, descriptive of a harvest, the argument would have to be proposed that the land under cultivation would have to have been far more extensive than physically possible both in terms of availability and manpower simply to feed the population attested by documentary and settlement evidence.

In conclusion it is of interest, perhaps, to consider the role of the granary on the mediaeval site of L'Esquerda (Ollich,1992) whence came the palaeobotanical evidence for the cereals, legumes and arable weeds of the period and to postulate that it might have been a repository for gifts or even tithes of agricultural produce from the surrounding landscape rather than a working granary within a farming community. If this were the case its rather limited volumetric capacity would become more comprehensible. In any event the above arguments, sustained by real and repeatable empirical data challenge the oft quoted yield ratios of the mediaeval period.

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