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ARTICLE

Resetting Archaeological Interpretations of Precontact Indigenous Agriculture: Maize Isotopic Evidence from Three Ancestral Mohawk Iroquoian Villages

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Abstract

Archaeologists working in eastern North America typically refer to precontact and early postcontact Native American maize-based agriculture as shifting or swidden. Based on a comparison with European agriculture, it is generally posited that the lack of plows, draft animals, and animal manure fertilization resulted in the rapid depletion of soil nitrogen. This required Indigenous farmers to move their fields frequently. In Northern Iroquoia, depletion of soil fertility is frequently cited as one reason why villages were moved to new locations every 20 to 40 years. Recent analysis of δ^{15}N ratios of maize macrobotanical remains from Northern Iroquoia, however, suggests that Iroquoian farmers were able to maintain soil nitrogen in their maize fields. An expanded analysis of maize kernel δ^{15}N ratios from three ancestral Mohawk villages indicates that farmers from those villages maintained soil nitrogen throughout the occupational spans of their villages. It further suggests that precontact Iroquoian agronomy was consistent with contemporary conservation agriculture practices.

Resumen

Les archéologues travaillant dans l'est de l'Amérique du Nord qualifient généralement l'agriculture à base de maïs pratiquée par les Autochtones avant et après le contact avec les Européens d'agriculture itinérante ou de culture sur brûlis. Sur la base d'une comparaison avec l'agriculture européenne, il est généralement admis que l'absence de charrue, d'animaux de trait et de fumier animal a entraîné un épuisement rapide de l'azote du sol. Les agriculteurs autochtones devaient donc déplacer fréquemment leurs champs. Dans l'Iroquoianie nordique, l'épuisement de la fertilité du sol est souvent cité comme l'une des raisons pour lesquelles les villages étaient déplacés tous les 20 à 40 ans. Une analyse récente des rapports de δ^{15}N dans les restes macrobotaniques de maïs de l'Iroquoianie nordique suggère toutefois que les agriculteurs iroquoiens étaient en mesure de maintenir l'azote du sol dans leurs champs de maïs. Une analyse poussée des rapports de δ^{15}N des grains de maïs provenant de trois villages mohawks ancestraux, présentée ici, indique que les agriculteurs de ces villages ont maintenu l'azote du sol tout au long de la période d'occupation de leurs villages. Elle suggère en outre que l'agronomie iroquoienne pré-contact était compatible avec les pratiques contemporaines de l'agriculture de conservation.

Keywords: Indigenous agriculture; northeastern North America; Northern Iroquoia; stable isotope analysis; maize

Mots clés: Indigène agriculture; nord-est de l'Amérique du Nord; l'Iroquoianie nordique; analyse des isotopes stables; maïs

Maize (*Zea mays* ssp. *mays*) is one of the world's most important agricultural crops, accounting for an estimated 39% of all grain production in 2017–2019, with approximately one-third of all farms producing it (Erenstein et al. 2021). The crop evolved from an annual teosinte (*Zea mays* ssp. *parviglumis*) in the central Balsas River Valley of Mexico some 7,000–9,000 years ago (Matsuoka et al. 2002). It gradually spread throughout the Western Hemisphere, reaching temperate northeastern North America about 2,300 years ago (Albert et al. 2018; Gates St-Pierre 2015; Hart et al. 2007). Some 1,600 years later, maize had become the dominant source of calories in the diets of Iroquoian-speaking peoples in parts of present-day New York, southern Ontario, and southern Québec, a region generally referred to as Northern Iroquoia (Birch 2015). Isotopic analyses of fourteenth- to seventeenth-century AD human teeth and bone from southern Ontario indicate that maize accounted for 50% to more than 70% of diets (e.g., Feranec and Hart 2019; Pfeiffer et al. 2016). This high degree of dependence on a single grain crop required major commitments of time and energy to agricultural production. As in other parts of the Western Hemisphere, Iroquoian agronomic practices were adapted to regional climatic and local edaphic and hydrological conditions (Hart and Feranec 2020; Mt. Pleasant 2011).

Archaeologists (e.g., Baden and Beekman 2001; Schroeder 1999) have typically discounted the productivity of precontact Indigenous agriculture in eastern North America, given the lack of plows and draft animals and the consequent lack of fertilization with draft animal manure to replace soil nitrogen.[1] The depletion of soil nitrogen, resulting in poor maize production, is thought to have required the clearing of new fields on a regular basis, contributing to the Iroquoian practice of relocating villages every 20 to 40 years (e.g., Birch and Williamson 2012). To the contrary, Doolittle (2000, 2004) and Mt. Pleasant (2011, 2015) suggested that Indigenous agriculture in eastern North America was permanent and that Indigenous agronomic practices maintained soil nitrogen.

Because centuries of Euro-American and Euro-Canadian plow-based agriculture have obliterated Iroquoian agricultural fields and changed soil chemistry, the most direct evidence for Iroquoian agronomic practices is macrobotanical remains, generally in the form of charred maize kernels and squash (*Cucurbita pepo*) and common bean (*Phaseolus vulgaris*) seeds. Recent analysis of maize macrobotanical remains nitrogen isotope ratios ($^{15}N/^{14}N$ or $\delta^{15}N$) from primarily fifteenth- and sixteenth-century sites in Northern Iroquoia suggests that Iroquoian farmers were able to maintain nitrogen in their agricultural fields (Hart and Feranec 2020) consistent with Mt. Pleasant's and Doolittle's scenarios. This article builds on that analysis by focusing on three fifteenth- to sixteenth-century ancestral Mohawk village sites located in the watershed of a tributary to the Mohawk River in east-central New York (Funk and Kuhn 2003). We obtained $\delta^{15}N$ ratios on additional samples of maize kernels from these three sites located near one another, which allowed an assessment of ancestral Mohawk farmers' abilities to maintain soil fertility in their agricultural fields. If these farmers were able to maintain soil fertility, then $\delta^{15}N$ ratios on maize macrobotanical remains should be significantly higher than those of plants outside agricultural fields throughout the occupational histories of those sites (Hart and Feranec 2020).

Soil Nitrogen and Indigenous Agriculture

Nitrogen is a limiting nutrient for plants (Kraiser et al. 2011). Plants obtain nitrogen from soil, the air, or both through symbiotic relationships with mycorrhizal fungi or endophytic bacteria (Gosling et al. 2006). Although maize is mycorrhizal (Wang and Qiu 2006), it is associated with arbuscular mycorrhizae, which have little effect on nitrogen uptake but enhance phosphorus uptake (Gosling et al. 2006). With the known exception of a few landraces in Mexico associated with endophytic bacteria (Estrada et al. 2002; Van Deynze et al. 2018), maize obtains all its nitrogen from the soil (Osterholz et al. 2017).

