Visualizing Agricultural Production during the Eneolithic: A Case Study from the Tripol'ye Giant-settlement of Tal'yanki

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Archaeologists seeking to understand the economic landscape of prehistoric farming societies often make use of theoretical models such as site catchment analysis to make inferences regarding agricultural production. Such exercises are necessarily deterministic in nature and the quality of their results fluctuates wildly depending on the quality and amount of inputs involved. The Eneolithic Tripol'ye giant-settlements of central Ukraine present a special problem for landscape studies due to the paucity of material evidence available beyond the architecture and layout of the settlements themselves. This paper seeks to re-analyze published material on the Tomashevskaya local group of the Western-Tripolian Culture, particularly relating to the largest of the giant-settlements, Tal'yanki. It is proposed that through a multi-disciplinary approach combining archaeology with agricultural science, a more coherent picture of subsistence behaviors and social organization can be formed.[*]

Introduction

The past four decades of research have established the Tripol'ye giant-settlements (*c.* 4100-3400 B.C.E.)[1] of the South Bug-Dnieper interfluve as a "real laboratory for the studies of many aspects of the Tripolian culture,"[2] including mathematical models of settlement rotation, paleodemography and paleoeconomy. While these settlements do not showcase any marked deviation from, or any special developments beyond, the rather homogeneous material assemblage of the general Tripol'ye culture, their unique size and character pose many questions for researchers. Of particular interest are speculative models for land-use and agricultural production, such as the cereal production estimates of S.N. Bibikov (1965) and the site catchment analysis for the settlement at Maidanetskoe conducted by B. Gaydarska (2003). The research presented focuses on creating a synthesis of these previously-applied methodologies, while striving to incorporate a wide variety of additional variables. The focus of this exercise is the settlement at Tal'yanki, located some 25 km from the town of Uman' in the Cherkassy region of Ukraine.

Tal'yanki

Only small samples of the giant-settlements have been excavated, but they can be characterized as "planned," unfortified settlements, situated around a central open area in several concentric rings.[3] With no internal differentiation of architecture, the political organization of the settlements is thought to be rather egalitarian, with authority vested in a number of big men or chiefs, each of whom would have represented a kin group or clan-like unit. Further evidence for this organizational scheme comes from the layout of the settlement plan, where subdivisions of up to twenty houses can be perceived.[4]

Tal'yanki is most often cited, based on the calculations of expedition leader Vladimir Kruts, as having approximately 2700 structures covering 450 hectares.[5] On the basis of a demographic reconstruction allowing five to seven inhabitants per dwelling,[6] these calculations have generated a population figure of roughly 14,000. Philip Kohl, advocating the higher end of Kruts' figures, characterizes Tal'yanki as having "possibly more than 15,000 people," with as many as 30,000 if one includes hypothetical satellite settlements.[7] While these are impressive numbers, their underlying calculations can be shown to be problematic.

According to Oleksandr Diachenko, the key problem is the issue of geometry.[8] Kruts' area of 450 hectares is derived as the product of the average width and length of the settlement. While this would be appropriate for a rectangular settlement, Tal'yanki, like most other Tripol'ye settlements, is oval in shape. Therefore, it is necessary to use the formula $a = \pi (0.5l) (0.5w)$, in this case yielding a result of approximately 350 hectares. In light of this recalculation, the rest of Kruts' extrapolated figures become untenable.

Placing the number of structures at 2700 is the result of extrapolation based on a geomagnetic survey conducted over 232 hectares of the site that yielded a count of approximately 1400 structures.[9] This average of about six houses per hectare, factored in with Diachenko's new measurements, gave him an adjusted total of approximately 2050 structures.[10] Another factor that must be considered is whether all the structures constitute dwellings, and whether all were simultaneously in use. A proportion of 78.4% was deemed appropriate for the nearby settlement at Maidanetskoe;[11] applied to Tal'yanki, this returns a figure of approximately 1600 chronologically-inhabited structures.

Analysis of the sex-age structure of human remains from the late Tripol'ye inhumation burials at Vykhvatintsy leads Diachenko to believe that, on the basis of high mortality rates, Kruts' five to seven individuals per household is possibly too high.[12] For the purposes of exploring as many scenarios as possible, calculations for the total population of Tal'yanki were made using averages of four to seven inhabitants per dwelling, returning a range of results from 6400 to 11,200. These calculations are tentative, and will be repeated with greater accuracy once more precise measurements can be integrated.

