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LAND USE CHANGES AND CROP PRODUCTIVITY IN EARLY AGRICULTURE: COMPARISON WITH CURRENT CONDITIONS IN THE MID-EUPHRATES VALLEY

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INTRODUCTION

Water management in either irrigated or rain-fed crops has been practised for thousands of years in the Mediterranean. Whereas history tell us that most irrigation-based societies of the region failed (Postel 1999)

, many traditional activities that have survived until present times are admirably adapted to particularly arid environments (Mortimore 1989). In general, the sustainability (and cost value) of traditional agricultural systems is substantially higher than that of today's systems, and therefore much can be learnt from the past. Several studies have addressed the benefits from combining indigenous with modern knowledge and have explored the potential of several techniques for water harvesting and their adaptation to local conditions (see references in Arous 2004). However, much less emphasis has been placed to valorise traditional agronomic practices, which may be of value and especially in rain-fed conditions. Thus traditional agronomic practices (related with water harvesting, sowing and soil conditions, fertilizing, fallow, etc) may provide by far more water and nutrients to rainfed crops and in a more sustainable manner than conventional (present-time) systems (Capillon and Séguy 2002; Prew *et al.* 1995; Raupp and König 1996). Moreover, most of these agronomic techniques were likely developed at the beginnings of agriculture and, probably, conformed the basis of the origin and spread of agriculture in the Region. In fact cultivation in (naturally) wet soils (Arous *et al.* 1999) and their positive consequences in terms of productivity (Arous *et al.* 2001; Arous *et al.* 2003) has been evidenced in Neolithic sites (ca. 10th millennium BP) of the Middle East.

Improving our knowledge about the way early farmers reacted to environmental constraints might help to unveil alternative methods to face current water issues. Up to now, the most evident way to get insight into ancient water management methods has been the study of archaeological structures related to water uptake or distribution. However, this approach is limited to relatively advanced societies, and does not give any information about the actual results of this management on crop performance or the characteristics of ancient crops. Agronomic and ecophysiological characteristics of plants at the time of emergence of agriculture as well as further changes occurring through time, may add additional clues on the interaction between agriculture, man and environment. Indeed, the study of archaeological plant remains have provided direct evidences about the evolution of land use (e.g. deforestation processes; see Willcox 2002), changes in the preferred crops (McCorrison and Weisberg 2002), crop management (Bogaard *et al.* 1999; Jones *et al.* 2000), and the origin and spread of relevant agronomic traits, such as greater grain size (Ferrio *et al.* 2004a; Willcox 2004) or non-shattering raquis (Harlan *et al.* 1976; Zohary and Hopf 1988).

In this work we compared crop distribution, cereal crop yields and population data for Tell Halula, a 10th millennium BP site on the Euphrates, with contemporary data from the surrounding region on population, crop management and productivity. Comparing contemporary changes in land use and management during the last 50 years with those recorded in archaeological contexts, we can get a

better understanding of the long-term effect of the interaction between man and environment in the area.

MATERIALS AND METHODS

Area of study

We focused our research on the area around the archaeological site of Tell Halula (36°25'N, 38°10'E, 337 m.a.s.l.), placed in the Mid-Euphrates region (Governorate of Rakka, Syria) about 105 km east of Aleppo and 25 km northwest of Membij (see Fig. 1). Tell Halula is a representative site for the beginnings of agriculture, and comprises (to date) three main excavated periods: Middle and Late Pre-Pottery Neolithic B (M-PPNB, 9750 years Before Present -BP- and L-PPNB, 9300 years BP, respectively), and Pottery Neolithic (PN, 8750 BP). The archaeological site was occupied in an uninterrupted way during ca. 2000 years, and since then till the second half of the 19th century, the region remained unsettled, being used only by the Bedouins for grazing. It was not until the 20th century when some of the tribes started a transformation from herders into farmers and founded current communities. The area is characterised by a steppe climate, with an average annual rainfall ranging from 255 to 265 mm, mean temperatures from 17.8°C to 17.9°C, and an annual ratio between precipitation and evaporative demand varying between 0.15 and 0.17.