Soil nitrogen is derived from soil organic matter (SOM). For soil nitrogen to be available to plants it must be mineralized through microbial decomposition. Craine and colleagues (2009) found a global positive correlation between increased soil nitrogen and higher $\delta^{15}N$ ratios in plants (also see Kahmen et al. 2008). Various processes related to soil nitrogen discriminate against ^{15}N, which results in higher $\delta^{15}N$ ratios in soil and therefore in plants (Kahmen et al. 2008; Pardo and Nadelhoffer 2010; for technical overviews, see Craine et al. 2015; Szpak 2014). By exposing SOM to air, plowing results in its oxidation, which in turn depletes nitrogen, as does soil erosion, which increases under plowing (Kassam et al. 2009; Mt. Pleasant 2011). As a result, after a number of years depending on its original density, SOM must be replaced through fertilization. From the Neolithic period onward in the Eastern

Hemisphere, replacement was often in the form of draft animal manure (e.g., Bogaard et al. 2007; Tao et al. 2022). Experiments have documented that increased manuring results in increased $\delta^{15}N$ ratios in the grains of both C_3- and C_4-pathway plants (e.g., Bogaard et al. 2013; Christensen et al. 2022; Fraser et al. 2011).

North American archaeologists often use European agronomy as a baseline of comparison for precontact Indigenous agriculture. Native Americans did not have draft animals and plows prior to the often-forced adoptions of Euro-American and Euro-Canadian agronomic practices in the eighteenth and nineteenth centuries (Hurt 1987). The lack of plows and domesticated animal manure for fertilizing has been the basis for discounting the ability of Iroquoian farmers to permanently cultivate fields. The practice of village communities abandoning established settlements after 20 to 40 years is commonly attributed to the depletion of agricultural soil fertility, among other factors (e.g., Birch 2012:650; Jones and Wood 2012:2595). Some propose that agricultural clearings were continually expanded during the occupation of a village to bring new soil under cultivation as the originally cultivated soils were depleted in nitrogen and maize productivity fell (Snow 1996:70). This scenario results in projected clearings of many hundreds to more than 2,000 acres for large villages (Birch and Williamson 2012:98–100).

Contrary to these interpretations, Doolittle (1992, 2000, 2004), based on an analysis of the ethnohistorical record, suggested that Indigenous agriculture in eastern North America, including Northern Iroquoia, was intensive, rather than shifting or extensive. Historical, tropical swidden or slash-and-burn agriculture is often used as an analogy for prehistoric eastern North American agriculture (e.g., Bamann et al. 1992; Creese 2016; Jones 2010; Snow 2012; Sykes 1980). Swidden fields are generally small and productive for only a few years. Doolittle (2004:184) cited difficulties in clearing forests to create agricultural fields, the gradual removal of tree stumps from fields, reforestation as a long-term process, fallowed fields covered in grass rather than trees when brought back under cultivation, and the cultivation of large fields as ethnohistorical evidence for permanent rather than swidden agriculture in eastern North America: "Fields were cultivated for multiple years, perhaps even permanently or semipermanently, and not for short periods of time as is characteristic of swidden systems" (Doolittle 2004:186). How was this possible if the fertility of soils was depleted after a short span of time?

Based on actualistic experiments, agronomic knowledge, and the ethnohistorical record, Mt. Pleasant (2011, 2015; Mt. Pleasant and Burt 2010) suggested that Iroquoian agronomic practices were well adapted to edaphic contexts and to maize as a crop. According to Mt. Pleasant, hand tools (e.g., digging sticks, hoes) had advantages over plows, and Iroquoian agriculture was more productive per unit of land than contemporaneous European and Euro-American/Canadian plow-based agriculture. In naturally fertile Alfisols and Inceptisols, Iroquoian agronomic practices, resulting in minimal disturbance to soils, maintained SOM and therefore soil fertility over extended time spans. The creation of small mounds ("corn hills") using hoes and the subsequent planting of a few maize kernels in each mound with minimal disturbance using digging sticks resulted in the retention of SOM, soil microbiota, and therefore nitrogen (Coban et al. 2022). SOM can also increase soil water-holding capacity, buffering water availability against fluctuating rainfall (Habbib et al. 2016; Williams et al. 2016). Mt. Pleasant (2015) suggested that such agronomic practices in naturally fertile soils resulted in highly productive, stable agricultural systems. Using actualistic experiments in present-day New York, Mt. Pleasant and Burt (2010) obtained yields of 22–76 bushels of maize per acre, with the higher yields in naturally fertile soils. Mt. Pleasant (2015:406) further suggested that across eastern North America Indigenous farmers were likely to have sustained yields of 25–50 bu/acre by cultivating naturally fertile Alfisols, Inceptisols, and Mollisols. She proposed this as "a new paradigm for Native American agriculture in Eastern North America" (Mt. Pleasant 2015:375).

Mt. Pleasant's estimates of maize yields stand at odds with those that have continuing influence on archaeological interpretations of Iroquoian agriculture, which suggest mean productivity of 10 (Schroeder 1999) or 8–12 (Baden and Beekman 2001) bu/acre. Baden and Beekman (2001:513) estimated optimal yields of 18–30 bu/acre, which were not sustainable because of soil nitrogen depletion, which they modeled as a monotonically decreasing function. They suggested that because soil fertilization was not practiced, yields decreased by 50% over the course of a few years as plant-available nitrogen in soils was depleted and not replaced. Native American farmers then shifted production to new fields to gain higher yields.

Although their focus is precontact Indigenous agriculture, these competing models are not based on archaeological evidence. Both models identified plant-available nitrogen as a critical component in the sustainability of Indigenous agriculture. Even though there is a distinct lack of preserved Iroquoian maize fields because of centuries of Euro-American/Canadian agriculture, it is possible to assess soil fertility through stable isotopic analyses of maize macrobotanical remains (Hart and Feranec 2020). Here we provide isotopic analysis of maize macrobotanical remains from three ancestral Mohawk village sites.

