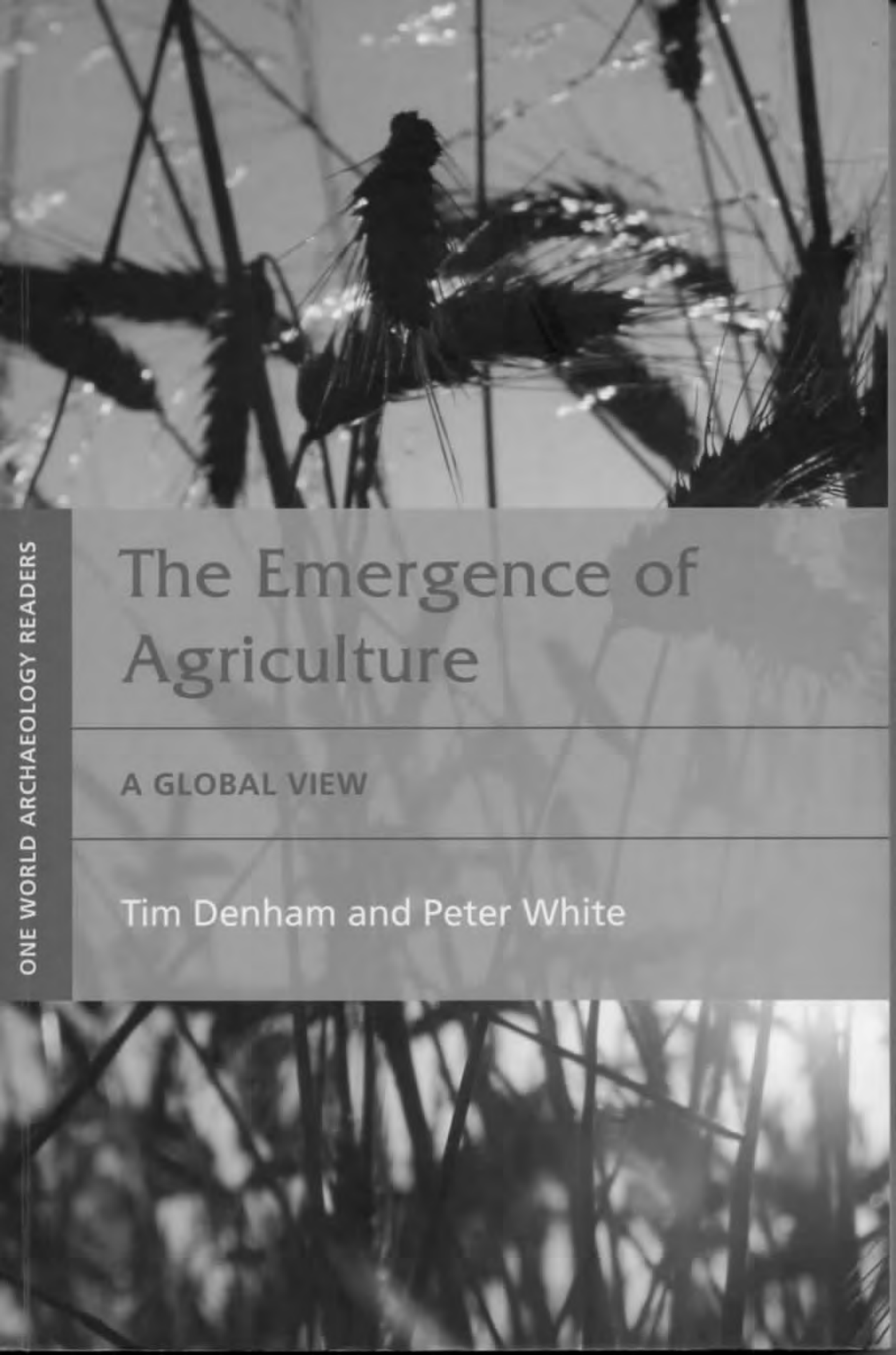

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The Emergence of Agriculture

A GLOBAL VIEW

Tim Denham and Peter White

12 Agrarian change and the beginnings of cultivation in the Near East

Evidence from wild progenitors, experimental cultivation and archaeobotanical data

George Willcox

Introduction

This chapter examines the change in the subsistence system in the Near East from a gathering economy to one of production (the beginnings of cereal and pulse cultivation), in the light of observations made during the experimental cultivation of primitive cereals at Jalès (France), together with field observations of wild cereals in their natural habitat at a number of stations in Syria. These observations are compared to recent archaeobotanical data.

Since the publications by Kislev on the difficulties of distinguishing wild and domestic emmer wheats (1989: 148, 1992), Hillman and Davies's (1990) publication on rates of domestication and Baruch and Bottema's (1991) work on climatic change, which Moore and Hillman (1992) suggest might be a contributing factor in the emergence of cereal cultivation, a number of new sites have been published and others are in the process of being analysed. Sites with well-preserved plant remains from the crucial period between 10,500 and 9000 BP are rare and frequently this period is represented only at the base of tells where extensive sampling has not been possible (Cayönü, Aswad and Cafer Höyük). Sites (see Figure 12.1) such as Cafer Höyük (de Moulins 1997) and Cayönü (van Zeist and de Roller 1994) have recently been published, and others such as Jerf el Ahmar, Dja'de (Willcox 1996), Nevali Cori (Pasternak 1995), Qermez Dere, M'lefaat, Hallan Cemi, and Nemrik (Nesbitt 1995) are now being analysed. In addition new evidence is coming to light on the distributions of wild cereals in Syria.

Experimental results from the cultivation of wild einkorn indicate that selective pressures in favour of domestic traits, such as the solid rachis, can be variable depending on harvesting techniques, and may be low (Hillman and Davies 1990; Willcox 1995). This is in contrast to the more conventional view that domestic traits were promptly selected for (Zohary 1992, 1996) once the progenitor was brought into cultivation. Low selective pressures could explain recent archaeobotanical finds which indicate that