Agricultural Activities

The Tripol'ye agriculturalists cultivated cereals such as barley, buckwheat, einkorn, emmer, millet, and wheat, as well as a variety of legumes and fruits (both wild and domesticated) such as plums and grapes.[13] While sheep, goats, cattle and pigs were tended in fairly large numbers, osteological finds of auroch, deer, elk and horse remains show that hunting still played an important role in diet supplementation. Copper and bone fish hooks and flint arrowheads attest to this as well.[14]

Animal husbandry formed an important part of the Tripolian economy, with cattle being the most numerous. In addition to being kept for meat and milk production, they were likely used as draft animals as well; the morphology of steer bones found at Tal'yanki attest to this, showing large muscle attachments.[15] Combined with the primitive ards found at the Cucuteni-Tripol'ye settlement of Novyie Ruseshty in Moldova and a clay model of bulls drawing a sledge discovered at Maidanetskoe, this provides evidence that Tripol'ye agriculturalists could have utilized animal labor extensively.[16] Indeed, it is hard to imagine a large, cereal-dependent population existing in the absence of this technology.

Cereal Production

The first calculations regarding Tripolian agricultural production were published by S.N. Bibikov during the mid-1960s. Bibikov's calculations have formed the basis of much work that has come after him.[17] Working from a dataset compiled from sixteenth- and seventeenth-century historical accounts of crop yields, Bibikov[18] concluded that early farmers would have sown 131-164 kilograms of cereal per hectare for a gross yield of 655 kilograms per hectare (kg ha^{-1}). Half of this amount would be removed due to harvesting and threshing losses, spoilage, and seed requirements for the next spring, providing a net consumable yield of 328 kg ha^{-1}. Given a base dietary requirement of approximately 197 kilograms of grain per person per year, Bibikov calculated a per-person land use figure of 0.6 hectares.

B. Gaydarska is considerably more conservative in her estimation of cereal yields.[19] Citing R. Dennel and D. Webley,[20] she states that a gross yield of 400 kg ha^{-1} would have been more appropriate for early agricultural societies. In her scenario the base dietary requirements are also slightly higher, at 210 kilograms of cereals per person per year. After a fifty percent reduction to account for losses, this produces a net yield of 200 kg ha^{-1}, translating to a land requirement of about 1.05 hectares per person per year, not inclusive of the other resource needs that she later addresses.

This amount, 200 kg ha^{-1}, is quite low; as a ratio of output to input inclusive of seed requirements for the next season, the net production (after waste) can be expressed as 2.2:1. This is analogous to marginal yield quantities from the medieval period. The historian Georges Duby states that yield ratios of 1.6:1 to 2.2:1, while poor, were not out of the ordinary for agriculturalists in medieval France and Italy.[21] Due to the possibility of crop failure, medieval magnates generally planned for a ratio no higher than about 1.7:1.

However, on the other side of the spectrum, based on J.Z. Titow's 1972 study of agriculture in medieval Winchester, England, Gordon Conway states that yields of 3:1 to 6:1 were more normal.[22] While poor yields (2:1 or lower) did occur, they were the exception rather than the rule. In light of this, it could be more reasonable to assume that Duby's "feeble productive capacity" and "abiding presence of famine"[23] during the medieval period were episodic calamities rather than a general trend. It is possible that the sources mentioned by Duby represent a greater desire to writing of calamities as opposed to a normal state of affairs.

It is important to note that none of these scenarios can be applied to the question of site-specific agricultural production with any large degree of confidence. A number of biological and climatological variables that dictate the growth of crops fluctuate greatly depending on the locale in question. They must be addressed with the use of a more comprehensive model than simply multiplying land area by average yield ratios. However, as a tool for informing hypotheses, this methodology of analogy should not be completely discounted. In examining the potential resource availability in the territory surrounding Tal'yanki, a range of figures will be utilized to illustrate a variety of different scenarios.

Site Catchment Analysis

The limit for land exploitation in sedentary societies is generally defined as five to six kilometers, or roughly one hour's walk, from a habitational site.[24] The use of artificial units such as circles with radii based on these figures should not be regarded as the be-all and end-all of spatial analysis.[25] However, they are a useful tool for estimation of possible resource procurement in the absence of clear material evidence regarding land utilization.