Three Ancestral Mohawk Villages along Caroga Creek

From 1960 through 1970 crews from the New York State Museum with the aid of university field schools extensively excavated three ancestral Mohawk village sites in the Caroga Creek drainage basin. Caroga Creek is a tributary of the Mohawk River in eastern New York (Figure 1). The

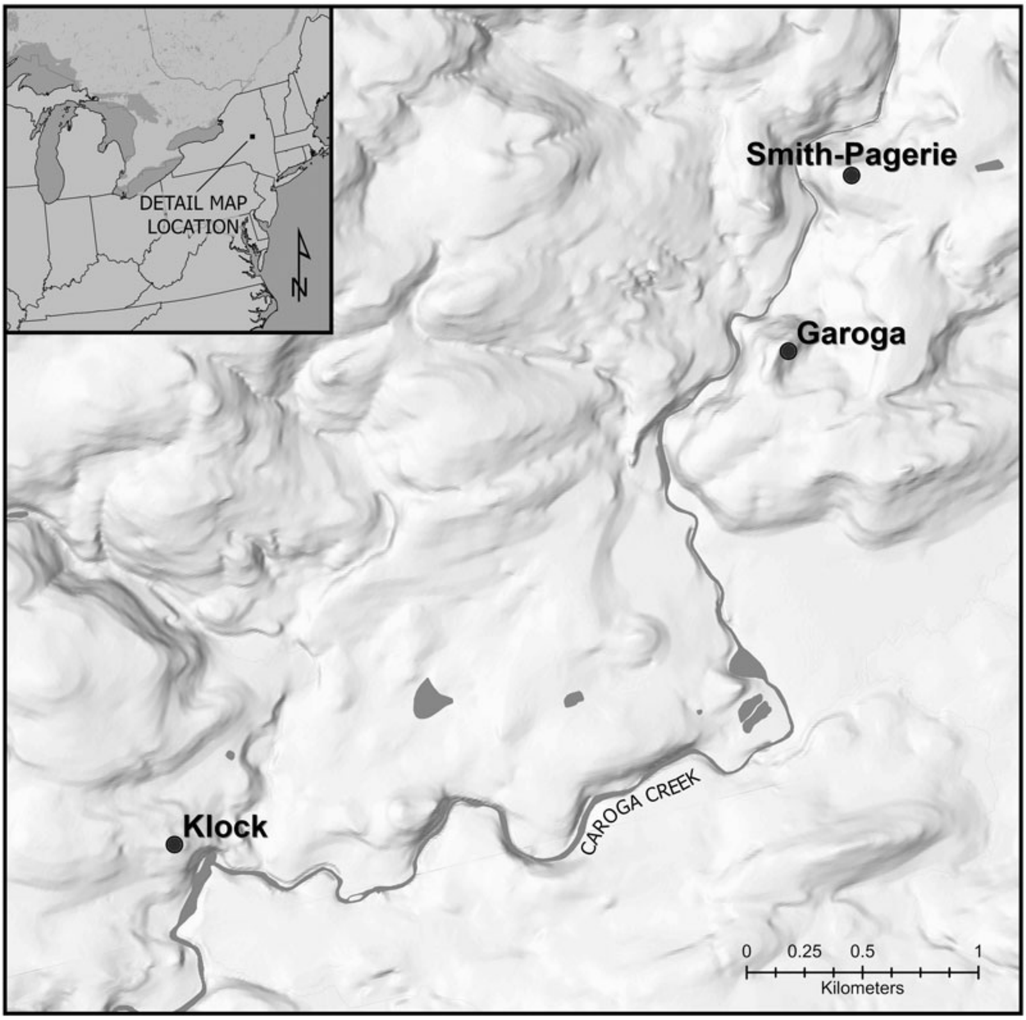

Figure 1. Locations of the Smith-Pagerie, Klock, and Garoga sites.

sites—Smith-Pagerie, Klock, and Garoga—are in defensive positions on peninsula-like ridges, with three sides having sheer drop-offs to Caroga Creek; the fourth side, from which the villages were accessed, was defended by palisades having posts with diameters up to 60 cm (Funk and Kuhn 2003; Ritchie and Funk 1973). Smith-Pagerie occupies approximately 4 acres of which 21,000 m^2 (13.0%) were excavated. Klock occupies an area of approximately 4 acres of which 1.950 m^2 (12.05%) were excavated. Garoga occupies 2.5 acres of which 1.5 acres (60.0%) were excavated. Multiple longhouses were identified at each site along with more than 150 pit features and hearths at Klock and Garoga and more than 450 at Smith-Pagerie (Funk and Kuhn 2003). Many of the pits at each site likely functioned as produce-storage facilities based on their size (diameter and depth; DeBoer 1988). Several large pits at each site had charred grass, tree bark linings, or both, further supporting this interpretation.

Although the sites were not completely excavated, they are the most extensively excavated ancestral Mohawk villages. They are also among the most intensively radiocarbon-dated Northern Iroquoian sites; Bayesian analyses of recently obtained and legacy radiocarbon dates place the Smith-Pagerie occupation at AD 1478–1498, Klock at AD 1499–1521, and Garoga at AD 1550–1582 (68.3% highest posterior density), with their occupations lasting 20–30 years (Manning et al. 2021). Although often interpreted as a sequence of villages representing the same community over the course of several generations (Funk and Kuhn 2003; Ritchie and Funk 1973), recent social network analysis suggests that the sites represent separate communities (Hart 2020).

Materials and Methods

Two sources of data are used to test the hypothesis that farmers at the three sites were able to maintain agricultural soil fertility: the distribution of naturally fertile soils in the vicinity of each site and isotope ratio mass spectrometry (IRMS) measurements of maize, other macrobotanical remains, and white-tailed deer collagen. All statistics were calculated in PAST 4.11 (Hammer et al. 2001).

Soils Data

Alfisols and Inceptisols are the two soil orders exploited by Iroquoian farmers for their natural fertility (Mt. Pleasant and Burt 2010). Mt. Pleasant (2015) used the National Commodity Crop Productivity Index (NCCPI) for corn (maize) to standardize comparisons of inherent soil fertility for non-irrigated maize production across eastern North America (Natural Resources Conservation Service 2022). Alfisols and Inceptisols orders and the NCCPI for maize acreage in proximity to the three Caroga Creek sites were calculated using GIS technology.

Soils datasets were derived from the Soil Survey Geographic Database (SSURGO; https://data.nal.usda.gov/dataset/soil-survey-geographic-database-ssurgo), which comprises digitized soils information collected across the United States since 1899. These datasets are available as map packages for ArcGIS Pro through the SSURGO Downloader and are organized by watershed sub-basins. Using the SSSURGO Downloader application, the Mohawk River Valley sub-basin soils map package was downloaded, extracted, and opened in ArcGIS Pro 2.9.1, the GIS software in which all calculations were made. Two of the 173 soil attributes were of interest: Dominant Soil Order (specifically, the soil orders Alfisols and Inceptisols) and NCCPI v3—Corn, a soil productivity index for growing maize.

