LETTER

Reply to Maxwell et al.: Stable isotopes and their potential for interpreting archaeobotanical remains

We thank Maxwell et al. (1) for their interest in our study and agree that multielement isotopic analysis helps interpret ancient agricultural systems. Measurements of $\delta^{15}N$ on archaeobotanical crop seeds have corroborated hypotheses of Near Eastern cultivation under gradually less-fertile soil conditions (2) and that early farmers used livestock manure to enhance crop yields (3). It is also understood that soil fertility along with salinity, evapotranspiration, and crop density causes variation in $\delta^{13}C$.

However, by stating that $\delta^{13}C$ data from archaeological cereal grains is unsuited to "distinguish between variation in nitrogen and water availability," Maxwell et al. introduce some misapprehension that we believe must be removed.

Maxwell et al. refer to $\delta^{13}C$ variation of 2.6‰ in barley caused by different sources of nitrogen in soil (1). These data have been obtained from greenhouse plants. In contrast, field experiments in the Near East demonstrated that the carbon isotope ratios in cereal grain and pulse seeds are largely unaffected by manuring (4). This was even stated in the work that Maxwell et al. use to support their argument (3). In figure 1*B* of Maxwell et al., $\delta^{15}N$ and $\delta^{13}C$ data on barley from a Neolithic site in Greece (red squares) are plotted on the $\delta^{15}N$ ranges of experimentally manured cereals (for original data, see ref. 3). The $\Delta^{13}C$ data on barley from the Neolithic site range between 18‰ and 19.2‰. The variation of 1.2‰ corroborates our model of smaller $\delta^{13}C$ ranges at coastal locations or in areas of higher precipitation (5).

In addition, we interpreted our $\delta^{13}C$ data from ancient barley clearly for their mean and their minima values, using intrasite variation of up to 6‰ (figure 5 in ref. 5), and not 1‰ as claimed by Maxwell et al. (1). The range between 16‰ and 17‰ is considered as a transitional area from signals of well-watered individuals (>17‰) to reduced water availability (<16‰), as described in our methods section.

Furthermore, the similarity of the carbon isotope signal in coevally charred barley grains and wood charcoals from archaeological sites strongly suggests a predominance of climate forcing in $\delta^{13}C$ responses of barley (2).

We therefore agree that $\delta^{15}N$ measurements on archaeobotanical crop seeds are useful to address local specifics of ancient agricultural practice, but they are of minor importance for our supraregional approach to patterns of past water availability.

Maxwell et al. further suggest the use of $\delta^{18}O$ to obtain information on the water status in relation with possible irrigation (1). Although oxygen is a useful physiological proxy in modern plants, it suffers from strong fractionation during charring of the plant remains. This is decisive for the applicability of the method, as more than 90% of the plant remains in archaeological sites are preserved through charring. Only in rare cases is biogenic carbonate present in some seed coats (*Celtis* spp. and *Lithospermum* spp.), and only in this case can $\delta^{18}O$ of the carbonate fraction be used for paleoenvironmental reconstruction (6).

Simone Riehl[a,b,1] ***and Konstantin E. Pustovoytov***[a,c]

[a]Institute for Archaeological Science, Department of Geosciences, University of Tübingen, 72070 Tübingen, Germany; [b]Senckenberg Center for Human Evolution and Palaeoenvironment, University of Tübingen, 72070 Tübingen, Germany; and [c]Institute of Soil Science and Land Evaluation, University of Hohenheim, 70599 Stuttgart, Germany

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[1]To whom correspondence should be addressed. Email: simone.riehl@uni-tuebingen.de.