

The Nature, History, and Distribution of Lithic Mulch Agriculture: An Ancient Technique of Dryland Agriculture

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Abstract

The mulching of agricultural fields and gardens with stones, pebbles, cinder and similar lithic materials is a variant agricultural strategy that has been used to evade drought and increase crop yield for more than a thousand years in the Old and New Worlds. Lithic mulch agriculture (LMA) is uniquely suited to the constraints of dryland environments, yet its use has remained confined both spatially and temporally. Prehistoric and contemporary LMA cases are synthesized and treated as a taxonomically discrete form of agriculture. This serves to alert scholars to the possibility of LMA at other historic sites.

LITHIC mulch agriculture (LMA) is a variant agricultural strategy employing lithic (stone) materials as a mulch for improving crop growth. Lithic mulch on an agricultural plot can increase soil moisture, reduce soil erosion, increase average soil temperature and moderate diurnal extremes, and increase crop biomass and crop yield. This technique allows for an expansion of arable land into regions previously considered unsuitable for agriculture, and (initially) improves the productivity of existing arid and semi-arid cropland.

Lithic mulch has been used to advantage for more than a thousand years in the Old and New Worlds, yet has remained confined both temporally and spatially. This paper will discuss the nature and function of lithic mulch and outline the known history of lithic mulch agriculture. Historic cases will be drawn from the Israeli Negev, Roman Italy/Mediterranean, the Peruvian Atacama, northwest Argentina, northern and southern Arizona, northern New Mexico, New Zealand, the Canary Islands, and central China. Contemporary agronomic experiments with lithic mulch will be framed against this historic experience as a way of assessing the future potential for LMA in arid lands.

This global-historical synthesis allows us to see a commonality in form and function, and forces us to view these features as more than aberrations to more established modes of production. Lithic-mulched plots are a taxonomically discrete field form, analogous to agricultural terraces and raised-fields. Like these more widely distributed agricultural forms, lithic mulch agriculture has ancient origins and is uniquely adapted to site-specific environments. Unlike either terracing or raised fields, however, LMA failed to diffuse beyond the few locales where it was independently invented, was rarely used for any length of time, and generally contributed little to the overall food supply. Because of these limitations, lithic-mulched fields have received little attention in the academic literature. If mentioned at all, gravel, rock, pebble, or ash-mulched plots have often been treated as non-agricultural features, or, at best, as marginal deviations in traditional form. Therein lies the importance of studying this unique agricultural field form: because it has enjoyed only limited success where employed it has remained relatively rare; because it is rare it has been recognized and studied by few scholars; yet a succession of independent experiments has already left its mark on the landscape, and these features are very real.

I

Lithic mulch agriculture involves the surface mulching of gardens or agricultural plots with pebbles, gravel, stones, volcanic ash and cinder, or any other lithic material, in the same fashion that a gardener or farmer will apply a mulch of bark or straw. These materials are raked or piled into mounds, ridges, terraces or extensive surface layers to improve crop growth, or to buffer against declining yields during periods of drought. Lithic-mulched plots are sometimes found in association with shallow borrow pits, where some of the pebbles or stones were 'mined', and were always sited within, or very near, surface or near-surface deposits of stone, gravel and the like (Fig 1).

Many features exist which might be (mis)interpreted as LMA but do not fit the precise definition of a 'mulch', or are created for non-agricultural purposes. For example, there are many historic and contemporary cases of natural stony or gravelly surfaces being used to grow crops.¹ However, such surfaces remain unaltered, save for the hoe or plough furrows, and lithic materials are not applied to the surface of the soil. In some cases, crops have been planted in soil underlying a thin layer of aeolian sand or volcanic ash.² Although such features emulate LMA and offer similar benefits, they rely on a naturally-deposited mineral layer and do not involve the purposeful craft of mulching.

In some cases fields or gardens have been altered by mixing soils of different qualities and textures to improve soil quality (for

example, 'liming' with calcium carbonate, 'marling' with clay-carbonate and lime mixes, or mixing sand into the soil),³ or by working coarse fragments into the soil (for example, stones, gravel, oyster shells, bones, coral).⁴ However, these strategies would fall under the category of soil mixing or amendments used to correct soil acidity and liberate plant nutrients; soils or lithic materials, in such cases, are incorporated into the soil horizon and co-mingle with the root mass of crops. In a lithic-mulched field the root mass will grow in the soil beneath a surface layer of stone or gravel.

