Prehistory of Agriculture

New Experimental and Ethnographic Approaches

edited by
Patricia C. Anderson

Monograph 40
Institute of Archaeology
University of California, Los Angeles

Chapter 28

Yields, Sowing, and Fertility

Analytical Significance of Yields

François Sigaut

IN THIS CHAPTER, I TRY TO GIVE A FEW ELEMENTS to define a problematic of the study of yields. For more than a century, we in Europe have become accustomed to expressing the result of our cereal cultivation in terms of volumes or quantities harvested per unit of surface area (bushels/acre; quintals or tons/ha). Until the eighteenth and nineteenth centuries, our ancestors tended, however, to think in terms of a weight yield for grain sown versus that harvested (5 for 1, 12 for 1). This concept of yield is quite ancient; it is mentioned by Roman agronomists. There are therefore at least two ways of measuring the physical result of a crop. Neither considers the factor of time, which is supposed to be equal to one year in both cases (but is not always so), or the factor of water, even though it is more important than the field surface in irrigated agriculture. There are also factors of scale to take into account; we all feel that a result expressed on a scale of a province or of a country has a different meaning than one obtained from one field only or from an experimental plot of a few m². Considering economic considerations would make the problem still more difficult. Even if I restrict the question to physical aspects, it is clear that no single universal and rational means of measuring the results of a production exists, but rather several, which have different meanings and correspond to different technical and social situations. It is among these different yields (better yet, proportions or ratios) that we must try to make sense so that discussions concerning the quantitative results of ancient agriculture are not biased from the outset.

Volumes or Masses

I begin with an apparently simple question: is it better to count in terms of volume measurements, that is, in bushels or hectolitres, as was commonly done until the end of the nineteenth century, or in terms of mass measurements, that is, in quintals or tons, as is done today?

It is generally believed that the scale is more accurate than the bushel, because the latter's capacity depends on the way in which it is filled, whether grain is compressed or not, and so on. In reality, what is weighed on scales? The envelopes of complete grains, which vary considerably in proportion from one species to the next, and even weight varies from one variety to another, especially between naked and hulled grains, of course; also, grains having different moisture contents, which usually measure between 12 to 13% and 18 to 20% at harvest. As the variation in the humidity ratio alone causes a margin of error of over 5%, it is illusory to think that scales are sufficient for providing an accurate result.

In fact, the use of bushel or hectolitre had the advantage of avoiding a false impression of accuracy. Those using capacity or volume measures in the past knew that a number of bushels or hectolitres was meaningful only in combination with other data, mainly the grain density, which is expressed in pounds per bushel or kilograms per hectolitre (mass volume). Measuring the grain density was not only aimed at converting a volume into a mass; it also happens that grain density is still the best synthetic indication of its quality today: a heavy (that is, dense) grain is always of a better quality, all other things being equal, than a light one; in particular, humidity reduces the grain density and increases the mass of the crop harvested.

In summary, neither mass nor volume alone are sufficient for measuring a crop. A volume measure, added to grain

density, is certainly the most efficient method of obtaining the most accurate result for the least effort. I do not believe that mass (weight), when measured alone (which is too often the case), improves accuracy: it only gives a (dangerous) impression of doing so. For a really accurate measurement of mass, one needs to know what is being measured, which means taking into account its degree of humidity and percentage of nonnutritional components This may be complex and expensive and, at any rate, does not guarantee that all nutritional components were actually used by people, given their methods of grinding and flour extraction.

I have no firm conclusion to make, but any textbook of physics begins with the question of errors in measurement. I believe that the same question would be useful in history textbooks and in experimental archaeology texts, if ever these are written.

Yield Per Unit Surface: Questions of Scale

Let us first take a familiar case: an evenly plowed and sown field. We might think that its yield is independent of the field size, but it is not. The border effect and the other reason is well-known: the fact that a small plot is always better kept and protected than a large one, so that results obtained on a small scale are only rarely transposable to a large scale. The literature from the eighteenth and nineteenth century is full of warnings against the misuse of extrapolation of results from small-scale experiments. Such caution remains quite valid today.

The border effect is well-known to experimenters. Inside an evenly sown field, each plant is surrounded by other plants, which limit the space from which it can take water and fertilizers and the quantity of light it receives. The plants that grow on the field borders, can, however, extend their roots further and receive more light, and are therefore usually better developed.