Using the Dominant Soil Order field in the attribute table, the text values Alfisols and Inceptisols were selected and exported to a new soil map unit polygon layer. The minimum and maximum range of the NCCPI v3—Corn (maize) values were identified, and the soil polygons were separated into four classes using the NCCPI v3 Corn Soil Map Unit Classification: (1) less than 20% productivity for corn, (2) >20%–55%, (3) >55%–75%, and (4) >75%–85%.

Point locations for Klock, Smith-Pagerie, and Garoga were added to the GIS map. The Buffer tool was then employed to create a 2 km catchment area around each site following Jones (2016; Jones and Wood 2012). The Summarize Within tool was then used on each catchment to calculate the total acreage of Alfisols and Inceptisols and the acreage of soil map units having an NCCPI class 3 (>55%–75%); class 4 is not present in the Caroga Creek drainage basin.

Isotope Data

IRMS $\delta^{15}N$ and $\delta^{13}C$ measures were obtained for 28 maize kernels (Hart and Winchell-Sweeney 2023: Table S1). Also included in the analysis are $\delta^{15}N$ and $\delta^{13}C$ measures for nine maize kernels and two maize cobs obtained from previously reported radiocarbon-dated specimens (Manning and Hart 2019; Manning et al. 2021). Maize for IRMS measurement was taken from feature macrobotanical assemblages held in the New York State Museum collections, which have multiple maize specimens. These included hearths and large, presumably storage, pit features. Hearths were located within longhouse postmold patterns. We assume that the hearths were used throughout the occupation span of the longhouses and were cleaned out occasionally. As a result, the maize remains from these features represent the later stages of use and village occupation (Manning et al. 2021). The large pit features generally had multiple strata representing post-use fill. In some instances, basal layers of charred grass, bark linings, or both were documented, presumably representing the original pit functions (Funk and Kuhn 2003). For Garoga and Klock it was possible in many instances to determine from profile drawings and field notes where in the large pit features the specimens originated. Maize recovered from on or immediately above a pit lining likely represented use of a pit for its original storage function.[2] Strata above the lining to the top of the pit represent post-use filling, presumably toward the end of a site's occupational span (Manning et al. 2021).

Macrobotanical sampling for IRMS was done in the New York State Museum's geochemistry lab. We removed approximately 10–15 mg from each specimen, which was weighed, placed in a labeled plastic tube with a lid, and shipped to the W. M. Keck Carbon Cycle lab at the University of California-Irvine for IRMS measurement. At Keck, samples were subjected to acid-base-acid (ABA) pretreatment before combustion. Isotope ratio measurements were made on the pretreated aliquots with a Frisons NA1500NC elemental analyzer/Finnigan Delta Plus isotope ratio mass spectrometer, with precisions of <0.1‰ for $\delta^{13}C$ and <0.2‰ for $\delta^{15}N$. These measurements were combined with previously obtained $\delta^{15}N$ and $\delta^{13}C$ measures done on maize at Keck for the three sites, as reported in Hart and Feranec (2020) and listed in Hart and Winchell-Sweeney (2023:Table S1). Charring discriminates against ^{15}N elevating $\delta^{15}N$ ratios in grains (Nitsch et al. 2015; Styring et al. 2013). Charring experiments of maize kernels resulted in a mean offset of +0.54‰ (Hart and Feranec 2020), which was subtracted from maize macrobotanical $\delta^{15}N$ values.

Also listed in Hart and Winchell-Sweeney (2023:Table S2) are $\delta^{15}N$ and $\delta^{13}C$ ratios for 27 samples of white-tail deer (*Odocoileus virginianus*) bone collagen from the Caroga Creek and other Mohawk Valley sites, as previously reported in Manning and Hart (2019). White-tailed deer have broad diets that vary throughout the year and include woody and herbaceous plants, as well as fruits and nuts (Averill et al. 2018; Horsley et al. 2003). Average $\delta^{15}N$ ratios for plants consumed by white-tailed deer were obtained by subtracting a trophic enrichment factor of 3.8‰ from the deer collagen ratios (Hart and Feranec 2020). The resulting $\delta^{15}N$ ratios provide a mean for the ratios of plants consumed outside agricultural fields (Hart and Feranec 2020), assuming a C_3-pathway (non-maize) plant diet; elevated $\delta^{13}C$ ratios provide a method for assessing whether a given deer had a diet with substantial C_4-pathway plant component, most likely maize from agricultural fields.

IRMS measurements were obtained on six American plum (*Prunus americana*) and six chokecherry (*P. virginiana*) endocarps from Garoga and Smith-Pagerie, respectively, as a second means of determining the range of $\delta^{15}N$ ratios of uncultivated plants (Hart and Winchell-Sweeney 2023). *P. americana* grows in a wide range of habitats from floodplains to upland forests in New York, whereas *P. virginiana* grows in hardwood forests and forest edges (Weldy et al. 2023). It was expected that these samples would provide $\delta^{15}N$ ratios in the range of the deer browse estimates.

Heating experiments were conducted on plum endocarps to determine whether charring results in increased $\delta^{15}N$ ratios, as it does on maize and other grains. Endocarps were extracted from 10 fresh, commercially grown plums (*P. domestica*). These were broken into pieces, and the seed was removed. Following previously established protocols, one piece of each endocarp was loosely wrapped in aluminum foil and placed in a ceramic crucible, which was then filled with sand. The samples were placed in the center of a muffle furnace preheated to 260°C and heated for two hours. The temperature and length of time were chosen based on experience in other charring experiments that this would likely result in completely charred specimens (Hart 2021; Hart and Feranec 2020), which did occur. A fraction of each fully charred and uncharred endocarp piece was submitted to the Keck facility for IRMS measurements. Unlike the archaeological specimens, these contemporary specimens, following laboratory protocols, were not subjected to ABA pretreatment.

Results

Soils

Naturally fertile soils are present near each of the three sites (Table 1). Acreages for Alfisols and Inceptisols were substantially larger than NCCPI 55%–75%, with the index taking slope into account. Were the acreages for agricultural fields sufficiently large enough for ancestral Mohawk farmers to produce enough maize to support the dietary needs of their villages?

Snow (1995) estimated a population of 1,350 at Smith-Pagerie, 900 at Klock, and 820 at Garoga. Funk and Kuhn (2003), in contrast, estimated populations of 1,760–2,325, 790–845, and 1,400–3,010, respectively. Regardless of these discrepancies and the large ranges in the Funk and Kuhn estimates, each community required large amounts of agricultural produce for sustenance. We assumed a daily diet in which an average 65% came from maize, resulting in the need for 8.5 bu/person/year (Heidenreich 1971). Using Snow's (1995) population estimates, farmers needed to produce 11,475 bu of maize for annual consumption at Smith-Pagerie, 7,650 at Klock, and 6,970 at Garoga. These figures do not consider spoilage and the need to store surplus for poor production years. Following Birch and Williamson (2012:100) we assumed the need to raise an additional 20% per annum, resulting in annual production needs of 13,770 bu for Smith-Pagerie, 9,180 for Klock, and 8,364 for Garoga. NCCPI soil categories are plotted in Figure 2 with 2 km catchments for the three sites. Table 1 indicates the number of acres needed to produce the required amount of maize at 25 and 50 bu/acre, suggested by Mt. Pleasant (2015) as the range of productivity for Indigenous agriculture in eastern North America. There was ample acreage of soils with the highest natural potential for maize production in the Caroga Creek valley within 2 km of each site and a substantial excess of Alfisols and Inceptisols.