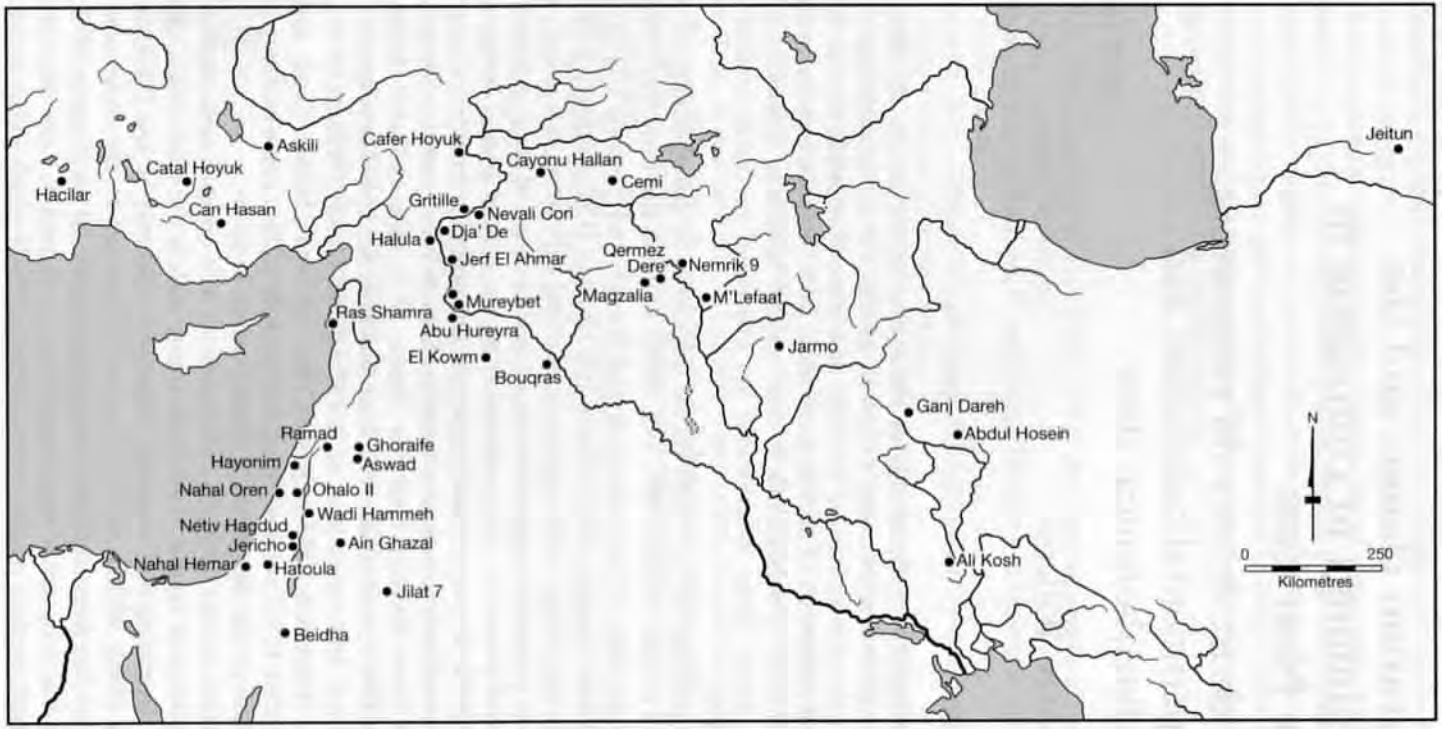

Figure 12.1 Map giving the distribution of sites mentioned in the text. The site of Franchti cave in Greece is not included for reasons of scale.

domestic and wild cereals occurred as mixtures on several early Neolithic sites over a period of at least a millennium. Archaeobotanical finds and field studies confirm that late Epipalaeolithic and early Neolithic distributions of wild cereals were more extensive (Hillman 1996) and environmental differences (soil types and humidity) between sites are reflected in the cereal assemblages at, and perhaps just after, the gathering stage (barley on poor dry soils for example). But once cultivation began, favourable soils would be chosen as would preferred crops. For example, emmer becomes more widespread at the expense of einkorn.

It is argued here that subsistence change in the Near East was a gradual process, proceeding over millennia rather than centuries, and that the adoption of cultivation required little innovation because, on the one hand, the 'tool kit' already existed and, on the other, the natural life cycle of the plants concerned had been exploited for some considerable time. After a period of small-scale cultivation an organized production economy was established, crops would have evolved more rapidly, and village size could increase and societies develop in new ways.

Present-day wild cereals

The evolutionary paths which led to present-day wild and domestic cereals are not fully understood. For example, we do not know when sterility barriers developed between *Triticum urartu* and *T. boeoticum*. Both species are present in the Levant today but we cannot tell how these compare genetically to the wild einkorn identified at sites such as Mureybet (van Zeist and Bakker-Heeres 1984a) and Abu Hureyra (Hillman *et al.* 1989). Even the BB genome donor is disputed (Konarev and Konarev 1993). Cytogenetic studies of modern populations are still providing new evidence for the early evolution of domesticates. A major limiting factor in the study of early crop evolution is the fact that we cannot know the cytogenetic relationships of ancient populations, particularly given the possibility of rapid evolution under domestication which may have led to a large number of extinctions of ancient domestic varieties. In addition, genetic exchange between different wild populations will have occurred over the last 10,000 years.

The distribution of wild cereals is well known in Turkey and Iraq (Bor 1968; Davies 1985), but has been somewhat neglected for Syria where primary stands of all four wild wheats are more widespread than has been previously suspected (Valkoun 1992; pers. comm., author's field studies in 1995). These populations, which are being studied by members of ICARDA (International Centre for Agricultural Research in Dry Areas, Aleppo), show high diversity and it is probable that genetic exchange between these closely related taxa occurs, despite the fact that they are predominantly inbreeders. *T. urartu* (AA donor for the tetraploid wheats) and *T. boeoticum* appear to be relatively common in areas with 300 mm of rain per annum but can occur occasionally in areas with as little as 250 mm. A number of recent discoveries have been made by Valkoun (1992) of ICARDA, and his results will be published in detail at a later date.

In northern Syria the present author collected *T. urartu* and *T. boeoticum* in the north-western part of the Jeseri at several stations near Ain al Arab. Mouterde (1966: 143) reports that he found wild einkorn on the Jebel Aziz (*Triticum thaoudar* Reut.). West of Aleppo several populations, which include *T. urartu*, *T. dicoccoides*, *T. boeoticum* and *T. araraticum*, have been found. A population of *T. urartu* was located north of Homs by Valkoun (pers. comms.). In the south, on the Jebel Druze, which is a basaltic massif rising to 1800 m, one can find vast stands of *T. urartu*, *T. dicoccoides* and *T. boeoticum* in their primary habitat. Finally, Valkoun (pers. comms.) reports that he has found a population of *T. urartu* as far south as Beida in southern Jordan. All these populations appear to be restricted to deep, rich, decalcified soils, such as *terra rossa* formed on limestone, or soils derived from basalt. But in higher rainfall areas they may occur on poorer soils. Wild wheats in Syria occur in open habitats, beyond the eastern margins of the Mediterranean vegetation zone, where they colonize open habitats with a continental climate. The four wild wheats found in Syria appear to occur in similar ecological zones; at certain locations they may occur as mixed populations, or in other cases will form pure stands. In either case they frequently grow with *Aegilops* spp. such as *A. speltoides*, *A. searsi*, *A. crassa* and *A. tauschii*, and form what might be described as a rich prairie habitat. In Syria wild einkorn penetrates the steppe habitat, whereas further north in Turkey it occupies the open deciduous oak parkland, described by Zohary (Zohary and Hopf 1988: 32) as the typical habitat for wild einkorn. This latter habitat does not exist in Syria today, but it is possible that this association was more widespread in the past and recent studies have indicated that deciduous oak charcoal is present on sites in Syria – not just from the Neolithic but also from the Bronze Age and later periods (Willcox 1991a, 1995, 1996). In southern Syria deciduous oak forests have been progressively replaced by evergreen oak forests (Willcox 1999) since the Bronze Age.