Data compilation

Archaeological data was compiled from the literature to provide information about the structure and socio-economics of ancient farming communities, including the estimation of past yields of the main crops cultivated (Araus *et al.* 1999; Araus *et al.* 2001; Araus *et al.* 2003; Araus *et al.*, submitted). Ancient population at the archaeological site was inferred by applying ethnoarchaeological criteria (population density in present villages from the Near East, following Aurenche (1981) and from built surface, taking an average of 21 m² person⁻¹, as established by Holladay (1992).

Contemporary data was derived from data published by the Syrian Ministry of Agriculture and Agrarian Reform (The Annual Agricultural Statistical Abstract, 1996), data provided by the Membij Farmers Union and Department of Agriculture, and from a field survey performed in twelve communities in the surroundings of the archaeological site (see Fig. 1b).

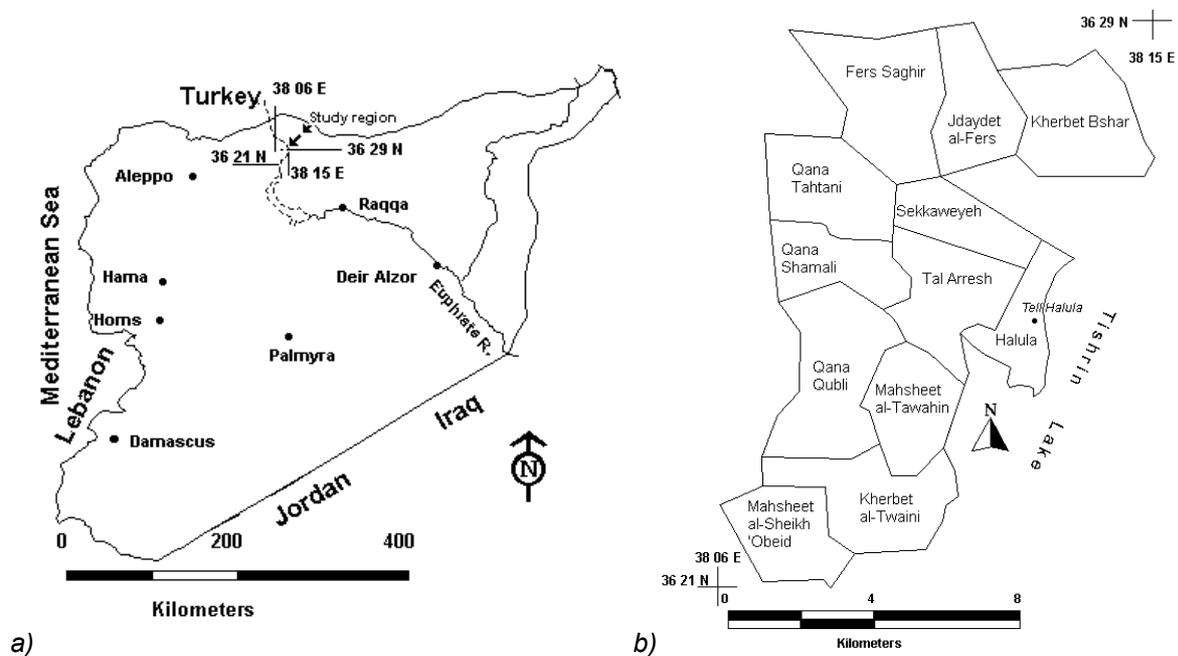


Fig. 1. a) Geographical location of the area of study and b) detail of the communities included in the field survey, indicating the location of the archaeological site, Tell Halula.