Another type of garden which might be confused with LMA are the stone gardens built in Japan and China by applying a layer of gravel and stone to the surface of a garden.⁵ However, these oriental gardens serve an aesthetic, not an agricultural/horticultural, purpose.

Control of evaporation is one of the most important goals of soil management aimed at improving the supply of water to crops.⁶ Lithic mulch can increase crop biomass and crop yield by acting as a one-way water valve to increase the amount of moisture available to plants growing on the mulched plots by reducing soil crust formation, thereby increasing infiltration capacity, and reducing evaporative losses of water from wind and sun.⁷ A lithic

³ Cato et al, *Roman Farm Management*; J W Gent, *Systema Agriculturae*, 1669; J C Loudon, *An Encyclopaedia of Agriculture*, 1844.

⁴ Gent, *Systema Agriculturae*, p 65; Loudon, *Encyclopaedia of Agriculture*, p 330; K D White, *Roman Farming*, Cornell UP, 1970.

⁵ K Fukuda, *Japanese Stone Gardens*, Charles E Tuttle Co, 1970; E T Morris, *The Gardens of China: History, Art, and Meanings*, Charles Scribner's Sons, 1983.

⁶ R. Heinonen, *Soil Management and Crop Water Supply*, Swedish University of Agricultural Sciences, 1985, p 57.

⁷ A T Corey and W D Kemper, *Conservation of Soil Water by Gravel Mulches*, Hydrology Papers No 30, Colorado State University, 1968; W D Kemper and R E Danielson, 'Gravel mulches, one way to catch and hold rainfall in arid regions', *Crops and Soils*, 21, 1969, p 22; M L Fairbourn and W D Kemper, 'Gravel mulches improve dryland tomato yields', *Colorado Rancher and Farmer*, 24, 1970, pp 64-5; M L Fairbourn, 'Effect of gravel mulch on crop yields', *Agronomy J*, 65, 1973, pp 925-28; J E Adams, 'Influence of mulches on runoff, erosion, and soil moisture depletion', *Proceedings, Soil Science Society of America*, 30, 1966, pp 110-14; J Lamb Jr and J E Chapman, 'Effect of surface stones on erosion, evaporation, soil temperature, and soil moisture', *J American Society of Agronomy*, 35, 1943, pp 567-78.

¹ Cato, Marcus Porcius, and Censorius, *Roman Farm Management: The Treatises of Cato and Varro*, 1913; E C Semple, *The Geography of the Mediterranean Region: Its Relation to Ancient History*, Henry Holt and Co, 1931; J I Rodale, *Stone Mulching in the Garden*, Rodale Press, 1949.

² N H Greenwood, 'North America', in G A Klee, ed, *World Systems of Traditional Resource Management*, 1980, pp 189-215; K L Jones, 'Dune soils and polynesian gardening near Hokianga North Head, North Island, New Zealand', *World Archaeology*, 16, 1984, pp 75-88; H S Colton, 'Sunset Crater: the effect of a volcanic eruption on an ancient Pueblo people', *Geog Rev*, 22, 1932, pp 582-90; *idem*, 'Sunset Crater', *Plateau*, 18, 1945, pp 7-14; *idem*, *Black Sand: Prehistory of Northern Arizona*, Greenwood Press, 1960; P J Pilles Jr, 'Sunset Crater and the Sinagua: a new interpretation', in P D Sheets and D K Grayson, eds, *Volcanic Activity and Human Ecology*, 1979, pp 459-85.

