
Supplementary information

‘White gold’ guano fertilizer drove agricultural intensification in the Atacama Desert from AD 1000

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Supplementary Information 1

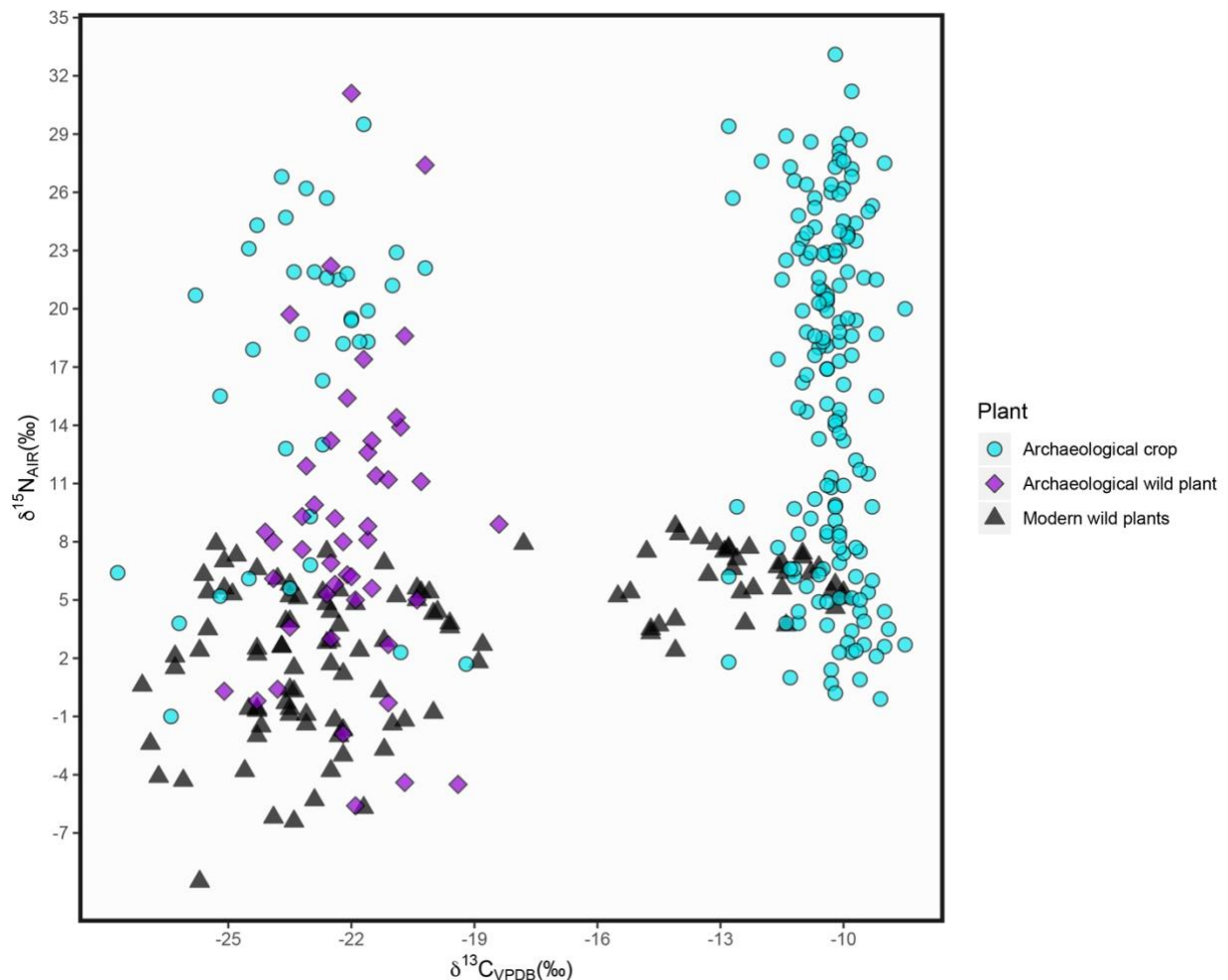
A brief description of the archaeological sites from which archaeobotanical remains were collected is given here.