How far do the present-day distribution and ecology relate to the early Neolithic period? It is clear that today the wild wheats are restricted to favourable soil types. In addition, wild wheat populations appear to be very susceptible to grazing and occur only in areas where grazing is restricted. Thus what is seen today is likely to be a much-reduced distribution; with less human pressure and perhaps a more favourable climate, wild wheats may have covered a much wider zone during the Epipalaeolithic and Neolithic periods. This is indeed confirmed by the archaeobotanical finds from what is today arid steppe in that part of northern Syria which flanks the Euphrates (see also Hillman 1996 for a reinterpretation of post-glacial forest-steppe colonization).

The fact that these closely related species of wild wheat are found together has led to high genetic variability, although this may not be identifiable archaeobotanically. However, regional differences between populations of wild cereals, where different species (barley, einkorn, emmer and rye) are dominant, should show up archaeobotanically at the collecting stage during the Epipalaeolithic; but once cultivation and domestication began one might expect specialization and selection at the species level and ultimately the development of a weed flora. This would result in more uniform assemblages on a regional scale.

Experimental cultivation results and selective tendencies

In 1985, following discussions between G. Hillman, P. Anderson, J. Cauvin and the present author, it was decided to set up experiments using primitive wheats, and in particular wild einkorn, in order to test their behaviour under cultivation. An important aspect was the recording of spikelet loss under different harvesting techniques in order to estimate selection pressures and the rapidity of the domestication process. Hillman and Davies in their article (1990) discuss a wide range of possibilities for pre-domestic agriculture using a mathematical model. It emerges that spikelet loss during harvesting is one of the crucial elements which influence selective pressures and affect rates of domestication. Thus in 1989 a large-scale experiment was set up to test this aspect of the model. The reader is referred to the original article by Hillman and Davies, which discusses in detail the different variables concerned, a wide range of scenarios and the mathematical model used to calculate the experimental results given here.

The principal population of *Triticum boeoticum* was collected in 1986 in eastern Anatolia near Karaçadag, between Diyarbakir and Siverek, at an altitude of approximately 800 m above sea level, in a region where there is an annual rainfall of approximately 600 mm. This wild population prospers under the climatic and edaphic conditions at Jalès, which is situated at the extreme southern limit of the Ardèche in southern France. The difference in altitude (Jalès 130 m above sea level) appears to be compensated for by the difference in latitude (5.5°) between the two locations.

The wild population that was collected in its natural habitat showed a high diversity in, for example, gliadin analyses, and in morphological features such as glume colouring and hairiness. This original population contained low frequencies of wild emmer and *Aegilops speltoides*; the latter remained in the population for several years while the former died out after two generations.

In addition a number of other populations of both wild and domestic cereals were cultivated. The populations which were obtained from plant breeders were single-line, true-breeding populations, and are therefore less representative of early farming practices.

Before discussing the principal experiment, set up in 1989 to examine selection rates, it is necessary to present the techniques used and some relevant results obtained during the first years (between 1986 and 1989). Additional results can be found elsewhere (Willcox 1991b, 1992).

Sowing

In their natural habitat wild cereals sow themselves immediately after ripening. Thus the time of sowing is dependent on the altitude and latitude of any particular ecotype in question. Timing of natural dispersion will therefore vary from May to August, depending on the relative ripening times in different geographical areas. The advantage of early sowing for the farmer is that there is less chance of loss from vermin during storage (our samples were attacked by weevils), and the young plants get a better start and give good tillering.

Vernalization is the major factor controlling whether barley and wheat are spring or autumn sown. All wheats and barleys can be planted in the winter, but only those which lack the need for vernalization may be planted in the spring. Wild cereals exhibit varying degrees of vernalization requirement (Mathon 1985). In 1987/8 we planted *T. boeoticum aegilopoides* in both winter and spring. The spring-sown crop exhibited poor tillering. The emmer crop when spring-planted gives a highly diminished yield. We conclude that in a Mediterranean climate primitive cereals would have been predominantly winter-sown. Thus it would appear that by following the natural life-cycle the best results are obtained, though of course this could result in diminishing selective pressure.

Seed was broadcast by hand at high density in its hulled condition, that is to say the equivalent of about 140 kilos per hectare once the weight of the chaff is removed. We do not know how the earliest farmers sowed, although we do know that by the beginning of the third millennium in Mesopotamia, cereals were sown in carefully spaced rows using a seed-drill (Postgate 1984: 102).

Dormancy/inhibition of germination

Germination tests were carried out by the local agricultural college at Aubenas on samples of our seed grain under laboratory conditions. Observations on 100 grains were made at seven and fourteen days; the grains were kept humid at a temperature of 18 °C. Table 12.1 gives the results of germination tests from 7–21 October 1987.

The results from the germination tests indicate that:

1 In the case of wild einkorn, a crop harvested before maturity, still green, gives viable seed for planting the following autumn;
2 The glumes in the twinned-grained einkorns tend to inhibit the germination of the 'second grain' over a fourteen-day period and there was no twinned germination in sample number 122;
3 Wild emmer and wild barley gave poor results, perhaps because of strong germination inhibitors;
4 Sample number 77 appears to lack the dormancy factor when harvested ripe. This sample, which appears to be a single-line (true-breeding) population, also tends to have a more solid rachis.

Table 12.1 Results of germination tests carried out over a fourteen-day period. Tests were made at varying degrees of ripeness to test the viability of harvests carried out before maturity. It is clear that naked caryops gave good germination rates, while in the hulled state the glumes inhibited germination and in all but one sample only one grain germinated.

Species	*Ref no.*	*Naked grain %*	*Hulled %*	*Double %*	*Comment*
T. monococcum	12	92	80	0	
T. dicoccoides	18	56	17.5	0	Only 40 spikelets
T. b. thaoudar	122	82	80	0	Green
"	62	42	0	0	Half green (mouldy)
"	92	90	0	0	Ripe
"	77	94	94	0	Green
"	98	96	18	0	Half green
"	92	84	46	0	Ripe
"	38	92	98	16	Green
"	100	95	10	0	Half green
"	100	100	20	0	Ripe
T. urartu	59	82	94	6	Ripe
T. compactum	13	90	–	–	Free threshing
H. spontaneum	33	97.5	58	–	Ripe
"	52	54	–	–	Green

Dormancy was shown to exist in the laboratory experiments but these tests were only carried out over a fourteen-day period. Thus it was necessary to test whether dormant grains could germinate in the field and provide a harvest the following year. In 1989/90 we harvested a plot of wild einkorn before the grains were formed to eliminate self-seeding. The following two years saw no new germination. Thus the dormancy period under the conditions at Jalès was less than a year. However, under drier conditions germination may be inhibited for longer periods.

