Estimating Productivity of Traditional Iroquoian Cropping Systems from Field Experiments and Historical Literature

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ESTIMATING PRODUCTIVITY OF TRADITIONAL IROQUOIAN CROPPING SYSTEMS FROM FIELD EXPERIMENTS AND HISTORICAL LITERATURE

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Results from field experiments in New York establish realistic yield levels for the Three Sisters, a polycultural cropping system of inter-planted corn, bean, and squash which was used by Iroquoian farmers in the 16th, 17th, and 18th centuries. A traditional open-pollinated white flour corn yielded from 22 to 76 bu/acre (1155 to 4127 kg/ha); the higher yields were obtained in New York's Lake Plain region with its fertile soils and long growing season. Corn grain yields were also higher at increased plant densities and closer spacing. We argue that these grain yields, which are significantly higher than other scholars have reported, are an accurate reflection of the yield potential of the productive soils of this region. Other researchers have failed to account for the complex and critical ways that soil organic matter and agronomic practices determine corn yields. Our yield estimates are further supported by eyewitness accounts that describe a highly productive agriculture practiced by Iroquoian farmers in the 16th through 18th centuries. Using Land Equivalency Ratios, we also demonstrate that the three crops grown as a polyculture were more productive than monocultures of individual crops. Corn grain yields were little affected by competition from bean and squash, but these two crops yielded much less in the polyculture compared to monocultures. We suggest that the Three Sisters, while widespread, was not universal across Iroquoia.

Key words: *Three sisters, Iroquois agriculture, maize, crop productivity*

Los resultados de experimentos de campo en Nueva York establecen niveles prácticos de rendimiento para las Tres Hermanas, un sitema policultural interplantando maíz, frijol, y calabaza que fue utilizado por agricultures Iroquíes entre los siglos 16 al 18. Un maíz blanco, abierto-polinizado y tradicional de la harina rindió de 1155 a 4127 kg/ha; los rendimientos más altos fueron obtenidos en el Lake Plain de Nueva York, una región con tierras fértiles y temporada larga de crecimiento. El rendimiento del maíz fue mayor con el aumento en las densidades de las plantas y con un distanciamiento menor. Discutimos que estos rendimientos de grano, que son significativamente más altos que lo que otros especialistas han informado, son una reflejo exacto del potencial de rendimiento de las tierras productivas de esta región. Nuestros estimados de rendimiento son apoyados aún más por anécdotas de testigos oculares que describieron a la agricultura de los Iroquíes como una sumamente productiva entre los siglos 16 al 18. Utilizando Proporciones de Equivalencia de Tierra, también demostramos que las tres cosechas crecidas como un policultivo fueron más productivas que monocultivos de cosechas individuales. El rendimiento del maíz fue poco afectado por la competencia con el frijol y la calabaza pero éstas dos cosechas rindieron mucho menos en el policultivo compardo con monocultivos. Sugerimos que las Tres Hermanas, aunque esparcido, no fue universal a través de Iroquoia.

Introduction

The traditional agricultural practices of the Haudenosaunee (Native peoples of northeastern North America who are also referred to as the Five or Six Nations of the Iroquois[1] Confederacy) have attracted the attention of outsiders beginning with

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Jacques Cartier who first arrived in Iroquoian communities near the St. Lawrence River in the 16th century (Cartier 1993). After Cartier, a steady stream of non-Native military men, missionaries, government representatives, and traders visited Iroquoia in the 17th and 18th centuries and often reported on their agricultural practices. More recently, academics from various disciplines have described Haudenosaunee agriculture across geographical and temporal landscapes (Day 1953; Doolittle 2000; Engelbrecht 2003; Hasenstab 1990; Jordan 2008; Lewandowski 1987; Mt.Pleasant 2006; Onion 1964; Parker 1968; Schroeder 1999; Snow 1994; Sykes 1980; Trigger 1990; Waugh 1991; Wessel 1970). Many of the colonial era eyewitness accounts and more recent interpretations were compiled by people who were at least initially unfamiliar with Iroquoian peoples and their communities, ignorant of agricultural principles, or both. Consequently, fragmentary or incorrect information has resulted in less-than-robust interpretations regarding how Iroquoian farmers managed their crops and soils and the ways in which agriculture shaped Haudenosaunee communities.

In this article, we use agricultural field experiments conducted from 1993 through 1997 in central New York and our expertise as agronomists to more fully describe and interpret the Three Sisters Mound System. This polycultural cropping system of inter-planted corn, bean, and squash on mounds or small hills was practiced by the Haudenosaunee and other Native peoples in the northeast from the middle of the 14th century through end of the 18th century, and has been central to the ceremonial, social, and economic spheres of Iroquoian peoples (Engelbrecht 2003; Fenton et al. 1978; Lewandowski 1987; Morgan 1962; Mt.Pleasant 2006; Onion 1964; Parker 1968; Snow 1994; Tooker and Sturtevant 1978; Wessel 1970). This article fills a gap in the literature on indigenous agriculture.

We designed and implemented field experiments to determine yield levels of the three crops in polyculture, to compare their productivity to monocultures, and to better characterize the parameters of soil fertility, climate, plant population, and spacing on crop yields. Results from these experiments provide: 1) insights into the effects of soil quality and local climatic conditions on the productivity of this traditional cropping system and on the settlement patterns of Iroquoian communities that depended on it; 2) realistic yield estimates for the three crops across geographical areas within present day New York State; and 3) descriptions of crop production strategies likely used by the Iroquois during the 16th, 17th, and 18th centuries.

First, we describe Iroquoian agriculture beginning with the records of European colonizers who observed Native agriculture first-hand in New York and Ontario in the 16th, 17th, and 18th centuries. Second, we summarize and critique the past 30 years of scholarly literature on corn yields in Native America. Third, we report on our field experiments and discuss the effects of soil, climate, and corn plant density/spacing on corn productivity. Finally we discuss yield differences between polycultures and monocultures of corn, bean, and squash, and link these conclusions with historical information about Iroquoian agriculture to provide a more complete assessment of its role and influence.

European Descriptions of Iroquoian Agriculture

Jacques Cartier provided the first written description of Iroquoian agriculture during his second voyage to North America in 1535, where he found evidence of extensive agriculture around the St. Lawrence River. ''It was *find* [sic] land and with large fields covered with the corn of the country…They live on this as we do wheat.….They have also a considerable quantity of melons, cucumbers, pumpkins, pease, and beans of various colours and unlike our own'' (Cartier 1993:61,69)[2]. Reports by subsequent French missionaries and explorers described key characteristics of Iroquoian agriculture, implicitly comparing it to European farming. These early accounts focused on aspects of Native agriculture that differed from their own experiences and knowledge of farming. They noted: 1) the presence of a cereal grain, corn (Zea *mays* L.), that was not grown contemporaneously in Europe; 2) the absence of draft animals and plows that were essential for successful European agriculture; and 3) that women farmed the land, in contrast to European farming which was implemented and controlled by men.

Samuel de Champlain (1907:244) wrote in 1613, ''They showed me their gardens and the fields, where they had maize…the trees having been burned, they dig up the ground a little, and plant their maize kernel by kernel…'' The reference to planting corn ''kernel by kernel'' contrasts with European practices of broadcast sowing small-seeded grains like barley, oat, wheat, and rye on freshly tilled soil.

A few years later Gabriel Sagard, a lay brother with the Recollects, missionaries to the Huron in Ontario, provided additional details:

> Clearing is very troublesome for them, since they have no proper tools. They cut down the trees at the height of two or three feet from the ground, then they strip off all the branches, which they burn at the stump…in order to kill them, and in the course of time they remove the roots. Then the women clean up the ground between the trees thoroughly, and at distances a pace apart dig round holes or pits. In each of these they sow nine or ten grains of maize, which they have first picked out, sorted, and soaked in water for a few days, and so they keep on until they have sown enough to provide food for two or three years, … and every year they sow their corn thus in the same holes and spots, which they freshen with their little wooden spade, shaped like an ear with a handle at the end. The rest of the land is not tilled, but only cleansed of noxious weeds… (Sagard 1939:103–104).

Pumpkins were mentioned briefly as a food item and beans even less, with no details about how either were cultivated.

Lafitau (1974:54), a Jesuit working in Canada in the early 18th century, described corn planting among the Iroquois:

> They do not use the plough…all they need is a piece of bent wood three fingers wide, attached to a long handle which serves them to hoe the earth as stir it lightly. The fields, which they are to sow, are not arranged in headlands and furrows as they are in Europe, but in little round hillocks three feet in diameter…They make nine holes in each of these mounds. They cast into each hole a grain of Indian corn which they cover over carefully…Besides maize, they sow horse beans or little limas, pumpkins of a species different from those in France, watermelons and

> great sunflowers. They sow the lima beans next to the grains of their Indian corn, the cane or stalk of which serves them (the lima bean plants) as support as the elm does to the vine. They prepare special fields for their pumpkins and melons, … They keep their fields very clean.