RESULTS AND DISCUSSION

Crop distribution and management in present times

Currently, the area of study is strongly limited in terms of land resources, considering that almost all arable land is cultivated. Of a total area of 9318 ha, 8019 ha are cultivated. Barley is the dominant rainfed crop in the area (66.1%), followed by wheat (28.2%), and the extension of fallow is very low (3.6%) (Table 1). Even considering also irrigated land, which covers 10.6% of the total cultivated area, cereals are by far the most abundant crop, representing the 91.2% of the total arable land. On the contrary, legume crops are restricted only to small irrigated plots, covering less than 1% of the total area. Thus, the situation is close to a monoculture, probably forced by the increasing population pressure, which is the main cause of the current limitation in land resources. On the other hand, the lack of fallow and rotation practices in the crop cycle has led to a progressive soil degradation, further enhancing the expansion of barley, as it grows relatively well in the poorest soils. Indeed, during the field survey, 92% of the farmers mentioned that their soils have degraded in terms of productivity, despite the increased use of fertilisers and improved varieties. When asked about the reasons that caused the degradation, 75% of them attributed this degradation to the exclusion of fallow from the crop rotation. Moreover, 67.5% of the soils in the region were classified in the survey as of category 1 (depth between 0-0.5 m, stony and with low fertility), whereas only 8% of the soils were classified as of category 5 (depth =5.1-25 m, without stones and with high fertility). On the other hand, and except for the communities just beside the new "Tishrin" dam on the Euphrates (e.g. Halula), the water table has decreased considerably in the last 50 years, from 29 m on average in the 1950s to 57 m depth twenty years ago, and 60 m depth at present, mostly due to an overexploitation of water reservoirs used for irrigation.

Table 1. Percentage of the different rainfed and irrigated crops sown in the season 2003-2004 in the area of study. Source: Membij Farmers Union and Department of Agriculture.

Rainfed crops (ha)	Barley (%)	Wheat (%)	Fallow (%)	Olive (%)	Pistachio (%)	Grape (%)	Almond (%)
7165	66.1	28.2	3.6	1.7	0.3	0.1	0.04
Irrigated crops (ha)	Cotton (%)	Wheat (%)	Broad beans (%)	Sesame (%)	Maize (%)	Vegetables (%)	Olive (%)
854	22.2	65.3	5.7	3.4	2.5	0.8	0.2

Crop distribution and management during the Neolithic

Up to now, 1662 seeds have been recovered and identified from the archaeological site of Tell Halula, 1154 from the PPNB layers (M-PPNB and L-PPNB samples were combined for quantitative analysis) and 508 from the PN period. Overall, naked wheat (*Triticum aestivum/durum*), emmer (*Triticum dicoccum*) and barley (*Hordeum vulgare*) were the main cultivated crops, together with two pulses: lentil (*Lens culinaris*) and pea (*Pisum sativum*) and a single oil-and-fibre crop, flax (*Linum usitatissimum*). Of minor importance were einkorn (*Triticum monococcum*) and wild cereals (wild barley, *Hordeum spontaneum* and wild rye, *Secale* sp.), as well as some fruit-trees, probably harvested from natural vegetation, such as *Amygdalus* sp., *Capparis* sp., *Ficus* sp. and *Pistacia* sp. Nevertheless, cereals were by far the most abundant crops (66.9% of the total findings), followed by legumes (18.9%). We found significant differences between the two periods studied, with a strong depletion in legume cultivation (from 26.7% to 1.2%), when compared with the cereals (Figure 2a). Similarly, the third major crop (flax) also showed a significant reduction from the PPNB to the PN (from 13.1% to 2.7%). Indeed, the situation during the PN was more similar to that found in present times, showing nearly a monoculture of cereals (92.1% of the seeds).

Looking at the distribution among different cereal crops (Fig. 2b), we found that their relative importance varied substantially between the two periods studied. Thus, for the PPNB layers, naked wheat was the most abundant cereal (42.5%), followed by emmer (28.8%) and 2-row barley (14.6%),

while 6-row barley and einkorn were relatively rare. During this period, significant amounts of wild cereals were still gathered, in particular *Hordeum spontaneum*. In contrast, during the PN phase, naked wheat lost its relevance (15.4%) and emmer became the dominant cereal, together with 2-row barley (43.6% and 37.6%, respectively). Whereas einkorn showed a slight expansion during this period, 6-row barley disappeared and wild cereals became very rare. Again, this situation resembles present conditions, in which the area dedicated to barley is almost two-fold greater than the area under wheat (4734 ha and 2578 ha, respectively) (see Fig. 2b).