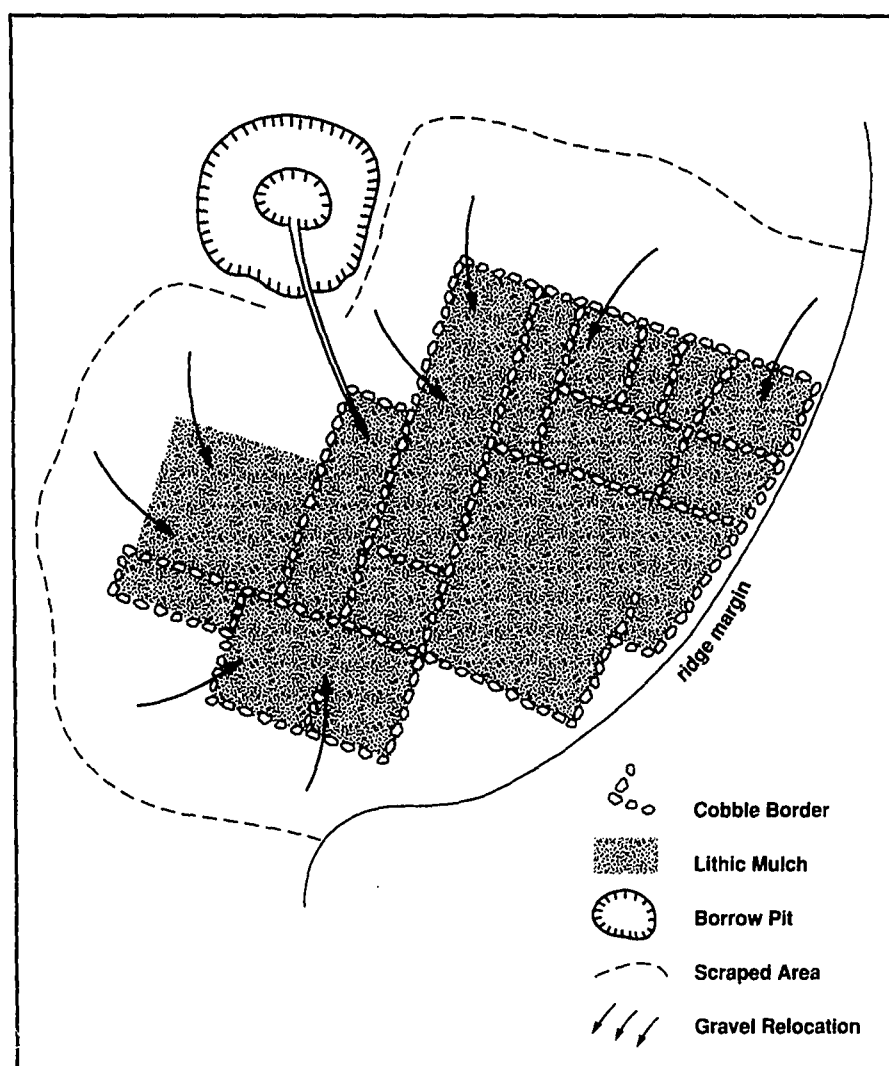


FIGURE I

A lithic mulch garden (solid pebble mulch) typical of those in northern New Mexico.

mulch also inhibits salinization because the evaporation of salt-laden water at the soil surface is dramatically reduced,⁸ and more water will percolate to lower soil and rock layers to recharge local aquifers and help to raise the water-table.⁹

Organic mulch (such as straw), like lithic mulch, can inhibit evaporation and also

help to control weeds. However, these mulches also lower the soil temperature, resulting in latent germination and/or a shortened growing season.¹⁰ Lithic mulch, on the other hand, will increase average soil temperature (which may be helpful or harmful, depending on the situation)

⁸ P W Unger, 'Soil profile gravel layers: (I) effect on water storage, distribution, and evaporation; (II) effect on growth and water use by a hybrid forage sorghum', *Proceedings, Soil Science Society of America*, 35, 1971, pp 631-34; 980-83.

⁹ Corey and Kemper, *Conservation of Soil Water*, p 19.

