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Supporting Information for

Isotopes prove advanced, integral crop production and stockbreeding strategies nourished Trypillia mega-populations

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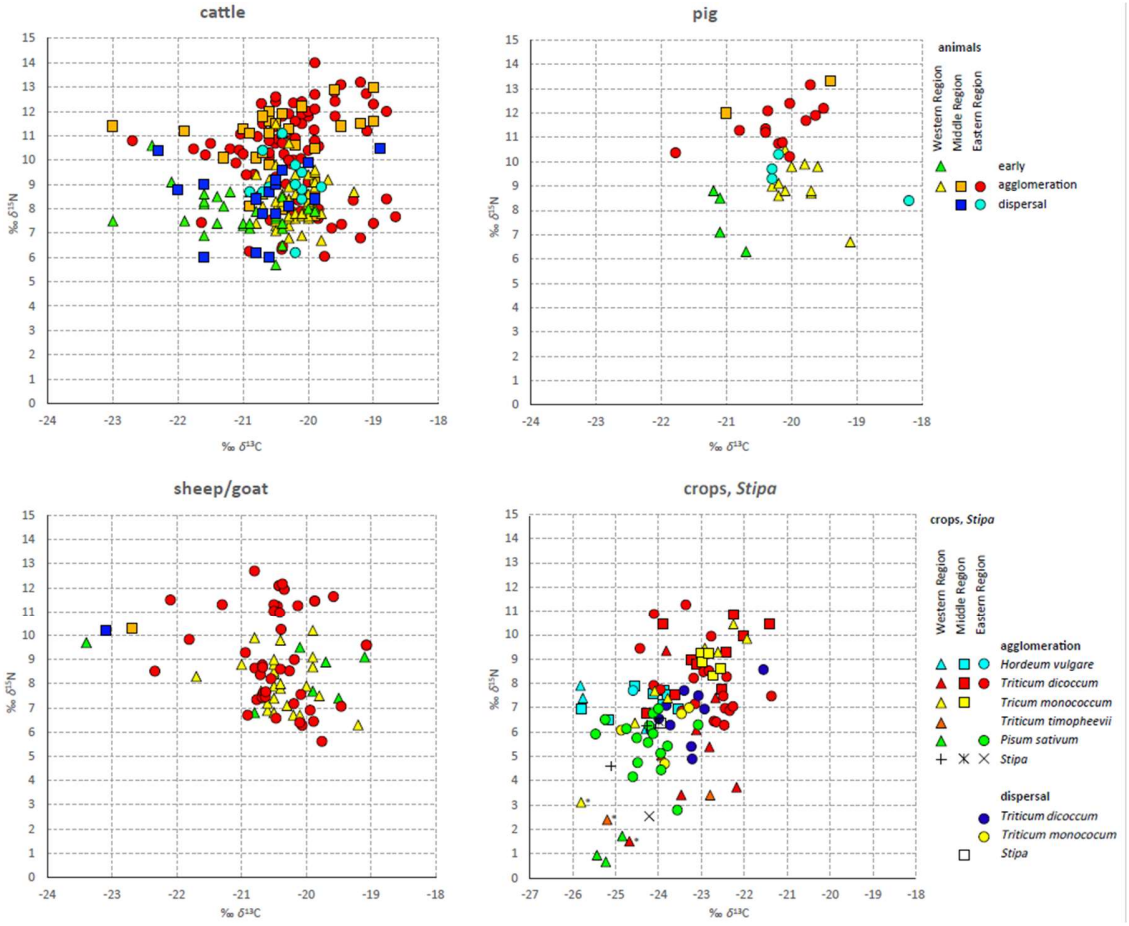

Fig. S1. Detailed scatter plots of $\delta^{13}C$ vs. $\delta^{15}N$ by animal groups bone collagen, crop (grains/seeds, *glume bases) and *Stipa* awns by archaeological phase and region.

