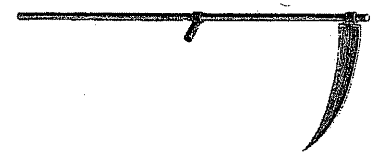
FOUR

Graveyard of Empires

To Protect Your Rivers, Protect Your Mountains

EMPEROR YU (CHINA)



IN THE EARLY 1840S NEW YORK LAWYER, adventurer, and amateur archaeologist John Lloyd Stephens found the ruins of more than forty ancient cities in dense Central American jungle. After excavating at Copán in Guatemala, traveling north to Mexico's ruined city of Pelenque, and returning to the Yucatán, Stephens realized that the jungle hid a lost civilization. His revelation shocked the American public. Native American civilizations rivaling those of the Middle East didn't fit into the American vision of civilizing a primeval continent.

A century and a half after Stephens's discovery, I stood atop the Great Pyramid at Tikal and relived his realization that the surrounding hills were ancient buildings. The topography itself outlined a lost city, reclaimed by huge trees, roots locked around piles of hieroglyphic-covered rubble. Temple-top islands rising above the forest canopy were the only sign of an ancient tropical empire.

With different characters and contexts, Tikal's story has been repeated many times around the world—in the Middle East, Europe, and Asia. The capital of many a dead civilization lives off tourism. Did soil degradation destroy these early civilizations? Not directly. But time and again it left societies increasingly vulnerable to hostile neighbors, internal sociopolitical disruption, and harsh winters or droughts.

Although societies dating back to ancient Mesopotamia damaged their environments, dreams of returning to a lost ethic of land stewardship still underpin modern environmental rhetoric. Indeed, the idea that ancient peoples lived in harmony with the environment remains deeply rooted in the mythology of Western civilizations, enshrined in the biblical imagery of the garden of Eden and notions of a golden age of ancient Greece. Yet few societies managed to conserve their soil—whether deliberately or through traditions that defined how people treated their land while farms filled in the landscape and villages coalesced into towns and cities. With allowances for different geographical and historical circumstances, the story of many civilizations follows a pattern of slow, steady population growth followed by comparatively abrupt societal decline.

Ancient Greece provides a classic example of too much faith in stories of lost utopias. Hesiod, a contemporary of Homer, wrote the earliest surviving description of Greek agriculture about eight centuries before the time of Christ. Even the largest Greek estates produced little more than needed to feed the master, his slaves, and their respective families. Like Ulysses' father, Laertes, the early leaders of ancient Greece worked in their own fields.

Later, in the fourth century BC, Xenophon wrote a more extensive description of Greek agriculture. By then wealthy landowners employed superintendents to oversee laborers. Still, Xenophon advised proprietors to observe what their land could bear. "Before we commence the cultivation of the soil, we should notice what crops flourish best upon it; and we may even learn from the weeds it produces what it will best support."[1] Xenophon advised farmers to enrich their soil both with manure and with burned crop stubble plowed back into the fields.

Ancient Greeks knew about the fertilizing properties of manure and compost, but it is not clear how widely such practices were followed. Even so, for centuries after the revival of classical ideals during the European Renaissance, historians glorified the ancient Greeks as careful stewards of their land. But the dirt of modern Greece tells a different story—a tale of destructive episodes of soil erosion.

With thin rocky soils covering much of its uplands, only about a fifth of Greece could ever support agriculture. The adverse effects of soil erosion on society were known in classical times; the Greeks replenished soil nutrients and terraced hillside fields to retard erosion. Nonetheless, the hills around Athens were stripped bare by 590 BC, motivating concern over how to feed the city. Soil loss was so severe that Solon, the famed reformer of

the constitution, proposed a ban on plowing steep slopes. By the time of the Peloponnesian War (431–404 BC), Egypt and Sicily grew between a third and three-quarters of the food for Greek cities.

Plato (427–347 BC) attributed the rocky slopes of his native Attica to pre-Hellenistic soil erosion following deforestation. He also commented on soil's key role in shaping Athenian society, maintaining that the soils of earlier times were far more fertile. Plato held that the soil around Athens was but a shadow of its former self, citing evidence that bare slopes were once forested. "The rich, soft soil has all run away leaving the land nothing but skin and bone. But in those days the damage had not taken place, the hills had high crests, the rocky plain of Phelleus was covered with rich soil, and the mountains were covered by thick woods, of which there are some traces today."[2] Seeing how harvesting the natural fertility of the surrounding land allowed Athens to blossom into a regional power, Plato held that the root of his city's wealth lay in its soil.

Aristotle (384–322 BC) shared Plato's conviction that Bronze Age land use degraded soil productivity. His student Theophrastus (371–286 BC) recognized six distinct types of soil composed of different layers, including a humus-rich layer above subsoil that supplied nutrients to plants. Theophrastus made a point of distinguishing fertile topsoil from the underlying earth.

Both Plato and Aristotle recognized signs that Bronze Age land use had degraded their region's soil. Several thousand years and several civilizations later, archaeologists, geologists, and paleoecologists vindicated Aristotle's estimate of the timing: farmers arrived about 5000 BC and dozens of agricultural settlements were scattered throughout the region by 3000 BC; cultivation intensified about the time Aristotle posited the first serious effects of soil erosion there. Such knowledge, however, did not prevent classical Greece from repeating the pattern.

Over the past several decades, studies of soils throughout Greece—from the Argive Plain and the southern Argolid in the Peloponnese to Thessaly and eastern Macedonia—showed that even the dramatic climate change at the end of the last glaciation did not increase erosion. Instead, thick forest soils developed in the warming climate as oak forest replaced grassland across the Greek countryside. Over thousands of years the soil grew half a foot to several feet thick depending on local conditions. Soil erosion began to exceed soil production only after introduction of the plow.

The first Greek settlements were located in valleys with good soils near reliable water supplies. As the landscape filled with people, farmers began

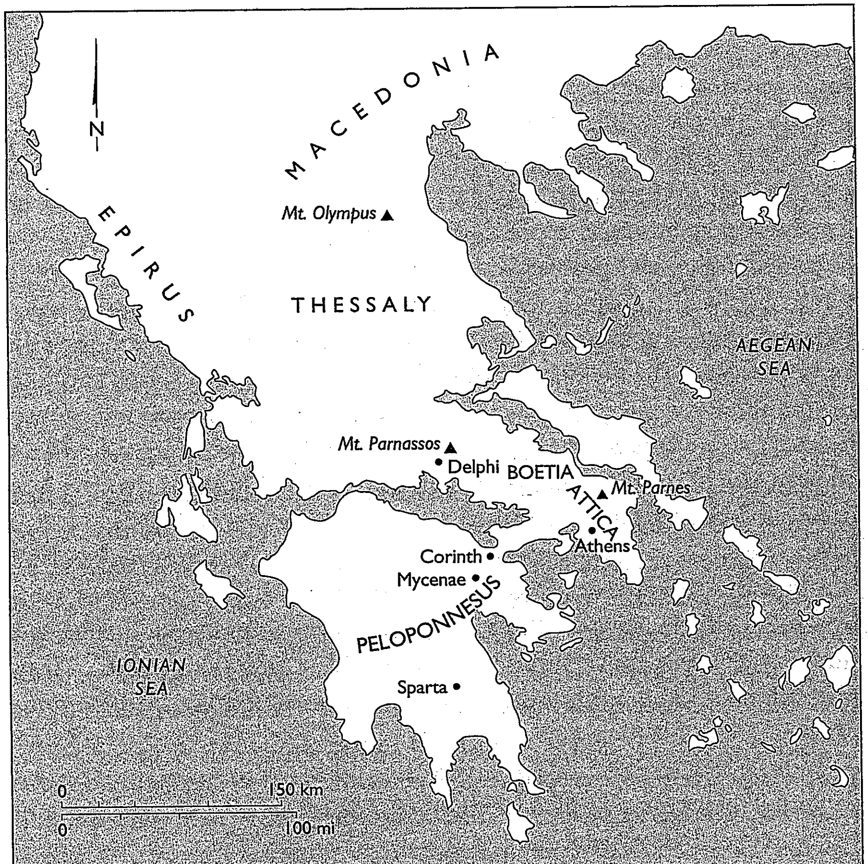


Figure 6. Map of ancient Greece.

advancing onto steeper, less productive slopes. Extensive tilling and grazing stripped soil from hillsides and piled thick deposits of reworked dirt in valleys. Ancient agricultural artifacts can still be found on the rocky slopes of areas that lack enough soil to grow much vegetation.