Table 1. Required Acreage at Productivity Levels and NCCPI 55%–75% and Total of Alfisols and Inceptisols (Soils) Acreages in 2 km Catchments for the Caroga Creek Sites.

	Required Acreage		2 km Radius Acreage	
Site	25 bu/acre	50 bu/acre	NCCPI	Soils
Smith-Pagerie	551	275	574	2,255
Klock	367	184	1,226	2,664
Garoga	335	167	817	2,149

Maize Isotopes

Although adequate acreages of naturally fertile soils were present, community farmers needed to maintain the productivity of these soils in their fields for two to three decades to support Doolittle's and Mt. Pleasant's interpretations of Indigenous agronomy. Summary statistics for δ^{15}N and δ^{13}C ratios are provided in Table 2, and the ratios for each specimen are given in Hart and Winchell-Sweeney (2023:Tables S1 and S2). Of note, the highest value for white-tailed deer collagen (4.60‰) was from a specimen that had an elevated δ^{13}C ratio (−14.9‰), which indicates that a large fraction of its diet came from C_4 plants, presumably maize. As a result, this individual is excluded from the data in Table 2. Guiry and associates (2020) noted that contemporaneous Passenger pigeon (*Ectopistes migratorius*) bone collagen from ancestral Huron-Wendat sites in southern Ontario with high δ^{15}N ratios also had high δ^{13}C ratios and attributed this to maize consumption.

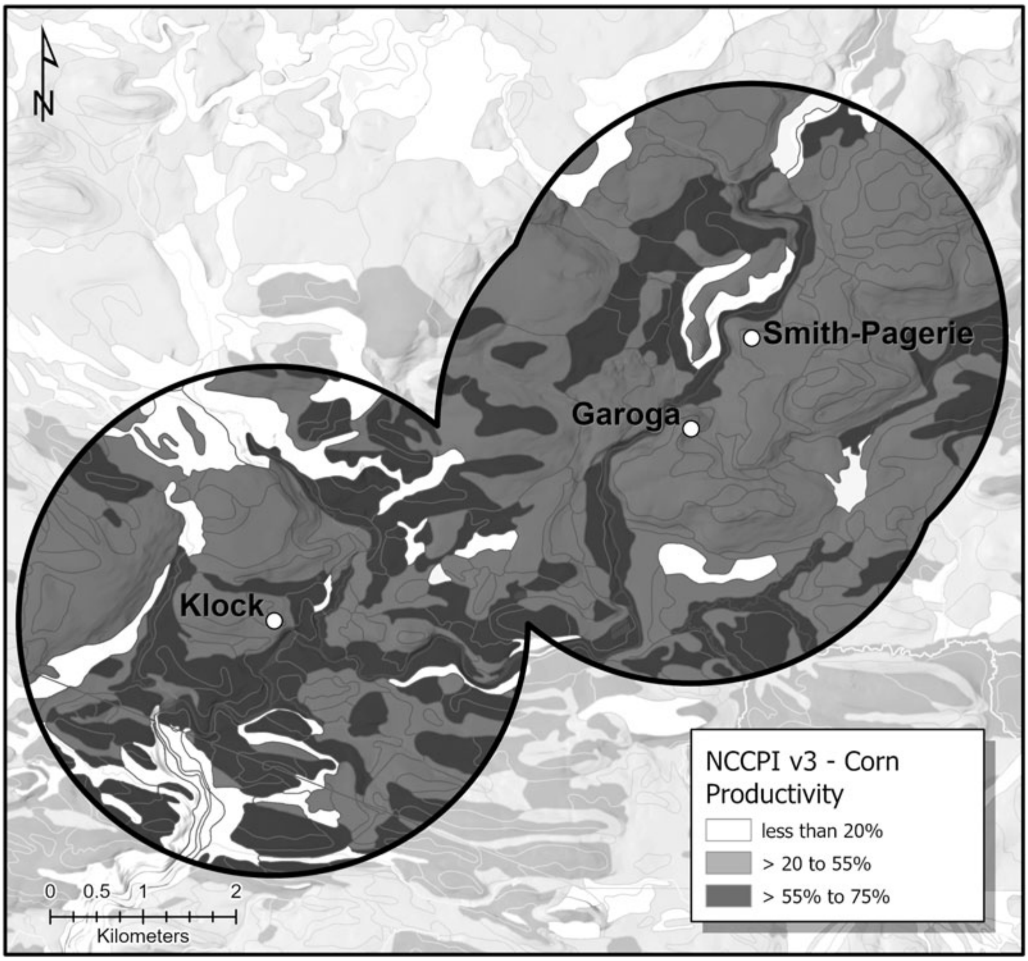

Figure 2. NCCPI corn (maize) soil categories and 2 km site catchments.

Table 2. Summary Statistics for δ^{15}N and δ^{13}C Ratios on Caroga Creek Samples and Estimated Mohawk Valley Deer Browse.

	δ^{15}N (‰, AIR)				δ^{13}C (‰, VPDB)			
Source	*n*	range	mean	median	*n*	range	mean	median
Maize	41	2.26–13.76	4.61 ± 1.87	4.16	41	−2.6 to −7.6	−9.38 ± 0.88	−9.4
Deer browse	26	−1.10–1.10	−0.22 ± 0.44	−0.25	26	−24.4 to −21.3	−22.95 ± 0.72	−23.1
Cherry endocarp	4	8.30–15.30	12.13 ± 3.65	12.45	6	−25.9 to −24.5	−25.55 ± 0.60	−5.5
Plum endocarp	4	6.00–9.40	6.78 ± 1.86	6.30	6	−22.1 to −27.0	−5.63 ± 1.84	−6.3

Figure 3 is a scatterplot of δ^{13}C and δ^{15}N ratios obtained on maize from the three Caroga Creek sites with the δ^{15}N ratio mean and one and two standard deviations for estimated deer browse. None of the maize ratios fall within two standard deviations of the estimated δ^{15}N ratio mean for plants consumed by white-tailed deer in the Mohawk River basin (excluding the value from the specimen with a C_4-plant diet). The mean maize ratio is significantly higher than the mean of the estimated deer browse ratio (unequal variance *t*-test $t = 15.685$, $p = 0.0000$). This indicates that the plant-available nitrogen in the agricultural fields was greater than that available for the plants in deer browse.