Let us assume that the border effect is felt at 2 m in depth: a square plot of 16 m^2 will be completely affected and thus able to give a noticeably higher yield (of up to the double, perhaps) than a square plot of 1 ha, in which less than 10% of the surface is affected by the border effect.

Therefore, these are two different scales, of small plots (a few dozen m^2) and large plots (about 1 ha), for which the yield per unit surface does not have the same meaning. In addition, we can note that in most nonmechanized agricultural systems, the small plot was the rule, not the large one, whose present form began only in the nineteenth century. Large fields certainly appeared once the ard came into use, in the fourth millennium BC. However, the distribution of the plants was not necessarily uniform, a question for which we have little information available. In Egypt, grain was broadcast sown, whereas in Mesopotamia it was apparently sown within drills, about 60 cm apart (Brun-Cottan 1989). Be that as it may, one conclusion prevails: the significance of a yield per unit surface depends on the size and shape of parcels as well as the way plants are distributed within it. This means that, from one system to the next (in which these parameters are different), the yields per hectare cannot be compared.

We must not forget that yield/hectare was developed within the context of only one agricultural system, ours, and that it is meant to enable performance comparison within this one system. Outside this specific case, it is applicable or not, depending on the circumstances. At any rate, it is absolutely necessary to justify its use.

Yield Per Unit Surface: Questions of Fertility

The two scales discussed above are not the only ones to take into account in determining the significance of a yield. There is at least one other, which involves soil fertility and the way it is renewed over time, either naturally or through deliberate or unintentional human intervention. Then the relevant scale is no longer that of the small (or large) plot but of the entire territory on which the fertility of the plot depends. Indeed, from Liebig's time (1840), we have known that the fertility of a soil was related to its resources in certain mineral elements, in a form assimilable by plants (for example, N, P, K, and Ca), which we have learnt to extract from the subsoil (essentially P and K) or directly from the atmosphere (N). Therefore, the fertility of a given field now depends only on the industry and trade in manure and chemical fertilizers. Before Liebig, it was the opposite: the fertility of a given plot was detemined mainly by the natural or artificial transfers of fertilizers which occurred.

Natural transfers

First, there exist negative transfers, or losses, because of leaching, which intensifies with humid climate (rainfall/evaporation relationship), when soils are permeable (sandy) or acid, and when the relief is flat. When there is the slightest slope, runoff increases at the expense of leaching and entails an erosion that may be destructive if too violent, but which is often favourable insofar as it rejuvenates the soils. In many regions with naturally rather acid soils, like Brittany, fields are located more often on moderate slopes than on absolutely flat ground. Leaching is a prime factor in pedogenesis, and so it is fairly easy to evaluate its significance by consulting a soil map.

The opposite of leaching, in hot and dry climates, where the potential for evaporation is higher than that for rainfall, is the rise of mineral elements to the surface. Unfortunately, in all regions where this happens, sodium salts are brought to the surface, making the land almost sterile.

However, leaching and salt rise balance out in some soils, such as the famous black earths (*Tchernozem*) of the Ukraine. Yet it is probable that their reputation for fertility comes not so much from their yields, which would not have been much higher than elsewhere, as from the fact they were obtained without fertilizer. In Hungary and southern Russia, the fact

that dung fertilizer was not used surprised travellers such as R. Townson, in the eighteenth century, and L. de Fontenay, in the nineteenth. At the beginning of the twentieth century, the promoters of dry-farming in North America, H. W. Campbell and J. A. Witsoe, believed that arid areas were mankind's future granaries, because their fertility was unlimited (Hargreaves 1977).

In western Europe, it is also the low annual rainfall (maximum of 600 mm) that has always contributed to the fertility of the extensive cereal plains in the Paris Basin and eastern England. It happens that we have a fairly good idea of their very long-term potential fertility. Indeed, between 1852 and 1925, in some plots at Rothamsted (Great-Britain), wheat was cultivated without manure each year, with a mean yield of 10 q/ha/year (Hénin et al. 1969:300). Why did the yield not decrease to nearly nothing over time? Apart from a low level of leaching, there are two sources of natural fertility: nitrogen fixation by soil microorganisms and settling of atmospheric dust (aerosols), either spontaneously or through rain or snow. This dust has diverse origins, including extra-terrestrial ones (earth receives 100,000 tons/year of dust from the cosmos); in France, the Gascony Landes region receives 10 kg/ha/year of potassium, in the form of aerosols from the ocean (Labeyrie 1978).