The journals of English and Dutch explorers, who visited Iroquoian villages in the Hudson and Mohawk valleys in the 17th century, often emphasized the productivity of Iroquoian agriculture. But they also drew attention to the ways in which this Native agriculture differed from European practices. Henry Hudson wrote, ''It [a house] contained a great quantity of maize, and beans of the last year's growth, and there lay near the house…enough to load three ships, besides what was growing in the fields'' (Jameson 1909:49). Dutch barber-surgeon van den Bogaert, on a fact-finding mission to Mohawk and Oneida territories in 1634, reported, ''These houses were full of grain that they call *onesti* and we corn; indeed, some held 300 or 400 skipples…We ate here many baked and boiled pumpkins'' (Snow et al. 1996:3). Visiting the village of Tenotoge, near present day Fort Plain, NY, van den Bogaert further recorded, ''The houses in this castle are full of grain and beans'' (Snow et al. 1996:5–6).

In 1653 Adriaen Cornelissen van der Donck provided a detailed description of the agriculture in the upper Hudson and Mohawk Valleys, contrasting Iroquoian agriculture somewhat unfavorably with European farming, but also remarking on its impressive productivity:

> The women do all the farming and planting. They grow no wheat, oats, barley, rye etc, and are unacquainted with plowing and spadework, and do not keep their lands tidy. Grain for bread and porridge they obtain by planting Turkish wheat or corn together with assorted beans…Garden vegetables they have none but pumpkins and squashes…Nevertheless they raise so much corn and beans that we purchase these from them in fully loaded yachts and sloops. They know nothing of manuring, fallow seasons, and proper tillage. The labor they devote is all manual, using small adzes…(Snow et al. 1996:121).

Marquis de Denonville came down from Montreal in 1687 to lead a French military attack against the Seneca. Denonville estimated that over a nine-day period his army destroyed 1.2 million bushels of corn, both as stored grain and from plants still standing in the field (O'Callaghan 1850).

> After having destroyed a vast quantity of fine, large corn, beans and other vegetables of which there remained not a single field, and after having burned so large a quantity of old corn that the amount dare not be mentioned…The quantity of corn which we found in store in this place, and destroyed by fire is incredible…(O'Callaghan 1853:367).

In 1696 Count Frontenac attacked the Onondaga and reported destroying cornfields that extended two and half leagues around the town (O'Callaghan 1853).

A century later, Sullivan's expedition during the Revolutionary War delivered a devastating blow to the towns and agriculture of the Seneca and

Cayuga nations. Sullivan wrote to George Washington, describing the agricultural productivity of the Cayuga towns.

> He [Col. Butler] also destroyed two hundred acres of excellent corn, with a number of orchards, one of which, had in it 1500 fruit trees…The quantity of corn destroyed at a moderate computation must amount to 160,000 bushels, with a vast quantity of vegetables of every kind (Sullivan 1930:134).

Two Sisters, Three Sisters, or Monocultures?

Historical records indicate that the Iroquois often grew both corn and beans inter-planted in the same field. For example, Issack Rasiers in 1628, describing Native agriculture on Manhattan Island, wrote:

> They make heaps like molehills, each about two and a half feet from the others, which they sow or plant in April with maize, in each heap five or six grains; in the middle of May, when the maize is the height of a finger or more, they plant in each heap three or four Turkish beans, which then grow up with and against the maize, which serves for props (Jameson 1909:107).

And Devries, describing the agriculture near Fort Amsterdam, wrote in 1643, ''The Indians also make use of French beans of different colors, which they plant among their maize… When the maize…is grown to two or three feet high, they stick the beans in the ground alongside of the maize-stalks'' (Jameson 1909:209). Lafitau (1974) also writes specifically of beans planted alongside corn. Peter Kalm, describing mid 18th century Iroquois agriculture wrote, ''One or two weeks after the…Iroquois have planted the maize, they plant beans in the same place. The maize thus serves as a prop on which the beans can lean and twine'' (Larsen and Kalm 1935:106). Samuel Shute, a lieutenant in Sullivan's campaign, recorded on Tuesday, September 7, 1779 at the north end of Seneca Lake that they ''found two hundred acres of exceedingly good corn, intermixed with beans, squashes, pompions & a few potatoes'' (Cook 1887:207). These eyewitness accounts indicate that at least some Iroquois fields were inter-planted with corn, bean, and squash in the 17th and 18th centuries.

Dutch, English, and French observers in the mid 17th to the early 18th centuries frequently mention corn and beans together as two major Iroquoian crops, but their descriptions are insufficiently detailed to determine whether they were grown as a two-crop polyculture or as monocultures in separate fields. For example, Sagard (1939) describes the cultivation of corn in great detail, but he reports nothing about the planting of beans.

According to Arthur Parker (1968:27), the Seneca ethnographer who reported on Iroquois agricultural practices in the late 19th and early 20th centuries, ''Among the Senecas, in planting corn, the seeds of squash and bean were sown in every seventh hill because it was thought that the spirits of these three plants were inseparable.'' And also, ''The Iroquois generally planted their squashes in the same hills with corn and some kinds of beans. Beside the land and labor saved…there was a belief that these three vegetables were guarded by three inseparable spirits and that the plants would not thrive apart in consequence'' (Parker 1968:92). But Parker uses the word ''generally,'' suggesting that the practice was not universal. The historical records for including squash as one of the three sisters are even less certain. In fact, Lafitau (1974) noted specifically that the Huron planted squash in fields separate from their corn/bean fields. Other European reports frequently mention squash in the list of crops grown by the Iroquois, but whether they were grown as part of polyculture or in their own fields, is not specifically described.

Critical Review of the Literature on Corn Productivity in Eastern North America

We have found only two reports of field trials or demonstrations to estimate yields of Northern flint corns that might be similar to what native farmers produced. Lewandowski (1987) reported yields of 27 bu/acre in a garden plot in central New York, using an open-pollinated corn similar to the type the Iroquois grew. He planted corn in hills spaced to give a final plant population of approximately 11,000 plants/acre. Munson-Scullin and Scullin (2005) planted an open-pollinated Northern flint in southern Minnesota in a three-year trial that used agricultural practices similar to those of the Hidatsa, Mandan, and Arikara. They recorded yields of 40, 30, and 25 bu/acre in the first, second, and third years, respectively, of the experiment. Neither of these trials was replicated and plot sizes were too small to give reliable estimates of corn yields. In addition, neither study provided a cropping history of the fields, nor was there an indication of the amount of nitrogen that might be available for the corn. Consequently, their results are not useful for estimating the productivity of Iroquoian corn.

Most of the literature on corn productivity among indigenous farmers comes from the anthropological and historical sources, which provides anecdotal information on yields but no data specifically relating a given quantity of corn produced on a unit of land area. Consequently, scholars have relied on the historical and ethnographic literature to make yield estimates. Sagard (1939) reported that corn grown by Huron farmers contained between 100 and 400 kernels on each ear. Heidenreich (1971) used this information to determine probable corn yields for the Huron. He estimated that their cornfields contained approximately 2500 hills per acre with three plants per hill, each plant bearing two ears. Heidenreich used the yields of 20th-century Ontario corn growers to estimate the effects of declining soil fertility on corn yields under continuous cultivation. He calculated that Huron farmers would have produced an average of 27 bu/acre over the ten-to-twelve year life of their fields, starting with a high of 46 bu/acre when the land was first put into production, and declining to seven to ten bu/acre when the field was abandoned because of declining soil fertility. Sykes (1980) reduced Heidenreich's estimate of Huron corn yields to 14 bu/acre to account for losses from corn pests and the reduction in area that could be cropped because of the presence of stumps etc. More recently, Baden (1987) and

Foster (2003) have used soil fertility depletion models to predict corn yields of indigenous farmers in the southeast in pre-contact and colonial times. They concluded that farmers in this region would have obtained no more than 30 bu/acre.

Heidenrich, Sykes, Baden, and Foster assumed that fields managed by Native farmers in Ontario and the southeast would have experienced declining soil fertility (and reduced corn yields) at rates similar to what Canadian and U.S farmers experienced in the 20th century when they plowed and planted continuous corn without the use of fertilizers or manures. But this conclusion neglects the critical role that primary tillage (plowing) plays in the loss of soil organic matter and the resulting inability of plowed soils to supply nutrients to crops (Magdoff and Weil 2004; Wolf and Snyder 2003).