Sediments trapped in valley bottoms, and remnant pockets of soil on the slopes themselves, record cycles of erosion and soil formation throughout Greece. The deepest layers of valley-filling sediments date from glacial to interglacial climate changes during the past quarter million years. Higher layers in the stack of dirt tell of more recent episodes of hillslope erosion as well as intervening periods when soils developed. The first postglacial

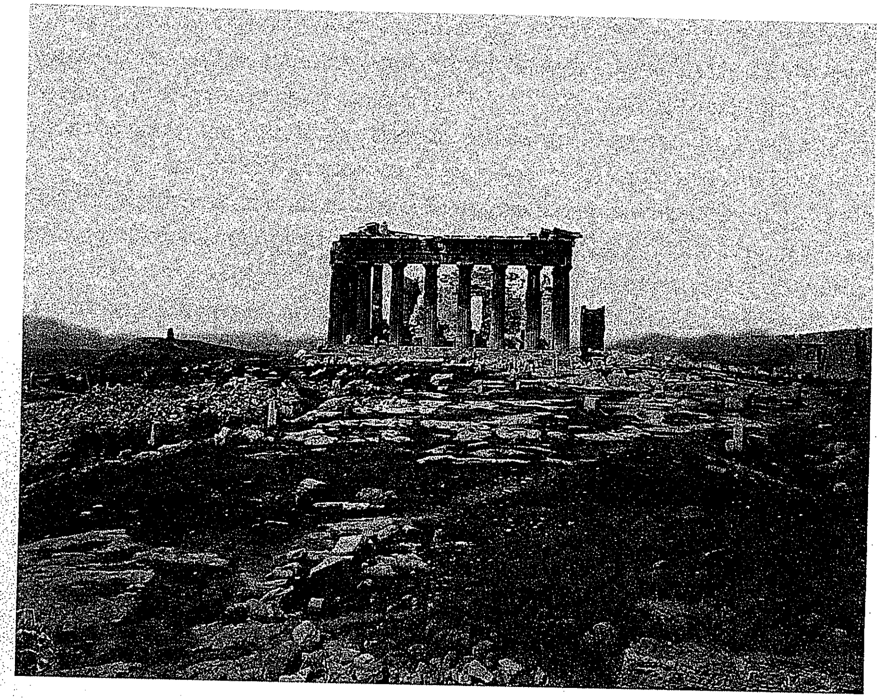


Figure 7. Parthenon. Albumen print by William James Stillman, 1869 (courtesy of Research Library, the Getty Research Institute, Los Angeles, California [92.R.84]).

deposits of reworked hillslope soils in the valleys generally date from the Bronze Age arrival of agriculture. Erosional episodes similar in outline, but different in detail, occurred across ancient Greece where farming spread out of the valleys and onto hillslopes.

Soils of the southern Argolid, for example, record four periods of postglacial erosion during times of intensive land use. The first, from roughly 4500 to 3500 BC, was a time when thick woodland soils were widely settled by early farmers. Introduction of the plow and the spread of farming into steeper terrain led to widespread erosion around 2300 to 1600 BC. Hillslope soils gradually rebuilt during the dark age before the rise of classical Greek civilization. The area was again densely settled in late Roman times and another period of depopulation followed in the seventh century AD. About fifteen inches of soil are estimated to have been lost from Argolid uplands since the start of Bronze Age agriculture. As many as three feet of soil may have been stripped from some lowland slopes.

Valley bottom sediments of the Argive Plain in the northeastern Peloponnese also testify to four periods of extensive soil erosion in the past five thousand years. Today, thick red and brown soils are found only in hollows and at the foot of slopes protected from streams. Remnants of hillslope soils and archaeological evidence show that since the Bronze Age there have been centuries-long periods with high settlement density, intensive farming, and accelerated soil erosion separated by millennia-long periods of low population density and soil formation.

Alexander the Great's homeland of Macedonia in eastern Greece underwent similar episodes of soil erosion accompanied by stream filling, and followed by landscape stability. The pace of soil erosion doubled in the late Bronze Age, and then doubled again from the third century BC to the seventh century AD. Another round started after the fifteenth century—defining a cycle with a roughly thousand-year periodicity, just as in other parts of Greece.

Regional climate changes cannot explain the boom-and-bust pattern of human occupation in ancient Greece because the timing of land settlement and soil erosion differed around the region. Instead, modern geoarchaeological surveys show that soil erosion episodically disrupted local cultures, forced settlements to relocate, led to changes in agricultural practices, and caused periodic abandonment of entire areas.

An ancient geopolitical curiosity provides further evidence that people destroyed Greek soils. The northern slopes of Mount Parness define the border between Boeotia and Attica. Oddly, the region belonged to Attica but was accessible only from Boeotia. So the region remained forested because Athenians could not get to it and Boeotians could not use it. While both city-states suffered severe soil erosion in their cultivated heartland, the no-man's-land on the border still retains a thick forest soil.

Extensive Bronze Age soil erosion coincides with changing agricultural practices that allowed a major increase in human population. The transition from highly localized, spring-fed agriculture using digging sticks to rain-fed agriculture based on clearing and plowing whole landscapes fueled an expansion of settlements. Initially, very low hillslope erosion rates increased slowly as agriculture spread until eventually erosion increased tenfold during the Bronze Age. Subsequently, erosion rates dropped back to close to the natural rate before once again increasing tenfold during the classical and Roman eras.

Almost the entire landscape was cultivated by classical times. Massive piles of dirt deposited in valley bottoms document extensive erosion of forest soils from hillsides disturbed by initial agricultural colonization. In places, later episodes of soil erosion were not as severe because continued farming and grazing prevented rebuilding thick soils. Even so, ancient erosion control measures like terraced hillsides and check dams built to slow the growth of gullies provide direct evidence of a fight to save soil.

The variety of crops excavated from Neolithic sites in Greece indicate that pre-Bronze Age agriculture was highly diversified. Sheep, goats, cows, and pigs were kept on small, intensively worked mixed-crop farms. Evidence of plow-based agriculture on estates worked by oxen records a progressive shift from diversified small-scale farms to large plantations. By the late Bronze Age, large areas controlled by palaces specialized in growing cereals. Olives and grapes became increasingly important as small farms spread into progressively more marginal areas prone to soil erosion. This was no coincidence—they grew well in thin, rocky soils.

Hesiod, Homer, and Xenophon all described two-field systems with alternate fallow years. It was normal to plow both fallow and planted fields three times a year, once in the spring, once in summer, and again in the autumn right before sowing. All this plowing gradually pushed soil downhill and left fields bare and vulnerable to erosion. Whereas Hesiod recommended using an experienced plowman who could plow a straight line regardless of the lay of the land, by later classical times terraces were built to try and retain soil and extend the productive life of hillside fields.

Modern examples show just how rapidly Greek soils can erode. On some overgrazed slopes, thickets of fifty-year-old oak standing on one-and-a-half-foot-high soil pedestals testify to modern erosion rates of just over a quarter of an inch per year. Live trees with roots exposed up to two and a half feet above the present ground surface record decades of soil erosion at around half an inch per year. When exposed to the direct effects of rainfall, land can fall apart at a rate apparent to even casual observers.

Little more than six centuries after the first Olympics were held in 776 BC, the Romans captured and destroyed Corinth, assimilating Greece into the Roman Empire in 146 BC. By then, after the second round of widespread soil erosion, Greece was no longer a major power. Some remarkable geologic detective work has shown how, like the ancient Greeks, the Romans also accelerated soil erosion enough to impact their society.

In the mid-1960s Cambridge University graduate student Claudio Vita-Finzi picked Roman potsherds from the banks of a Libyan wadi out of deposits previously thought to date from glacial times. Puzzled by the large amount of sediment so recently deposited by the stream, he poked around ancient dams, cisterns, and ruined cities and found evidence for substantial historical soil erosion and floodplain deposition. Intrigued, he set about trying to determine whether these geologic changes in historical times told of climate change or land abuse.

Traveling from Morocco north to Spain, and then back east across North Africa to Jordan, Vita-Finzi found evidence for two periods of extensive hillslope erosion and valley bottom sedimentation in river valleys around the Mediterranean. Deposits he called the Older Fill recorded erosion during late glacial times. Convinced that what he at first thought to be a Libyan curiosity was instead part of a broader pattern, Vita-Finzi attributed the younger valley fill to lower stream discharge caused by increasing aridity at the beginning of the late Roman era.

As often happens with new theories, people trying to fit additional observations into a simple framework found a more complicated story. The timing of soil erosion and valley filling differed around the region. How could Vita-Finzi's proposed regional drying affect neighboring areas at different times, let alone cause repeated episodes of erosion in some places? Just as in Greece, evidence now shows that people accelerated soil erosion in the Roman heartland as well as Roman provinces in North Africa and the Middle East. Even so, a simple choice of causes between climate and people is misleading. Droughts and intense storms accelerated erosion periodically on land where agricultural practices left soils bare and vulnerable.

As in other Paleolithic hunting cultures in southern Europe, an almost exclusive reliance on hunting large animals in central Italy gave way to more mixed hunting, fishing, and gathering as forests returned after the glaciers retreated. Thousands of years later, sometime between 5000 and 4000 BC, immigrants from the east introduced agriculture to the Italian Peninsula. Sheep, goat, and pig bones found along with wheat, barley seeds, and grinding stones reveal that these first farmers relied on mixed cereal cultivation and animal husbandry. Occupying ridges mantled with easily worked, well-drained soils these farmers relied on an integrated system of cereal cultivation and grazing similar to traditional peasant agriculture described by Roman agronomists thousands of years later. Between 3000 and 1000 BC, agricultural settlements spread across the Italian landscape.