A third natural source of fertility is alluviation, which concerns the foot of slopes, valleys, and areas of deposit on the seaside. These sites are limited in general, but are historically significant, because people quickly realized their advantages and exploited them to the best of their ability.

A given territory contains a general level of natural fertility, which depends mainly on the relationship between leaching of soils and natural mechanisms that renew their fertility (moderate erosion and aerosols). (For example, this level is 10 q/ha/year of wheat at Rothamsted.) This same territory also contains some privileged areas where fertility accumulates naturally (alluviation) and which may (or may not) be used by humans.

Artificial transfers

It is quite possible that agriculture first colonized such privileged areas, particularly in arid zones, where floodplain agriculture is both the simplest and most productive process imaginable. The main drawback of such areas is their limited size. There are major exceptions, however (the Nile Valley), and it seems that people long derived a major benefit from them, before cultivating more ordinary land; this may hold true even in Europe, according to Sherratt (1980). The problem of ordinary land is its lack of natural renewal of fertility: in dry climates, the crops are variable; in humid climates, leaching and competition with weeds can be a threat. Compensating for these two drawbacks requires a great deal of extra work as well as—of particular interest here—using part of the territory to fertilize others. Here, transfer of fertility takes on its full meaning. There are two general methods of compensation for leaching:

- Moving the fields, in order to benefit, through grubbing or burn-beating, from the fertility accumulated over several decades. This corresponds to the principle of shifting cultivation, well-known to geographers. Here, no more than 20% of the territory can be used at any one time, often much less. Yields per parcel are high, but they are obtained on only a small area of the territory.

- Fixing the fields, and regularly adding fertilizers collected elsewhere indirectly, through cattle and their excrements, and directly, by gathering plants used as manure.

A few examples

In the Gascony Landes region (very poor sandy land), it was estimated that 40 ha of pastures were required for maintaining the quantity of sheep to produce enough dung for 1 ha of rye and millet (Féret, 1878:519). In all the mountain areas of the southern Midi in France, the practice of clearing of undergrowth meant that, in waste lands and forests, various plant residues, brushwood, weeds, dead leaves and others were collected, then strewn over courtyards and pathways; after a few months, when they had become street dung, they were brought to the fields. In some regions, this was regular practice. In the Béarn, there were true fields of furze (Ulex europeus), devoted exclusively to supplying fertilizer for other lands; in southern Brittany (Morbihan), a metairie normally kept nearly half the land as moors to mattock, for fertilizer. This kind of practice is not solely European and is largely attested to in India and Africa, where the system called citimene was made famous by A. I. Richards' description (1939): branches are trimmed from forest trees and gathered on the site of a future field, where they are burned; sowing is then done in the ashes. Richard gives the figure of 6.25 acres of forest for 1.25 of cultivated land, or a land surface ratio of 5.2/1[1].

What could be the age of this kind of agricultural system? The majority of those revealed by history and ethnography imply significant technical means (iron tools for the gathering of vegetal manure; means of transport) and still greater quantities of labor, which suggests that such systems are recent. However, this is not necessarily always the case: the example from the Landes shows that massive use of animals can replace tools and labor. At any rate, Danish archaeologists believe that this sort of system existed in Europe from the Neolithic (J. Troels-Smith 1984).

Of course, the above examples give only a general idea of the diversity of real practices. Here, the main point is that the whole territory is necessary to produce the crops obtained each year over a small part of this territory, whether this proportion be 2, 5, or 50% of the total. Yield per plot is

therefore a partial yield. From an ecological and demographic standpoint, it is the yield of the whole territory that counts, the territory itself being defined by the extent of the transfers of fertility; in a sense, the territory is a fertility watershed.