When soils are plowed and cropped, total soil organic matter declines by 50% within 30 years, but more importantly, at least 90% of the active fraction of organic matter is lost within the first ten years of cultivation (Brady and Weil 2002). This active fraction controls nitrogen mineralization, the primary mechanism for providing nitrogen to corn that is grown without inorganic fertilizer or manure, or without forage legumes (i.e., clover or alfalfa) in rotation. Once soil organic matter levels fall below 2%, most of the organic matter is in the passive fraction, which releases little nitrogen through mineralization (Brady and Weil 2002). Loss of soil organic matter results primarily from oxidation that occurs when soils are plowed and exposed to air. Although highly productive crops deplete organic matter, in less intensive agricultural systems, the largest loss comes from tillage; soils that are cropped, but not plowed, have much higher levels of soil organic matter than soils that are plowed and cropped (Brady and Weil 2002; Weil and Magdoff 2004; Wolf and Snyder 2003).

In most cropping systems nitrogen is the major limiting nutrient for corn, and its availability controls yield levels. When farmers do not apply inorganic nitrogen fertilizers or animal manure or do not use crop rotations with forage legumes, corn yields are determined primarily by the amount of organic matter in their soils. Soils with high amounts of organic matter (4% and above) can supply large amounts of nitrogen through mineralization. Approximately 20 to 40 lb of nitrogen is released per acre annually for each percent organic matter; consequently, soils with 4% organic matter could supply nitrogen between 80 and 160 lb/acre (Wolf and Snyder 2003), which is more than sufficient for moderate corn yields of 40 to 75 bu/acre without the use of inorganic fertilizer or manure applications. Provided that soils are not plowed, the organic matter levels will remain in this range for long periods of time because oxidation of the organic matter is limited and these modest yields can be sustained. For example, a corn yield of 50 bu/acre removes nitrogen at a rate of approximately 50 lb/acre in the grain (Martin et al. 2006). An Alfisol[3] in central New York with 4% organic matter would release approximately nitrogen at a rate of 90 lb/acre annually (Brady and Weil 2002; Wolf and Snyder 2003). Precipitation would provide an additional 15 lb/acre and contributions from decomposing plant resides could be expected to provide an additional 10 to 15 lb/acre resulting in 115 lb/acre total available nitrogen (Loomis 1978). Even though a corn crop can use only 50% of the available nitrogen, this soil can readily supply the 50 lb/acre of nitrogen needed to produce 50 bu/acre. As long as crop yields are moderate and the field is not plowed, organic matter levels and corn yields will remain stable.

In order to predict initial yield levels at any site, one needs to know how much organic matter was present before the soils were plowed. Organic matter levels in unplowed soils vary according to climate, vegetation, soil texture, and drainage. They are higher in soils formed under grassland than forests, and higher in humid, cool regions compared to hot, dry areas (Brady and Weil 2002). But soil organic matter levels are specific to particular fields or small geographic areas, and they cannot be predicted accurately over larger regions. Heidenreich, Baden, and Foster did not establish soil organic matter levels during the pre-contact period in Ontario or the southeastern US that would have provided an accurate prediction of corn productivity in each area prior to the establishment of Euro-American agriculture. Consequently, we believe they underestimated corn yield levels because they incorrectly assumed that soil organic matter levels and fertility levels in unplowed Native corn fields would be similar to those of Canadian and US farmers who had plowed their fields for decades.

Schroeder (1999), combining yield data from 19th-century Native farmers practicing traditional agriculture with a reassessment of the historical/anthropological literature, asserted that corn yields in the eastern woodlands and Great Plains averaged 10 bu/acre in prehistoric times and less than 19 bu/acre in the early 19th century. According to Schroeder, estimated corn yields for Native American farmers in 17th, 18th, and 19th centuries of 15 to 45 bu/acre are inflated for several reasons. 1) Accounts by first-hand observers are suspect because they were provided by people who knew little about corn and many accounts are not detailed enough to provide reliable information. 2) Euro-American farmers in the 19th and early 20th centuries seldom produced more than 15 to 30 bu/acre even though they used plows, planted corn at higher densities, and grew corn in monocultures, all of which lead to higher yields. Consequently, Native Americans farmers of earlier times who did not utilize these practices would have obtained much lower yields. 3) Nineteenth-century censuses of Native American agriculture consistently record yields between 15 to 30 bu/acre, indicating that yields in earlier times would have been lower still. We limit the following discussion to Schroeder's arguments that concern Native corn production in general or within Iroquoia in particular, and exclude those for the Great Plains, the southeast, or New England.

Schroeder questions a Jesuit report in 1639 that Huron corn yielded one hundred grains for each one planted, and a report in 1750 that the corn yielded a thousand fold (Thwaites 1959). She suggests that the French missionaries had little knowledge of corn and cared little about its production; consequently, the ''productivity estimates given in the Jesuit Relations should be considered as unreliable…'' (Schroeder 1999:501). We disagree. Although the Jesuits in Huronia were not agricultural experts, their observations of corn productivity are quite reasonable. A single ear of Northern flint corn contains 200 to 400 kernels (Brown and Anderson 1947) and each kernel can produce a plant with one primary, and one, two, or more secondary ears. Consequently, as Sagard and the Jesuits observed, Huron farmers, could have frequently harvested 100 to 400 kernels for every kernel planted, and in good years, as many as 400 to 600 kernels. Although this is still well below the 1000 return reported in the 1750 Jesuit record, we believe the lower estimates by both Sagard and the Jesuits are sound.

Schroeder omits the many first-hand observers who provided detailed reports of corn productivity of Iroquois farmers in central New York in the 17th and 18th centuries. She makes no reference to the reports of Denonville's expedition (described above) to Seneca and Onondaga territories in 1687 (O'Callaghan 1853) or the journals of the Sullivan Campaign Revolutionary War soldiers (Cook 1887). These soldiers (Beatty, Blake, Burrows, Dearborn, Fogg, Gookin, Hubley, Jenkins, McKendry, Norris, and Shute), who were primarily colonial Euro-American farmers and likely very knowledgeable about corn production, provided a remarkably consistent assessment of corn productivity in the heartland of the Iroquois Confederacy. In the late summer of 1779, they described:

> Beatty, August 30: ''Our Brigade destroyed about 150 acres of the best corn I ever saw'' (Cook 1887:27).
> Burrowes, August 27: ''We got this night at a large flat three miles distant from Chemung where corn grows as cannot be equaled in Jersey…in such quantities…would be almost incredible to a civilized people'' (Cook 1887:44).
> Burrowes, August 30: ''The land exceeds any that I have ever seen. Some corn stalks measured eighteen feet, and a cob one foot and a half long'' (Cook 1887:45).
> Fogg, August 27: ''Here was an immense quantity of corn, some of whose stalks measured fifteen feet. Beans and squash were in abundance…'' (Cook 1887:94).
> Gookin, August 13: ''… destroyed large fields of their corn, beans, potatoes, squashes, cucumbers, water melons &c, they plant with as much exactness as any farmer…''(Cook 1887:105).
> McKendry, September 10: ''…the Army proceeded on ½ mile and encampt near their Corn, which was in great plenty, near a mile in length'' (Cook 1887:205).
> Shute, September 7: ''It [town of Chemung] is situate 2 miles from Seneca Lake which is thirty five miles long and in some places 10 broad & the most rich and fertile country al around it-We found 200 acres of exceedingly good corn intermixed with beans, & squashes pompions & a few potatoes'' (Cook 1887:271).

In addition to these qualitative descriptions, four officers (Norris, Dearborn, Burrows, and Hubbley) estimated the amount of corn destroyed at particular sites of the campaign, ranging from 5,000 to 60,000 bu. As noted above, Sullivan reported destroying 160,000 bushels of corn (Cook 1887).

One might question these estimates on three counts: first that armies routinely exaggerate their accomplishments; second, that it is impossible to determine corn productivity because the accounts do not distinguish between corn that was destroyed in the field from that in storage; and third, that there is no link between quantity of corn and the area of land from which it was harvested. We argue that although corn productivity per unit land area cannot be determined from these accounts, taken as a whole the accounts contradict Schroeder's assertion that Native farmers in the northeast produced corn yields in the range of 10 to 19 bu/acre. A primary purpose of the Sullivan Campaign was to destroy the food-producing capability of the Iroquois (Sullivan 1930) because in addition to supplying their own villages with corn they were also supplying corn to the British army. Cornfields that yield less than 20 bu/acre would hardly have produced sufficient food for the needs of Iroquois communities, let alone those of the British army in western New York. Nor would Sullivan's army have spent days destroying such meager cornfields. Finally, the sheer size of many Iroquois agricultural fields, 100 to 200 acres, indicates that the Iroquois were very successful agriculturalists. No farmer in a humid, temperate region with fertile soils would invest effort in planting such large acreages of corn for a return of 10 bu/acre. Farmers in this region would likely have regarded such low corn yields as a crop failure.

Schroeder's second argument asserts that early American farmers grew corn that yielded only 15 to 30 bu/acre while using advanced plant management techniques such as plowing, high plant density, and monocultures to obtain even these low yields. Neither the historical record nor agronomic knowledge supports this claim. Although *average* corn yields in eastern North America were very low in the 17th through early 20th centuries, numerous records document that American farmers in the northeast frequently produced corn yields of 50 to 100 bu/acre, and yields of 100 to over 200 bu/acre were recorded in many parts of the country, including 19th-century New York (Enfield 1866; Montgomery 1913; Plumb 1895).