Overall, we found a wider variety of crops during the earlier phases of the settlement, which afterwards moved into a cereal monoculture. During this transition, harvesting of wild material (fruits, nuts and wild cereals) almost disappeared. This probably reflect a significant expansion of the area dedicated to agriculture, which should be necessarily restricted to extensive crops requiring relatively low labour efforts, such as cereals. Indeed, it has been reported in traditional farming communities that intensive crops tend to be located near the settlement, while more extensive ones can spread over wider territories, and this was probably also a common practice among Early Neolithic farmer communities (Hillman 1973; Wilkinson 1994). On the other hand, the expansion of cultivated land would imply the cultivation in poorer soils, with lower water table and/or poorer in nutrients, as land resources began to be limited. This would explain the relative reduction in wheat cultivation, in favour of emmer and 2-row barley, as the latter tend to perform better under harsher conditions than wheat (López-Castañeda and Richards 1994; Stallknecht *et al.* 1996). Moreover, as we will discuss later, estimated crop yields showed a declining trend during this period, further confirming this explanation.

The significant reduction in legume cultivation might have also implied the lost of crop rotation, as happened during the last decades in the area (due to the scarcity of land resources), further enhancing soil degradation and nutrient losses. Nevertheless, previous studies have shown that the legumes and flax were generally grown under more humid conditions than the cereals, suggesting the potential use of irrigation in small plots, rather than an extensive cultivation, in alternation with cereals (Araus *et al.* 1999; Ferrio *et al.* 2004b; Ferrio *et al.* 2005). Indeed, the site of Tell Halula provided one of the oldest evidences of waterworks in the Near East (dated about 8000 years BP), an irrigation/drainage ditch located just outside the walls of the village (Molist 1996). On the other hand, among the cereals, naked wheat showed generally better water availability than barley (Ferrio *et al.* 2004b; Ferrio *et al.* 2005), suggesting that it was planted either in naturally wet soils or under supplementary irrigation. Nowadays, it is a common traditional practice to reserve the best soils for wheat and legumes, given their added value and their higher requirements, when compared with barley. Effectively, in our area of study, crop legumes (broad beans) and wheat are currently among the preferred species for irrigation, although they are combined with more recently introduced crops, such as cotton, sesame and maize (see Table 1).

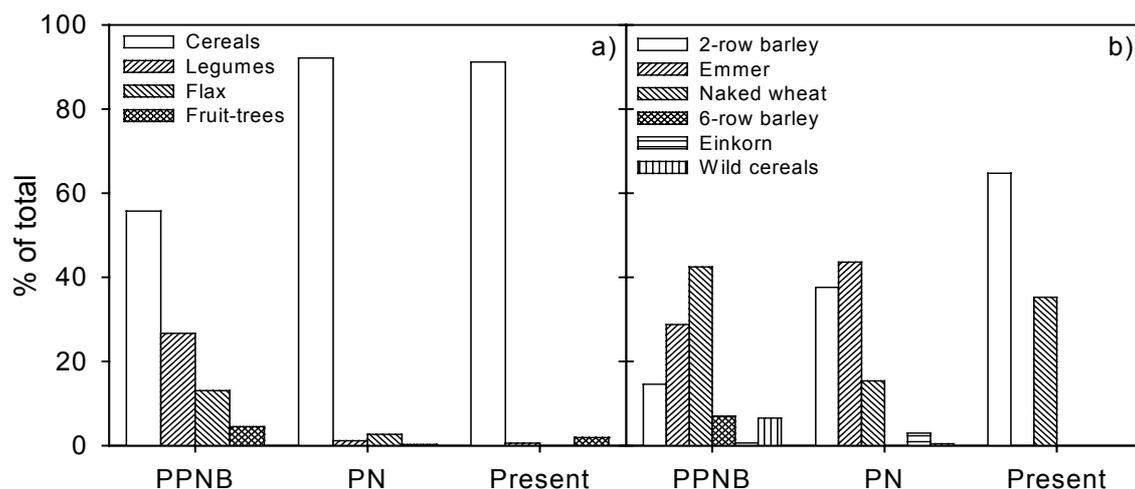


Fig. 2. Comparison between the percentage of seeds from each kind of crop that were recovered in the archaeological site of Tell Halula (a surrogate for crop distribution in the past) and the percentage of land currently dedicated to each crop, as derived from Table 1. PPNB, Pre-pottery Neolithic B; PN, Pottery Neolithic.