¹⁰ C O Othieno and P M Ahn, 'Effects of mulches on soil temperature and growth of tea plants in Kenya', *Experimental Agriculture*, 16, 1980, pp 287-94; W R Van Wijk, W E Larson, and W C Burrows, 'Soil temperature and the early growth of corn from mulched and unmulched soil', *Proceedings, Soil Science Society of America*, 23, 1959, pp 428-34.

because the stone, gravel, or ash on the surface of the soil acts as a solar collector to absorb the sun's energy during the day and then re-radiate much of that heat into the soil throughout the day and night.¹¹

A lithic mulch also increases surface roughness, generating more turbulent air flow over the garden surface. This has the effect of reducing the hottest day-time temperatures and raising the lowest night-time temperatures, thus providing a more thermally stable and healthy environment for the emergence of seedlings and the growth of crops.¹² The increase in wind turbulence also lowers the velocity of wind, thereby reducing wind erosion. Furthermore, lithic mulch protects the soil surface from runoff to reduce erosion by water on agricultural plots.¹³

In addition to extending the growing season, a warmer soil temperature also increases the rate at which roots can take up water and nutrients from the soil¹⁴ (although published reports on the effects on nitrogen uptake are contradictory, showing both enhanced and depressed nitrification¹⁵). The combination of increased moisture retention and higher temperature in a lithic-mulched field results in accelerated germination and higher crop yields.¹⁶ Increases in yield serve to utilize available soil moisture even better because the efficiency of water utilization by crops

(kg of dryweight biomass produced per cm water consumed) increases with crop yield.¹⁷ A lithic mulch also leads to the development of better distributed roots throughout a greater depth of the soil,¹⁸ which improves crop tolerance to drought (Fig 2).

Although soil structure is not significantly affected by lithic mulch, the organic content of the soil can decrease by as much as 10 per cent after one year of mulching, and may become a detriment to agriculture over a long period of time.¹⁹ A layer of lithic mulch on the surface of a field will hinder the application of fertilizer and discourage the return of crop wastes following harvest. This could disrupt nutrient cycles and lead to the depletion of some essential soil nutrients.

II

The literature on gardens and agricultural fields is vast, yet the sources are sparse which describe stone, gravel, or ash-built forms on arable land, or ascribe an agricultural purpose to these lithic mounds, ridges and fields. Rarer still are reports which describe the morphology, associated crops, and cultural ecology of lithic-mulched fields.

There follows a compilation of cases, listed chronologically, where lithic-mulched forms have been assigned an agricultural role by one or more researchers (Fig 3). Because of the lack of detail presently available on the first four cases, hypotheses regarding their purpose and use are conjectural. The remaining six cases of prehistoric and historic LMA have been better studied through empirical fieldwork and/or are more recent features, and their agricultural function is more convincingly documented. Alternative hypotheses are

¹¹ Fairbourn, 'Effect of gravel mulch on crop yields', p 928; D R Lightfoot and F W Eddy, 'The agricultural utility of lithic mulch gardens: past and present', *Geojournal*, 34, 1994, pp 425-37; J E Adams, 'Effect of mulches on soil temperature and grain sorghum development', *Agronomy J*, 57, 1965, pp 471-74.

¹² Lamb and Chapman, 'Effect of surface stones', p 575; Yen-hu Chang, *Climate and Agriculture: An Ecological Survey*, Aldine Press, 1968.

¹³ Adams, 'Influence of mulches', p 112.

¹⁴ E W Russell, *Soil Conditions and Plant Growth*, 10th ed, 1973.

¹⁵ Adams, 'Effect of mulches', p 474; A H Hakimi and R P Kachru, 'Silage corn responses to different mulch tillage treatments under arid and semiarid climatic conditions', *J Agronomy and Crop Science*, 147, 1978, pp 15-23.

¹⁶ Fairbourn, 'Effect of gravel mulch on crop yields', Hakimi and Kachru, 'Silage corn responses'; D G Barkley, R E Blaser, and R E Schmidt, 'Effect of mulches on microclimate and turf establishment', *Agronomy J*, 57, 1965, pp 189-92; J M Walker, 'One-degree increments in soil temperatures affect maize seedling behavior', *Soil Science Society of America Proceedings*, 33, 1969, pp 729-36.

¹⁷ Chang, *Climate and Agriculture*.

¹⁸ Othieno and Ahn, 'Effects of mulches', p 291.

¹⁹ R B Alderfer and F G Merkle, 'The comparative effects of surface application versus incorporation of various mulching materials on structure, permeability, runoff, and other soil properties', *Soil Science Society of America Proceedings*, 8, 1943, pp 79-86.