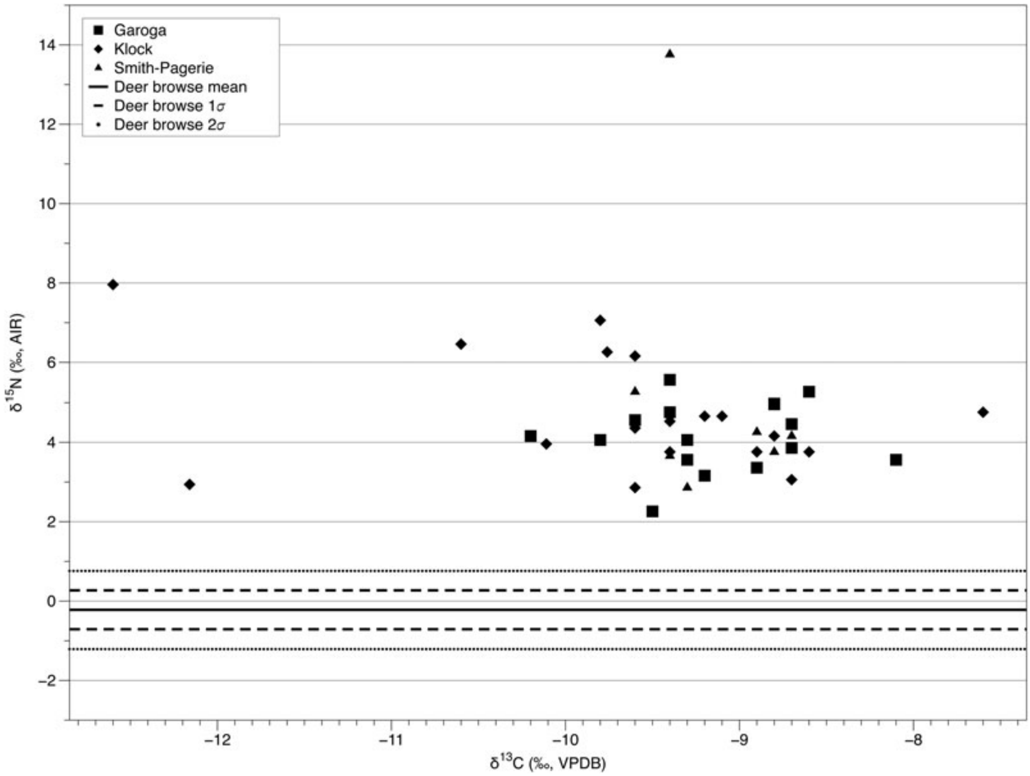

Figure 3. Scatterplot of δ^{13}C and δ^{15}N ratios for the Smith-Pagerie, Klock, and Garoga sites with mean and standard deviations of estimated δ^{13}C and δ^{15}N ratios for white-tailed deer browse.

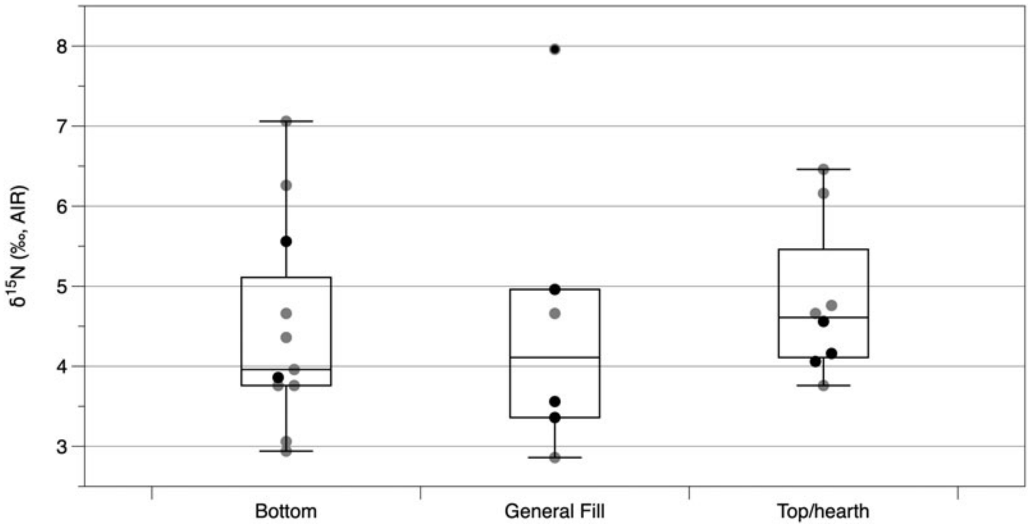

Figure 4. Boxplots of maize δ^{15}N ratios recovered from differing feature contexts at the Klock and Garoga sites. Dots represent individual maize sample δ^{15}N ratios: Garoga black, Klock gray.

Figure 4 is a boxplot of δ^{15}N ratios from Klock and Garoga maize remains recovered from different contexts within features; summary data are presented in Table 3. The lowest values come from contexts that can be considered to represent the original functions of the pits and general fill strata. The δ^{15}N

Table 3. Feature Context Maize δ^{15}N Ratios.

Context	*n*	Minimum δ^{15}N ratio	Median δ^{15}N ratio	Maximum δ^{15}N ratio
Bottom	9	2.94	3.96	6.26
General fill	9	2.84	4.38	13.71
Top/hearth	10	3.72	4.72	7.97

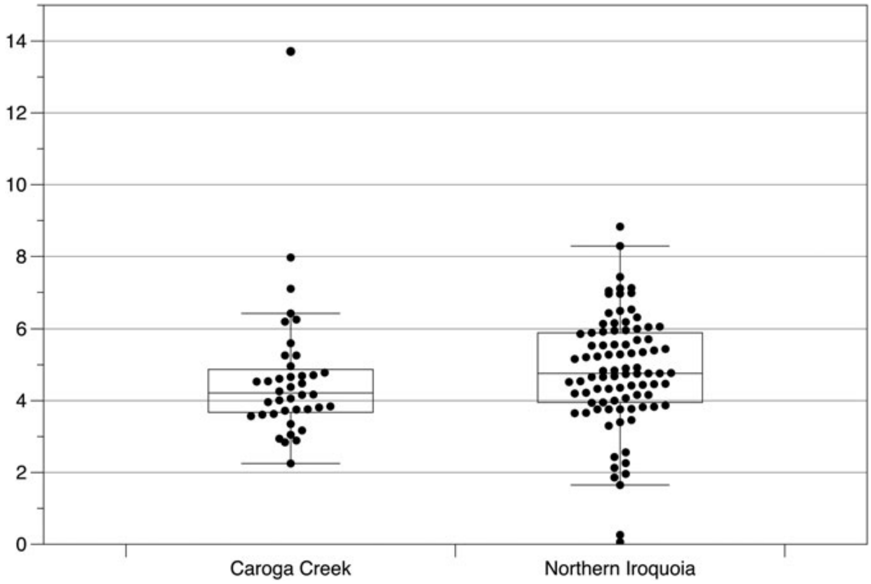

Figure 5. Boxplot of δ^{15}N ratios from Smith-Pagerie, Klock, and Garoga sites and ratios obtained for maize from sites elsewhere in Northern Iroquoia. Dots represent individual maize sample δ^{15}N ratios.