In her site catchment analysis of Maidanetskoe, Gaydarska utilizes circles of increasing radius from the center of the settlement, with the settlement area itself subtracted from the calculated catchment.[26] In preparation for replicating this methodology for analyzing Tal'yanki, two criticisms came to mind: firstly that, since the site is not circular, a circular catchment area is inappropriate; secondly, that utilizing the sparsely-populated middle of the site as a starting-point was inappropriate for most of the settlement's population, which would have lived in the dense outer rings. Thus, the resulting catchment analysis of Tal'yanki has an oval catchment area and is exclusive of the site itself (see Figure 10 and Table 1).

Gaydarska takes a very comprehensive approach, computing spatial requirements for not only arable land, but also fallow territory, pasture lands, and "natural resource" zones, which would have provided territory for limited hunting and fuel wood harvesting.[27] However, her differentiation between fallow territories and dedicated pasture land may needlessly inflate the land requirements. The presence of livestock is taken into account in the analysis for Tal'yanki, as well as the figures for natural resource zones, but fallow land is deducted and assumed to have doubled as grazing territory for herds.

This analysis for Tal'yanki (see Table 2), depending on one's view of possible population sizes and net cereal yields, can be interpreted as either contradicting or supporting the necessity for hierarchical social organization and satellite settlements. However, given the author's position on reasonable yield levels (preferring Bibikov's figures, if not higher), it is stressed that a population level of 6400-8000 is a preferable interpretation, utilizing land resources that are available within a five to six kilometer radius of the settlement boundary.

Depletion of Soils

The environmental impact of the giant-settlements is conventionally estimated to have been severe, with soil nutrients completely exhausted from intensive agricultural cultivation and woodland area reduced by eighty percent over a fifty year period.[28] Shifting settlement patterns are attributed to ecological destruction wrought by intensive agricultural activities, with an anthropogenic environmental crisis ultimately contributing to the downfall of the Tripol'ye culture in the South Bug-Dnieper interfluve.[29] However, what is the scientific basis for this line of reasoning? Throughout history, the black earth soils (chernozem) of Ukraine have been an agricultural boon, earning it the epithet "bread basket of Europe." It is a testament to the productivity of these soils that they continue to be highly prized for cereal production in the present day.[30]

Agricultural scientists have conducted numerous crop trials over the past two centuries, some lasting several decades.[31] The usual focus of these studies is to determine the long-term effects of various modern agronomic inputs that are irrelevant to the study of Eneolithic farming, such as inorganic fertilizers. However, the performance of control treatments from modern trials is very useful not only for examining production figures, but also the effects of soil nutrient depletion over a long timescale. One such example is control treatment 21 of the Ivanovice Crop Rotation Experiment, begun in the eastern Czech Republic in 1956. This study was conducted on black earth soils that are roughly analogous to the chernozemic soil of the South Bug-Dneiper interfluve. Over the course of five decades (1956-2006), winter wheat yields from this treatment increased from 3.6 to 4.2 t ha^{-1}, despite an inexorable drop in soil nutrient availability.[32] This was attributed to improved plant genetics over the course of the study. It is also worth noting that while nutrient concentrations tested significantly lower in 2006 than they had at the project's start, the levels of soil nitrogen (N), phosphorous (P), potassium (K) and magnesium (Mg) were still within a very productive range.[33]

The Magruder Plots, a winter wheat fertility study that has been in continuous operation since 1891 at the Oklahoma State University, are another example.[34] Unlike the ICRE study, the Magruder Plots are not rotated, and thus provide data on monoculture cropping. Even under these conditions, which are generally seen as anathema to responsible field management, it took seventy years for a nutrient-limited growth response to be perceived.[35]

E. Kunzová and M. Hejcman state in their analysis of the ICRE study that archaeological theories regarding population shifts due to the soil nutrient depletion of chernozemic soils are very unlikely.[36] In this regard, perhaps archaeologists have overextended themselves through over-reliance on behavioral assumptions and qualitative comparisons. Site context is everything with regards to predicting environmental impacts, and efforts should be made to simulate early agricultural practice quantitatively.

Mathematical Modeling

Several models exist to simulate crop growth and study the environmental and economic impacts of agricultural production. They can be configured to take into account nutrient availability and precipitation limitations, and are generally tailored to a region-specific context. Although output is easy to obtain, the success of studies such as these is contingent on the input of accurate data reflecting regional patterns of environment and biology,[37] as well as the element of human behavior.