Uneven ripening and the brittle rachis

Wild cereals exhibit uneven ripening between different plants. In the case of wild einkorn grown at Jalès, at least a month may elapse between the earliest and the latest maturation in the same field. Uneven ripening also occurs between spikelets on the same ear, which mature progressively, with the uppermost spikelets ripening first. Primitive domestic cereals such as spelt, emmer and einkorn retained this trait, which indicates that it was not selected against during the early stages of domestication.

If the fallen grain survives to be harvested with part of the crop kept back for sowing the fragile rachis continues to be selected for in the population. The germination tests given above show that a premature harvest before ripening produces viable grain, but because of uneven ripening a small proportion of ripe grain will in fact fall (see Table 12.2). If this self-sown seed

Table 12.2 Results obtained from experimental cultivation of wild einkorn as part of a CNRS project. The experiments were devised to test rates of spikelet loss under different harvesting conditions. Initially, rates were put forward in predominantly model form by Hillman and Davies (1990), but see also Willcox (1991a, 1992). Spikelet loss was measured using two variables, maturity measured by the humidity and harvesting technique (column two). Selection coefficients (using Hillman and Davies' calculation) based on losses during the first year's harvest indicate that domestication would proceed. But if we take into account the quantity harvested in 1991 from spontaneously sown plants, this would seriously reduce selection coefficients.

Plot	*Methods*	*m²*	*Date*	*1989*	*Hum. (%)*	*1990*	*l/m²*	*l (%)*	*s/c*	*1991*	*S (%)*	*1992*	*SI (%)*	*1993*
A	Shaking	12.5	26.6	0.65	10.36	0.169	0.242	94.5				1.76		0.34*
B	Sickle	25	19.6	1.2		5.5	0.027	10.93	0.114	2.05	37.27	1.55	75.6	
C	Hand	25	21.6	1.2	31.16	1.55	0.088	58.6		2.3	148.38	1.49	64.7	
D	Sickle	12.5	12.6	0.65	50.86	3.3	0.015	5.36	0.106	2.06	31.21†	1.01	49	
d	Sickle	12.5	29.5	0.65	57.40‡									
E	Sickle	25	12.6	1.2	52.68‡	7.5	0.018	5.6	0.105	1.56	20.8			
F	Hand	25	13.6	1.2	53.00‡	5.5	0.057	20.57	0.134	2.25	40.9			
G	Uprooting	12.5	14.6	0.65	49.81	2.55	0.020	8.92	0.110	1.04	18.57†			
g	Uprooting	12.5	19.6	0.65		3.35	0.022	7.58	0.112					
H	Sickle	12.5	13.6	0.65	47.50	2.25	0.018	9.09	0.111	1.97	51.16†			
h	Sickle	12.5	21.6	0.65		1.6	0.031	19.47	0.130					
Poc	Sickle	15	11.6			3	0.011	5.21						
Lf	Sickle	91	21.6		33.59	14.8	0.093	36.8						

Key
1989 = weight sown 1989
Hum. % = percentage of humidity at harvest time
1990 = weight harvested 1990
l/m² = loss per square metre
m² = area planted in square metres
l (%) = percentage lost (i.e. fallen after harvest)
s/c = selection coefficient after Hillman's model <0.1 no domestication
1991 = weight harvested in 1991
S (%) = percentage of 1991 zero planting harvest compared to the 1990 harvest
1992 = weight of 1992 harvest with no planting
SI (%) = percentage of 1992 zero planting harvest compared to the 1991 harvest
1993 = average of all plots compared for 1993 harvest weight in kilos of hulled grain

Notes
* combined result; † two half plots combined; ‡ estimation.

is harvested then selective pressures in favour of uniform ripening and against uneven ripening would have been minimal.

Self-seeding and its effect on domestication

The domestication experiment was set up in 1989 and continued until 1993. Eight plots, A to H, each measuring 5 × 5 metres, were planted in August with 1.2 kilos of third-generation hulled wild einkorn. The quantity sown may seem high but it must be remembered that the chaff fraction represents well over half of the total weight. The first harvest took place during the last two weeks of June. Two variables were tested: method of reaping (shaking, sickle, hand picking and uprooting) and the degree of maturity, which was measured by the level of humidity. The results, are given in Table 12.2. The main aim of these experiments was to test grain loss through self-seeding under differing conditions and to estimate its effect on the domestication process.

It was found that the combined traits of uneven ripening and brittle rachis resulted in a certain amount of grain falling during harvest regardless of the technique (see Table 12.2). This occurred particularly during the harvest of the last plots, which were riper than those harvested earlier. In theory, loss through fallen spikelets during the harvest results in an increase in selective pressure in favour of solid-rachised domestic plants. Loss was measured by collecting fallen spikelets from a randomly chosen square metre for each twenty-five-metre square. As can be seen, loss is highly variable depending on the conditions of harvesting.

The plots were left fallow and the following year, 1990, a second harvest was obtained and the effects of spontaneous sowing were measured. Harvests were continued through to 1993 by which time competition, essentially from perennial grasses, seriously reduced the yield. As can be seen in Table 12.2, the first year of grow-back in 1991 represents a reasonable harvest. On the one hand, if early farmers opened up new fields, they could hardly ignore the spontaneously sown fallow fields; on the other, if they worked and replanted the same fields, the effects of even short-term dormancy would mean that a reasonable proportion of viable spikelets would in fact survive. Given the results obtained it would appear reasonable to assume that harvests could have contained 25 per cent of self-seeded plants. This 25 per cent could come from continuously cultivated fields, or from fallow fields.

This estimate does not include any spikelets which may have been harvested from natural stands, which is probable during the transition period, because the annual rainfall may not have been reliable. Under the present-day climate the rainfall for the Near East is irregular, particularly in the Euphrates valley, and years with low rainfall are frequent (Traboulsi 1981; Kerbe 1987). This may well have been the case 10,000 years ago. Thus, in poor years, whether due to such climatic abnormalities, disease or social upheaval, gathering from the wild could have supplemented the cultivated harvests. If the gathered cereal became mixed with the seed grain it would have slowed down the rate of domestication. Keeping morphologically identical populations apart would have been difficult. Thus there are at least three factors which would slow selection rates and the process of domestication: (1) supplementary gathering, (2) spontaneous sowing under cultivation, and (3) introgression (Zohary 1969).