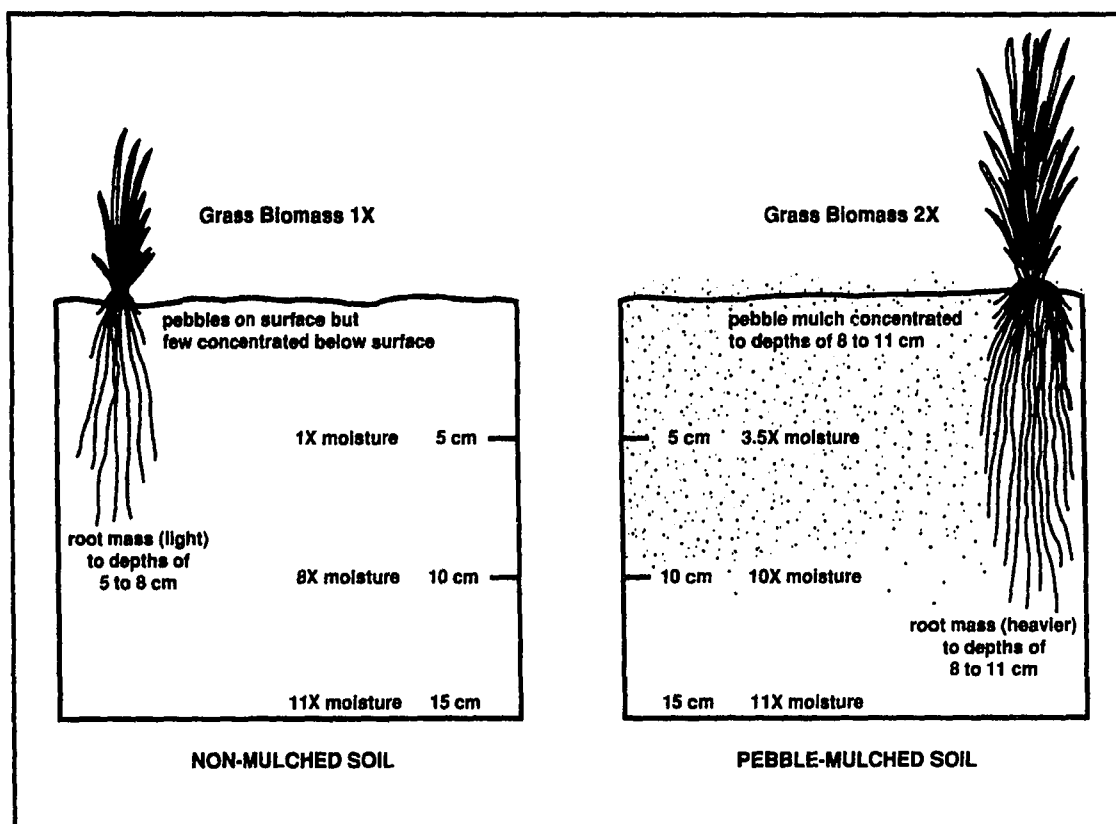


FIGURE 2

Comparative soil moisture and biomass for pebble-mulched and non-mulched soils in the Galisteo Basin, northern New Mexico.

provided where there has been disagreement among scholars over the precise function of these features. The area, number, and morphology of features, crops presumably grown, dates of use, and associated cultural groups are summarized. This compendium is derived (second-hand) from published reports, combined with a personal familiarity with lithic-mulched features gained through a detailed empirical study of pebble mulch gardens in New Mexico, and observation of prehistoric rock mounds in Arizona and Israel and contemporary rock mulching in Syria.

1. Negev Desert, Israel

Many thousands of stone mounds and ridges cover scores to hundreds of hectares around the sites of Shivta-Nitzana (aka

Subeita or Esbeita) and Avdat (aka Abda) in the Negev desert of southern Israel.²⁰ The rock/stone mounds (some with gravel fill) were constructed on hillslopes in sizes ranging from 1 to 5 m in diameter and 15 to 70 cm in height; small mounds are spaced 2–4 m apart while larger mounds may have 20–30 m separation.²¹ The 15–25 cm high flintstone and gravel ridges were built in 2–3 m wide rows at 6–10 m intervals, layed out on hillsides parallel to the slope, in perfectly straight rows with canals or raised furrows running between every row.²²

²⁰ M. Evenari, L. Shanan, and N. Tadmor, *The Negev: The Challenge of a Desert*, Harvard UP, 1971; Y. Kedar, 'Water and soil from the desert: some ancient agricultural achievements in the central Negev', *Geog J*, 123, 1957, pp 179–87; D. Zohary, 'Notes on ancient agriculture in the central Negev', *Israel Exploration J*, 4, 1954, pp 17–25.