From the early Neolithic to the end of the Bronze Age, Italian agriculture expanded from a core of prime farmlands into progressively more marginal land. The basic system of small-scale farms practicing mixed animal husbandry and growing a diversity of crops remained remarkably stable during this period of agricultural expansion—Bronze Age farmers still

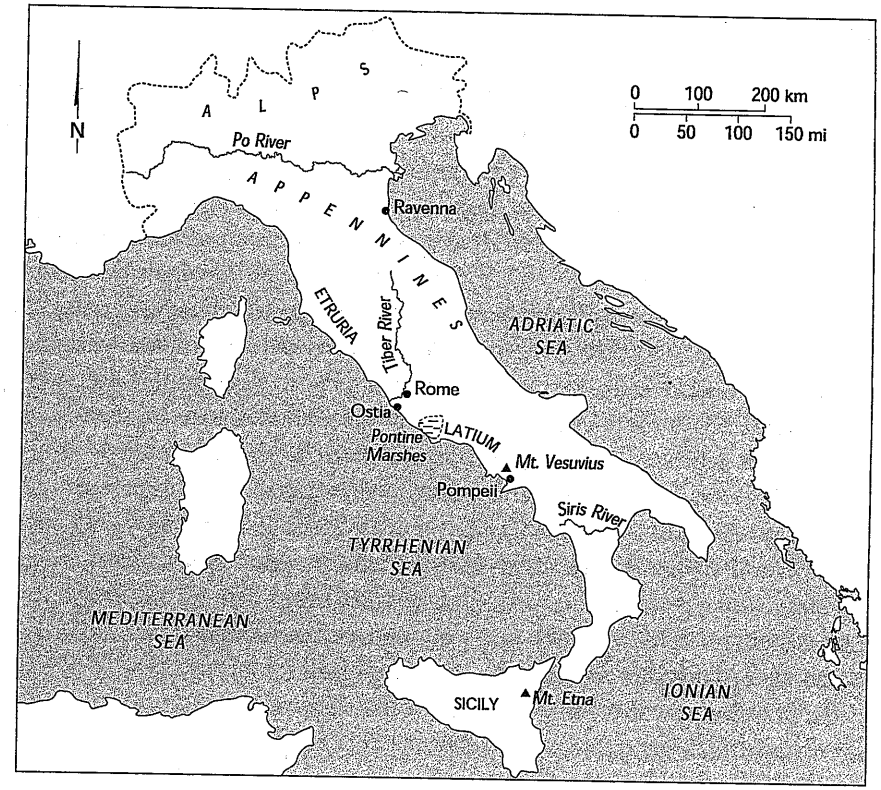


Figure 8. Map of Roman Italy.

followed the practices of their Neolithic ancestors. Between about 4000 and 1000 BC, agriculture spread from the best sites used by the first farmers to steeper slopes and hard-to-work valley bottom clays.

Iron came into widespread use about 500 BC. Before then only the wealthy and the military had access to metal tools. More abundant and cheaper than bronze, iron was hard, durable, and readily formed to fit over wood. Farmers began fitting plows and spades with iron blades to carve through topsoil and down into denser subsoil. Most of Italy remained forested around 300 BC, but new metal tools allowed extensive deforestation over the next several centuries.

When Romulus founded Rome in about 750 BC, he divided up the new state into two-acre parcels, a size his followers could cultivate themselves. The soils of central Italy were famously productive when the Roman

Republic was founded in 508 BC. The average farm still consisted of roughly one to five acres (half a hectare to two hectares) of land, just enough land to feed a family. Many prominent Roman family names were derived from vegetables their ancestors excelled at growing. Calling a man a good farmer was high praise in the republic. Cincinnatus was plowing his fields when summoned to become dictator in 458 BC.

Early Roman farms were intensively worked operations where diversified fields were hoed and weeded manually and carefully manured. The earliest Roman farmers planted a multistory canopy of olives, grapes, cereals, and fodder crops referred to as *cultura promiscua.* Interplanting of understory and overstory crops smothered weeds, saved labor, and prevented erosion by shielding the ground all year. Roots of each crop reached to different depths and did not compete with each other. Instead, the multicrop system raised soil temperatures and extended the growing season. In the early republic, a Roman family could feed itself working the typical plot of land by hand. (And such labor-intensive farming is best practiced on a small scale.) Using an ox and plow saved labor but required twice as much land to feed a family. As plowing became standard practice, the demand for land increased faster than the population.

So did erosion. Extensive deforestation and plowing of the Campagna increased hillslope erosion to the point that antierosion channels were built to stabilize hillside farms. Despite such efforts, sediment-choked rivers turned valley bottoms into waterlogged marshes as plows advanced up the surrounding slopes. Malaria became a serious concern about 200 BC when silt eroded from cultivated uplands clogged the Tiber River and the agricultural valley that centuries before supported more than a dozen towns became the infamous Pontine Marshes. Large areas of worn-out hills and newly marshy valleys meant that formerly cultivated regions were becoming pastures of little use beyond grazing. Once-flourishing towns emptied as pastures supported fewer farmers than did the former fields.

Romans recognized that their wealth came from the earth; after all they coined the name Mother Earth *(mater terra)*. As did the Greeks before them, Roman philosophers recognized the fundamental problems of soil erosion and loss of soil fertility. But unlike Aristotle and Plato, who simply described evidence for past erosion, Roman philosophers exuded confidence that human ingenuity would solve any problems. Cicero crisply summarized the goal of Roman agriculture as to create "a second world within the world of nature." Yet even as Roman farmers used deeper plows and adapted their choice of crops to their denuded slopes, keeping soil on

the Roman heartland became increasingly problematic. As Rome grew, Roman agriculture kept up by expanding into new territory.

Central Italy has four main types of soil: clay-rich soils prone to erosion when cultivated; limestone soils including ancient, deeply weathered Terra Rossa; fertile, well-drained volcanic soils; and valley bottom alluvial soil. Agricultural practices induced severe erosion on both clay-rich and limestone soils that mantled upland areas. The original forest soils have been so eroded in places that farmers now plow barely weathered rock. In many upland areas, limestone soils have been reduced to small residual pockets. Across much of central Italy, centuries of farming and grazing left a legacy of thin soils on bare slopes.

Roman farmers distinguished soils based on their texture (sand or clay content), structure (whether the particles grouped together as crumbs or clods), and capacity to absorb moisture. They assessed a soil's quality according to the natural vegetation that grew on it, or its color, taste, and smell. Different soils were rich or poor, free or stiff, and wet or dry. The best soil was a rich blackish color, absorbed water readily, and crumbled when dry. Good dirt did not rust plows or attract crows after plowing; if left fallow, healthy turf rapidly covered it. Like Xenophon, Roman agriculturalists understood that different things grew best in different soils; grapevines liked sandy soil, olive trees grew well on rocky ground.

Marcus Porcius Cato (234–149 BC) wrote *De agri cultura,* the oldest surviving Roman work on agriculture. Cato focused on grape, olive, and fruit growing and distinguished nine types of arable soils, subdivided into twenty-one minor classes based mainly on what grew best in them. He called farmers the ideal citizens and considered the agricultural might of its North African rival, Carthage, a direct threat to Roman interests. Carthage was an agricultural powerhouse capable of becoming a military rival. In perhaps the earliest known political stunt, Cato brought plump figs grown in Carthage onto the Senate floor to emphasize his view that "Carthage must be destroyed." Ending all his speeches, no matter what the subject, with this slogan, Cato's agitating helped trigger the Third Punic War (149–146 BC) in which Carthage was torched, her inhabitants slaughtered, and her fields put to work feeding Rome.

Cato's businesslike approach to farming appears tailored to help Rome's rising class of plantation owners maximize wine and olive oil harvests while keeping costs to a minimum. Low-tech versions of the plantation agriculture of colonial and modern times, the agrarian enterprises he described became specialized operations with a high degree of capital investment.

Falling slave and grain prices began driving tenant farmers off the land and encouraged raising cash crops on large estates using slave labor.

The next surviving Roman agricultural text dates from about a century later. Born on a farm in the heart of rural Italy, Marcus Terentius Varro (116–27 BC) wrote *De re rustica* at a time when these large estates dominated the Roman heartland. Varro himself owned an estate on the slopes of Vesuvius. Recognizing almost one hundred types of soil, he advocated adapting farming practices and equipment to the land. "It is also a science, which explains what crops are to be sown and what cultivations are to be carried out in each kind of soil, in order that the land may always render the highest yields."[3] Like most Roman agricultural writers, Varro emphasized obtaining the highest possible yields through intensive agriculture.

Although cereals grew best in the alluvial plains, Italy's lowland forest was already cleared and cultivated by Varro's time. Increasing population had pushed cereal cultivation into the uplands as well. Varro noted that Roman farmers grew cereals all over Italy, in the valleys, plains, hills, and mountains. "You have all traveled through many lands; have you seen any country more fully cultivated than Italy?"[4] Varro also commented that the widespread conversion of cultivated fields to pasture increased the need for imported food.

Writing in the first century AD, Lucius Junius Moderatus Columella thought the best soil required minimal labor to produce the greatest yields. In his view, fertile topsoil well suited for grain should be at least two feet thick. Cereals grew best on valley bottom soils, but grapes and olives could flourish on thinner hillslope soils. Rich, easily worked soils made grains the major cash crop along Italy's river valleys. Focused like his predecessors on maximizing production, Columella chastised large landowners who left fields fallow for extended periods.

Columella described two simple tests of soil quality. The easy way was to take a small piece of earth, sprinkle it with a little water, and roll it around. Good soil would stick to your fingers when handled and did not crumble when thrown to the ground. A more labor-intensive test involved analyzing the dirt excavated from a hole. Soil that would not settle back down into the hole was rich in silt and clay good for growing grains; sandy soil that would not refill the hole was better suited for vineyards or pasture. Although little is known about Columella himself, I learned a version of his first test in graduate school at UC Berkeley.