- 1) Pircas 1. Located in the northern area of the Tarapacá Ravine, Pircas is a domestic site with 562 circular stone structures, distributed over c. 90 ha¹. The site has been dated to the Formative Period, and is associated with the cemetery Pircas 6.
- 2) Caserones 1. Located in the southern area of the Tarapacá Ravine, Caserones is a village dating to the Formative and beginning of the Late Intermediate Period². It shows a complex structure that includes 646 domestic and storage areas, as well as mud walls, distributed over 3.75 ha. Macrobotanical remains analyzed in the present paper come from Formative contexts.
- 3) Tarapacá 40. Located on the northern side of the Tarapacá Ravine in between Pircas 1 and Caserones 1, Tarapacá 40 is a cemetery mainly of the Formative Period³, but there is some Late Intermediate Period activity. The crops and wild fruits obtained from this site are considered to be largely associated with the Formative Period. Two outlier $\delta^{15}\text{N}$ values representing a *Prosopis* sp. and a *Lagenaria* sp. sample, respectively, were excluded as statistical outliers based on the Median Absolute Deviation (MAD) method. The exclusion of these outliers does not make any difference to the results obtained. The Kruskal Wallis tests are not altered either when including or excluding the outliers.
- 4) Guatacondo 1. Located in the southern area of the Guatacondo Ravine, Guatacondo is a domestic site with 177 structures distributed over 0.78 ha⁴. This site has been dated to the Formative Period, showing important agricultural activity based on field crops.
- 5) Iluga Tumulos. Located in the *Pampa del Tamarugal* this site is associated with extensive agricultural fields, a vast spread of ceramic debris, and round and square public structure and tumuli (Uribe unpublished). Based on the diagnostic material on the surface the site was occupied from the Formative to the Colonial Period. Radiocarbon dates have shown direct evidence of occupation during the Formative Period. Plants analyzed here come from an excavation unit with two dates in the Formative Period. Nevertheless, there could be later material present considering the multi-occupational character of this site. One of the crop samples came from surface collection.
- 6) Tana Norte and Sur. Located in the Tana Ravine these two sites are associated with funerary contexts. Initially, the site was suggested to belong to the Formative Period⁵, but new direct dates on crops for the present study only reflect the Late Intermediate Period, indicating activity at that time as well.
- 7) Quillagua La Capilla. Located in the southern margin of the Loa river, La Capilla is a domestic site with 72 structures next to the modern town of Quillagua⁶. Radiocarbon dates obtained from the site are associated with the Late Intermediate Period.
- 8) Pica 8. This is a cemetery located in the Pica oasis, with more than 250 burials most of which date to the Late Intermediate Period⁷.
- 9) Mocha 2. Located in the Precordillera of the Tarapacá Ravine at 2400 m above sea level, Mocha 2 is a cemetery dating to the Late Intermediate Period⁸.
- 10) Tiliviche 1B. This is a domestic site located in the Tiliviche Ravine, with occupations associated with the Middle and Late Archaic Periods, but also the Late Intermediate Period⁹. Samples collected for this study are from Late Intermediate Period contexts.

- 11) Tarapacá 13. Located in the southern area of Tarapacá ravine, Tarapacá 13 is a domestic site with square architectural structures¹⁰. The site dates to the Late Intermediate Period, following direct radiocarbon dates carried out on archaeobotanical remains (Vidal, unpublished).
- 12) Tarapacá 49. Located in the southern area of Tarapacá Ravine, next to the modern town of Tarapacá, this domestic site with at least 108 architectural structures is associated with Inca and Spanish occupations during the Late and Colonial Periods¹¹. The samples analyzed here come from Late Period contexts.
- 13) Alero Cerro Colorado 7. This is a 28 m² rockshelter located at the Precordillera near Cerro Colorado area. This site has occupations dating to the Formative and Colonial Periods¹². There is evidence for ceremonial use of the site. Samples collected for this study date to the Colonial Period.