²¹ Evenari et al, *The Negev*, pp 129–32.

²² *Ibid*, pp 129–32; Kedar, 'Water and soil from the desert', p 184.

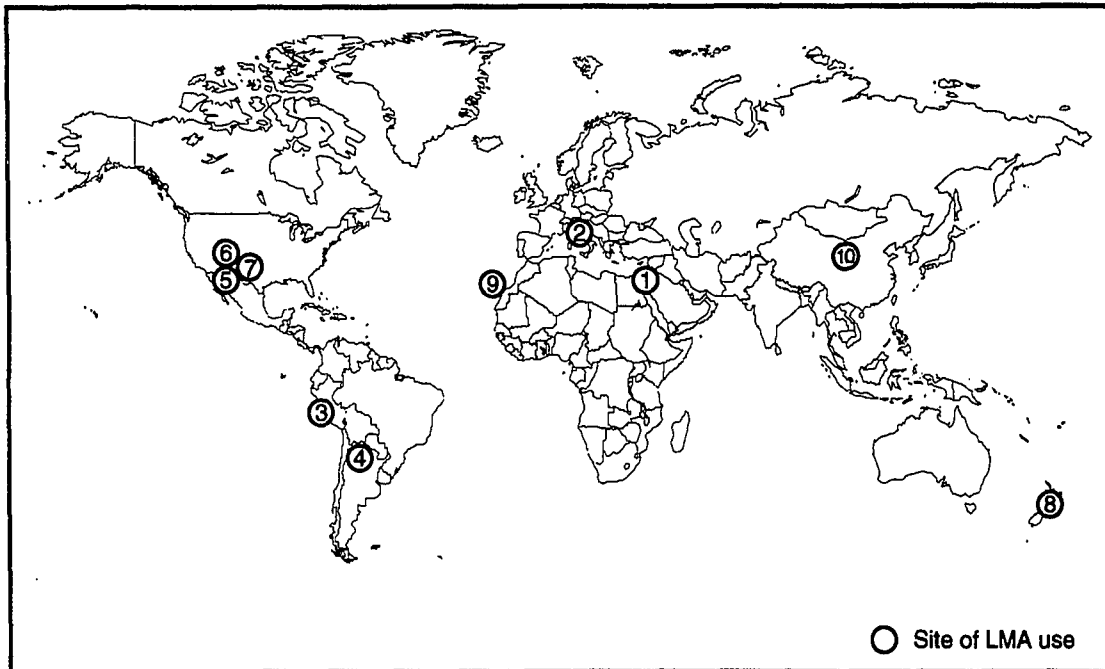


FIGURE 3
Sites of ancient and historic use of lithic mulch agriculture (pre-1900).

All these features are associated with ancient Nabatean sites²³ and were most likely used during the period 200 BC to AD 600,²⁴ though some may have been used as early as 2000 BC²⁵ or as late as AD 700.²⁶ A number of researchers have ascribed to these features an agricultural role.²⁷ By collecting dew water and transmitting it to

the soil²⁸ or by helping to retain scant rainfall or pot-irrigation water,²⁹ these stone forms may have been used to grow grape vines³⁰ or olive trees.³¹ The local Arabic name for the stone mounds is 'tuleilat el anab' or 'rujum el kurum', both making reference to 'grape mounds' or 'vine mounds'.³²

Some scholars remain sceptical of their agricultural functions, arguing that they did not collect dew,³³ and did not improve the water regime of the soil below to any significant degree.³⁴ Alternative hypotheses

²³ Kedar, 'Water and soil from the desert', p 179; *idem*, 'Ancient agriculture at Shivta in the Negev', *Israel Exploration J.*, 7, 1957, pp 178-89; M Evenari and D Koller, 'Ancient masters of the desert', *Scientific American*, 194, 1956, pp 39-45; H Aschmann, 'Historical development of agriculture in semi-arid regions of winter precipitation', *Proceedings, International Symposium on Rainfed Agriculture in Semi-Arid Regions*, Riverside, California, April 17-22, 1977, pp 87-110.