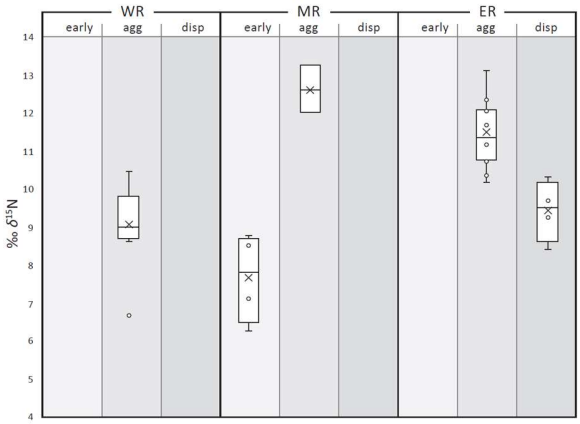

Fig. S2. δ^{15}N values of pig bone collagen for the early, agglomeration (agg), and dispersal (disp) phases in the western (WR, Prut–Dniester), middle (MR, Dniester–Southern Bug), and eastern (ER, Southern Bug–Dnepr) regions.

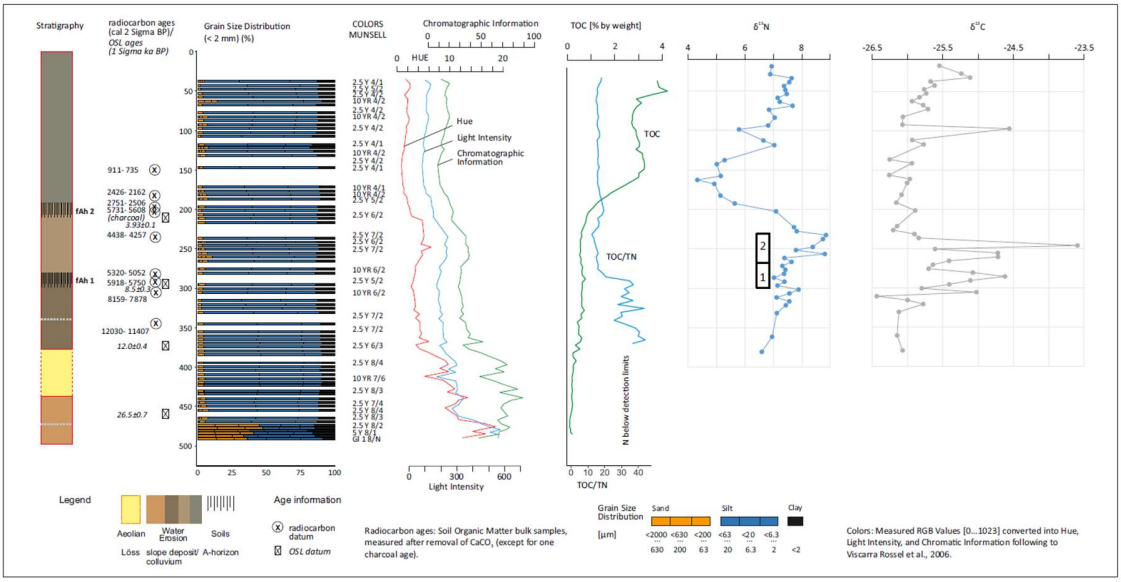

Fig. S3. Selected laboratory data from a long percussion-drilling core near Maidanetske including 1) a (pre-)Trypillia paleosoil and 2) lower part of a Trypillia colluvium. TOC Total organic content, TN Total nitrogen, ‰ δ^{15}N of TN, ‰ δ^{13}C of TOC, OSL optically stimulated luminescence. For details see (1).

Table S1. Statistics of animal bone collagen by animal groups, regions and phases.

	WR						MR						ER					
	early		agg.		disp.		early		agg.		disp.		early		agg.		disp.	
	d13C	d15N	d13C	d15N	d13C	d15N	d13C	d15N	d13C	d15N	d13C	d15N	d13C	d15N	d13C	d15N	d13C	d15N
Cattle	1		56		-		27		31		17		1		86		16	
mean	-20.50	5.70	-20.23	8.28	-	-	-21.10	7.84	-20.43	10.73	-20.71	8.46	-21.70	10.60	-20.23	10.20	-20.34	8.82
SD	-	-	0.31	0.93	-	-	0.74	0.92	0.80	1.35	0.82	1.39	-	-	0.69	1.89	0.29	1.13
Sheep/goat	-		26		-		8				-		-		31		1	
mean	-	-	-20.37	7.96	-	-	-20.38	8.44	-20.77	10.15	-	-	-	-	-20.48	8.81	-20.40	8.60
SD	-	-	0.47	1.09	-	-	1.34	1.05	0.82	1.63	-	-	-	-	0.79	2.02	-	-
Sus	-		11		-		4		2		-		-		13		4	
mean	-	-	-19.89	9.06	-	-	-21.03	7.68	-20.20	12.65	-	-	-	-	-20.21	11.49	-19.75	9.43
SD	-	-	0.35	1.00	-	-	0.22	1.18	1.13	0.92	-	-	-	-	0.59	0.85	1.03	0.80

