nature portfolio

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Reporting Summary

Nature Portfolio wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Portfolio policies, see our Editorial Policies and the Editorial Policy Checklist.

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a	Confirmed	
☐	☒	The exact sample size (*n*) for each experimental group/condition, given as a discrete number and unit of measurement
☐	☒	A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly
☐	☒	The statistical test(s) used AND whether they are one- or two-sided *Only common tests should be described solely by name; describe more complex techniques in the Methods section.*
☐	☒	A description of all covariates tested
☐	☒	A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons
☐	☒	A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals)
☒	☐	For null hypothesis testing, the test statistic (e.g. *F*, *t*, *r*) with confidence intervals, effect sizes, degrees of freedom and *P* value noted *Give P values as exact values whenever suitable.*
☒	☐	For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
☒	☐	For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
☒	☐	Estimates of effect sizes (e.g. Cohen's *d*, Pearson's *r*), indicating how they were calculated

Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	Data collection was performed using standard, pre-programmed commercial data loggers (e.g., CR6, Campbell Scientific) and the automated routines of the FluxCrane system. No custom software code was developed for the data collection process.
Data analysis	Data analysis was performed using custom R-scripts based entirely on standard, established mathematical equations (e.g., ideal gas law for flux calculations, Keeling-Plot method). No novel software or new modeling architectures were developed for this study. For data-driven modeling, we solely utilized existing, simple machine learning models from standard R libraries, specifically a standard Random Forest (RF) algorithm and Self-Organizing Maps with Sammon's Mapping (SOM-SM) using the established R-packages "caret" and "kohonen". The custom R-scripts used for data processing are available from the corresponding author upon reasonable request.

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio guidelines for submitting code & software for further information.

Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our policy

The data will be available upon publication (BonaRes repository).

Research involving human participants, their data, or biological material

Policy information about studies with human participants or human data. See also policy information about sex, gender (identity/presentation), and sexual orientation and race, ethnicity and racism.

Reporting on sex and gender	-
Reporting on race, ethnicity, or other socially relevant groupings	-
Population characteristics	-
Recruitment	-
Ethics oversight	-

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☐ Behavioural & social sciences ☒ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	This is a quantitative field study investigating the dynamics of evapotranspiration (ET) and its stable water isotopic composition in an agricultural ecosystem. The study utilized a randomized, full-factorial design over three distinct soil types representing local erosion stages (non-eroded, strongly eroded, extremely eroded). The experiment included 36 total plots (12 per soil type) with measurements of stable water isotopes on 18 of these plots (6 per soil type). The study uses the simple machine learning approache, random forest, to model ET and its stable water isotopic composition to investigate the Soil-Plant-Atmosphere-Continuum within the given ecosystem.
Research sample	The research sample comprises high-resolution, continuous measurements of ambient water vapor, precipitation, and ET stable water isotopic compositions (δ18O and δ2H), as well as standard micrometeorological parameters (e.g., air temperature, soil moisture, photosynthetically active radiation). The sampling represents the cultivated season with winter oil rapeseed followed by winter wheat.
Sampling strategy	The sampling relied on the fully automated 5-meter-high gantry crane system -FluxCrane - that allowed for continuous sampling across the field to capture both spatial variability and temporal diurnal dynamics. The randomized measurement design resulted in each plot being measured approximately twice per week (approx. once per hour).
Data collection	Data was collected continuously and automatically by the FluxCrane system deploying two transparent polymethyl methacrylate (PMMA) chambers. ET fluxes were measured via changes in H2O concentrations using LI-COR 850 infrared gas analyzers and recorded on a CR6 data logger. Stable water isotopes were collected using a Picarro L2130-i CRDS analyzer connected to one of the chambers. Two-week bulk precipitation samples were collected and analyzed in the laboratory.
Timing and spatial scale	Data was collected over two complete growing seasons from September 2021 to the end of August 2023. The system performed high-frequency measurements (4-second frequency). The isotope and gas concentration analyzer was removed for maintenance during the winter of the 2022-2023 season. The experiments were conducted on two identical 100 x 16 meter fields at the AgroFlux

experimental platform near Dedelow, Germany.

Data exclusions

Pre-established exclusion criteria were applied using an automated R-script. During the Keeling-Plot calculation for δET, measurements displaying a water vapor concentration difference of less than 1000 ppm or a negative slope were discarded. Additionally, the nighttime period between 11 p.m. and 4 a.m. was excluded from analysis because relative humidity approached saturation, rendering ET negligible.

Reproducibility

Experimental reproducibility was ensured by monitoring the plots continuously over two complete, consecutive cultivation periods (rapeseed in 2021/22 and winter wheat in 2022/23) using the FluxCrane system. The statistical robustness and uncertainty of the calculated δET values from the Keeling-Plots were rigorously tested using bootstrap resampling with 1000 iterations.

Randomization

The 36 experimental plots were established and allocated to the different treatments using a randomized, full-factorial design within each of the three soil types. The sequence of plot measurements taken by the FluxCrane was also randomized.

Blinding

Blinding was not relevant to this study. Data acquisition was completely automated via programmed micrometeorological sensors, gas analyzers, and the FluxCrane, eliminating human bias during data collection.

Did the study involve field work? ☒ Yes ☐ No

Field work, collection and transport

Field conditions

The field experiments were conducted in a continental climate zone. During the investigated 2021/22 and 2022/23 cultivation periods, the mean air temperatures were 10.5 °C and 10.1 °C, and total precipitation was 363 mm and 376 mm, respectively. These conditions were significantly drier and warmer compared to the local long-term (1991–2020) averages of 8.8 °C and 467 mm.

Location

The study took place at the AgroFlux experimental platform of the Leibniz Centre for Agricultural Landscape Research (ZALF) near Dedelow in the Uckermark region, northeast Germany. The specific coordinates are N 53°22′45", E 13°47′11", at an elevation of approximately 50-60 m a.s.l..

Access & import/export

Not applicable.

Disturbance

Physical disturbance to the soil and crop canopy was minimized by utilizing a fully automated 5-meter-high gantry crane system (FluxCrane), which eliminated the need for manual trampling on the experimental plots. To prevent negative impacts on plant physiological activity during measurements, the PMMA measurement chambers were transparent (~76% light transmittance) and were only closed for short durations (seven minutes). Furthermore, two axial-flow fans (5.61 m^3/min) continuously homogenized the chamber headspace air during deployment. To secure the system and prevent indirect damage to the site, the robotic system automatically shut down during high wind velocities and extreme cold.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☒	☐ Clinical data
☒	☐ Dual use research of concern
☐	☒ Plants

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging

Plants

Seed stocks

The study involved standard commercial agricultural crops cultivated sequentially: winter oil rapeseed (Brassica napus L., variety 'Architect') and winter wheat (Triticum aestivum, variety 'Ponticus'). The crops were cultivated under standard agricultural practices at the AgroFlux experimental platform.

Novel plant genotypes

Not applicable.

Authentication

Not applicable.