Roman agriculturists recognized the importance of crop rotation—even the best soils could not grow the same crops forever. Farmers would periodically let a piece of ground lie fallow, grow a crop of legumes, or raise a cover crop well suited for the local dirt. Generally, they left fields fallow every other year between cereal crops. As for plant nutrition, Romans understood that crops absorbed nutrients from the soil and recognized the value of manure to achieve the greatest yields from the soil and prevent its exhaustion. In line with Cato's advice to keep "a large dunghill," Roman farmers collected and stored manure from oxen, horses, sheep, goats, pigs, and even pigeons for spreading on their fields. They applied marl—crushed limestone—as well as ashes to enrich their fields. Varro recommended applying cattle dung in piles but thought bird droppings should be scattered. Cato recommended using human excrement if manure was unavailable. Columella even cautioned that hillside fields required more manure because runoff across bare, plowed fields would wash the stuff downslope. He also advised plowing manure under to keep it from drying out in the sun.

Above all else, Roman agronomists stressed the importance of plowing. Repeated annual plowing provided a well-aerated bed free of weeds. Varro recommended three plowings; Columella advised four. Stiff soils were plowed many times to break up the ground before planting. By the peak of the empire, Roman farmers used light wooden plows for thin easily worked soils, and heavy iron plows for dense soils. Most still plowed in straight lines with equal-size furrows. Just as in Greece, all that plowing slowly pushed soil downhill and promoted erosion, as runoff from each storm took its toll—slow enough to ignore in one farmer's lifetime, but fast enough to add up over the centuries.

Roman farmers plowed under fields of lupines and beans to restore humus and maintain soil texture. Columella wrote that a rotation of heavily manured beans following a crop of cereal could keep land under continuous production. He specifically warned against the damage that slave labor did to the land. "It is better for every kind of land to be under free farmers than under slave overseers, but this is particularly true of grain land. To such land a tenant farmer can do no great harm . . . while slaves do it tremendous damage."[5] Columella thought that poor agricultural practices on large plantations threatened the foundation of Roman agriculture.

Caius Plinius Secundus, better known as Pliny the Elder (AD 23–79), attributed the decline of Roman agriculture to city-dwelling landlords leaving large tracts of farmland in the hands of overseers running slave labor. Pliny also decried the general practice of growing cash crops for the highest profit to the exclusion of good husbandry. He maintained that such practices would ruin the empire.

Some contemporary accounts support the view that the Romans' land use greatly accelerated erosion despite their extensive knowledge of practical husbandry. Pliny described how forest clearing on hillslopes produced devastating torrents when the rain no longer sank into the soil. Later, in the second century, Pausanias compared two Greek river basins: the Maeander, actively plowed agricultural land, and the Achelous, vacant land whose inhabitants had been removed by the Romans. The populated, actively cultivated watershed produced far more sediment, its rapidly advancing delta turning islands into peninsulas. But by how much did Roman agriculture increase erosion rates in Roman Italy?

In the 1960s Princeton University geologist Sheldon Judson studied ancient erosion in the area around Rome. He saw how the foundation of a cistern built to hold water for a Roman villa around AD 150 stood exposed by between twenty and fifty-one inches of erosion since the structure was built, an average rate of more than an inch per century. He noted a similar rate for the Via Prenestina, a major road leading west from Rome. Originally placed flush with the surface of the ridge along which it runs, by the 1960s its basalt paving stones protruded several feet above easily eroded volcanic soil of the surrounding cultivated slopes. Other sites around Rome recorded an average of three-quarters of an inch to four inches of erosion each century since the city's founding.

Sediments accumulated in volcanic crater lakes in the countryside confirmed the account of dramatic erosion. Cores pulled from Lago di Monterosi, a small lake twenty-five miles north of Rome, record that land shedding sediment into the lake eroded about an inch every thousand years before the Via Cassia was built through the area in the second century BC. After the road was built, erosion increased to almost an inch per century as farms and estates began working the land to produce marketable crops. Sediments from a lake in the Baccano basin, less than twenty miles north of Rome along the Via Cassia, also recorded an average erosion rate on the surrounding lands of a little more than an inch every thousand years for more than five thousand years before the Romans drained the lake in the second century BC. Thick deposits of material stripped from hillslopes and deposited in valley bottoms along streams north of Rome further indicate intense erosion near the end of the empire.

These diverse lines of evidence, together with Vita-Finzi's findings, point to a dramatic increase in soil erosion owing to Roman agriculture. Considered annually, the net increase was small, just a fraction of an inch per year—hardly enough to notice. If the original topsoil was six inches to a

foot thick, it probably took at least a few centuries but no more than about a thousand years to strip topsoil off the Roman heartland. Once landowners no longer worked their own fields, it is doubtful that more than a handful noticed what was happening to their dirt.

It was easier to see evidence of soil erosion downstream along the major rivers, where ports became inland towns as sediments derived from soil stripped off hillsides pushed the land seaward. Swamped by sediment from the Tiber River, Rome's ancient seaport of Ostia today stands miles from the coast. Other towns, like Ravenna, lost their access to the sea and declined in influence. At the southern end of Italy, the town of Sybaris vanished beneath dirt deposited by the Crathis River.

Historians still debate the reasons behind the collapse of the Roman Empire, placing different emphases on imperial politics, external pressures, and environmental degradation. But Rome did not so much collapse as consume itself. While it would be simplistic to blame the fall of Rome on soil erosion alone, the stress of feeding a growing population from deteriorating lands helped unravel the empire. Moreover, the relation worked both ways. As soil erosion influenced Roman society, political and economic forces in turn shaped how Romans treated their soil.

When Hannibal razed the Italian countryside in the Second Punic War (218 to 201 BC), thousands of Roman farmers flooded into the cities as their fields and houses were destroyed. After Hannibal's defeat, vacant farmland was an attractive investment for those with money. The Roman government also paid off war loans from wealthy citizens with land abandoned during the war. The estimated quarter of a million slaves brought back to Italy provided a ready labor supply. After the war, all three of the primary sources of agricultural production—land, labor, and capital—were cheap and available.

The growth of large cash crop–oriented estates *(latifundia)* harnessed these resources to maximize production of wine and olive oil. By the middle of the second century BC, such large slave-worked plantations dominated Roman agriculture. The landowning citizen-farmer became an antiquated ideal but a convenient emblem for the Gracchi brothers' popular cause in 131 BC. They promoted laws giving a few acres of state-owned land to individual farmers, yet many of those who received land under the Gracchi laws could not make a living, sold their land off to larger landowners, and went back on the dole in Rome. Less than two centuries after the Gracchi brothers were assassinated, huge estates accounted for nearly all the arable land within two days' travel from Rome. Forbidden to engage directly in commerce, many wealthy senators circumvented the law by operating their estates as commercial farms. The total area under Roman cultivation continued to expand as the transformation from subsistence farming to agricultural plantations reshaped the Italian countryside.

The land fared poorly under these vast farming operations. In the first decade AD the historian Titus Livius wondered how the fields of central Italy could have supported the vast armies that centuries before had fought against Roman expansion—given the state of the land, accounts of Rome's ancient foes no longer seemed credible. Two centuries later Pertinax offered central Italy's abandoned farmland to anyone willing to work it for two years. Few took advantage of his offer. Another century later Diocletian bound free farmers and slaves to the land they cultivated. A generation after that, Constantine made it a crime for the son of a farmer to leave the farm where he was raised. By then central Italy's farmers could barely feed themselves, let alone the urban population. By AD 395 the abandoned fields of Campagna were estimated to cover enough land to have held more than 75,000 farms in the early republic.

The countryside around Rome had fed the growing metropolis until late in the third century BC. By the time of Christ, grain from the surrounding land could no longer feed the city. Two hundred thousand tons of grain a year were shipped from Egypt and North Africa to feed the million people in Rome. Emperor Tiberius complained to the Senate that "the very existence of the people of Rome is daily at the mercy of uncertain waves and storms."[6] Rome came to rely on food imported from the provinces to feed the capital's unruly mobs. Grain was shipped to Ostia, the closest port to Rome. Anyone delaying or disrupting deliveries could be summarily executed.

North African provinces faced constant pressure to produce as much grain as possible because political considerations compelled the empire to provide free grain to Rome's population. The Libyan coast produced copious harvests until soil erosion so degraded the land that the desert began encroaching from the south. The Roman destruction of Carthage in 146 BC, and its salting of the surrounding earth to prevent its resurrection are well known. Less widely appreciated are the longer-term effects of soil degradation when the growing Roman demand for grain reintensified cultivation in North Africa.

The Roman Senate paid to translate the twenty-eight volumes of Mago's handbook of Carthaginian agriculture salvaged from the ruined city. Once the salt leached away, land-hungry Romans turned the North African coast

into densely planted olive farms—for a while. Major farming operations centered around great olive presses developed in the first century AD. Proconsuls charged with producing food for Rome commanded legions of up to two hundred thousand men to protect the harvest from marauding nomads. The barbarians were kept at bay for centuries, but the threat of soil erosion was harder to stop as political stability under the *pax romana* encouraged continuous cultivation aimed at maximizing each year's harvest. By the time the Vandals crossed from Spain into Africa and took Carthage in AD 439, the Roman presence was so feeble that fewer than fifteen thousand men conquered all of North Africa. After the Roman capitulation, overgrazing by herds of nomadic sheep prevented rebuilding the soil.