Farmers obtained these higher corn yields from fields with high organic matter levels, either fields brought into cultivation from a virgin state, or fields where applications of animal manures or forage legumes increased organic matter levels. Conversely, lower yields were produced on soils that had been continuously plowed and cropped without amendments. By the early 20th century, agricultural scientists recognized that soil depletion resulted from the loss of soil organic matter; that soils that had ''once produced from seventy-five to one hundred bushels of corn per acre will not now produce twenty bushels to the acre'' (Smith 1914:12). Most agricultural scientists and some farmers knew that higher yields could be obtained on worn-out soils by applying animal manure or using leguminous crops to increase soil organic matter (Enfield 1866; Plumb 1895). Contrary to Schroeder's assertions, American farmers in the 19th century were capable of producing very high corn yields if they increased soil organic matter levels. Management practices of American farmers, however, differed greatly from those of Native farmers. Below we discuss effects of tillage (plowing), plant density, and intercropping on corn yields.

While plowing can be beneficial to crop production, it also leads to the destruction of organic matter and increased soil erosion (Brady and Weil 2002; Weil and Magdoff 2004; Wolf and Snyder 2003). Since the 1950s agricultural scientists have urged US farmers to reduce or eliminate the amount of tillage used to prepare soils for planting. Corn yields under reduced or no tillage can be equal to or even greater than those under conventional tillage with moldboard plows (Weil and Magdoff 2004; Wolf and Snyder 2003). As noted above, plowing in the 17th, 18th, and 19th centuries actually contributed to the lower soil fertility and decreased corn yields. Thus, because Iroquois farmers *did not plow*, their soils probably had higher levels of organic matter and consequently they likely had higher corn yields than American farmers.

Higher plant populations can increase corn yields, but there is no indication that Native farmers planted at lower plant densities than their Euro-American counterparts. In fact, settler farmers likely grew corn at *lower* plant populations than Iroquois farmers because Americans planted corn in 36-to-48-inch rows to accommodate the animal drawn plow, planter, and cultivator. These row spacings produce corn populations of approximately 14,500 plants/acre for 36-inch rows and 8000 plants/acre for 48-inch rows. Since Native farmers used neither plows nor draught animals, they could easily have planted at higher densities.

Schroeder also attributes higher corn yields to mono-cropped fields compared to those that are intercropped and concludes that because many Native Americans farmers planted corn in polycultures, their yields would be lower. The agronomic literature does not support this assertion, showing that crops gown in polycultures can yield the same as monocultures, and often higher (Andrews and Kassam 1976; Gliessman 1986; Hiebsch and McCollum 1987; Innis 1997; Kass 1978; Sanchez et al. 1982; Vandermeer 1989; Willey 1979). Although much of the highest yielding corn today is grown as monocultures in industrialized countries, these high yields come primarily from efficiencies and advancements related to chemical weed control, inorganic fertilizers, and hybrid varieties, technologies unavailable to American farmers in the 19th century. Under less mechanized and industrialized conditions, polycultures have distinct advantages over monocultures because of more efficient use of limited resources, more stable ecosystems, and reduced risk (Innis 1997; Mt.Pleasant 2006; Vandermeer 1989; Willey 1979).

Schroeder used agricultural census data to support her claim for reduced Native American corn yields, noting nine incidences of corn yields ranging from 10 to 31 bu/acre from eight Iroquois reservation communities in an 1845 census (Schoolcraft 2002). With the defeat of the Iroquois Confederacy following the Revolutionary War, Iroquois communities were forced from their traditional homelands, which encompassed most of present day New York State, to small tracts of land that were less than five percent of their original territories. By the end of the 18th century, many of their social, cultural, political, and economic systems were radically disrupted, and most communities struggled to adapt to these new conditions. Agriculture was perhaps most affected by these wrenching changes. Throughout the first half of the 19th century, Iroquois communities were systematically removed from the best agricultural land to allow American farmers to settle on them (Hauptman 1999). Iroquois women, who had been their communities' farmers for hundreds of years, were pressured to step down from farming to allow men to become the primary agriculturists (Bonvillain 1989; Holly 1990; Jensen 1977; Rothenberg 1980; Wallace 1972). Yield levels reported by Schoolcraft reflect corn production in disrupted Iroquois communities, on less productive farmland. Although Iroquois women were likely still involved in some agricultural activities, at the time of the census much of the farming was done by men who lacked the long experience and knowledge of Iroquois women. Consequently, these corn yields cannot be considered representative of Iroquois agriculture prior to the Revolutionary War.

Field Experiments

In order to more effectively evaluate current views of traditional agricultural practices of the Haudenosaunee and expand our knowledge of the Three Sisters Mound System, we designed experiments to establish yield levels, to determine the effects of mound spacing and plant density on corn yields, and to compare the Three Sisters polyculture yields with monocultures of the same crops. We conducted these experiments in two different soil resources and climactic regimes.

Tompkins County

The first field experiments were conducted in eastern Tompkins County, New York in 1993 and 1994 on land that had gone out of agricultural production in the previous decade. The field we chose had not been farmed for more than 20 years. The soil resources here are typical of much of the New York's Southern Tier. Although capable of producing moderate crop yields, the acidic soils, combined with a short growing season because of high elevation, made many farms in this area increasingly uncompetitive in the 20th century.

Long before New York farmers settled and farmed these lands, they were likely part of the extensive territories of the Iroquois Confederacy, controlled by either the Onondagas, who originally occupied a large swath of land through the central portion of what is now New York State, or the Cayugas who controlled land to the west of the Onondagas. The original Onondaga and Cayuga homelands contained large tracts of very productive soils. Consequently, it is unlikely that either Onondaga or Cayuga farmers used the Tompkins County land where we conducted our first field trials for corn production. Instead, they would have chosen the high-lime soils that lie in a band across the center of the state for most of their corn growing (Figure 1). Although the soil and climatic resources on the Tompkins County farm are marginal for corn grain production, the land was owned and occupied by a Native American family who were actively homesteading it and growing a modest acreage of traditional Iroquois open-pollinated corn.

Methods

The first experimental crop was planted in early June on a field that had been moldboard plowed earlier in the season. Located at 1700 ft elevation, on a Lordstown Channery silt loam (a Typic Dystrudept), the farm had approximately 1900 growing degree days[4], or 130 to 150 frost free days.

We used a randomized block design with eight replications of eight treatments: corn, bean, and pumpkin polycultures planted in 30-, 40-, and 48-inch-spaced mounds; corn monoculture planted at the same spacing; bean monoculture in 40-inch-spaced mounds. Since squash/pumpkin plants spread aggressively, regardless of their original density, we planted only five mounds per plot in the squash monoculture. Each plot measured 10 ft by 20 ft. Mounds

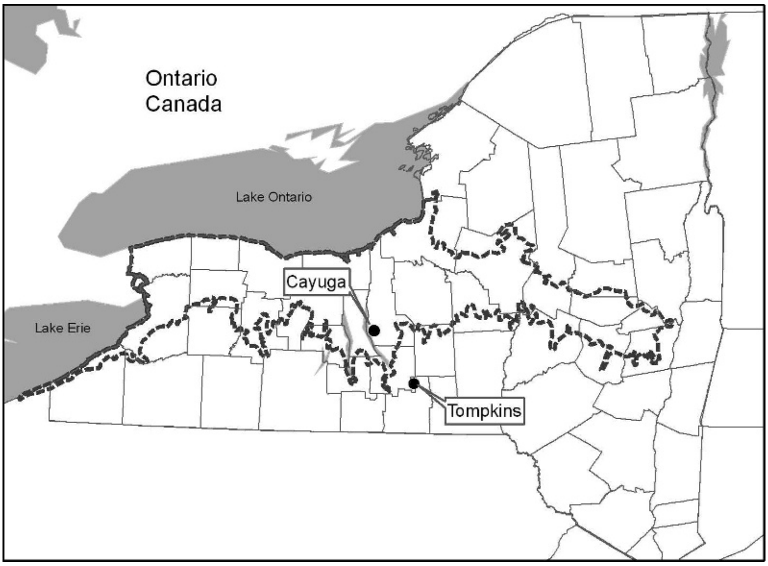

FIGURE 1. Location of the two field sites. Area within dotted lines contains New York State's most productive agricultural areas based on the presence of fertile soils, sufficient rainfall and growing season.

were formed by hand and measured approximately 24 inches wide by 8 inches high.