We observed the presence of accidentally self-seeded cereals occurring in and around threshing areas at Jalès. This phenomenon must also have occurred during the gathering stage millennia before domestication, when cereals or legumes were displaced for processing, storage or consumption; such unintentional cultivation could have led to the extension of natural stands during the gathering stage.

Problems of identifying morphological domestication

Observations of a wide range of material reveal certain problems when identifying archaeobotanical remains. While it is well known that distortion by carbonization can lead to overlap between einkorn and emmer (this we have confirmed by experimentation), it is less well known that the proportion of single-grained spikelets in twinned-grained einkorn and emmer is extremely variable. This can lead to confusion. In one modern sample of *T. boeoticum thaoudar*, single-grained spikelets considerably out-numbered double-grained ones (Table 12.3). The reduction in number of grains appears to be related to stress caused, for example, by high sowing density or drought. These observations indicate that domestication criteria based on grain morphology alone could be misleading, particularly if based on a limited number of grains.

Table 12.3 The ratio of single- to double-grained spikelets in three wheat species. The variability appears to correlate with varying environmental conditions.

		Double : single
T. b. thaoudar	1987	2.6 : 1
	1988	3.6 : 1
	1991 d	1 : 5.3
	g	1.7 : 1
	c	1.9 : 1
T. urartu	1988	1 : 1
	1987	4.5 : 1
T. b. aegilopoides	1988	0 : 1
T. dicoccum	1993	1.2 : 1

The abscission layer which is formed well before maturity causes the spikelets to dehisce on drying, even when harvested green. The early harvest does not affect the mechanism, which causes the rachis to break up. However, as pointed out by Hillman (1981) and Kislev (1992) and confirmed among our populations, about 10 per cent of wild barley rachis fragments show solid domestic-type fused basal internodes. Thus, 10 per cent or less of domestic types is not necessarily indicative of domestication. If harvesting occurred late, with many of the upper spikelets already fallen, the percentage could be higher.

The distinction between domestic and wild wheats is based on the disarticulation scar. The break occurs in the same place, and in modern material one is rough and the other smooth. However, in ancient carbonized remains the surface is very often too poorly preserved to allow this distinction. The semi-solid rachis in barley has not been recognized archaeologically; however, although not generally known, varieties do exist. The author has collected specimens of semi-solid rachis, two-rowed 'black' barley near Bosra in southern Syria. The disarticulation scar is similar to that of the wild barleys.

Yield

The relevance of crop yield in cultivation (i.e. harvest weight compared to planted area) is likely to have been of limited interest to early farmers, who would have been more concerned with the return from a given amount of grain seed regardless of the planted area (yield ratio). Constant return, despite natural environmental fluctuations, would also have been favoured. Results obtained at Jalès are given by Willcox (1992: 176). Wild einkorn gave variable results in 1986; for example, a plot of 130 square metres gave a yield equivalent to 500 kg per hectare including chaff, but the ratio of harvest to seed corn was 8.6 : 1. In 1989, 1.2 kg was sown for 25 square metres which in the best plot gave 7.5 kg, which is the equivalent of 3000 kg per hectare but only 6.25 : 1 for the harvest/seed ratio. According to our cultivation results and results obtained in the field, wild einkorn can give between 0.5 and 1.5 tons of threshed grain per hectare. To take the totally hypothetical example of 200 grams of grain per day per person (72 kilos per annum), one hectare would supply enough grain for 7–21 people. Unfortunately it is not possible to estimate the population of early Neolithic village sites. But one might speculate that a small farming community of fifty people would need between 2.5 and 7 hectares for their cereals.

Conclusions based on experimental data

Traits such as dormancy and uneven ripening are not as disadvantageous as expected when cultivating wild cereals (Zohary 1996). Losses due to spikelets falling before and during the harvest are unavoidable, but these lead to germination and greatly reduce the chances of a mutant solid rachised type being kept back for sowing and increase its chances of ending up on the dinner table, thus diluting selective pressures in favour of a solid ear. In addition, early farmers may have encouraged a system where minimal seed corn gave a maximum return, which would also lead to a higher proportion of lost mutants on the dinner table. In this respect our estimates for the proportion of grain held back for sowing may be too high.

During the initial stages of cultivation, one might expect field size to be relatively small, with a high risk of contact with wild populations at the periphery leading to introgression. In order for selection rates to be high enough to favour a solid rachis population, wild and cultivated populations would have to be separated. In reality this would prove difficult, given the spontaneous germination of fallen spikelets and the probability that gathering from wild populations would be needed in poor years to supplement harvests from cultivated fields which had failed.

The results thus indicate that selective pressures in favour of domestication vary according to the proportions of self-seeded (including wild seed grain) and harvested seed grain from deliberately sown plots. It is clear that once the level of wild seed dropped below 15 or 10 per cent, domestication would advance relatively quickly (Hillman and Davies 1990). For this to occur communities would have to be almost totally reliant on sown crops and have a well-organized farming system; if not, selective tendencies would be too low and cultivation might continue indefinitely without domestication taking place.

Archaeobotanical results compared to observations based on present-day populations

A summary of archaeobotanical results is given in Table 12.4 (on pages 230–231). The earliest evidence for cereal exploitation dates from 19,000 BP at Ohalo II near the sea of Galilee, where wild barley and emmer were recovered (Kislev *et al.* 1992). For the later Epipalaeolithic period (12,000–10,000 BP), there is more information. Small village sites such as Mureybet and Abu Hureyra on the Euphrates in Syria, Hayonim in Israel, Wadi Hammeh in Jordan, Franchthi cave in Greece and Qermez Dere, Nemrik 9 and M'lefaat in northern Iraq indicate that wild cereals were exploited together with a number of edible fruits and pulses. Indirect evidence from glossed tools indicates that plants with high silica contents were harvested at the Epipalaeolithic sites of Nahal Oren, Hatula, and Kebara in Israel, and Beidha in Jordan where plant remains were not recovered (Anderson 1994: 292, and pers. comm.). It is clear that morphologically wild progenitors of Old World cereals and legumes were exploited for several millennia before the appearance of their domestic counterparts. The geographical extent is impressive, stretching from northern Iraq to the southern Levant, and perhaps Western Anatolia, since we have the site of Franchthi in Greece. As was expected from observations of modern distributions, strong regional differences can be seen between Epipalaeolithic sites. Einkorn is dominant at Mureybet and Abu Hureyra (which also has wild oats, rare elsewhere); barley and some emmer are present at Ohalo II. Rye is also present at a number of these sites (Hillman *et al.* 1993).