ratios of the presumed end-of-site occupation are not statistically different than those for maize recovered from on or immediately above grass or tree bark pit linings, thus representing the original functions of the pits (Mann-Whitney $U = 31.5$, $z = 0.99305$, exact permutation $p = 0.3193$).

The IRMS measurements that we obtained add to a growing database of measurements on maize macrobotanical remains from Northern Iroquoia that includes 129 δ^{15}N ratios, all but two of which were obtained on kernels (Hart and Winchell-Sweeney 2023:Table S3). Figure 5 is a boxplot of maize δ^{15}N ratios from Caroga Creek and elsewhere in Northern Iroquoia. The mean of the ratios obtained on the Caroga Creek samples is not significantly different from the mean of the samples obtained on samples from other sites in Northern Iroquoia ($t = 0.68508$, $p = 0.49545$).

Exceptionally Elevated δ^{15}N Ratios

δ^{15}N ratios of one maize kernel (13.76‰) and four cherry endocarps (8.30‰–15.30‰) from Smith-Pagerie are substantially higher than the next highest ratio for maize (7.96‰) and estimated ratios for deer browse. Four plum endocarps from Garoga (6.00‰–9.40‰) have substantially higher δ^{15}N ratios than the estimated range for deer browse. Soils in the region fall within a band with estimated bulk soil δ^{15}N ratios of 3.5‰–4.8‰ (Amundson et al. 2003). The inorganic components of soil nitrogen generally have lower δ^{15}N ratios than bulk soil, and there is little fractionation during plant uptake of inorganic nitrogen: “In most non-boreal sites, plants mainly acquire NH_4^+ and NO_3^- from soil and this uptake occurs without any large isotopic fractionation” (Craine et al. 2015:9). Therefore, these elevated values cannot be the result of unaltered soils.

Charring of plant tissues can result in increased δ^{15}N ratios. To determine whether charring has the potential to substantially increase δ^{15}N ratios in *Prunus* spp. endocarps, heating experiments were conducted for 10 contemporary domesticated plum (*P. domestica*) endocarps. These experiments produced no statistically significant difference in δ^{15}N ratios between charred and uncharred fractions of 10 endocarps (Wilcoxon test, $W = 32$, $z = 1.8226$, exact $p = 0.078125$; Hart and Winchell-Sweeney 2023:Table S4)

The most likely source of nitrogen resulting in the exceptionally elevated δ^{15}N ratios in the Caroga Creek samples is Passenger pigeon guano. Animal manure and bird guano deposits and applications as fertilizer increase δ^{15}N ratios in plants; both seabird (Szpak 2014; Szpak et al. 2012) and passerine (Finity 2011) guano can have exceptionally elevated δ^{15}N ratios. Passenger pigeons migrated in massive flocks across eastern North America (Ellsworth and McComb 2003). The species' bones have been identified in several ancestral Mohawk village faunal assemblages including Garoga (Kuhn and Funk 2000:33; Ritchie and Funk 1973:329), and its presence in the Mohawk Valley is attested by the eighteenth-century ethnohistoric record (Snow et al. 1996:256).

Passenger pigeon roosting sites, generally in hardwood forests, often included millions of individual birds that produced massive amounts of guano, killing the trees within the roosting area. Nesting sites, although not as densely occupied, also produced substantial amounts of guano (Ellsworth and McComb 2003:1552). Passenger pigeons were omnivorous, consuming worms and snails in addition to annual plant products. They were largely dependent on mast, primarily Beechnut (*Fagus grandifolia*), acorn (*Quercus* spp.), and Chestnut (*Castanea dentata*; Bucher 1992:4), all of which are native to New York and occur in the Mohawk Valley (Weldy et al. 2023). Guiry and colleagues (2020:9) suggest that a correlation between high δ^{15}N and δ^{13}C ratios in the collagen of Passenger pigeon bone recovered from Iroquoian sites in southern Ontario resulted in part from the pigeons feeding on maize.

Fruit was an important Passenger pigeon food source in summer (Bucher 1992:4). Feeding episodes on fruit trees and shrubs also resulted in guano deposits, although not as substantial as in roosting and nesting sites, given the relatively short duration of feeding. Because of fluctuations in mast production and previous damage to forests, migration patterns were inconsistent (Bucher 1992). Given that *P. virginiana* and *P. americana* are shade-intolerant and are early successional species after disturbances such as forest fires (Francis 2004; Welch 2004), the exceptionally elevated δ^{15}N endocarp ratios likely represent plants that grew in previous Passenger pigeon roosting or nesting areas. Bird guano can be an important source of nitrogen in early successional stages, with consequent elevated δ^{15}N ratios in plants (Schrama et al. 2013; also see Guiry et al 2020:11). The elevated maize kernel δ^{15}N ratio likely represents encroachment of a maize field on a previous pigeon roosting or nesting area.

Summary

The δ^{15}N measurements presented here expand the archaeological evidence for Iroquoian agronomy. Comparison of δ^{15}N ratios of maize macrobotanical remains and estimates of deer browse indicate higher nitrogen levels within than outside agricultural fields. δ^{15}N ratios on maize from different contexts within features suggest no decrease in nitrogen ratios over the course of site occupation. Exceptionally elevated δ^{15}N ratios for one maize kernel and cherry and plum endocarps suggest plant growth within previous Passenger pigeon roosts or nesting areas. The maize δ^{15}N ratios from the Caroga Creek sites are not significantly different from those obtained on maize from other sites in Northern Iroquoia.