Seed Yield

The sowing yield (expressed as "for one": 5/1 or 8/1, for instance) was so prevalent in Europe, and doubtless elsewhere, until the nineteenth century that its absence today is surprising. It represents as important an analytical tool as surface yield, and its loss has considerably impoverished analysis. One of its several advantages was that it was not used alone, since it had meaning only when complemented by sowing density, which enabled calculation of surface yield. In the past, everyone was aware that seed yield was only one index among others, which is unfortunately no longer the case for surface yield.

Extraordinary yields

> M. Georges Villers shows us a wheat plant, called "Scottish red wheat," which is a remarkable example of fertility. This plant, produced by a single grain deposited by chance in the Bayeyx cemetery, bore 116 ears having an average of 35 grains, giving a total 4060 grains. (Bull. de la Soc. d'agriculture de Bayeux 1850–1851, 1:296)

Such stories are not unusual. Pliny cites two in his *Natural History* (XVIII, 21). Without special effort, I found ten in my notes on the seventeenth to the twentieth century, in England as well as in France.[2] The record is undoubtedly held by a stalk of barley which, according to Humphry Davy [1820:240], produced 249 stems and over 18,000 grains. Ordinary figures, however, are lower: those found in the literature are 6855, 4060 (example above), about 4000, 1560, 1440, and 1235.

There is no apparent reason to doubt the truth of these anecdotes. They must have occurred with a fairly constant frequency throughout history, but are they of interest to researchers? They have relevance on several levels. First, they illustrate perfectly the effect of scale I described for surface yields. Second, these findings gave rise to comments and technical or selection tests, such as the following: In the 1760s, a Mr. Miller, from Cambridge, tried to find how far one go in multiplying a grain of wheat. Out of one grain sown early in June, and after three transplantings from separation of tufts early in August, in September to October and in March to April, he obtained 21,109 ears containing about 576,840 grains. At the beginning of the twentieth century, quite independently, Russian agronomists, inspired by observations in Manchuria, tried to develop a system of temperate cereal (wheat, rye, and oat) cultivation, based on transplanting and ridging. Diffloth made a cautious analysis: "This system enables rapid multiplication for varieties from which only a small number of seeds are available" (1929:319-348). It was not profitable, however, in the French economic background of his time, even using the various machines developed by Russian agronomists. The same conclusion had been reached by Norman agronomists more than one century before:

> M. de Janville has harvested in his Eterville estate a stalk of wheat which gave 108 ears and 1560 grains. This extraordinary product induced us to try to plant wheat, according to the method practiced in the duchy of Suffolk, in England, and described by Larochefoucault-Liancourt. This first test was unsuccessful. Besides, we observed that planting required too many hands and that manpower was too expensive here for efficiency; it seemed that this method, instead of leading us to perfect the art, would be taking us back to its origins. (Rapport sur les trav. de la Soc. royale d'adg. et de com. de Caen 1806:18)

This latter remark is very important, and I will return to it. First, I wish to give a last example of the consequences of such extraordinary findings in the creation of new varieties. The story is told by W. Marshall, in *The Rural Economy of Yorkshire*:

> Of late, the raising of varieties has perhaps been little attended to[...] The only instance in which I have had an opportunity of tracing the variety down to the parent individual has occurred to me in this District.
>
> A man, whose observation is ever on the wing in the field of husbandry, having perceived, in a piece of wheat, a plant of uncommon strength and luxuriance, diffusing its branches on every side, and setting its closely surrounding neighbors at defiance, marked it, and at harvest removed it separately. The produce was fifteen ears, yielding six hundred and four grains, of a strong-bodied liver-colored wheat, different in appearance from every other variety I have seen. The chaff smooth, awnless, and the color of the grain. The straw stout and reedy.
>
> These six hundred grains were planted, singly, nine inches asunder, filling about forty square yards of ground, not in a garden or in a separate piece of ground, but upon a clover stubble; the remainder of which was, at the same time, sown with another wheat, by which means extraordinary trouble and destruction by birds were equally avoided.
>
> The produce of these forty yards was two gallons and a half, weighing twenty pounds and a half, of prime grain, fit for seed; besides some pounds of second. One grain produced thirty-five ears, yielding twelve hundred and thirty-five grains.
>
> The second year's produce being sufficient to plant an acre of ground, the variety was of course sufficiently established.
>
> This, the fifth year, I have seen it grow in quantity; the