Today we hardly think of North Africa as the granary of the ancient world. Yet North African grain had relieved the Greek famine in 330 BC, and Rome conquered Carthage in part to secure its fields. The Roman Senate annexed Cyrenaica, the North African coast between Carthage and Egypt, in 75 BC, a year when war in Spain and a failed harvest in Gaul meant that the northern provinces could barely feed themselves, let alone the capital. With hungry rioters in Rome, it is likely that the Senate annexed Cyrenaica for its ability to produce grain.

Evidence for extensive ancient soil erosion in the region challenges the idea that a shifting climate caused the post-Roman abandonment of irrigated agriculture in North Africa. Although much of North Africa controlled by Rome was marginal agricultural land, archaeological evidence reported from UNESCO surveys in the mid-1980s confirms the record of initial Roman colonization by farmers in individual, self-sufficient households. Over the next few centuries, irrigated agriculture had gradually expanded as farms coalesced into larger operations focused on growing grains and olives for export.

The first Christian to write in Latin, Quintus Septimius Florens Tertullianus (known today simply as Tertullian), lived in Carthage around AD 200. In describing the end of the Roman frontier in North Africa he warned of overtaxing the environment. "All places are now accessible, well known, open to commerce. Delightful farms have now blotted out every trace of the dreadful wastes; cultivated fields have overcome woods. . . . We overcrowd the world. The elements can hardly support us. Our wants increase and our demands are keener, while Nature cannot bear us."[7]

The UNESCO archaeological surveys described evidence that helps explain Tertullian's unease as increased population densities led to widedirectly in commerce, many wealthy senators circumvented the law by operating their estates as commercial farms. The total area under Roman cultivation continued to expand as the transformation from subsistence farming to agricultural plantations reshaped the Italian countryside.

The land fared poorly under these vast farming operations. In the first decade AD the historian Titus Livius wondered how the fields of central Italy could have supported the vast armies that centuries before had fought against Roman expansion—given the state of the land, accounts of Rome's ancient foes no longer seemed credible. Two centuries later Pertinax offered central Italy's abandoned farmland to anyone willing to work it for two years. Few took advantage of his offer. Another century later Diocletian bound free farmers and slaves to the land they cultivated. A generation after that, Constantine made it a crime for the son of a farmer to leave the farm where he was raised. By then central Italy's farmers could barely feed themselves, let alone the urban population. By AD 395 the abandoned fields of Campagna were estimated to cover enough land to have held more than 75,000 farms in the early republic.

The countryside around Rome had fed the growing metropolis until late in the third century BC. By the time of Christ, grain from the surrounding land could no longer feed the city. Two hundred thousand tons of grain a year were shipped from Egypt and North Africa to feed the million people in Rome. Emperor Tiberius complained to the Senate that "the very existence of the people of Rome is daily at the mercy of uncertain waves and storms."[6] Rome came to rely on food imported from the provinces to feed the capital's unruly mobs. Grain was shipped to Ostia, the closest port to Rome. Anyone delaying or disrupting deliveries could be summarily executed.

North African provinces faced constant pressure to produce as much grain as possible because political considerations compelled the empire to provide free grain to Rome's population. The Libyan coast produced copious harvests until soil erosion so degraded the land that the desert began encroaching from the south. The Roman destruction of Carthage in 146 BC, and its salting of the surrounding earth to prevent its resurrection are well known. Less widely appreciated are the longer-term effects of soil degradation when the growing Roman demand for grain reintensified cultivation in North Africa.

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The UNESCO archaeological surveys described evidence that helps explain Tertullian's unease as increased population densities led to widespread erosion on slopes beyond the small floodplains along rivers and streams. Pressure to defend a frontier with limited water and vanishing soil had gradually transformed Roman agricultural settlements in Libya into massive fortified farms staked out every few hundred feet along valley bottoms. The region was no longer a prosperous agricultural center by the time that ʿAmr ibn al ʿAṣ overran the remnants of Byzantine colonial authority in the seventh century.

In 1916 Columbia University professor Vladimir Simkhovitch argued that lack of dirt caused the decline of the Roman Empire. Soil exhaustion and erosion had depopulated the Roman countryside in the empire's late days; he pointed out that the amount of land needed to support a Roman farmer had increased from the small allotment given to each citizen at the founding of Rome to ten times as much land by the time of Julius Caesar. Simkhovitch noted how the philosopher Lucretius in his epic poem *De rerum natura* echoed other contemporary sources referring to the declining productivity of Mother Earth.

Did the perception of a general decline in soil fertility in the Roman heartland accurately reflect reality? That's hard to say. Columella, writing around AD 60, addresses the issue in a preface to *De re rustica.* "I frequently hear the most illustrious men of our country complaining that the sterility of our soil and intemperate weather have now for many ages past been diminishing the productivity of the land. Others give a rational background to their complaints, claiming that the land became tired and exhausted from its productivity in the former ages."[8]

Columella goes on to state that previous agricultural writers, most of whose works have not survived, uniformly complained of soil exhaustion. But soil need not inevitably succumb to old age, worn out by long cultivation. Instead, Columella argues, since the gods endowed soil with the potential for perpetual fecundity, it was impious to believe it could become exhausted. He qualifies his words, though, offering the opinion that soil would retain its fertility indefinitely if properly cared for and frequently manured.

Why begin a practical guide to farmers this way? In casting his argument as he did, Columella was pointing out that Rome's agricultural problem did not reflect some natural process of universal decay but rather Roman farmers' treatment of their land. Their problems were of their own making. In the second century BC Varro had referred to abandoned fields in Latium, describing an example of notoriously sterile soil where meager foliage and starved vines struggled to survive on land that had supported

families a few centuries earlier. Taking up the point several centuries later, Columella insisted that the people of Latium would have starved without a share of the food imported to feed the capital.

Some historians see the growing indebtedness of Roman farmers as contributing to the empire's internal turmoil. Farm debt can come from borrowing to provide the tools necessary to run the farm or because farm income fails to meet the needs of the farmer's family. The low capital requirements of Roman farming suggest that farmers working the republic's traditional small farms were having a hard time feeding themselves. Large estate owners took advantage of their distressed neighbors and bought up huge tracts of land. Contrary to the conventional wisdom that civil strife and wars had depopulated the Roman countryside, the disappearance of small farms occurred during a period of unprecedented peace. Roman laws prohibiting the separation of agricultural slaves from the land they worked passed in response to the abandonment of the Roman countryside. Eventually the problem became so acute that even free tenant farmers were decreed tied to the soil they plowed—and thus to the land's owners. The social arrangement between farmer-serfs and landowning nobles established by these laws survived long after the empire crumbled (to set the stage, many historians believe, for medieval serfdom).

Still, how could Italy's soil decline when Romans knew about agricultural husbandry, crop rotations, and manure? Such practices require using a portion of the farmer's income to improve the soil, whereas maximizing its immediate yield involves cashing in soil fertility. In addition, farmers sinking into debt or hunger understandably push to get everything they can from even degraded soil.

To some degree, the Roman imperative to acquire land was driven by the need to secure food for the growing populace. Viewed in this context, the shrinking harvests from central Italy's fields encouraged intensive agriculture in newly conquered provinces. Soil erosion progressively degraded the Roman heartland and then spread to the provinces—except Egypt, which became a colony exploited to feed Rome upon the death of Cleopatra in 30 BC.

Egypt remained immune because of the life-giving floods of the Nile. The Nile's importance to the Roman Empire is clear in Egypt's status as the emperor's personal possession. In the first century AD Emperor Augustus forbade senators or Roman nobility to enter Egypt without his permission. "Whoever made himself master of Alexandria . . . might with a small force . . . reduce all Italy to a famine."[9] By the end of the empire, the dirt of the Nile fed Rome. Soil erosion alone did not destroy Rome, but the dirt of modern Italy and former Roman colonies speaks for itself.

More than a thousand years after the fall of Rome, a widely traveled New England lawyer explored the role of soil erosion on ancient societies. Born in 1801 in the frontier community of Woodstock, Vermont, George Perkins Marsh traveled extensively through the Old World and published *Man and Nature,* the foundational work of environmentalism in 1864. Marsh was a voracious reader who gave up law to run for Congress in 1843 and was appointed U.S. minister to Turkey five years later. With minimal duties and ample time for travel, he collected plants and animals for the Smithsonian Institution during an expedition through Egypt and Palestine in 1851 before returning home. A decade later President Abraham Lincoln appointed Marsh ambassador to Italy. Extending his travels to the Alps, Marsh saw the Old World's degraded land as the end result of soil neglect like that he witnessed as Vermont's forests were converted into wheat fields and pastures.

> Territory larger than all Europe, the abundance of which sustained in bygone centuries a population scarcely inferior to that of the whole Christian world at the present day, has been entirely withdrawn from human use, or, at best, is thinly inhabited. . . . There are parts of Asia Minor, of Northern Africa, of Greece, and even of Alpine Europe, where the operation of causes set in action by man has brought the face of the earth to a desolation almost as complete as that of the moon; and though, within that brief space of time which we call "the historical period," they are known to have been covered with luxuriant woods, verdant pastures, and fertile meadows.[10]

Marsh's revelation was twofold: land did not necessarily recover after being abused, and people destroyed the balance of nature unconsciously in the pursuit of more immediate ends. Calling attention to how unintended consequences of human activity affected the ability of the land to support societies, he was confident that America could prevent repeating the Old World's folly.