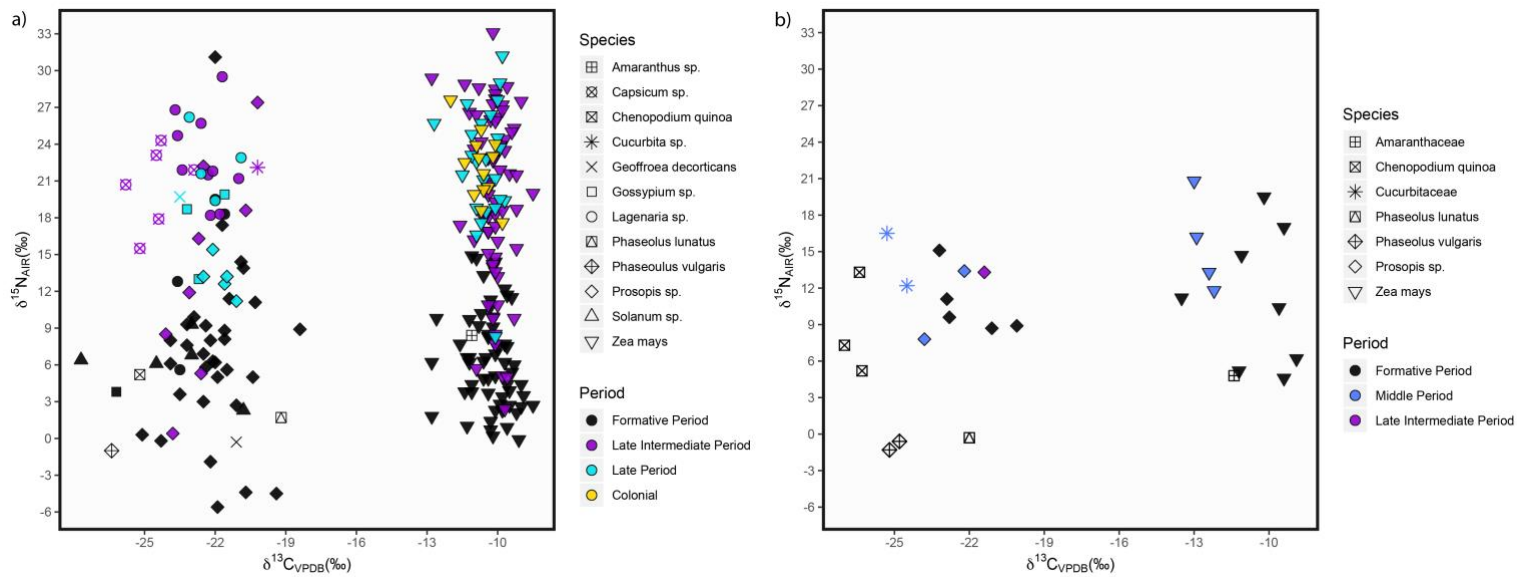
Supplementary Information 2

Bivariate plot of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for modern plants^{13,14}, archaeological crops (analysed here) and archaeological wild plants from the Atacama Desert (between latitudes 20°25'S and 23°50'S) Modern plants $\delta^{13}\text{C}$ values were corrected by +1.5‰ for the Suess effect¹⁵.