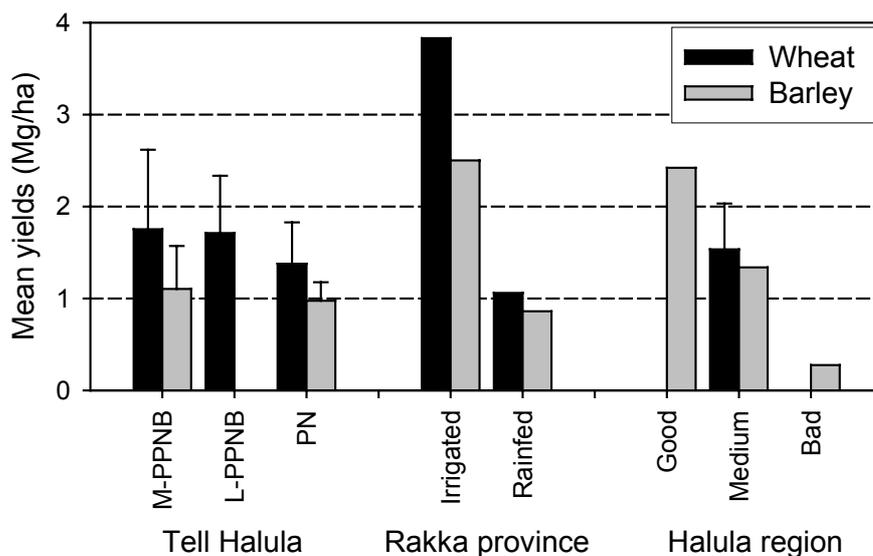


Fig. 3. Comparison between estimated yields for the archaeological site of Tell Halula (derived from carbon isotope discrimination of cereal grains, as described in Araus *et al.* (1999); Araus *et al.* (2001); Araus *et al.* (2003), current yields in the Rakka province (1987-1996) for irrigated and rainfed crops, and average yields in “good”, “medium” and “bad” years for rainfed barley in Halula region (1994-2004), according to the Membij Farmers Union and Department of Agriculture and the data from the field survey (for wheat only the average value across communities for 2004 is given). M-PPNB, L-PPNB, Middle and Late Pre-pottery Neolithic B; PN, Pottery Neolithic.

Cereal yields in the past and in present times: evidences of land degradation

During the last years, our group developed a method to estimate ancient cereal yields from the analysis of carbon isotope discrimination in archaeological grains Araus *et al.* (1999). The method is based on the strong relationship observed between carbon isotope discrimination and grain yield, across a wide range of environmental conditions, but taking into account the effect of recent changes in harvest index and atmospheric CO₂ (see details in Araus *et al.* (2003). Using this methodology, we obtained estimations of grain yield for the archaeological site of Tell Halula, which could be directly compared with those currently found in the area (Fig. 3). Our estimates are similar or even higher than present yields under rainfed conditions. Thus, despite the recent agronomic and genetic advances, the better growing conditions prevailing during the Neolithic allowed ancient farmers to obtain relatively high yields. On the other hand, considering the high yields attained in the past, and the fact that wild species were still rather common in the archaeological context (at least during the PPNB), it is likely that the pressure of agriculture over the soils were smaller in the Neolithic than in present. Nevertheless, a declining trend in grain yield was found for both wheat and barley, suggesting an effect of land degradation. This coincides with a significant reduction in the size of the site in terms of occupied area and, presumably, of population, along with an overall degradation in the quality of built structures (e.g. the substitution of “cemento”-coated soils by bare soils; Molist 1996). As shown in Fig. 2, the change from a mixed culture of cereals, legumes and flax (probably including some crop rotation or, at least, fallow) to a nearly monoculture regime of cereals might be the cause behind the lost in crop yields, thus resembling the present situation.