Table S2. Barley yields estimated based on the mean $\Delta^{13}C$ of sites with barley (2) applying formula and correction factor (3, 4).

site with barley	$\Delta^{13}C$ ‰	yield tons/ha
Stolniceni	19,4	2,0
Bilyi Kamin	18,4	1,6

Table S3. Detailed results of protein proportions when animals are divided into extensively pastured animals (Ae) and intensively pastured animals (Ai) for Kosenivka, Stolniceni, and Maidanetske calculated in FRUITS v. 3.1 (5), including mean, standard deviation (sd), median, 68% and 95% value ranges, and p-values for of the models. C cereals, P pulses.

		n	mean	sd	median	16pc	84pc	2.5pc	97.5pc	p-value
Kosenivka	C	14	0.8145	0.1025	0.8273	0.7136	0.9167	0.5767	0.97	0.806
	Ae	3	0.09346	0.08288	0.07042	0.0185	0.1724	0.003086	0.309	
	Ai	2	0.09201	0.07704	0.07227	0.0194	0.1660	0.00287	0.2861	
Stolniceni	P	3	0.4358	0.1216	0.4389	0.3141	0.5575	0.1843	0.6642	0.715
	C	20	0.3288	0.1848	0.3237	0.1215	0.5233	0.02124	0.6919	
	Ae	42	0.1155	0.0972	0.09074	0.0242	0.2098	0.003327	0.3598	
	Ai	1	0.1199	0.09525	0.09826	0.0267	0.2170	0.004068	0.349	
Maidanetske	P	16	0.5411	0.1886	0.5629	0.3440	0.7274	0.111	0.8545	0.788
	C	20	0.2756	0.202	0.2346	0.0719	0.4881	0.0123	0.752	
	Ae	8	0.09431	0.08434	0.07054	0.0188	0.1733	0.002957	0.3073	
	Ai	7	0.08902	0.07117	0.07263	0.0201	0.1598	0.003334	0.2623	

Table S4. Detailed results of protein proportions when animals grouped together as one source (A) for Kosenivka, Stolniceni and Maidanetske calculated in FRUITS v. 3.1 (5), including mean, standard deviation (sd), median, 68% and 95% value ranges, and p-values for of the models. C cereals, P pulses.

		n	mean	sd	median	16pc	84pc	2.5pc	97.5pc	p-value
Kosenivka	C	14	0.8818	0.09433	0.9033	0.7881	0.9728	0.6527	0.996	0.760
	A	5	0.1182	0.09433	0.0967	0.0272	0.2119	0.004012	0.3477	
Stolniceni	P	3	0.3813	0.132	0.383	0.2467	0.5134	0.1167	0.632	0.658
	C	20	0.475	0.1902	0.4863	0.2757	0.6651	0.0774	0.8243	
	A	43	0.1438	0.112	0.1189	0.0331	0.2598	0.004713	0.4112	
Maidanetske	P	16	0.5356	0.2106	0.5533	0.3126	0.7518	0.08246	0.8932	0.742
	C	20	0.347	0.2271	0.3195	0.1035	0.5902	0.01723	0.8398	
	A	15	0.1173	0.09548	0.09439	0.0264	0.2134	0.004197	0.3496	

Table S5. Mean protein proportion of crops and animals in the human diet of the Trypillia settlements of Kosenivka, Stolniceni, and Maidanetske from two different source approaches, performed in FRUITS v. 3.1 (5), for cereals (C); pulses (P); extensively pastured animals (Ae); intensively pastured animals (Ai); and animals grouped together as one source (A).