We used an open-pollinated, white flour corn obtained from Mohawk farmer, Solomon Cook, in Hogansburg, New York. Cook maintained the seeds of numerous traditional Iroquois varieties for several decades on his farm in the Akwesasne Reservation of the St. Regis Mohawks. Brown and Anderson (1947) note that northeastern flour corns grown by some Native populations closely resemble the northeastern flints in their morphological characteristics, with little difference except the degree of hard versus soft endosperm in the kernel; they are considered part of the Northern flint group, a group of varieties with eight to ten rows, slender ears, and wide kernels, the most common type of maize in eastern North America and present since at least 1000 A.D (Brown and Anderson 1947). The Northern flints are relatively homogenous morphologically and have retained their morphological similarity over multiple centuries (Doebley et al. 1986). Cook's open pollinated flour corn closely resembles Brown's description of the Northern flint group. It also matches the white flour variety described by Parker (1968) and Waugh (1991); referred to as 'Tuscarora White,' it is still planted today by Haudenosaunee farmers in the northeast. Consequently, we are confident that this corn is similar to that used by Iroquois farmers in the 17th and 18th centuries.

The corn was planted by hand in early June with five kernels in each mound, evenly spaced. These were thinned to three plants after they emerged. Scarlet runner beans (*Phaseolus coccineus* L.) were planted by hand approximately two weeks after the corn emerged, with one seed planted at the base of each emerged corn plant in the polyculture plots and three beans per mound in bean monoculture plots. We obtained these beans, identified as ''Seneca bean'' from a collection of heirloom Iroquois seeds. They are planted widely across contemporary Iroquoia and have been grown in the area for more than 100 years. We later discovered that these were scarlet runner beans (*Phaseolus coccineus* L.), not *Phaseolus vulgaris*, which would have been used in the 17th and 18th centuries. We judged, however, that *P. coccineus* would perform similarly to many varieties of *P. vulgaris*. We provided poles for the beans to climb in bean monoculture plots. Pumpkin (*Cucurbita pepo* L.) variety Connecticut Field was planted between the mounds in each of the polyculture treatments. Given their aggressive growth habit, we planted only three seeds for every six mounds within polyculture treatments. In the squash monoculture plots, we planted three seeds in each of five mounds.

Deciding how to provide the nutrients for the crops was a complex decision. Crops can be supplied with macronutrients (nitrogen, phosphorus and potassium) through four strategies: 1) decomposition/mineralization of organic nitrogen present in soil organic matter; 2) applications of animal manure or compost; 3) decomposition/mineralization of forage legumes grown in rotation or as green manures; and 4) applications of inorganic fertilizers. Most farmers today use some combination of these strategies, but Iroquois farmers relied exclusively on soil organic matter. When Euro-American settlers displaced Iroquois farmers, they introduced new crop management practices–frequent use of plows and more intensive row crop agriculture, both of which decreased soil organic matter. Under these practices, soils can provide satisfactory crop yields for several years, perhaps even decades, depending on the original levels of soil organic matter; but yields eventually decline when organic matter levels reach 2% or less. All of New York's agricultural soils were intensively plowed beginning in the 19th century. Because New York farmers did not regularly apply animal manure and rotate crops with forages until the middle of the 20th century, within a couple of decades fields planted in corn and other row crops would have had much lower levels of soil organic matter than the same fields when they were managed by Iroquois farmers in the 17th and 18th centuries.

Since it was impossible to restore organic matter to levels similar to those Iroquois farmers would have encountered, we relied on a combination of strategies to meet crop needs. Our goal was to provide sufficient quantities of plant nutrients to mimic the conditions found in Iroquois fields so that crop yields would not be compromised by a lack of nutrients. We surmised that because we were planting an open–pollinated corn variety with limited yield potential, nutrient requirements would be moderate. The field had been in meadow/pasture for many years, and with close to 3% soil organic matter it would likely release sufficient nitrogen for the corn crop during the growing season. But prior to its use as pasture, it had a long history of cash crop production. To eliminate yield constraints from a shortage of macro-nutrients early in the growing season, we applied 25 lb/acre nitrogen, 22 lb/acre phosphorus, and 42 lb/acre potassium after the field was plowed and before the mounds were formed. No additional fertilizer was applied after the crops were planted. During the growing season, we weeded the plots by hand multiple times, but weed pressure was considerable and likely hindered crop yields. All plots were harvested by hand in October with fresh and dry matter weights obtained for corn grain, bean, and pumpkin.

We repeated the experiment in 1994 with identical treatments, fertilizer, and weed control practices in the same plots. Plots were again harvested by hand and yields reported as in 1993. Analysis of variance and least significant differences among yield data in both years were determined using SAS program version 9.1.

Cayuga County

In 1996 and 1997 we established Three Sisters experiments at Cornell University's Musgrave Research Farm. The plots were on a Honeoye/Lima soil (a Glossic Hapludalf) located at 860 ft elevation in an area with approximately 2200 growing-degree days or 150–170 frost-free days. The Musgrave Farm lies within the band of the state's most productive agricultural land (Figure 1). These lands were originally part of the ancestral territories of the Cayuga Nation which recently reestablished its presence in the area with the purchase of land located about 5 miles from the Cornell farm. With large acreages of relatively level fields in predominantly high-lime soils, and the additional advantage of a longer growing season, Iroquoian farmers would have used this area intensively before they were removed and displaced by Euro-Americans in the late 18th and early 19th centuries. The Musgrave Research farm today is surrounded by active dairy and cash grain farms, so we chose a relatively isolated field to minimize the risk of cross-pollination from hybrid corn.

Methods

The design of our earlier experiments in Tompkins County had confounded the effects of plant density by allowing plant population to change when spacing between mounds was varied. In 1996 we established three corn plant populations: 10,000, 15,000, and 20,000 plants/acre, and then planted each of these populations at three different mound spacings: 40, 48, and 60 inches. In 1996 we planted only one replication of the nine treatments (three populations by three mound spaces). No monoculture treatments were established.

In 1996 the field was plowed and disked in early June. Mounds (approximately 24 inches in diameter and 8 inches high) were constructed by hand on June 6th, 7th, and 10th in plots that measured 10 ft by 10 ft. We used corn seed (Tuscarora White) saved from earlier experiments in Tompkins County, and purchased scarlet runner bean and Connecticut Field pumpkin seeds. Corn was planted by hand on June 11th, pumpkin on June 18th, and bean on June 27th. The corn was over-planted in each plot and later thinned to the desired density for each treatment. Bean densities varied according to corn population/spacing. Pumpkin densities were uniform across the experiment; they were planted in eight small hills (three seeds per hill) established between the larger mounds in each plot.

We used the same approach to providing plant nutrients to these fields as in Tompkins County, but with different outcomes. Before we initiated the field trials in 1996, the Cayuga field site had been in continuous corn production for at least three years and had not been planted to a forage legume in the previous five years. For at least several decades before Cornell purchased the land in the late 1940s, it was a cash-grain farm with no manure applications; it was seldom if ever manured from then on. The field had also been moldboard or chisel plowed almost exclusively for its entire cropping history, both before and after Cornell's acquisition. We anticipated that nitrogen would be limiting because organic matter levels were just over 2%. These soils have poor structure, decreased water-holding capacity, and less ability to provide nutrients to crops.

Soil tests also indicated that phosphorus and potassium were in the low to moderate range. Although the yield potential of the open-pollinated Iroquois white corn is lower than modern hybrids and therefore has a lower nitrogen requirement, we expected higher yields in this environment compared to Tompkins County. Soils in this field, prior to use by Euro-American farmers, would have had soil organic matter levels sufficient to produce at least 50 bu/acre. Consequently, we calculated that supplying about 100 lb/acre nitrogen and modest amounts of potassium and phosphorus would provide an equivalent level of fertility as that of Iroquois fields. We applied 25 lb/acre nitrogen, 22 lb/acre phosphorus, and 42 lb/acre potassium before the mounds were built in early June to ensure that the crops had adequate soil nutrients to germinate and make good early growth. Then, in mid-July we applied additional 80 lb/acre of nitrogen to supply sufficient nitrogen for the corn in its most rapid growth phase. All plots were weeded by hand multiple times in July. We harvested the entire plot of each treatment on October 22nd and 23rd and recorded fresh weights for corn, bean, and pumpkin in each plot. Sub-samples of each crop were subsequently dried with dry matter yields reported for each crop.

In 1997 at the Musgrave Research Farm, we established a new experiment in another section of the same field. We planted corn at two spacings (40 and 60 inches) and two densities (10,000 and 20,000 plants/acre). We also included monocultures of corn, bean, and pumpkin. Each of the seven treatments was replicated twice in plots that measured 10 ft by 10 ft. The field was prepared similarly to 1996; it was plowed and disked in late May and mounds formed by hand shortly after. Corn (Tuscarora White) was planted in early June, with bean (Genuine Cornfield) and pumpkin (Connecticut Field) approximately two weeks later, after the corn had emerged. We used the same fertilizer regime as 1996, and hand weeded multiple times during July. All plots were harvested by hand in early October and crop yields determined as in 1996.