²⁴ Kedar, 'Water and soil from the desert', p 179, and 'Ancient agriculture at Shivta', p 178.

²⁵ Evenari *et al*, *The Negev*, p 127.

²⁶ Kedar, 'Water and soil from the desert', p 179.

²⁷ Aschmann, 'Historical development of agriculture'; E H Palmer, *The Desert of the Exodus*, 1871; C L Wooley and T E Lawrence, *The Wilderness of Zin: Archaeological Report*, 1914; J E Spencer and G A Hale, 'The origin, nature, and distribution of agricultural terracing', *Pacific Viewpoint*, 2, 1961, pp 1-40; A Reifenberg, *The Struggle Between the Desert and the Sown: Rise and Fall of Agriculture in the Levant*, Government Press, Jerusalem, 1955; P Mayerson, 'Ancient agricultural remains in the central Negev: The Teleilat el Anab', *Bulletin of the American Schools of Oriental Research*, 153, 1959, pp 19-31.

²⁸ Reifenberg, *The Struggle Between the Desert and the Sown*, p 45.

²⁹ Mayerson, 'Ancient agricultural remains in the central Negev', p 134.

³⁰ Palmer, *The Desert of the Exodus*; Spencer and Hale, 'The origin, nature, and distribution of agricultural terracing', p 21; Reifenberg, *The Struggle Between the Desert and the Sown*, p 45.

³¹ Spencer and Hale, 'The origin, nature, and distribution of agricultural terracing', p 21.

³² Kedar, 'Water and soil from the desert', p 185; Reifenberg, *The Struggle Between the Desert and the Sown*, p 45; Mayerson, 'Ancient agricultural remains in the central Negev', p 136.

³³ Evenari *et al*, *The Negev*, pp 132-34; D Hillel, *Negev: Land, Water, and Life in a Desert Environment*, Praeger Scientific, 1982.

³⁴ Hillel, *Negev: Land, Water, and Life*, p 136.

view these mounds and ridges as water harvesting features, constructed while clearing stones from the hillslopes to increase the runoff of water to the valley below.³⁵ One scholar suggested that their primary function was to allow sediment, eroded from hillslopes during runoff, to accumulate on arable land in the valley bottom,³⁶ but this is not likely as slope runoff was also engineered to drain into cisterns; and water, not arable soil, was the limited resource.³⁷ Other scholars reported that the stones were heaped into mounds in order to prepare the ground between piles for cultivation.³⁸

Empirical tests at some of these sites have demonstrated a 30–40 per cent increase in water runoff from surfaces where stones were cleared by rock mounding.³⁹ However, this does not negate the ability of stone mounds and ridges to increase infiltration and reduce evaporation in the soil underlying each mound or ridge. (The authors of the runoff theory, noted above, have contradicted their own hypothesis, in another section of their book, by praising the role of stones and desert pavement in increasing infiltration and preserving soil moisture under the stones.⁴⁰) Perhaps these features were built primarily to increase runoff to the valley below, and then the heaps of stones that were piled up during clearing were employed to grow grape vines, thereby diversifying planting locations, minimizing subsistence risk, and allowing for an expansion of arable land. Just as plausible is the initial construction of stone mounds for the planting of grape vines, followed by an expansion of this practice after it was discovered that runoff increased from the

hillslopes where grape-vine mounds had been built. Besides, these mounds are found not only on slopes but also on hill crests where they could not have contributed much to runoff. These water harvesting and LMA functions would both operate simultaneously and are not mutually exclusive.

2. Roman Italy/Mediterranean

An unknown number of stone mounds were used in Roman Italy and nearby Mediterranean regions for growing grapes and (perhaps) olive trees.⁴¹ Roman LMA was most likely applied in the period 100 BC to AD 400, and perhaps a century on either side of this range.⁴² Precise morphological details have not been recorded, but general descriptions of stone mulching have been noted by Roman and modern writers who describe the practice of placing stones on top of the soil and making stone mounds.⁴³ Far more has been written about the Roman use of naturally stony soil, and their practice of burying 'thirsty stones or rough shells' into the ground to reduce soil seal and maintain infiltration.⁴⁴ However, such methods fall short of stone 'mulching' if stones are not purposely layed on top of the soil.