	Kosenivka		Stolniceni		Maidanetske	
	A	Ae, Ai	A	Ae, Ai	A	Ae, Ai
	Proteins	Proteins	Proteins	Proteins	Proteins	Proteins
P	-	-	*38.1*	43,6	*53.6*	54.1
C	*88.2*	81.5	*47.5*	32.9	*34.7*	27.6
∑ P, C	*88.2*	***81.5***	*85.6*	***76.5***	*88.3*	***81.7***
Ae	-	9.3	-	11.5	-	9.4
Ai	-	9.2	-	12.0	-	8.9
(∑)A	*11.8*	***18.5***	*14.4*	***23.5***	*11.7*	***18.3***

Table S6. Isotope values of humans as target and crops and animals as sources applied in the food web models as calculated in FRUITS v. 3.1 (5).

	Humans		Pulses		Cereals		Animals, undiff.		Animals, extensiv		Animals, intensiv	
	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
Kosenivka	-19.9	12.2	-	-	-23.47	6.54	-20.4	9.57	-20.38	8.8	-20.55	10.75
Stolniceni	-19.8	10.3	-25.17	1.21	-23.44	7.21	-20.22	8.27	-20.23	8.09	-20.11	10.08
Maidanetske	-19.9	12.2	-24.25	5.55	-22.97	7.99	-20.31	9.01	-20.43	7.44	-20.10	11.65

Dataset S1 (separate file). Isotope values of animal bone collagen used in this publication. Data of Nebelivka from (6) and Maidanetske from (7).

Dataset S2 (separate file). Isotope values of soils used in this publication from the (pre-)Trypillian palaeosoil (s) and the late Trypillian colluvium (c) (1).

Dataset S3 (separate file). Isotope values of humans used in this publication (8, 9).

Dataset S4 (separate file). Isotope values of plants used in this publication. Data from (2).

SI References

1. Dreibrodt S et al. (2020) Holocene soil erosion in Eastern Europe-land use and/or climate controlled? The example of a catchment at the Giant Chalcolithic settlement at Maidanetske, central Ukraine. Mountain glaciation and landscape evolution 367.
2. W. Kirleis, M. D. Corso, G. Pashkevych, F. Schlütz, R. Hofmann, A. Terna, S. Dreibrodt, V. Rud, M. Y. Videiko, J. Müller, A complex subsistence regime revealed for Cucuteni–Trypillia sites in Chalcolithic eastern Europe based on new and old macrobotanical data. *Veget Hist Archaeobot*. 10.1007/s00334-023-00936-y (2023).
3. M. Aguilera, J. L. Araus, J. Voltas, M. O. Rodríguez-Ariza, F. Molina, N. Rovira, R. Buxó, J. P. Ferrio, Stable carbon and nitrogen isotopes and quality traits of fossil cereal grains provide clues on sustainability at the beginnings of Mediterranean agriculture. Rapid Commun. Mass Spectrom. 22, 1653–1663 (2008).
4. J. L. Araus, G. A. Slafer, R. Buxó, I. Romagosa, Productivity in prehistoric agriculture: physiological models for the quantification of cereal yields as an alternative to traditional approaches. Journal of Archaeological Science 30, 681–693 (2003).
5. Fernandes R (2016) A Simple(R) Model to Predict the Source of Dietary Carbon in Individual Consumers. Archaeometry 58:500–512.
6. J. C. Chapman, B. Gaydarska, M. Nebbia, A. Millard, B. Albert, D. Hale, M. Woolston-Houshold, S. Johnston, E. Caswell, M. Arroyo-Kalin, T. Kaikkonen, J. Roe, A. Boyce, O. Craig, D. Miller, S. Arbeiter, N. Shevchenko, V. Rud, M. Videiko, K. Krementski, GEOINFORM Ukrainii, Trypillia mega-sites of the Ukraine. Available at http://dx.doi.org/10.5284/1047599 (deposited 2018).
7. C. A. Makarewicz, R. Hofmann, M. Y. Videiko, J. Müller, Community negotiation and pasture partitioning at the Trypillia settlement of Maidanetske. *Antiquity* **96**, 831–847 (2022).
8. L. Shatilo, *Tripolye typo-chronology: Mega and Smaller Sites in the Sinyukha River Basin* (Sidestone Press, 2021).
9. S. Ţerna, A. Vornicu-Ţerna, R. Hofmann, M. Dal Corso, L. Shatilo, M. Vasilache-Curoşu, V. Rud, H. Knapp, W. Kirleis, K. Rassmann, J. Müller, Stolniceni – Excavation results from the 2017 campaign. *Journal of Neolithic Archaeology* **21**, 209–282 (2019).