Marsh believed agricultural technology could keep up with the world's rising population—as long as there was soil left to plow. But he recognized that the capacity for damaging land also increased with technological sophistication. Popularizing the notion that deforestation and soil erosion ruined civilizations in the Middle East, Marsh challenged American confidence in the inexhaustibility of resources. His book became an instant

classic, supporting three editions that he worked on revising literally until the last day of his life.

Half a century later, on the eve of the Second World War, the U.S. Department of Agriculture sent renowned soil expert Walter Lowdermilk to survey the effects of land use on erosion in the Middle East, North Africa, and Europe. Hitler's invasion of Poland prevented him from continuing on to central Europe and the Balkans, but like Marsh before him Lowdermilk had already seen enough of Europe and Asia to consider the Old World's soils a graveyard of empires.

Visiting the ancient Roman agricultural colonies in Tunisia and Algeria on the northern coast of Africa, Lowdermilk found a landscape Cato would hardly have considered a threat. "Over a large part of the ancient granary of Rome we found the soil washed off to bedrock and the hills seriously gullied as a result of overgrazing. Most valley floors are still cultivated but are eroding in great gullies fed by accelerated storm runoff from barren slopes."[11] At Cuicul, the ruins of a great city lay under three feet of dirt washed off rocky slopes formerly covered with olive plantations. A few remnant groves remained perched on soil pedestals a foot or two above bedrock slopes.

The ancient city of Timgad impressed Lowdermilk even more. Founded by Trajan at the height of Roman power in the first century AD, the city supported a large public library, a 2,500-person theater, more than a dozen bathhouses, and public bathrooms with marble flush toilets. Lowdermilk found the city housed a few hundred inhabitants living in stone buildings recycled from the ancient ruins. Abandoned for more than a thousand years, the remains of giant olive presses standing on bare, treeless slopes spoke of better days.

In Tunisia, Lowdermilk pondered the ruins of a 60,000-seat amphitheater, in its day second in size only to Rome's coliseum. He estimated the modern population of the surrounding district to be less than a tenth of the amphitheater's capacity. Could a drying climate have forced people to abandon their fields to the desert? Lowdermilk doubted the conventional proposition. The director of archaeological excavations at Timgad had grown an olive grove using Roman methods on an unexcavated portion of the valley. Its good health showed that the climate had not changed enough to explain the region's agricultural decline.

At Sousse, Lowdermilk found live olive trees thought to be 1,500 years old, confirming that a drying climate was not responsible for the collapse of North African agriculture. Soil remained on the slopes in these ancient

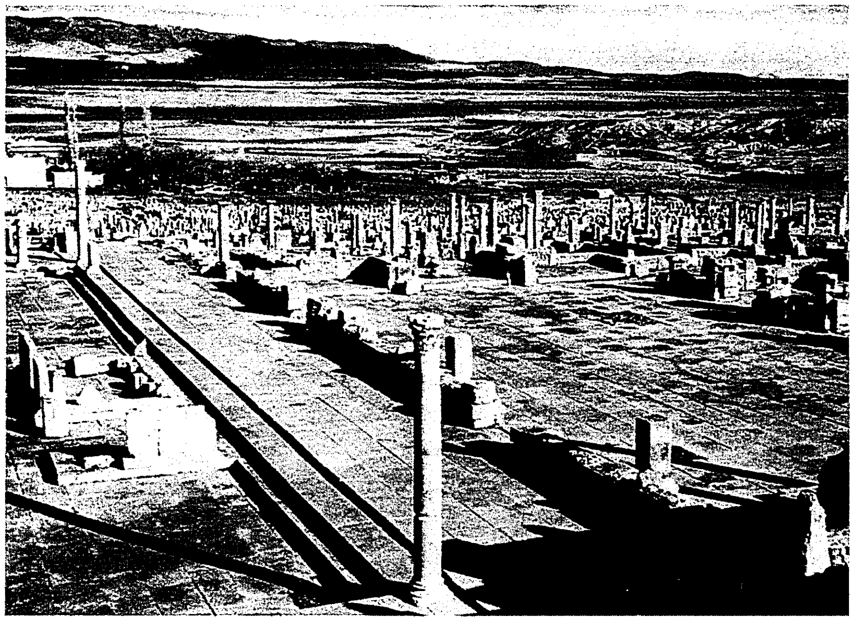

Figure 9. Ruins of the first century A.D. Roman city of Timgad, North Africa (Lowdermilk 1953, 17, fig. 9).

groves, held in place by ancient terraces and banks of earth that guided runoff from the surrounding slopes to the fields. Hills protected from grazing retained soil covered by grass and scattered trees. Concluding that elsewhere the soil had been washed from the slopes, Lowdermilk blamed overgrazing for unleashing erosion that destroyed the capacity of the land to support people.

Traveling east, Lowdermilk's party reached the area where Moses led the Israelites out of the desert and into the Jordan Valley. Stopping at Jericho, Lowdermilk found the red soil had been stripped from more than half the upland area. Deep gullies sliced through valley bottoms, the remnants of which were still being farmed. More than three-quarters of the ancient villages on steep slopes had been abandoned, while nine out of ten on the valley bottom remained inhabited. Abandoned villages stood where the soil had been stripped away. Thick soil remained on cultivated slopes where stone terraces were well maintained.

At Petra, the capital of the Nabataean civilization carved from bedrock

on the edge of the Arabian Desert around 200 BC, Lowdermilk saw more bare rocky slopes covered with ruined terraces. Pondering where the soil once held by the terraces had gone, he concluded that the city ate food grown on nearby slopes until invading nomads triggered a breakdown in soil conservation measures. Today the great theater that could seat thousands entertains few tourists.

Crossing into Syria, Lowdermilk visited the ruined Roman city of Jerash. Home to a quarter of a million people in biblical times, the ancient city lies beneath more than ten feet of dirt washed off the surrounding slopes. Contrary to archaeologists' then-favored theory, Lowdermilk found no evidence that the water supply had failed. Just like those at Petra and Jericho, rock-walled terraces once retained soil on slopes now stripped down to bedrock. What was left of the original soil lay trapped in the valley bottoms. Home to just a few thousand people in the 1930s, the area once supported luxurious villas that sent boatloads of grain to Rome.

Continuing north, Lowdermilk reached Antioch where Paul began preaching the Gospel to the region's largest supply of potential converts. A hundred villages and towns surrounded the greatest and richest city of ancient Syria during the Roman occupation. Only seven villages remained inhabited in the 1970s. Four times as many lay beneath a marshy swamp built up by silt eroded off hillsides under aggressive Roman cultivation. Archaeologists had to dig down twenty-eight feet to uncover parts of the ruined city.

They also found clues as to where all the dirt came from. Most telling were rough, unfinished parts of foundations not intended to be seen and doorsills lacking steps stranded three to six feet above bare rocky ground in the uplands north of Antioch. With the soil long gone, the region once famous for exporting grain and olive oil now supports a few seminomads. Lowdermilk described the region's ruins as stark stone skeletons rising high above the bare rock slopes of a desert its inhabitants inadvertently made, leaving an enduring legacy of impoverishment. Whatever else may have happened in the region, Syria's upland soil was gone.

Lebanon's dirt met a similar fate. About 4,500 years ago the Phoenicians moved west from the desert to the eastern shore of the Mediterranean. Starting on a narrow strip of land on the coastal plain, they brought Mesopotamian agricultural practices to their new home, a land of cedar forests with little flat land to cultivate. After plowing up the narrow coastal plain, Phoenicians cleared sloping fields and sold the timber to their treeless neighbors in Mesopotamia and Egypt. Whether the great cedar forest was cut primarily for timber or farmland, the two went hand in hand as farms spread up the slopes.

Pounded by heavy winter rains, soil eroded rapidly from plowed hillsides. Adapting their agricultural methods to this new problem, Phoenicians began terracing to retain soil. Lowdermilk described how the ruined walls of ancient terraces lay scattered throughout the region. Few agricultural practices are as labor-intensive as terracing—especially on steep slopes. Effective at slowing erosion if maintained, terraces rapidly lose effectiveness if neglected.

But only a fraction of Lebanon's steepest land was terraced. Storm by storm, soil eroded off most slopes. By the ninth century BC Phoenician emigrants began colonizing North Africa and the western Mediterranean, sending manufactured goods to distant outposts in exchange for food. By the time Alexander the Great conquered Lebanon in 322 BC, Phoenicia's golden age was over. Cut off from the colonies, and with most of the homeland's topsoil gone, Phoenician civilization never recovered.

By the time of Lowdermilk's visit four small cedar groves were all that remained of the great cedar forest that covered two thousand square miles of ancient Phoenicia. Seeing that these remnant groves grew in patches of valley bottom soils protected from goats convinced Lowdermilk that the forest did not disappear because the climate changed. The big trees could not grow back once the soil was gone, and overgrazing kept it from rebuilding.

In the summer of 1979 radiocarbon dating of sediment cores recovered from the Sea of Galilee (Lake Kinneret) showed that the erosion rate from the surrounding land more than doubled around 1000 BC. This time corresponds to increased settlement and agricultural expansion into mountainous areas following the Israelites' arrival. Pollen preserved in the different layers of lake sediments show that between the founding of the kingdom of Israel and the end of the Roman occupation about thirteen hundred years later, olives and grapes replaced the native oak forest.