Studies of inorganic fertilizer application suggest that the growth response of crops is directly correlated with nutrient availability, conforming to a predictable regression.[38] Long-term studies that have addressed nutrient depletion scenarios, such as ICRE and the Magruder Plots, also show similar trends in the inverse.[39] It seems feasible to adapt these regression models to problems of Eneolithic agricultural production, but there are many variables that must be adequately addressed before proceeding:

1. Base nutrient availability; utilizing soil testing, site-specific baseline levels for important macronutrients (N, P, and K) must be established for relevant stratigraphic horizons.
2. Presence and predominance of cultivars; the prevalence of relevant crops must be established to determine nutrient requirements, yield quantities, and dietary information.
3. Climactic data; together with geomorphology and paleoclimate specialists, figures for mean seasonal temperatures and precipitation must be established, as these variables greatly affect the maturation of crops.
4. Human behavior; the study must take into account several scenarios regarding agricultural practices and management behaviors. Among these are the types of fallow cycles and crop rotations undertaken (if any), harvesting behaviors, coefficients for harvesting, threshing and storage efficiency, and analysis of site catchment and resource availability.

The end result of this line of inquiry could either involve the use of a preexisting model, or it could necessitate the construction of a dedicated model for archaeological applications. Nothing short of experimental research into the on-site production of ancient cultivars over the course of many years would yield thoroughly testable results. However, in the absence of such it is at least important to improve upon current speculative methods.

Conclusion

When so much of the scholarship regarding the agricultural landscape of Tripol'ye farming communities is built upon layers of theoretical inference, it is necessary to deconstruct the methodologies involved in constructing these layers. From recalculations of settlement size to well-informed spatial analysis and mathematical modeling, a more coherent picture of life at Tal'yanki and other settlements can be formed. Instead of questioning how the residents of the giant-settlements could have lived in such a crowded manner in settlements as populous as 14,000 individuals, perhaps it is more pertinent to question the assumptions that have guided research until now. In other words, lacking clear data as to *why* the people of Tal'yanki lived in the manner that they are assumed to have lived, perhaps it is also worth questioning *whether* they lived in this way.

The 2011 field season will offer opportunities to further explore the topics introduced here. It is hoped that through the acquisition of quantitative data such as soil nutrient concentrations and the performance of spatial analysis, a clearer picture of life at the giant-settlements can be crafted. Few fields have such far-reaching social and political ramifications as agriculture, especially when the feasibility of entire settlement systems is predicated upon its sustainability and consistency.

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[1] Personal communication with Diachenko, January 11, 2011. Kohl (2002, 153), drawing on Videjko (1996, 53), gives a range of *c.* 4200-3600 B.C.E. There is some disagreement on the area required for a site to be branded a "giant-settlement;" Videjko interprets early sites larger than 30 ha as being formative giant-settlements.
[2] Kruts 2008a, 47.
[3] Kohl 2007, 44.
[4] Kohl 2007, 44.
[5] Kruts 2008b, 58.
[6] Kruts 2008a, 46.
[7] Kohl 2007, 44.
[8] Diachenko (forthcoming).
[9] Kruts 2008b, 58.
[10] Personal communication with Diachenko, December 19, 2010.
[11] Diachenko (forthcoming, 7).
[12] Personal communication with Diachenko, December 19, 2010.
[13] Kohl 2007, 44.
[14] Kohl 2007, 45.
[15] Videjko 1996, 70.
[16] Kohl 2007, 45.
[17] See Kruts 1989; Videjko 1993; Gaydarska 2003.
[18] Bibikov 1965, 53.
[19] Gaydarska 2003, 212.
[20] Dennel and Webley 1975, 106.
[21] Duby 1978, 28.
[22] Conway 1987, 107-108.
[23] Duby 1978, 29.
[24] Chisholm 1968, 131.
[25] Roper 1979, 124.
[26] Gaydarska 2003, 214.
[27] Gaydarska 2003, 214.
[28] Kruts 2008a, 47.
[29] Kohl 2007, 45.
[30] The Tripol'ye stratigraphic horizon underlies much of the chernozemic layer and Tal'yanki, as it does at other settlements. At this level, the soil is less humic in composition and soil nutrient availability in the Eneolithic soil was likely less than its modern counterpart. Testing is needed to establish the scope of these differences.
[31] Kunzová and Hejcman 2009, 227.
[32] Kunzová and Hejcman 2009, 227.
[33] Kunzová and Hejcman 2009, 229.
[34] Mullen et al. 2001, 6.
[35] Mullen et al. 2001, 8.
[36] Kunzová and Hejcman 2009, 232.
[37] Mantel 1997, 13-14.
[38] Lana 2008, 20-23.
[39] Kunzová and Hejcman 2009, 229; Mullen et al. 2001, 7.