Discussion and Conclusions

Archaeological models of precontact Indigenous agriculture in eastern North America have used plow-based European and Euro-American/Canadian agriculture as baselines for comparisons. These models focus on the lack of evidence for fertilization of agricultural soils by Indigenous farmers and posit that nitrogen was rapidly depleted after the establishment of new fields, resulting in substantially decreased maize productivity (Baden and Beekman 2001). This in turn resulted in the clearance of new fields or the expansion of existing fields to restore maize productivity to levels sufficient to support village communities. Doolittle (2000, 2004) and Mt. Pleasant (2011, 2015; Mt. Pleasant and Burt 2010) suggested instead that Indigenous agricultural practices in eastern North America included permanent fields and the maintenance of soil fertility over multiple decades. Yet, archaeological evidence for Indigenous agronomic practices has been lacking to support their proposals. The current and previous (Hart and Feranec 2020) analyses of maize macrobotanical $\delta^{15}N$ ratios provide the first evidence that is consistent with Doolittle's and Mt. Pleasant's propositions. Elevated $\delta^{15}N$ ratios suggest that ancestral Mohawk farmers were able to maintain soil fertility in their agricultural fields, likely through agronomic practices adapted to naturally fertile Alfisols and Inceptisols, which were present in ample amounts for agricultural fields within 2 km of each site explored in this study.

Guiry and associates (2020:9) suggested that elevated maize $\delta^{15}N$ ratios from ancestral Huron-Wendat sites in southern Ontario were "due to $\delta^{15}N$ shifts in soil nitrogen associated with differing symbiotic mycorrhizal fungi relationships and increased nitrogen cycle openness" in agricultural fields relative to forests. However, more of an explanation is needed for Iroquoian agronomic practices that evidently resulted in the maintenance of soil nitrogen. Hart and Feranec (2020) suggested several possible agronomic practices that would result in nitrogen maintenance. Here we offer as a hypothesis that Iroquoian agronomy was equivalent to contemporary conservation agriculture.

Conservation agriculture comprises a series of agronomic practices that are used to maintain soil health and fertility, including nitrogen levels (e.g., Friedrich et al. 2012; Kassam et al. 2009, 2019). This system has three primary components: (1) no or minimal soil disturbance (no-till), (2) maintenance of organic mulch over a minimum of 30% of soil, and (3) crop rotation or balanced mixes of legumes and nonlegume crops (Kassam et al. 2019:2). Mulch can consist of crop residue and stubble, as well as cover crops, all of which contribute to SOM and, therefore, the maintenance of soil nitrogen. These systems produce many sustainable benefits for soil health, fertility, and water retention and filtration by increasing soil organic matter (for an analysis of how no-till farming with crop residue restores SOM in previously plowed fields, see Prairie et al. 2023) and soil microbial biodiversity and activity, which can increase or maintain crop productivity over extended spans of time without external inputs when the system is properly adapted to local edaphic, hydrological, and societal contexts (Kassam et al. 2009; Page et al. 2020).

Page and associates (2020:8) summarize conservation agriculture's (CA) effects on nutrients: "Where CA successfully leads to greater residue addition and thus input of nutrient containing organic material into the soil, this can lead to higher plant nutrient stores, with greater nitrogen" and other nutrient concentrations as a response to increased SOM. They continue that such results are not absolute and various localized conditions can result in negative effects to nutrients. Kassam and associates (2009:304) list four primary benefits of conservation agriculture: "(a) physical: better characteristics of porosity for root growth, movement of water and root-respiration gases; (b) chemical: raised CEC [cation exchange capacity] gives better capture, release of inherent and applied nutrients: greater control/release of nutrients; (c) biological: more organisms, organic matter and its transformation products; (d) hydrological: more water available."

Contemporary conservation agriculture is similar to the ethnohistorically documented Iroquoian agronomic practices, which involved the intercropping of maize, common bean, and squash, and sometimes sunflower (*Helianthus annuus*). Iroquoian farmers initially created small mounds of soil ("corn hills") in which they planted maize, common bean, and squash seeds. Once the mounds were established, seeds were planted in them annually, with the large maize, common bean, and squash seeds planted with minimal disturbance using digging sticks. Maize stalks provided climbing poles for bean vines, and squash vines with large leaves acted as mulch. As described by Mt. Pleasant (2011, 2015) these agronomic systems obviated the need for fertilization, as is required in plow-based agronomy, by maintaining SOM and soil microbes that converted organic nitrogen into inorganic nitrogen available to plants.

Iroquoian maize harvesting generally involved stripping ears from the stalks and leaving the stalks in place until the next year (Waugh 1916:39), although they were sometimes removed with the ears (Parker 1910:31). As described by Waugh (1916:20), the only "cultivation given formerly was to chop down the weeds, or to clear away the last year's cornstalks." The Iroquoian agronomy, then, was the equivalent of contemporary conservation agriculture in that it involved minimal disturbance to agricultural soils, maintenance of mulch (squash vines during the growing season, maize stalks during the winter, and potentially the use of other crop residues) that contributed to SOM, and intercropping of maize with a legume (common bean). The isotopic evidence suggests that these systems maintained soil fertility in precontact Iroquoian agricultural fields.

In effect, precontact Iroquoian agronomy is an example of sustainable eastern North American Indigenous agriculture. Given the consistent high maize kernel $\delta^{15}N$ ratios, Iroquoian agronomic practices successfully implemented the equivalent of contemporary conservation agriculture practices: nitrogen depletion was apparently not a problem for Iroquoian farmers. This is a hypothesis that will be best tested through actualistic experiments using traditional maize varieties and monitoring soil chemistry over the course of several years with and without soil amendments other than the continuous addition of organic matter from the previous year's crops.

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Competing Interests. The authors declare none.

Notes

1. Archaeologists often refer to Indigenous agronomic practices as horticulture because they did not include plows and draft animals. However, the term "horticulture" is generally equated with gardening in the general English lexicon (e.g., Jewell and Abate 2001:822) and anthropological literature (e.g., Morris 2012:122) and thus does not accurately reflect Iroquoian cultivation practices. We prefer a behavioral definition following Rindos (1984:256): "an integrated set of . . . behaviors that affect the environment inhabited by domesticated plants throughout the whole life cycle of those plants."
2. Although Morgan (1851:319) described a Haudenosaunee practice of caching "charred green corn" in storage pits, most likely he was referring to parched green maize kernels (see Parker 1910:35). The recovery of massive deposits of charred maize at the bottom of storage pits on Iroquoian sites suggests burning in place during the pit's primary use, especially when charred grass and/or bark linings were also present. Small numbers of kernels found on or immediately above a charred organic lining also suggest burning in place at the end of the pit's use life before filling the pit with debris and soil. Parker (1910:35) claimed that "after the corn had been removed the pit was filled with rubbish and the entire matter burned or charred." It is likely that some maize kernels on the lining would be overlooked before burning.

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