Results

Tompkins County

In 1993 and 1994, temperatures during the growing season in Tompkins County closely tracked long-term averages for the region (Figure 2). In 1993 rainfall was somewhat higher than normal in June and slightly lower than average in July and August, but the variation was not sufficient to affect the crop growth and development (Figure 3). In 1994 rainfall in both June and August was much higher than normal. But this site has well drained soils that were not negatively affected by the high rainfall.

In 1993 corn yields ranged from 22 to 50 bu/acre (1155 to 2625kg/ha) with significantly higher yields found at the closer spacing (30-inch mounds) compared to wider spaced (48-inch mounds), but there were no differences

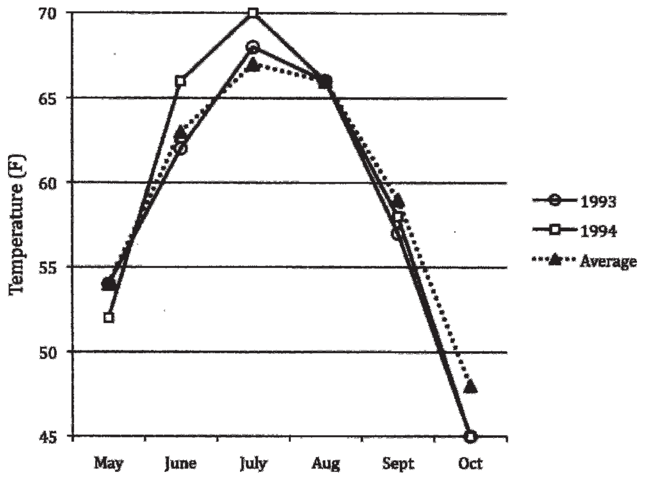

FIGURE 2. Temperatures in Tompkins County in 1993 and 1994 compared to long-term average.

between corn grown in the monoculture compared to corn in the Three Sisters polyculture except at the widest spacing (Table 1). In contrast, while mound spacing had no effect on bean yields, monoculture beans produced approximately six times as many beans as those planted with corn and pumpkin. Pumpkin yields in the polyculture varied with mound spacing, almost 6 times higher at 48-inch compared to 30-inch mounds, and were significantly higher still when planted in monoculture (Table 1).

Corn yields in 1994 ranged from 26 to 40 bu/acre (1390 to 2109 kg/ha). Among the six treatments with corn, only corn in Three Sisters at 48-in spacing yielded lower than corn grown in either polyculture or monoculture at the other spacings. Bean and pumpkin again yielded higher in monoculture than in the Three Sisters, and both bean and pumpkin yielded more in 48-in mounds compared to 30-in mounds (Table 1).

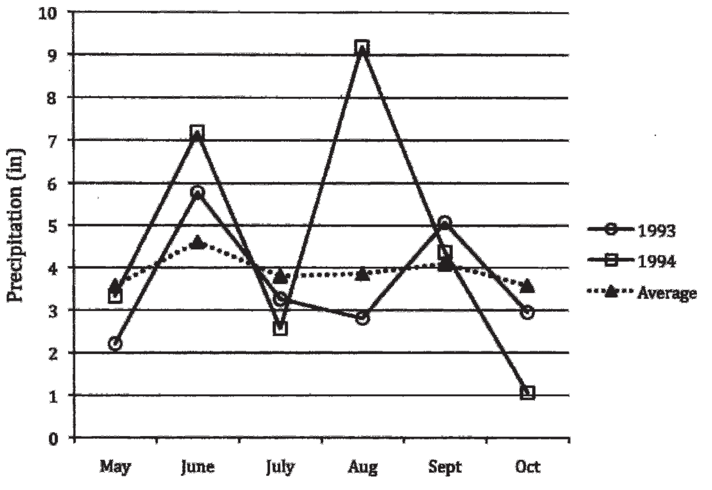

FIGURE 3. Precipitation in Tompkins County in 1993 and 1994 compared to the long-term average.

TABLE 1. Effects of mound spacing on yields of corn, beans, and pumpkin in Three Sisters and monoculture cropping systems. Tompkins County, NY 1993 and 1994. Values within a single column followed by same letter are not significantly different at 5% level of significance.

	Crop Yields[1]					
	Corn (bu/acre)		Bean (lb/acre)		Pumpkin (lb/acre)	
Cropping System/Mound Spacing	1993	1994	1993	1994	1993	1994
Three Sisters						
30 inch	48 a	35 a	149 b	53 b	3368 d	2992 c
40 inch	36 bc	33 ab	118 b	71 b	12915 c	4718 bc
48 inch	22 d	26 b	139 b	24 b	19703 b	7334 b
Corn Monoculture						
30 inch	50 a	40 a				
40 inch	44 ab	39 a				
48 inch	31 c	37 a				
Bean Monoculture			979 a	774 a		
Pumpkin Monoculture					35861 a	30834 a

[1] Corn yields are reported in bu/acre at 15% moisture; bean yields in lb/acre dry matter (DW); pumpkin yields in lb/acre fresh weight (FW).

Cayuga County

Although we did not replicate treatments or establish monocultures of each crop for comparison, in 1996 we measured crop yields at three corn spacings and three corn populations, providing nine observations for each crop in the Three Sisters polyculture. Individual plots were quite large (100 ft^2), and we harvested the entire plot to obtain yields. Consequently, although these data were not appropriate for statistical analyses, we have considerable confidence that these yields reflect the yield potential of the Three Sisters polyculture at this site.

In 1996 and 1997 temperatures were close to normal throughout the growing season (Figure 4), but rainfall varied considerably from long-term means (Figure 5). Above average rainfall in May and September 1996 had little effect on crop growth and development because it occurred early and late in the season. Crops are most susceptible to drought during their fertilization periods that occur in the middle of the growing season. We discuss below the effects of the below average rainfall in August 1997.

In 1996 corn yields in the Three Sisters ranged from 43 to 63 bu/acre (2308 to 4127 kg/ha). The lowest yields came from corn planted at the lowest density, 10,000 plants/acre, and the widest spacing, 60 inches. Overall, corn yields increased with increased corn population and decreased with mound spacing (Table 2). Bean yields were very low, from 16 to 46 lb/acre (18 to 52 kg/ha) with no consistent response to either corn population or mound spacing. Similarly, pumpkin yields varied from 236 to 783 lb/acre (264 to 877 kg/ha) with no consistent effect from corn population or mound spacing (Table 2).

In 1997 all treatments were replicated twice and we included monocultures of each crop, allowing us to compare crop yields in the two cropping systems. We had eight observations for each Three Sisters crop (two repetitions at two corn populations and two mound spacings), giving us considerable confidence in the yield levels. However, with just two replications we could not perform statistical

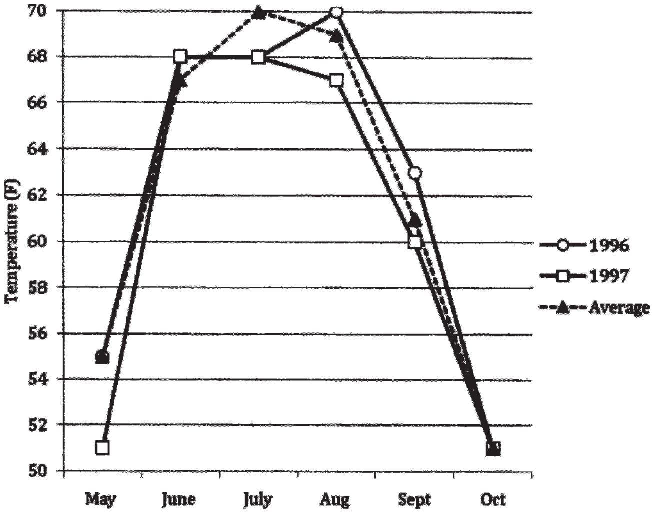

FIGURE 4. Temperatures in Cayuga County in 1996 and 1997 compared to long-term average.

analyses. Corn yields ranged from 51 to 76 bu/acre (2719 to 4052 kg/ha) in the Three Sisters, compared to 70 bu/acre (3731 kg/ha) in corn monoculture (Table 3). Highest corn yields were found at the highest corn population (20,000 plants/acre) and at the closest mound spacing (40 inches). Bean yields in the Three Sisters varied from 16 to 31 lb/acre (18 to 35 kg/ha), highest at the lower corn density and the higher mound spacing. Beans grown as a monoculture yielded over ten times more than the highest bean yields in the Three Sisters (385 versus 31 lb/acre; 431 to 35 kg/ha). Pumpkin yields were considerably lower compared to 1996, with Three Sisters yields ranging from 17 to 76 lb/acre (19 to 85 kg/ha). Pumpkin yields were higher at lower corn densities and less affected

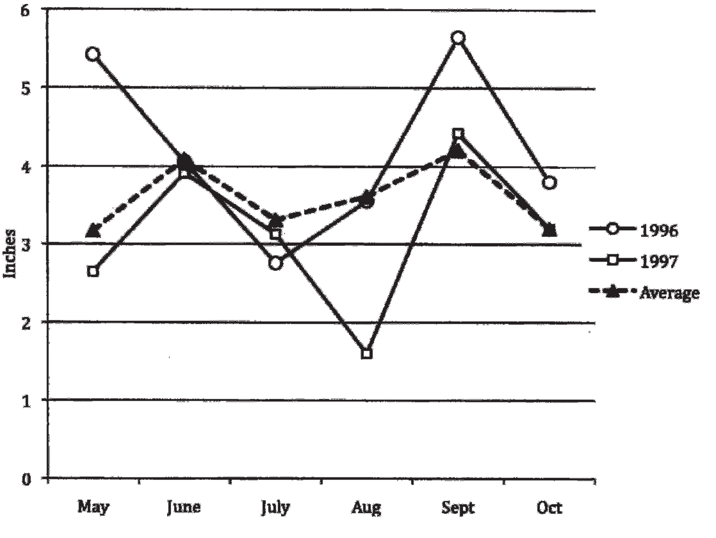

FIGURE 5. Precipitation in Cayuga County in 1996 and 1997 compared to long-term average.