The Pre-Pottery Neolithic A (PPNA: 10,000–9600 BP) sites are less frequent but the architecture of small round houses is more substantial. No unequivocal morphological evidence for domestication at sites such as Mureybet, Jerf el Ahmar and Netiv Hagdud is forthcoming. For the very earliest levels at Aswad IA and Jericho, remains are numerically too meagre to be certain of domestication, but what is clear for this period is that the plant/crop assemblages vary remarkably between sites. Emmer is dominant at Aswad (van Zeist and Bakker-Heeres 1984b), einkorn at Mureybet and barley at Jerf el Ahmar in northern Syria (Table 12.5). This suggests that the inhabitants of these sites were still gathering local cereals, but this does not exclude small-scale cultivation as described by Harris (1996: 553) using locally available wild cereals as seed stock. Lentils are common on most sites even in the most arid zones.

During the next chronological period (Early PPNB: 9600–9000 BP) architecture is distinctly rectangular. Emmer domestication has been reported for sites such as Cafer Hüyök and Cayönü in eastern Anatolia and for Aswad near Damascus (however, some researchers prefer to rely on the solid rachis in barley and the naked wheats as sure evidence for domestication, especially when sample size is small). At Aswad, between 9730 and 8560 BP (PPNA and early PPNB), 26 per cent of the barley rachis fragments are solid domestic types, but it is not clear if they occur in the earliest levels. At Dja'de (Willcox 1996) preliminary studies indicate that the cereals are not yet domesticated, but indirect evidence of weed associations strongly suggests the presence of cultivation and similar assemblages are seen at Aswad, Cayönü and Cafer Hüyök.

The Middle PPNB (9200–8600 BP) sites are more extensive, more frequent and cover a wider geographical area comprising central Anatolia (Asikli Höyük) and Cyprus (Shillourokambos). Crop evolution and morphological domestication are clearly shown by the appearance of a solid rachis in barley and naked wheat – for example, at Aswad West phase II (van Zeist and Bakker-Heeres 1984b) and at Halula (Willcox 1995, 1996). For the first time there is evidence for the introduction of crop plants into new areas. Domestic emmer was introduced to the middle Euphrates at Abu Hureyra and Halula. But wild types remain at significant frequencies, which are evidenced at Cayönü, Cafer Höyük (wild wheats), Aswad, Ganj Dareh (wild barley), Halula (wild wheats and barley) and also in the Azraq basin (Colledge 1994). These mixed finds could be interpreted in three ways: (1) as evidence of the exploitation of wild stands, (2) as unwanted weeds, and (3) as an integral part of the crop consisting of a mixture of wild and domestic cereals. The relatively high proportion of wild types and the lack of pure finds of domesticates suggest that the wild plants may have been considered as a

Table 12.4 The major cereals, pulses and tree species from sites in the eastern Mediterranean (adapted from Nesbitt and Samuel 1996). There is considerable chronological overlap between sites, particularly for the

			einkorn	*emmer*	*barley*	*einkorn*	*emmer*	*naked wheat*	*barley 2r*
Site	*Phase*	*Date BP non cal.*	*w*	*w*	*w*	*d*	*d*	*d*	*d*
Ohalo II		19,000		O	O				
Franchthi		12,400–9000			O				
Hayonim		12,300–11,900			O				
Wadi Hammeh 27		12,200–11,900			O				
Abu Hureyra		11,000–10,000	O		O				
Hallan Cemi		10,600–9900							
Mureybet I	I–III	10,200–9500	O		O				
Qermez Dere		10,100–9700			O				
Netiv Hagdud		10,000–9400		O	O				
Jerf el Ahmar		9800–9700	O		O				
M'lefaat		9800–9600	?		O				
Tell Aswad	Ia	9700–9600			O		?		?
Dj'ade		9600–9000	O		O		?		
Cayönü rh		9500–9200	?	?					
Jericho	PPNA	9500–9000			?	?	?		?
Mureybet	IV	9400–8500	O		O				
Cafer Höyük	XIII–X	9400–9000	O	O		O	O		
Tell Aswad	Ib	9300–8800			O		O		?
Cayönü	gp bp c	9200–8500	O	O	?	O	O		?
Nevali Cori		9200			O	O			
Ain Ghazal		9000–8500					O		O
Jericho	PPNB	9000–8500			O	O	O		O
Cafer Höyük	IX–VI	9000–8400	O		O		O		
Nahal Hemar		9000–8200					O		O
Bheida		8900–8700				O	O		?
Ganj Dareh		8900–8200			O				O
Ali Kosh	BM	8800–8000	O		O	O	O		O
Jilat 7		8800–8400	O		O	O	O		
Asikli Höyük		8800–8400	O			?	O	O	O
Abu Hureyra PPNB		8800–8000	O		O	O	O	O	O
Tell Aswad	II	8700–8400	O		O	O	O	O	O
Ghoraifé	I	8700–8100			O		O	O	O
Abdul Hosein		8700–7500					O		O
Halula		8700	?	O	O		O	O	O
Magzalia		8600–7800			O		O	O	O
Gritille		8500–7700					O		O
Can Hassan III		8500–7600	O	O		O	O	O	O
Jarmo		8500	O	O	O	O	O		O

Key
w = wild
d = domestic
? = wild and/or domestic

later periods. Note that lentils are very frequent; however, domestication appears over a wide area during the last half of the tenth millennium BP. Lentils are common on most sites. Oak is also well represented.

barley 6r	*aegilops*	*lentil*	*pea*	*bitter vetch*	*oak*	*almond*	*pistacia*	*flax*	
d	*w*	*?*	*?*	*?*	*w*	*w*	*w*	*?*	*Reference*
		O			A	O	O		Kislev *et al.* 1992
		O	O	O		O	O		Hansen 1991
		O		O					Hopf and Bar Yosef 1987
		O			W		O		Willcox 1991a; Colledge 1994
		O		O	W	W	O		Hillman *et al.* 1989
		O		O		O	O		Rosenberg *et al.* 1995
		O			W		O		van Zeist and Bakker-Heeres 1984a
	O	O		O			O		Nesbitt 1995
		O							Bar-Yosef *et al.* 1991
	O	O	O	O	W	O	O		Willcox 1996
	O	O		O			O		Nesbitt 1995
		O	O	O		O	O		van Zeist and Bakker-Heeres 1984b
	O	O	O	O	W	O	O		Willcox 1996
		O			W	O	O		van Zeist and de Roller 1994
		O					O		Hopf 1983
		O			W		O		van Zeist and Bakker-Heeres 1984a
		O	O	O	W	O	O		Willcox 1991c; de Moulins 1997
		O	O				O		van Zeist and Bakker-Heeres 1984b
		O	O	O	W	O	O	O	van Zeist and de Roller 1994
	O	O	O	O		O	O		Pasternak 1995
		O	O		W		O	O	Rollefson *et al.* 1985
		O	O					O	Hopf 1983
		O			W	W	O		de Moulins 1997
		O			A	O	O		Kislev 1988
	O						O		Helbaek 1966
		O				O	O		van Zeist *et al.* 1986
O					A		O		Helbaek 1969
O				O			O		Colledge 1994
O		O	O	O		O	O		van Zeist and De Roller 1995
	O	O			W		O		de Moulins 1997
		O	O				O	O	van Zeist and Bakker-Heeres 1984b
		O	O				O	O	van Zeist and Bakker-Heeres 1984b
		O				W	O		Hubbard 1990; Willcox 1990
	O	O	O	O	W	W	O	O	Willcox 1996
	O	O							Willcox 1999
		O		O					Voigt 1984
		O		O	W	O	O		French *et al.* 1972
		O			W		O		Braidwood and Braidwood 1983