Table 2. Estimated population, barley yields, minimum required land area per person (based on nutritional needs), and total cultivated area per person and settlement (assuming that 50% of land is under fallow) for the PPNB layers of Tell Halula. For comparison, present average values for the same variables across the twelve communities of the area of study are also included.

Period	Population	Average yield (kg ha ⁻¹)	Required area (ha person ⁻¹)	Cultivated area (ha person ⁻¹)	Total cultivated area (ha site ⁻¹)
PPNB	625 ± 100 ^a	1104 ± 467 ^b	0.29 ± 0.11 ^b	0.29 ± 0.11 ^b	180 ± 70 ^b
1994	655 ± 249 ^c	1140 ± 844 ^d	0.57 ± 0.45 ^d		
2004	921 ± 350 ^c	1140 ± 844 ^d	0.57 ± 0.45 ^d	0.66 ± 0.20 ^c	611 ± 421 ^c

^a Average ± range of estimated values

^b Average ± standard deviation across archaeological samples

^c Average ± standard deviation across communities (results from the field survey)

^d Average ± standard deviation across years for the whole study area (period 1994-2004)

Changes in demography and land resources

The inferred population in Tell Halula during the PPNB, based on ethnoarchaeological criteria (Aurenche 1981) was of 525.4 inhabitants, whereas using the estimations from built surface (Holladay 1992) the estimation was of 711.6 inhabitants (M. Molist, pers. comm.). Thus, we adopted as the most probable population the range between 525 and 625 inhabitants (Table 2). This population is almost identical to the average population across the twelve communities studied in 1994. Nevertheless, the average size of the communities has grown notably in the last ten years (40.6% of increase), and thus present population per settlement is significantly higher.

In order to assess the potential effect of demographic pressure on land resources in prehistoric settlements, one approach is to estimate land requirements based on the nutritional demand to be satisfied. Considering an average nutritional requirement of 2600 kcal day⁻¹ person⁻¹, and the known energetic values of cereal grains (ca. 3.5 kcal g⁻¹), we can determine how much cereal is required to meet an individual's minimum annual nutritional demand (Araus *et al.* 2003). Thus for a cereal monoculture settlement, the result is ca. 300 kg yr⁻¹ person⁻¹, assuming that 10% of production is reserved for sowing, as previously reported (Wilkinson 1994). Following these assumptions, and taking into account population and yield estimates, we can finally obtain an estimation of the required cultivated area per person, as well as for the whole settlement, as displayed in Table 2. For simplicity, we took the average yield estimated for barley, although the approach could be refined by considering the relative frequencies of each crop (see Fig. 2). When compared with the current situation, we found that estimated land requirements were significantly lower during the PPNB, despite having similar average yields. In this case, the main difference is the lower variability observed in ancient yields when compared with present data, which may indicate more stable climatic conditions. Indeed, according to the field survey, during the period 1994-2004 the mean number of "good", "medium" and "bad" years across communities were 2.3, 3.5 and 4.2 respectively, which means that every ten years, four are giving very low yields (275 kg ha⁻¹ on average, see Fig. 2). Thus, yield stability, as much as yield itself, strongly determines the extension of land required by the settlement. On the other hand, comparing actual cultivated area in present times with the estimations from nutritional requirements, we found that current productivity is so low that only exceeds slightly these minimum needs, leaving few margin for commercial purposes. Moreover, during "bad" years, cultivated area per person is well below the nutritional needs of the population under such conditions (1.09 ha person⁻¹).

CONCLUSIONS

Despite the constraints of comparing past and present conditions, when the source data available for each period is not directly comparable, we have shown that it is possible to make reliable estimations of population, past yields and land use from the study of archaeobotanical remains, together with other archaeological data. Such estimations can be related to the current conditions in farmer communities from the area, in order to understand the long-term consequences of agronomic practices. We found that ancient crop yields in the area were similar to those found in present times,

despite recent agronomic and genetic advances, and that land requirements per person appeared to be lower in the past due to more stable climatic conditions. On the other hand, we found evidences of progressive soil degradation in the area not only during the last decades, but also in the Early Neolithic settlement. In both cases, such degradation appears to be associated with the lost in crop diversity and a trend towards a cereal monoculture.

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