TABLE 2. Effects of corn population and spacing on yields of corn, beans, and pumpkin in Three Sisters cropping system, Cayuga County, NY, 1996.

		Yield[1]			
Crop	Mound Spacing	10,000 corn plants/acre	15,000 corn plants/acre	20,000 corn plants/acre	Mean
Corn (bu/acre)	40 inch	57	63	63	61
	48 inch	51	59	56	55
	60 inch	43	52	60	52
	Mean	50	58	60	56
Bean (lb/acre)	40 inch	46	27	37	37
	48 inch	16	35	18	23
	60 inch	18	28	19	22
	Mean	27	30	25	27
Pumpkin (lb/acre)	40 inch	522	613	236	457
	48 inch	582	316	494	464
	60 inch	401	462	783	549
	Mean	502	464	504	490

[1] Corn yields reported in bu/acre at 15% moisture; bean yields reported in lb/acre dry matter (DM); pumpkin yields reported in lb/acre fresh weight (FW).

by mound spacing. Monoculture increased pumpkin yields almost 20 times over polyculture. The lower-than-normal precipitation in August 1997 likely reduced bean and pumpkin yields without affecting corn yields because corn fertilization occurred in July, when there was sufficient rainfall, but bean and pumpkin fertilization occurred later.

Agronomists use land equivalency ratio (LER) to compare agricultural productivity of polycultures and monocultures for crops that would otherwise be

TABLE 3. Effects of corn population and mound spacing on yield of corn, beans, and pumpkin in Three Sisters and monoculture cropping systems, Cayuga County, NY, 1997.

			Yield[1]			
Crop	Crop System	Mound Spacing	10,000 corn plants/acre	20,000 corn plants/acre	Mean	No Corn
Corn (bu/acre)	Three Sisters	40 inch	66	76	71	
		60 inch	51	55	53	
		Mean	59	66	62	
	Monoculture	40 inch		70		
Bean (lb/acre)	Three Sisters	40 inch	16	16	16	
		60 inch	31	20	26	
		Mean	24	18	21	
	Monoculture	40 inch				385
Pumpkin (lb/acre)	Three Sisters	40 inch	46	21	34	
		60 inch	76	17	47	
		Mean	61	19	40	
	Monoculture					1376

[1] Corn yields reported in bu/acre at 15% moisture; bean yields reported in lb/acre dry matter (DM); pumpkin yields reported in lb/acre fresh weight (FW).

TABLE 4. Land equivalency ratios (LER) for Three Sisters cropping systems in Tompkins and Cayuga Counties, New York, 1993, 1994, and 1997.

	Tompkins 1993	Tompkins 1994	Cayuga 1997
Corn yield (bu/acre) polyculture	1874	1739	4052
Corn yield (bu/acre) monoculture	2231	2075	3731
Ratio	**0.82**	**0.84**	**1.09**
Bean yield (lb/acre) polyculture	132	80	18
Bean yield (lb/acre) monoculture	1096	867	385
Ratio	**0.12**	**0.09**	**0.05**
Pumpkin yield (lb/acre) polyculture	14465	5284	24
Pumpkin yield (lb/acre) monoculture	40164	34534	1541
Ratio	**0.36**	**0.15**	**0.02**
LER	**1.30**	**1.08**	**1.16**

incomparable because they have no common unit of yield (Andrews and Kassam 1976; Vandermeer 1989; Willey 1979). Dividing the yield of each crop in the polyculture by its yield in monoculture provides the ratio; the ratios of each crop are then summed. If the resulting number is over 1.0, the polyculture cropping system is judged more productive than if each of the component crops had been grown as monocultures. In order to make these calculations credible, one must have yield data from monocultures and polycultures at the same site in the same year under the same treatment protocols. Our data met those criteria for 1993 and 1994 in Tompkins County and 1997 in Cayuga County. In all three site/years, the calculated LER was greater than 1.0, ranging from 1.08 to 1.30, indicating that the agricultural productivity was higher with the Three Sisters than under monocultures (Table 4).

Discussion

Corn

We focus on three aspects of these experimental results: corn yields; effects of soil and climate on crop yields; and comparative yields under polycultures versus monocultures. Our corn yields across four site/years, from 22 to 76 bu/acre (1155 to 3508 kg/ha), are much higher than others have reported from field experiments or estimated from the historical and ethnographic literature. Both soils and climate greatly affect corn yields and our field experiments in two different soil and climatic areas convincingly demonstrate that the highest yields were obtained in the band of the highly productive soils across central New York (Figure 1). Yields were almost double, 62 versus 37 bu/acre (3218 versus 1873 kg/ha corn grain) in the high-lime soils and longer growing season of Cayuga County compared to the more marginal soils and shorter growing season in Tompkins County. We argue that these corn yields are similar to, if not somewhat lower than those Native farmers would have obtained.

We manipulated corn plant spacing and population, which can significantly affect corn yields. In our field experiments, Tuscarora White responded to increased plant density and closer spacing with higher yields; we obtained the highest yields (76 bu/acre) with a corn population of 20,000 plants/acre with 40-

inch spacing between mounds (Table 3). These corn yields are similar to those of open-pollinated corn varieties, with comparable morphologies and yield potentials to the Tuscarora White, planted at similar densities in the first half of the 20th century (Castleberry et al. 1984).

We can compare these experimental results with the historical records of mound spacing and population used by Iroquoian farmers in Ontario and New York. Sagard (1939) and Champlain (1907) reported that Huron farmers formed mounds about a pace apart and planted nine to ten corn kernels per mound. If all ten kernels germinated and the seedlings survived, they would have populations over 68,000 plants/acre. But Huron farmers probably over-planted in order to compensate for seed and seedling losses from disease, insects, birds, and other pests. A final plant population of three to four plants per mound is probably realistic, resulting in corn populations ranging from approximately 20,000 to 30,000 plants/acre.

Peter Kalm traveled in eastern North America from 1748 to 1751 and provided detailed descriptions of corn growing, primarily by Euro-Americans. He reported that non-Native farmers planted corn in hills formed by the intersection of perpendicularly plowed furrows. The resulting hills were four to six feet apart, but others were more closely spaced at three feet or less (Larsen and Kalm 1935). Using these measurements we calculate corn populations on Euro-American farms would range from about 3,500 to 14,000 plants/acre, assuming that three plants matured in each hill. During Sullivan's Campaign in 1779, Daniel Brodhead, in a letter to George Washington reporting on his expedition against the Seneca in southwestern New York, wrote, ''I never saw finer corn altho' it was planted much thicker than is common with our farmers.'' (Cook 1887:308). By the 18th century, almost all Euro-American settlers who planted corn were using plows and other tillage implements that required at least 36 in between the rows to allow passage of a horse-drawn plow or cultivator. In contrast, Seneca and Cayuga farmers who planted and cultivated by hand would not be similarly constrained regarding mound spacing. Brodhead's comments may reflect Iroquois knowledge of the importance of high plant populations to achieve optimum grain yields on their fertile fields, and the fact that they could plant their corn much more densely than their Euro-American counterparts because they were not using draft animals. Our Cayuga County experiments used plant populations (10,000 and 20,000 plants/acre) that were considerably higher than Heidenreich estimated (7500 plants/acre) for 17th-century Huron farmers in Ontario, where the growing season was shorter and the soils less fertile, and those Kalm observed for non-Native farmers in New York in the 18th century. Iroquois farmers probably used higher plant densities in the Lake Plain environment of central New York to take advantage of the area's longer growing season and more fertile soils.