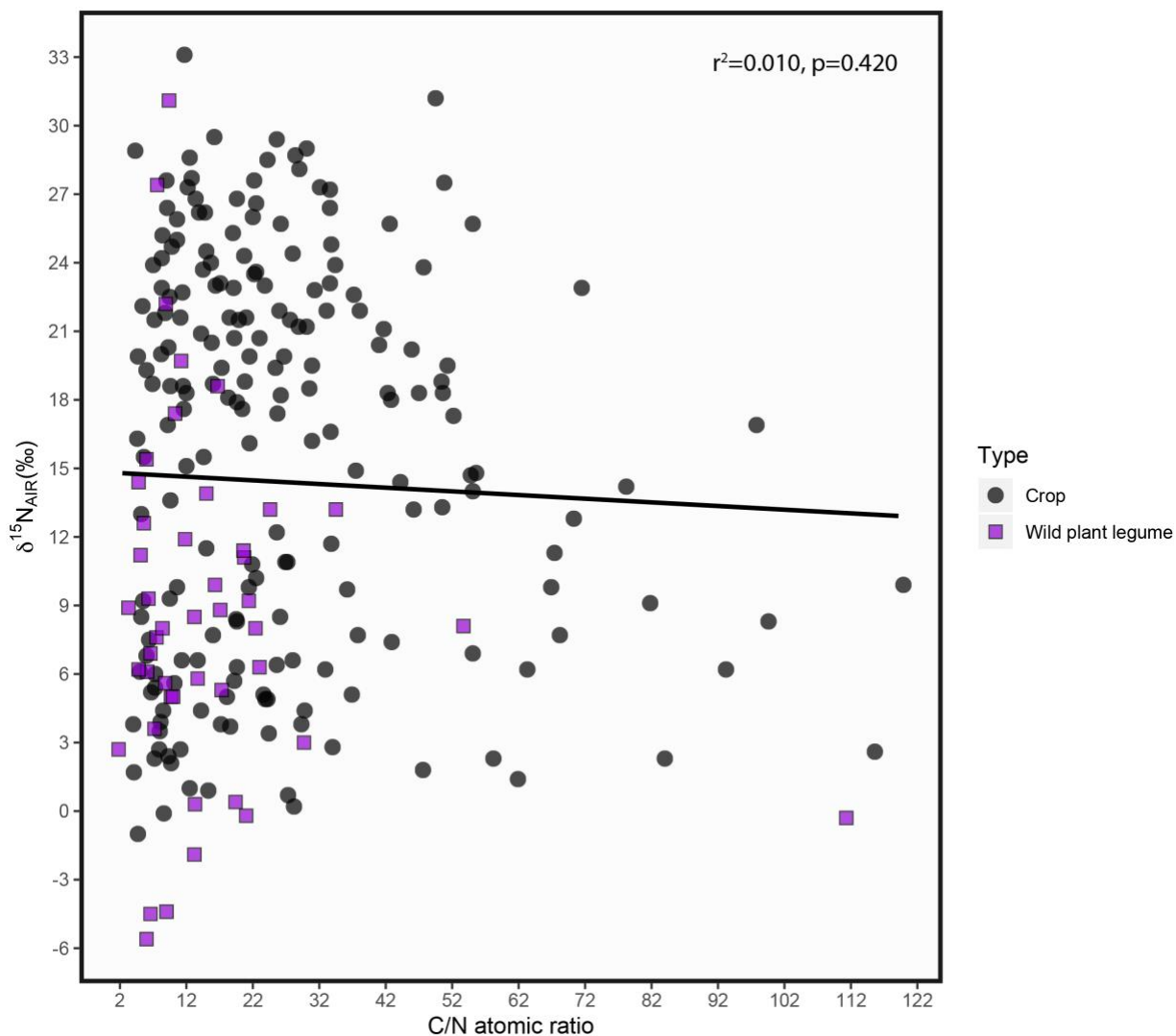
Supplementary Information 3

Bivariate plot of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ for (a) archaeological plants analysed in this study compared to (b) archaeological plants published for the Loa-San Pedro cultural area¹⁶. Plant species are indicated by symbols, while periods are indicated by colours.



Supplementary Information 4

Bivariate plot of C/N atomic ratios and $\delta^{15}\text{N}$ values for archaeological plants analysed in this study including crops (maize, chili peppers, squash, pumpkin, quinoa, beans, potatoes) and wild



plant legumes (*algarrobo* and *chañar*).

We compared $\delta^{15}\text{N}$ of plants versus their C/N ratios in order to check whether there was any correlation following suggestions earlier¹⁷ that very low nitrogen to high carbon concentrations may produce abnormally high $\delta^{15}\text{N}$ values.

An experimental study¹⁷ on archaeological desiccated macrobotanical (n=10) and charred plant remains (n=16) from the northern coast of Peru, was carried out to reevaluate an earlier study¹⁸ that inferred diagenesis in desiccated coastal plants with very high $\delta^{15}\text{N}$ values. They¹⁷ reported a mean $\delta^{15}\text{N}$ of $10.2 \pm 5.1\text{‰}$ for all plants with C/N atomic ratios below 20. Using this as a dividing point, they found a statistically significant difference in $\delta^{15}\text{N}$ values for desiccated plants in the earlier study¹, with those exhibiting C/N <20 having lower values ($13.9 \pm 7.9\text{‰}$ vs. $20.3 \pm 8.1\text{‰}$; $t = 3.33$, $p = 0.001$). They proposed on this basis that those with higher values were suspect, due mainly to the difficulties of measuring such low amounts of nitrogen. There are two issues with this conclusion. First, carbon and nitrogen isotope values for plant remains in the earlier study were measured using cryogenic distillation and entirely separate measurement of CO_2 and N_2 , rather than continuous flow IRMS, so that relative gas concentrations inferred from C/N ratios are less relevant. Second, the comparison included legumes, which, because they are higher in nitrogen, were heavily biased towards the group of plants with C/N <20 (comprising 43% vs. 14% in those with C:N >20). Removing legumes (with a mean of $11.6 \pm 6.0\text{‰}$) from the comparison makes the difference between the two plant groups statistically insignificant ($16.5 \pm 8.2\text{‰}$ vs. $21.0 \pm 8.0\text{‰}$; Student's t -test, $t = 1.82$, $p = 0.073$), with no correlation between C:N and $\delta^{15}\text{N}$ values ($r^2 = 0.010$, $p = 0.420$). Similarly, the Atacama Desert macrobotanical remains in this study show no correlation between $\delta^{15}\text{N}$ and C/N atomic ratios ($r^2 = 0.001$, $p = 0.567$; Sup. Inf. 3). Just 3 samples out of 246 had C/N ratios above 100 and they show relatively low $\delta^{15}\text{N}$ values.

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