> season being moist, and the soil good, it was most of it lodged. The crop upon the ground is abundant: seventy full stocks an acre. But the produce of Zealand wheat, in the same piece, is equal to it; and, on examination, I think the grain of this better, its skin is somewhat thinner. [1796, II:5-7 (English)]

This kind of tale must have been repeated thousands upon thousands of times since the emergence of cereal cultivation, but with different frequency for different forms of agriculture. In the eighteenth century Europe, with its wide fields broadcast sown, the events could only have been exceptional, and it was only with the arrival of specialised breeders (for example, Vilmorin in France) that regular production of new varieties became possible. Marshall describes only seven varieties of wheat for Yorkshire, two of which are in the process of disappearing; even though they have not been calculated, we suppose that, in the England of his time, no more than a few dozen varieties existed. Things were quite different for the majority of the tropical countries, for instance India:

> Accustomed as we are to find the plant spoken of merely as rice it is somewhat surprising to learn that there are in Bengal alone 4,000 different sorts, suitable for different soils and climates. And yet the Indian peasant knows the various kinds and the right places in which to grow them. M. C. B. Clarke, an experienced and accurate botanist, speaking of the marvelous intuitive knowledge possessed by the hereditary paddy-cultivators in recognizing the different kinds of rice, says:- "I do not know how, in the young state, the cultivator tells the *ri* (wild rice) from the *aman* (winter rice). I cannot." (J. Kenny, *Intensive farming in India*, 1912:246, English)

Why is there such a difference? The marvelous intuition of peasants in tropical regions evidently plays a much smaller role than a more prosaic factor: the sowing technique and its consequent seed yields.[3]

Ordinary yields and sowing techniques

Undoubtedly for thousands of years, there has been a clear contrast between the sowing techniques of the West (from the Atlantic to Afghanistan) and those of the other parts of the world. In the West, grain is most often broadcast sown, which gives seed yields of 4 to 10 for 1. In the rest of the world, sowing techniques are varied, but broadcast sowing is relatively infrequent. Sowing is generally done either in lines (by hand or with a seed-drill) or by dibbling or by transplanting in seed beds (rice); in many cases, grains are germinated before being sown. Each technique gives a different seed yield, but in general this is between 50 and 150 for 1—that is, 10 to 20 times more than with broadcast sowing. The extraordinary yields above show that there is nothing miraculous about them. Surface yield remains invariable (except for effects of scale). What changes is the quantity of seed, and it is clear that, if 10 times less is sown for the same harvest, the seed yield will be 10 times higher. The first consequence will be that the selection pressure will be 10 times stronger. It is not merely by chance that corn, the cereal perhaps most transformed by humans, gives the highest seed yields.

Two questions may be asked: can such differences between sowing techniques be explained, and what consequences (other than the evident effect on selection pressure) are attributable to them? The plant's size is certainly one factor: corn and sorgho, among others, are most often dibbled because of their large size. But the reverse can be argued: these plants have acquired their present morphology because they were sown dibbled for thousands of years. Moreover, the same cereals can be sown in different manners in different regions. Wheat and barley were sown with seed-drills in Sumer and broadcast in ancient Egypt; in a region near Quito (Ecuador), in 1735, travellers relate that wheat and barley sown by dibbling, no doubt as for corn, produce 100/1 to 150/1 (Duhamel du Monceau 1765:123-4).

There is not one, but a series of, causes, acting in combination. I lack space here to go into the full complexity of the problem, and also because I do not yet know all the factors. I would like to emphasize one of these factors, which is shown by recent European history and can be analyzed: the relationship between cost of grain and cost of work.

The above anecdote (about M. de Janville) gives us an abridged version of the solution to the problem, but we have to further explain it to make it understandable. This beginning of the nineteenth century in France had been, as for a long time before, a period of Anglophilia, at least for agriculture: everything English was praised, admired, recommended, imitated. Now there had existed for some time an innovation much spoken of in England: the practice of planting—that is, dibbling—wheat, which had begun in a small region situated on the border between Norfolk and Suffolk. It was of recent origin and seemed to have begun as a method applied to peas and beans which was transposed to cereals. Whatever the explanation, it is interesting that this method had become a local tradition, because it enables a comparison, all other things being equal, whose lesson is valuable. What was its result? "A sower of ordinary strength covers an average of four hectares per day with cereals" by broadcast sowing (Moslan:35). Using dibbling, a team composed of a man making holes and three helpers (women or children) planting grains sows one half-acre per day—that is, about 0.2 ha. This means 20 times less area is sown by the team, and 40 to 50 times less per person if the three helpers are considered to be equivalent to one adult worker or a little more. To compensate for this much lower work productivity, there is a single advantage: savings in seed. In Norfolk of 1787, says W. Marshall, the team of dibbling sowers was paid 9 shillings