O = present
? = identification based on a small number of poorly preserved finds
W = identification based on wood
A = acorn

Table 12.5 Comparison of percentages of cereals at four PPNA sites. The differences indicate that the inhabitants were still using local cereals rather than introduced crops, which start to appear in the Middle PPNB.

	Jerf el Ahmar (%)	*Mureybet (%)*	*Aswad 1a (%)*	*Netiv Hagdud (%)*
Einkorn	15.80	96	0	0
Emmer	0	0	89.50	Present
Barley	84.20	4	10.50	Dominant

useful part of the crop, as opposed to unwanted weeds. This suggests cultivation of wild and domestic types together but does not exclude gathering from wild stands in a kind of mixed economy. Even during later periods (Late PPNB: 8600–8000 BP), for example at Ramad between 8210 and 7880 BP, domestic barley rachis fragments are only at 52 per cent. A similar situation was noted at Magzalia (Willcox unpublished report). However, at other contemporary sites such as Bouqras (van Zeist and van Waterbolk 1985) and Ras Shamra (phase Vc) wild types are rare or absent. These sites also contain naked wheat. During the Late PPNB, einkorn becomes a minor component and could be interpreted as a weed for most of the Near East. However, it reappears as a major component later at Jeitun in Central Asia (Harris *et al.* 1992) and at many sites in Europe.

Experimental results indicate that particular agricultural conditions are necessary in order for domestication to occur. As Hillman and Davies (1990: 213) point out, both seed corn from the wild, or that originating from fallen spikelets during the harvest, must be kept apart, and in reality this is not easy. This could explain why significant mixtures occur over a period of at least a millennium and would appear to indicate that selective pressures stayed relatively low. If this interpretation is correct, then it follows that cultivation without domestication would have occurred for some considerable time prior to the appearance of the solid rachis. If this is indeed the case, then archaeobotanists need to look for indirect indicators. Hillman examined the possibility of identifying a weed assemblage from Epipalaeolithic Abu Hureyra (Hillman *et al.* 1989: 253). His results were negative. Preliminary results from a later site, Dja'de, on the Euphrates (Willcox 1996), look more promising. Van Zeist examined the problem for later sites and the possibility of identifying weeds of irrigated fields (van Zeist 1993); he also points out that a number of taxa present at Cayönü are potential field weeds.

Evidence for *in situ* evolution under cultivation

At sites with long sequences such as Aswad and Cayönü it is possible to trace evolutionary trends. At Cayönü wild-type emmer grains are progressively replaced by domestic types (van Zeist and de Roller 1994), whereas at Aswad and near-by Ghoraifé, as already mentioned, wild-type barley rachis internodes are replaced progressively by solid-type domestic rachis fragments (van Zeist and Bakker-Heeres 1984b). The period of time necessary to recognize these changes appears to be about a millennium; that is to say, between the early tenth and early ninth millennia. Other sites such as Mureybet show no evolutionary trends; however taxa which are interpreted as weed assemblages at other sites are present. For example at Cayönü similar taxa are considered by van Zeist to be potential field weeds; these taxa also occur at other PPNA sites, suggesting predomestic agriculture.

Conclusions

Archaeobotanical evidence indicates that wild cereals were exploited in the Near East for several millennia before the appearance of domestic types. Specialized gathering and especially storage of cereals and pulses would have provided a secure subsistence base, making possible a sedentary existence. In the northern Levant it is not clear whether early tenth millennium cereals were domesticated. During the second half of the tenth millennium there is evidence of emmer domestication. However, a millennium after the appearance of domestication wild types still persisted at frequencies which suggest they were part of the crop rather than unwanted weeds. Experimental cultivation indicates that cereal cultivation need not necessarily lead to rapid domestication. Selective pressures were found to be low because wild types continued to propagate under cultivation through spontaneous sowing. Further dilution could occur from occasional gathering from the wild and through crosses with wild populations. However, a number of scholars insist that domestication was a rapid process suggesting that after the appearance of a given mutation the establishment of mutant lines could take place in a few years (McCorriston and Hole 1991; Zohary 1992, 1996). They therefore see the appearance of domestication as simultaneous with the beginnings of cultivation.

The area occupied by these sites is vast, which suggests the possibility that domestication could have occurred independently in different localities. Indeed genetic evidence points to at least two different origins for barley, and according to Zohary emmer and the pulses were taken into cultivation perhaps 'once or at most only very few times' (Zohary 1996: 155). However, still other varieties may have been taken into cultivation but subsequently died out or do not show up because of genetic modifications which have occurred over the last 10,000 years.

The point at which people started to cultivate remains elusive, but small-scale or intermittent cultivation of pulses and perhaps cereals may have occurred over a long period (PPNA and earlier) without leading to domestication, as suggested by Kislev (1992). Not until large-scale cereal cultivation in the Middle PPNB do we see the appearance of domestic barley and naked wheat and the spread of emmer. As for the identification of predomestic cultivation the best evidence would appear to come from weed assemblages.

How much can we say about cultural change in subsistence systems from the observations we have made? It would appear that the transition was gradual, as there is no evidence for an abrupt change. During the period of transition there was little need for innovation in material culture. The tools for processing of gathered and cultivated cereals remain essentially the same. Storage, and storage structures, could be the same for both economic systems. During the Late Epipalaeolithic one might consider the possibility that natural wild stands were to some extent managed to avoid over-exploitation. Then occasional sowing was adopted. As we have seen, inadvertent or accidental sowing around crop processing areas during the collecting stage is inevitable and could hardly have been totally ignored. Sowing would be enhanced if the soil was worked, and it is possible that suitable tools already existed for other activities such as collecting earth for building or digging up roots and tubers.