Corn yields are also determined by the amount of plant-available nutrients. We argue that central New York soils, when they were cropped by Native farmers prior to the influx of US farmers in the 19th century, were highly productive because they had high levels of organic matter and were inherently fertile. In order to match the nutrient supplying power of 17th- and 18th-century soils, we applied inorganic fertilizers in our experiments to compensate for the loss of soil organic matter resulting from Euro-American farming. If anything, crop yields should be lower on soils amended with inorganic fertilizers compared to soils with high levels of organic matter (Weil and Magdoff 2004).

We also expect that Native farmers could have obtained similar or higher corn yields from the Tompkins County field. Although the yield potential is lower here than in Cayuga County because of less fertile soil and a shorter growing season, the starting organic matter levels were somewhat higher than in Cayuga County because the field had been in pasture/meadow for several years. However the field had been intensively cropped and plowed for many decades during the 19th and 20th centuries, and organic matter levels were likely much lower than those indigenous farmers would have encountered in the 17th and 18th centuries. Consequently, for both sites we argue that corn yields we recorded are similar to or somewhat less than Native farmers would have obtained in these same regions.

These higher yield levels obtained in Cayuga County compared to Tompkins County may explain the clustering of Seneca and Cayuga sites in the band of productive soils and longer growing season after AD 1350 when corn, bean, and squash first appeared together in the archaeological record (Hart and Scarry 1999). The Lake Plains soil/climatic environment is characterized by high-lime soils, formed on glacial till or lacustrine sediments, with 74 to 114 cm precipitation per year, and a frost-free period of 145 to 205 days. In comparison, the Allegheny Plateau has poorer soils and a shorter growing season and consequently has much less agriculture today. These same advantages of the Ontario Lake Plain region would have been evident to farmers in the 17th and 18th centuries. Niemczycki (1984), Hasenstab (1990), and Engelbrecht (2003) all note a larger portion of Iroquois villages located in the Lake Plains and central river valleys of New York in the proto-historic and prehistoric time periods when maize agriculture was a dominant characteristic of Iroquois communities.

Three Sisters compared to monocultures

Land Equivalent Ratios were greater than 1.0 for the Three Sisters, indicating increased productivity per unit area land and suggesting why Iroquoian farmers would have grown the three crops in association. Multiple scholars report that the Three Sisters are deeply rooted in Iroquois ceremonial life and are featured prominently in oral traditions (Fenton et al. 1978; Lewandowski 1987; Morgan 1962; Parker 1968). Lewandowski (1987) and Mt.Pleasant (2006) assert that the Three Sisters cropping system represents a rational and effective use of natural resources to optimize crop yields without the use of animal manures, fertilizers, or pesticides.

Agronomists recognize that crop polycultures can provide increased productivity and decreased risk compared to monocultures, particularly for subsistence farmers (Andrews and Kassam 1976; Mt.Pleasant 2006; Vandermeer 1989). Subsistence farmers grow cereal grains (i.e., corn, wheat, and rice) with beans, lentils, and peas because these leguminous crops make atmospheric nitrogen available through a bacterial association on their roots. Thus, they provide not only their own nitrogen in the absence of soil-available nitrogen, but some that can be used by cereals, which typically have large nitrogen needs. But the amount of nitrogen that beans make *immediately* available to associated crops is not large. Bean root nodules slough off small amounts of available nitrogen that can be taken up by corn roots, but most of the nitrogen fixed by legumes ends up in the bean seed, which if harvested, removes the nitrogen. Nonetheless, small amounts of nitrogen are contained in bean leaves and stems, and these residues, plus any unharvested bean seeds, would decompose in the field over time, releasing their nitrogen. Over several years, this can represent a fairly substantial pool of soil nitrogen that would become available to corn through the normal decomposition of crop residues and the oxidation of soil organic matter. Most subsistence farmers recognize that corn over time grows better in association with a legume; Iroquoian farmers would likely have observed these same benefits. Corn competes aggressively against other plants because of its size and rapid early growth. If it can get ahead of other crops and weeds, it will outcompete them for light, water, and nutrients. Subsistence farmers usually count on corn to provide most of their calories and will adapt their cropping systems to take advantage of its tremendous productivity. From the historical records on Iroquois communities, we know that corn played a dominant role in agriculture and diet; our experiments confirm its ability to sustain yields even in the presence of other crops.

Our experiments also show more than 50% reductions in bean and pumpkin yields when they were grown with corn compared to monocultures. But farmers can add bean and/or pumpkin to their cornfields without sacrificing corn yields. So if they are primarily interested in harvesting corn, planting a polyculture of corn, beans, and squash will not jeopardize their corn crop and provides a bonus of beans and pumpkins with no additional land required and little additional labor. But if they are primarily interested in harvesting beans or pumpkins, adding corn to the field results in very large reductions in bean and pumpkin yields. If beans and pumpkins are the focus of their agricultural endeavors, it is better to plant each of these crops in its own field as a monoculture. Surely Iroquoian farmers would have noted the dramatic yield reductions of beans and pumpkins when they were planted with corn and the stability of corn yields when it was interplanted with beans and pumpkins.

This suggests that the decision to grow corn, beans, and squash as a polyculture likely involved complex decision-making dependent on multiple and changing objectives. Iroquois farmers probably juggled several factors in deciding whether the trade-off in bean or pumpkin yields compensated for long-term yield increases in corn and the overall increased productivity of the polyculture. Factors such as the availability of other sources of protein and overall stores of food would have figured in their decisions. Pumpkins, in contrast to beans, would not contribute long-term nitrogen benefits when they were grown in association with corn, although they might reduce weed pressure and increase overall plant productivity (Lewandowski 1987; Mt.Pleasant 2006), or as noted by Parker above, serve spiritual beliefs and save labor and land. Squash, unlike corn and beans, has the disadvantage of limited storage life. Where beans and corn could be safely stored for years, allowing accumulation of surplus yields for trade or lean years, harvested squash, even when partially dried, would not likely last more than 6 to 12 months. We suggest that corn, bean, and pumpkin polycultures, while common, were not necessarily uniform across Iroquoia. Farmers' decisions to plant the crops as individual monocultures or as a polyculture resulted from weighing multiple factors which would likely change from year to year and among individual households and communities.

Conclusions

During the 16th, 17th, and 18th centuries Iroquoian agriculturalists cultivated large acreages of multiple crops across present-day New York and Ontario. Their agricultural systems were productive, complex, and dynamic. Since corn grain yields are closely tied to soil and climatic resources, when researchers estimate crop productivity they must distinguish crops grown in agriculturally productive regions from those in more marginal areas. For corn in particular, knowledge of soil characteristics before Euro-Americans began farming the land is especially important. The level of soil organic matter primarily controls corn yields when farmers do not use manure, forage legumes, or inorganic fertilizers in areas that are otherwise suitable for crop production. Euro-Americans used plows to prepare cropland for more than 200 years in eastern North America; over time, these tillage operations dramatically reduced soil organic matter in much of the region's cropland. Consequently, current soil conditions are unlikely to represent the ability of these same soils to supply nutrients to crops grown by Native peoples who did not use plows.

In our research, we found much higher corn yields in the Lake Plain Region of New York compared to the Allegheny Plateau. Results from field experiments indicate that corn yields of 50 to 75 bu/acre are a realistic estimate on the highly productive soils found within the original territories of the Iroquois Confederacy. To achieve these yield levels corn would have been planted at populations of 15,000 to 20,000 plants/acre. Land Equivalency Ratios from these experiments further demonstrate that growing corn, beans, and squash as a polyculture provided greater productivity compared to monocultures of the individual crops because corn yields were not affected by the presence of bean and pumpkin. But we observed large reductions in bean and squash yields when they were grown with corn, indicating that these two crops are much less competitive than corn when grown as a polyculture. However, overall we are less confident of the bean and pumpkin yield estimates because we had many fewer yield samples of these crops and because low rainfall may have reduced yields of both crops in 1997. In addition, since beans and pumpkins have much higher yields when grown as a monoculture, it is impossible to estimate yields of these crops unless one knows whether they were grown alone or intercropped with corn. Our research results, combined with a careful examination of the historical literature, suggests that Iroquoian farmers did not always plant corn, beans, and squash together, but more likely varied their cropping systems according to multiple factors and changing needs.

Notes

[1] We use 'Iroquois' here to refer specifically to the nations and communities that make up the Five (or later Six) Confederacy and 'Iroquoian' to mean the larger group of Native

peoples who were speakers of Northern Iroquoian languages, including, for example, Mohawk, Oneida, Onondaga, Cayuga, Seneca, Tuscarora, and Huron.

[2] Some of the crops noted by Cartier are likely misidentified.

[3] Alfisols have high base status and favorable texture, making them fertile and productive when they are located in areas with sufficient rainfall.

[4] Growing Degree Days (GDD) relates plant growth to air temperature. For corn in New York State, the figure for an individual day is obtained by first averaging the daily maximum temperature and daily minimum temperature, and then subtracting 50 (50° F represents the minimum temperature needed for corn growth). The daily numbers are then summed over the growing season, from the day after the last spring frost to the day before the first fall frost.

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