per acre, and the savings in seed were about one half, that is 1.5 bushel or more. Everything comes into play in the cost ratio of grain to labor. It is advisable to save seed when grain is expensive and to sow a maximum amount when labor is costly. Far from being a primitive technique, broadcast sowing is an elaborate one, which can be used only in societies where the price of labour is relatively high.

Therefore, we understand the remark made by the *Société d'agriculture de Caen* in 1806, that planting demanded too many hands and labor was too expensive here that this be efficient: it seemed to them that this method, instead of leading them to perfect the art, would lead them back to its origins. Indeed, grain dibbling was made possible solely because England, in particular Norfolk, had experienced a considerable decrease in real wages from the end of the seventeenth century. N. Riches (1937) spoke of "starvation wages," principally owning to the Act of Settlement of 1662, which reduced the mobility of laborers and placed workers more or less at the mercy of their employer.

In France, at least in Normandy, where exploitation of laborers was not as far advanced, wheat dibbling would appear to be economic regression.

Conclusion

In reality, the only yield of universal value was labor yield, but it is usually very difficult to assess, especially in moneyless economies. Consequently, we are obliged to fall back on other ratios, and this raises for each of them the question of significance and area of validity.

Surface yield is an agronomical concept, applied for barely two centuries. It can be used only in systems with fields, meaning evenly cultivated and sown plots such as those we know today. The very existence of fields is most often related to animal-drawn farming implements. A great number of systems considered as primitive have no such fields and for them a yield per plot means nothing, or at least cannot be compared with its meaning in other systems. The only surface yield to be universally valid is what I have called the territorial yield, which considers the individual plot as well as the entire area supplying, by transfer, the elements necessary to renewing its fertility. Such yield takes the factor of time into consideration as well.

Lastly, we have the seed yield. This yield has fallen into disuse since the second half of the last century, after having been in virtually universal use before. For historical analysis, we would be wrong not to use it, especially as it is rich in significance. Seed yield is meaningful only when the sowing density, hence the sowing technique, is known, but this is just the data required to characterize an agricultural system. Relatively low sowing yields (4 or 5 for 1) do not imply that the system is poor, only that broadcast sowing and thick sowing are used, in other words spared in order to save labor, which is expensive. High yields (100 and more for 1), on the contrary, imply almost certainly cheap labor or only limited technical means available.

Acknowledgements. This chapter was translated from French by Jacqueline Gaudey, Centre de recherches archéologiques, CNRS, France.

Notes

1. About clearing of undergrowth and street dung in, see Sigaut 1975:45-51, 131-133 (France) and Gokhale & Habbu 1927 (India). Since Richards' study, the African system called *citimene* has been the subject of other publications, the latest of which is Stromgaard 1985.
2. On extraordinary yields, my sources are as follow (in chronological order): Tull 1733:61; Turbilly 1761:217,218; Watson 1768; Marshall 1796; Janville 1806 (Davy 1820:240; Villers 1850–1851; Diffloth 1929:322. There surely exist many others. In the 1850s, a M. Mangocé recommended a method consisting in sowing 25 l/ha only and producing 150/1; this was certainly neither the first time nor the last.
3. It is evident that the expression "marvelous intuition" is exaggerated and merely translates its author's surprise. I will not resist citing a few lines from Kenny's preface:

> To preach dry-farming to men to whom it was a hoary tradition when Englishmen used paint instead of clothing did not appear to me the surest way to gain the confidence of the Kunbi, nor did I consider it wise to suggest seed selection in a land where 4,000 different sorts of paddy are grown in one province alone, and carefully differentiated according to their qualities and the land suitable for them.

The enthusiasm is effusive, but it perfectly expresses the attitude of anyone who discovers a fact which he had been trained to despise.