When Moses led the Israelites out of the desert into Canaan, they appeared to have arrived in an agricultural paradise. "For the Lord thy God bringeth thee into a good land, a land of brooks of water, of fountains and depths that spring out of valleys and hills; a land of wheat and barley and vines and fig trees and pomegranates, a land of olive oil and honey" (Deuteronomy 8:7–8). Inconveniently, however, the best valley-bottom land was already occupied.

When Moses and company arrived, Canaan was a collection of city-states subjugated by Egyptian military superiority. Heavily fortified Canaanite cities controlled the agricultural lowlands. Undeterred, the new arrivals farmed the vacant uplands. "But the mountain-country shall be yours. Although it is wooded, you shall cut it down, and its farthest extent shall be yours" (Joshua 17:18). Settling in small villages, they cleared the forests and farmed terraced slopes in the hill country to gain a foothold in the Promised Land.

The Israelites adopted traditional Canaanite agriculture in their new hillside farms, growing what their neighbors grew. But they also practiced crop rotation and fallowing and designed systems to collect and deliver rainwater to their terraced fields. With the development of new iron tools, greater harvests led to agricultural surpluses that could support larger settlements. Leaving fields fallow every seventh year was mandated and animal dung was mixed with straw to produce compost.[12] Land was regarded as God's property entrusted to the people of Israel for safekeeping. In the Judean highlands, Lowdermilk noted how a few well-maintained stone terraces still held soil after several thousand years of cultivation.

Agriculture expanded so much under the later Roman occupation that the empire's Middle East provinces were completely deforested by the first century AD. Grazing typically replaced forests on terrain too steep to farm. Throughout the region, flocks of goats and sheep reduced vegetation to stubble. Catastrophic soil erosion followed when too many livestock grazed steep hillsides. Forest soils built up over millennia disappeared. Once the soil was gone, so was the forest.

In a radio address from Jerusalem in June 1939, Walter Lowdermilk offered an eleventh commandment he imagined Moses might have slipped in had he foreseen what was to become of this promised land. "Thou shalt inherit the Holy Earth as a faithful steward, conserving its resources and productivity from generation to generation. Thou shalt safeguard thy fields from soil erosion . . . and protect thy hills from overgrazing by thy herds, that thy descendants may have abundance forever. If any shall fail in this stewardship of the land . . . thy descendants shall decrease and live in poverty or perish from off the face of the Earth."[13]

As Marsh had before him, Lowdermilk worried about the implications of what he saw in the Middle East for America's long-term prospects. Both looked to the Old World for lessons for the New World. Neither realized that the scenarios they worried about had already happened in America.

Mayan civilization provides the best-studied, but by no means the only, example of soil degradation contributing to the collapse of a society in the Americas. The earliest Mayan settlements grew from the lowland jungle of the Yucatán Peninsula and slowly consolidated into increasingly complex settlements. By the second century BC, large ceremonial and commercial centers like Tikal coalesced into a complex hierarchical society of city-states with a common language, culture, and architecture. Mayan cities were comparable in size to Sumerian city-states. At its peak Tikal was home to from thirty thousand to fifty thousand people.

The first settled Mesoamerican communities grew to regional prominence after maize was domesticated about 2000 BC. Over the next thousand years, small villages came to depend on cultivating maize to supplement hunting and gathering from the wild lands between villages. Small-scale forest clearing for agriculture gradually expanded and maize became an increasingly important component of the Mesoamerican diet. As in Mesopotamia, dispersed networks of settlements grew into ceremonial centers and towns with priests, artisans, and administrators to oversee the redistribution of surplus food.

Initially, the productivity of domesticated maize was similar to wild varieties, which could be readily gathered. Tiny cobs about the size of a human thumb were simply chewed. People began grinding maize into flour once high-yield varieties allowed the development of permanent settlements. The region supported a diffuse rural population until large towns emerged between 350 BC and AD 250. By then some parts of the Mayan world were already severely eroded, but in many areas the greatest soil erosion—and evidence for soil conservation efforts—date from about AD 600–900. The subsequent lack of artifacts has been interpreted to show a dramatic population decline (or dispersal) as Mayan society crumbled and the jungle reclaimed Tikal and its rivals.

Mayan population grew from less than two hundred thousand in 600 BC to more than a million by AD 300. Five hundred years later at the peak of Mayan civilization, the population reached at least three million and perhaps as many as six million. Over the next two hundred years the population fell to less than half a million people. When John Stephens rediscovered ruined Mayan cities the region appeared deserted except for areas on the edge of the jungle. Even today the population density in the rapidly growing region remains below that of ancient times. So what happened?

Mayan agriculture began with a system known as slash-and-burn agriculture, in which a patch of jungle was cleared with stone axes and then burned before the onset of the rains, when maize and beans were planted. Ash from burning the cleared forest fertilized the soil and guaranteed good crops for a few years, after which fertility of the nutrient-poor tropical soil fell rapidly. Cleared patches could not be farmed for long before being abandoned to the jungle to restore soil fertility. A lot of jungle was needed to keep a few fields under cultivation. As in ancient Greece and Italy, the first evidence for extensive soil erosion coincides with pioneer farming.

Slash and burn worked well while the population density remained low and there was enough land for farmers to move their fields every few years. As the great Mayan cities rose from the jungle, people kept clearing land as their ancestors had done, but they stopped moving their fields. The tropical soils of the Yucatán Peninsula are thin and easily eroded. Under sustained cultivation, the high productivity obtained right after clearing and burning rapidly declines. Compounding this problem, the lack of domesticated animals meant no manure for replenishing the soil. Just as in Greece and Rome, rising demand for food and declining productivity compelled cultivation of increasingly marginal land.

After about 300 BC the region's increasing population led people to begin farming poorly drained valley bottoms and limestone slopes with thin, fragile soils. They built raised fields in swamps by digging networks of drainage canals and piling up the excavated material in between to create raised planting beds perched above the water table. In some areas extensive terracing began around AD 250 and then spread across the landscape as the population continued to expand for another six and a half centuries. Mayan farmers terraced hillsides to create flat planting surfaces, slow erosion by overland flow, and divert water to fields. However, in major areas like Tikal and Copán there is little evidence for soil conservation efforts. Even with erosion control efforts, deposition of soil eroded from surrounding slopes disrupted wetland agriculture practiced in sinkholes.

Sediment cores from lakes in the Mayan heartland suggest that agricultural intensification increased soil erosion. The rate that sedimentation piled up on lakebeds increased substantially from 250 BC through the ninth century AD. While not necessarily responsible for the collapse of Mayan society, soil erosion peaked shortly before Mayan civilization unraveled about AD 900 when the food surpluses that sustained the social hierarchy disappeared. Some Mayan cities were abandoned with buildings half finished.

In the 1990s geographers studying small depressions, known as *bajos,* around Mayan sites in northwestern Belize found that cultivated wetlands had filled with soils eroded after deforestation of the surrounding slopes. The southern Yucatán is broken into depressions that formed natural wetlands extensively cultivated during the peak of Mayan civilization. Trenches revealed buried soils dating from the pre-Mayan period covered by two and a half to six feet of dirt eroded from the surrounding slopes in two distinct episodes. The first corresponded to forest clearing during the spread of pioneer farmers from the valleys up onto the surrounding hillslopes. The second occurred during agricultural intensification immediately before the end of Mayan civilization, after which soil began to rebuild as the forest reclaimed fields and wetlands.

Researchers also found evidence for accelerated soil erosion caused by extensive deforestation of sloping land in the Mayan lowlands. Where Mayan terraces remain intact, they hold three to four times more soil than lies on adjacent cultivated slopes. Development of erosion control methods allowed the Mayan heartland to support large populations but the expansion depended on intensive cultivation of erosion-prone slopes and sedimentation-prone wetlands. Eventually, Mayan civilization reached a point where its agricultural methods could no longer sustain its population.

Modern deforestation in the Petén is beginning to repeat the cycle of erosion after a thousand years of soil development. Since the early 1980s landless peasant farmers have turned much of the region's forest into traditional Mayan *milpas* (small cultivated fields). A twentyfold increase in population from 1964 to 1997 has transformed the region from nearly unbroken forest to a nearly deforested landscape.

Soils on most of the region's hillslopes consisted of an organic horizon above a thin mineral soil sitting directly on weakly weathered limestone bedrock. One study found that under the region's last virgin forest, hillslope soils were about ten to twenty inches thick, whereas modern cultivated fields are already missing three to seven inches of topsoil—most of the O and A horizons. In some places, the rapid erosion following modern slope clearing and cultivation had already stripped the soil down to bedrock. Another study of soil erosion following modern forest clearance in central Belize found that one to four inches of topsoil were lost in a single ten-year cycle of clearing for corn and cassava for two to three years of cultivation followed by a fallow year. Complete removal of the soil would require just four milpa cycles. In a particularly striking example from the northern Yucatán, about eight inches of soil on the upland surfaces around a sinkhole named Aguada Catolina was eroded to bedrock in a decade of renewed cultivation. Similarly, researchers investigating ancient soil erosion in the Mayan of the Petén noticed that the soil was stripped down to bedrock on newly cleared slopes in under a decade.

Rates of soil formation in the Central American jungle are far slower than rates of erosion under Mayan agriculture. The region's limestone bedrock weathers about half an inch to five inches in a thousand years. An average soil depth of about three inches developed on Mayan architecture abandoned a thousand years ago indicates rates of soil formation similar to the geologic erosion rate. Both are about a hundred times slower than erosion from cultivated slopes.