The change from a subsistence system to a production economy in the Near East has also been correlated with climatic change, notably the return of a cooler, dryer period (Younger Dryas) between 11,000 and 10,000 BP which, it is suggested, could have been a contributing factor to the subsequent development of agriculture (Moore and Hillman 1992). Movement of populations into drier areas might have the same effect. Given the steep gradient in isohyets between the Mediterranean vegetation zone and the interior steppe zone, even a small climatic change in the marginal areas would have a profound effect.

The evolution towards and the adaptation to a production economy with resulting domestication required certain pre-conditions. In other words it required a combination of complex circumstances leading to an evolutionary path, which resulted in an economy dependent on cereal cultivation. On the one hand the plants had to have the right biological attributes (see Zohary 1996), and on the other humans had to have prerequisite behavioural attributes. They would have to be sedentary gatherers of wild progenitors with a minimum village size and a storage system. As pointed out by Cauvin, humans would have to be culturally ready (Cauvin 1994). Once all these conditions were fulfilled a full-scale farming economy (symbiosis) becomes inevitable. This would provide a subsistence system where production was guaranteed to supply demand (and/or surplus) in an expanding economy, ultimately leading to an irreversible process. We are not in a position to say whether cultural change played a more important role than climatic change. To assume that a single factor such as climatic change could have led to the adoption of plant husbandry is too simplistic.

The archaeobotanical remains, as we have seen, indicate that the change to a production economy was slow. The biological process of domestication appears to require that sowing be systematically carried out and that spontaneously sown seed be kept to a minimum. This would require that the soil be worked rigorously and field systems be carefully managed. Cultivation of pulses and cereals during the early stages, even during the eleventh and tenth millennia, could have been an occasional option, but not necessarily systematically adopted. If occasional domesticates arose they may not have survived in the long term. But ultimately social organization developed to a point where farming became more and more organized, leading to high selective pressures for domestic types. Archaeological evidence during the Middle PPNB indicates the simultaneous emergence of rectilinear architecture, a considerable increase in village size, the consistent appearance of domesticated cereals, and the domestication of sheep and goat. Could these changes be correlated with a more developed and organized sociocultural system which became increasingly reliant on a highly managed agricultural system? This could have coincided with the adoption of rectangular field systems. Ultimately the process led to irreversible domestication combined with a steep rise in population. It appears that these changes were gradual and occurred more or less simultaneously over a wide area; that is to say the Euphrates valley, eastern Anatolia, the southern Levant and the Zagros foothills. Differences in material culture over the area as a whole are slight and contact across the region between geographically widely separated populations has been shown to occur from finds of marine shells and obsidian, which were traded across vast distances. If the area as a whole went through the pre-domestic cultivation stage then it is highly probable that domestication of the so-called founder crops occurred independently in different areas. However, at some sites, for example at Mureybet, only wild cereals were exploited during the Middle PPNB, while at the majority of sites, for this period, domestic cereals were predominant.

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Update: Rates of domestication assessed

George Willcox

Since the 1999 publication much new archaeobotanical information has become available from early farming sites in the Near East. I cautiously advocated a gradualist domestication model and the possibility of multiple domestication events. New information and new interpretations which support these views have since appeared (Willcox 2002, 2005). The cultivation of morphologically wild cereals prior to their domestication (pre-domestic agriculture) is now accepted by most archaeobotanists for the PPNA in both the northern and southern Levant. Earlier cultivation has been posited for Natufian levels at Abu Hureyra and Khamian levels at Mureybet (Colledge 1998; Hillman *et al.* 2001). This implies that the transformation of shattering wild cereal populations into non-shattering domestic populations was a slow process, because the latter do not appear until the Early PPNB. Indeed, Tanno and Willcox (2006) demonstrate that wild and domestic forms persisted together at relatively high frequencies under cultivation in the Near East for a considerable period of time, further supporting a gradualist model of domestication.

The original article used information from experimental cultivation of wild cereals at Jalès in southern France during 1989–1993. This research has continued and a number of significant observations have been made. In the late 1990s, the wild einkorn population was accidentally contaminated with domestic einkorn. Because the two populations are morphologically similar, neither the exact date nor degree of contamination are known. The separation of a mixture of wild and domestic einkorn is difficult. They continued to be cultivated together. It took less than ten years for the wild population to be almost totally replaced by the domestic non-shattering varieties. This demonstrates that once a small number of present-day domestic plants are introduced, selection will rapidly favour them at the expense of the wild types. However, our cultivation techniques did not simulate the situation of early farmers. During this ten-year period the harvests took place late, well after shattering had started, which would have strongly favoured the domestic varieties. This would not have been the case for early farmers who would have harvested before shattering started, to avoid loss. Under these circumstances non-shattering was far less advantageous.

Furthermore, in the original article I posit that when crops failed, early subsistence farmers would have had to gather from the wild to replenish their seed stock. Poor harvests with low yields occurred occasionally on our plots, but because we were not keeping back grain for consumption we always had enough for sowing, which would not have been the case for early Neolithic farmers. I argue that a combination of early harvests and replenishment from the wild would make the selection of the rare non-shattering mutants highly improbable, implying that a long period would be required for domestic populations to become established (Kislev 2002 gives additional supporting arguments).

Concerning the cultivation of wild two-rowed barley (*Hordeum spontaneum*), we noticed that from the late 1990s the population had some six-rowed specimens. Because they produced more grains, they became dominant at the expense of the two-rowed types in a few years. This can be explained because our original population was collected from an area where domestic barley was cultivated. The appearance of the six-rowed trait was probably due to the fact that the original 'wild' population had grown in close proximity to cultivated barley; either it had introgressed or it was an escape from cultivation (Zohary and Tanno, pers. comm.).

Artificial selection leading to rapid changes, as opposed to (slow) natural selection, was improbable, because domestic traits such as non-shattering and lack of dormancy would not have been readily visible to early farmers. Selection for larger grains in the case of einkorn and barley was slow. This has been established by measurements taken from ancient grains which demonstrate no significant size increase for wheat and barley grains between

9500 and 6500 uncal. BP (Willcox 2004). Selection of large grains is not a straightforward process because grain size depends more upon the position on the ear and environmental conditions than genetic diversity.

Finally, in 2004 we started cultivating wild rye (*Secale vavilovii*) gathered from volcanic soils on Karaça Dag. We had excellent results despite adverse soil conditions, implying that wild rye could have been cultivated on less acidic soils than those found in the Karaça Dag region.

To conclude, the evidence points more and more to slow change in food procuring strategies, crop adaptation and social change at the dawn of farming. Societies may have chosen reliability over the risk of innovation. Small-scale cultivation by 'hunter-gatherers' may well have led to socio-cultural complexity, which has recently been demonstrated by new spectacular finds such as those at the site of Göbekli (Schmidt 2006). This social complexity may have produced incentives to cultivate more intensively, leading to a production economy. A full production economy with systematic domestication did not appear until after the beginning of the Holocene and coincides with the appearance of a stable climate.

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