The Mayan heartland was not the only place where soil influenced Native American civilizations. Soils of central Mexico tell similar stories of severe erosion on steep hillslopes undermining agriculture.

In the late 1940s UC Berkeley professor Sherburne Cook drove around the central Mexican plateau and concluded that the land was in poorest condition in areas that had supported the largest populations before the Spanish conquest. The thick soil and sod covering uncultivated areas contrasted with the truncated soil profiles, slopes stripped down to weathered rock, and thick, artifact-rich valley fills derived from former hillslope soils that characterized more densely populated areas. Cook saw evidence for two periods of erosion, an ancient episode that stripped soils from hillsides and a more recent episode that entrenched deep gullies into the valley bottoms. "Evidently the entire range was once cleared for cultivation, abandoned, allowed to become covered with young forest, and finally, the lower portion again cleared."[14] Despite Cook's revelation, the timing of these cycles remained uncertain until development of radiocarbon dating in the 1950s.

Analyses of sediment cores from Lake Pátzcuaro, east of Mexico City in Michoacán, revealed evidence for three distinct periods of rapid soil erosion. The first period accompanied extensive land clearance about 3,500 years ago shortly after maize cultivation began. The second period of high erosion occurred in the late preclassic period between 2,500 and 1,200 years ago. The third erosional period peaked immediately before the Spanish conquest, when up to a hundred thousand people lived around the lake. Despite the introduction of the plow, soil erosion rates dropped as diseases decimated the region's population after Cortez arrived in AD 1521.

Just as in ancient Greece and around the Mediterranean, cycles of soil erosion in different parts of central Mexico occurred at different times and so were not driven by changes in climate. For example, in the Puebla-Tlaxcala area of the central Mexican highland, accelerated erosion of hillslope soils around 700 BC coincided with rapid expansion of settlements. A period of soil formation and cultural stagnation beginning about AD 100 was followed by a second period of accelerated erosion and rapid expansion of settlements before the Spanish conquest. Geoarchaeological surveys of hillslopes in the region revealed that agricultural fields were abandoned owing to soil erosion progressively from top to bottom, much as in ancient Greece.

As in the *bajos* of the Mayan jungle, pits dug into the swampy valley bottom sediments in the Upper Lerma Basin in central Mexico also record increased soil erosion from the surrounding slopes beginning around 1100 BC. Soil erosion then intensified during expansion of settlements in the late classic and early postclassic periods beginning about AD 600. On his tour fourteen centuries later, Cook recognized that the areas populated most densely in preconquest times had the worst soil exhaustion.

The soils in Mexico's "cradle of maize" in the Tehuacán Valley about a hundred miles southeast of Mexico City also bear witness to extensive pre-Columbian soil erosion. In the early 1990s field surveys of soils around the town of Metzontla revealed striking differences between areas that had been cultivated and those that had not. Intensively cultivated hillslopes were extensively eroded, with thin soils above weathered rock. Remnants of subsoil exposed at the ground surface documented soil erosion from fields, leaving a modern soil that consists of little more than a thin mantle of broken rock. In contrast, areas with little evidence of past cultivation contained a foot and a half of well-developed soil above weathered rock. Abrupt transitions in soil depth between long-cultivated and uncultivated areas suggest that a foot and a half of soil was missing from the farms.

Expansion of agriculture from irrigated valley bottoms up onto the surrounding hillslopes about 1,300 to 1,700 years ago supported a growing population and triggered widespread soil erosion that still impoverishes the region. Agriculture on the slopes of the region today supplies only about a quarter of the small town's maize and beans. Metzontla's residents produce handcrafted ceramics or work at wage labor in other towns. In this semiarid area where soil production proceeds slowly, the residents' primary environmental concern is access to firewood for domestic use and for firing ceramics. Their soil disappeared slowly enough that they don't know it is gone.

Erosion from agriculture also caused abandonment of parts of southern Central America. Pollen from a long core pulled from the bottom of La Yeguada's small lake in central Panama records that the rainforest was cleared for slash-and-burn agriculture between 7,000 and 4,000 years ago.

Archaeological records from this period indicate considerable population growth as intensified agriculture stripped the forest from the lake's watershed. By the time of Christ, accelerated erosion in the foothills and uplands led to agricultural abandonment of the watershed. Slow forest regeneration suggests depleted soils, and later agricultural settlements were concentrated along previously unoccupied floodplains and coastal valleys. The uppermost layers in the long sediment core revealed that the primeval rainforest actually dates from the time of the Spanish conquest, when the indigenous population of the area again declined dramatically—this time felled by disease.

In the American Southwest, the spectacular ruins of Mesa Verde, Chaco Canyon, and Canyon de Chelly—all abandoned well before discovery by Euro-Americans—have long intrigued archaeologists. Between about AD 1250 and 1400, the native Pueblo culture vanished from the Southwest. The usual suspects of war, disease, drought, and deforestation have been proposed to explain the mystery.

Pollen sequences recovered from different depths in valley bottom sediments show little to no change in the vegetation community at Chaco Canyon for thousands of years—until the Pueblo people arrived. Plant remains preserved in crystallized packrat urine built up on the floor of caves show that the native vegetation was pinyon-juniper woodland, and that the local vegetation changed dramatically during Pueblo occupation. The inhabitants of Chaco Canyon used thousands of ponderosa pines to construct buildings between AD 1000 and 1200. Countless more trees were burned as fuel. Today the local vegetation on most of the valley floor is a mix of desert scrub and grasses. But if you hike near the canyon you can still see ancient stumps in areas where few trees now grow.

Many have argued that droughts led to the abandonment of Chaco Canyon. Although droughts probably contributed to the Pueblo culture's decline, the regional climate for the past thousand years falls within the range of variability for the past six thousand years. It seems more likely that salinization of the Pueblos' fields and soil erosion limited the life span of their agriculture as a growing population led to dependence on neighboring areas for basic resources. These conditions set up an agricultural disaster during the next drought.

Domesticated maize arrived at Chaco Canyon about 1500 BC. Initially grown near ephemeral streams or freshwater marshes, maize production increasingly depended on floodplain irrigation as agriculture expanded. By about AD 800 to 1000, rain-fed farming was practiced wherever feasible throughout the Southwest. Agricultural settlements ranged in size from small communities of a few dozen people to villages with hundreds of inhabitants. Foraging remained an important component of the diet—particularly during droughts.

At first sites were occupied for a few decades before people moved on to new locations, but by about AD 1150 there was no unused arable land to move into or cultivate when local crops failed. The landscape was full, the desert's rainfall was capricious, and its soil was fragile. As in the Old World centuries earlier, settlements became increasingly sedentary and their heavy investment in agricultural infrastructure discouraged farmers from leaving fields fallow every few years. Beginning about AD 1130, two centuries of drought and chaotic rainfall patterns occurred while all the arable land was already under cultivation. When crop failures on marginal land forced people to move back into more settled areas, the remaining productive land could not support them.

Comparison of ancient agricultural soils and uncultivated soils in New Mexico and Peru shows that agricultural practices need not undermine societies. Soils at a site in the Gila National Forest, typical of prehistoric agricultural sites in the American Southwest, were cultivated between AD 1100 and 1150, at the peak of Pueblo culture, and subsequently abandoned. Soils of sites cultivated by the Pueblo culture are lighter colored, with a third to a half of the carbon, nitrogen, and phosphorus content of neighboring uncultivated soils. In addition, cultivated plots had gullies—some more than three feet deep—that began during cultivation. Even today, little grass grows on the ancient farm plots. Native vegetation cannot recolonize the degraded soil even eight centuries after cultivation ceased.

In contrast, modern farmers in Peru's Colca Valley still use ancient terraces cultivated for more than fifteen centuries. Like their ancestors, they maintain soil fertility through intercropping, crop rotations that include legumes, fallowing, and the use of both manure and ash to maintain soil fertility. They have an extensive homegrown system of soil classification and do not till the soil before planting; instead they insert seeds into the ground using a chisel-like device that minimally disturbs the soil. These long-cultivated soils have A horizons that are typically one to four feet thicker than those of neighboring uncultivated soils. The cultivated Peruvian soils are full of earthworms and have higher concentrations of carbon, nitrogen, and phosphorus than native soils. In contrast to the New Mexican example, under traditional soil management these Peruvian soils have fed people for more than fifteen hundred years.

The contrast between how the Pueblos and the Incas treated their dirt is but another chapter in the broader story of how the rise of agriculture set off a perpetual race to figure out how to feed growing populations by continuously increasing crop yields. Sometimes cultures figured out a way to muddle through without depleting soil productivity, often they did not.

A common lesson of the ancient empires of the Old and New Worlds is that even innovative adaptations cannot make up for a lack of fertile soil to sustain increased productivity. As long as people take care of their land, the land can sustain them. Conversely, neglect of the basic health of the soil accelerated the downfall of civilization after civilization even as the harsh consequences of erosion and soil exhaustion helped push Western society from Mesopotamia to Greece, Rome, and beyond.

Efforts to feed the world today often include calls for a cultural revolution, a new agrotechnological revolution, or a political revolution to redistribute land to subsistence farmers. Less widely known is how, after centuries of agricultural decline, a preindustrial agricultural revolution began in the still-fertile and revitalized fields of Western Europe, setting the stage for the social, cultural, and political forces that forged colonial powers and shaped our modern global society.