3. Atacama Desert, Peru

Roughly 1500 stone-lined pits, averaging 1 m in depth and diameter, were built by the Lapa Lapa people in the 'lomas' or fog oases around the site of Chilca, south of

³⁵ Evenari et al, *The Negev*, pp 134–47; Hillel, *Negev: Land, Water and Life*, pp 135–44.

³⁶ Kedar, 'Water and soil from the desert', p 185; Kedar, 'Ancient agriculture at Shivta', p 186.

³⁷ Hillel, *Negev: Land, Water, and Life*, p 136.

³⁸ Wooley et al, *The Wilderness of Zin*.

³⁹ Evenari et al, *The Negev*, pp 135–47.

⁴⁰ *Ibid*, pp 260–61.

⁴¹ Rodale, *Stone Mulching in the Garden*, p 58; J Chilwell, 'Stone mulches increase productivity of soil', *Farmer's Weekly of South Africa*, 84, 1952, pp 41–2.

⁴² White, *Roman Farming*; Cato et al, *Roman Farm Management*; Rodale, *Stone Mulching in the Garden*.

⁴³ Rodale, *Stone Mulching in the Garden*, p 58; P W Unger, 'Water conservation: Southern Great Plains', in H E Dregne and W O Willis, eds, *Dryland Agriculture*, Soil Science Society of America, 1983, pp 35–48; G V Jacks, W D Brind, and R Smith, *Mulching*, Farnham Royal, 1955, p 12.

⁴⁴ White, *Roman Farming*, pp 229–30; Cato et al, *Roman Farm Management*; Rodale, *Stone Mulching in the Garden*, p 58.

Lima, Peru.⁴⁵ Estimated dates of use range from 100 BC to AD 200, and perhaps a bit later.⁴⁶ Both maize and potatoes have been identified as crops associated with the loma pits.⁴⁷ Some scholars believe that these features were used to collect and retain subsurface moisture, which would flow by gravity around these pits.⁴⁸ It has also been suggested that they collected dew from fog moisture, the only form of precipitation in this arid region.⁴⁹

Tests of the dew-harvesting principle in the Negev desert of Israel have cast doubt on this latter theory; dew will condense on piles of rock, but not in harvestable or usable quantities.⁵⁰ The rocks and gravel in these pits would have been a nuisance to potato cultivation,⁵¹ so they may have been used only as storage pits.⁵² Regardless, maize has not been ruled out as a stone-pit cultivar; nor has the possibility that these features increased, even slightly, the moisture content of the soil beneath the stone veneer. Even today, plant growth is seasonally more luxuriant within these pits, compared to plants growing naturally outside of the pits.⁵³

4. Northwest Argentina

Extensive areas of stone strips, mounds and ridges are found around four prehistoric sites (Coctaca, Cachi, Quilmes, and Angualasto) in northwest Argentina.⁵⁴ All these features

appear to have been used at least during the period AD 300–700, and possibly as early or late as AD 1 and AD 1500.⁵⁵ Cultures associated with these sites include Humahuaca (at Coctaca), Calchaqui (at Cachi and Quilmes), Aimogasta (at Angualasto), and Inca (if these features were still in use by the late 1400s when the Inca occupied the region).⁵⁶

The form of LMA found throughout this region varies from site to site. At Coctaca there are 1.5–3.0 m wide strips of pebbles over a finer soil, laid out between masonry walls less than 75 cm high, as well as longitudinal mounds of small stones (5 m high and 8–10 m across), perhaps built and irrigated to grow maize.⁵⁷ It is possible that crops did not grow in the pebble-covered soil, within the low masonry walls, but between these features, which may have served as traditional terraces.⁵⁸ In the Cachi area, many stone mounds were built for planting maize, and/or to increase runoff to the valley below.⁵⁹ A number of terraces with a sandy and pebbly pavement are found around the Quilmes site.⁶⁰ These may be a form of LMA, or possibly a feature of natural deflation; neither hypothesis can be ruled out until these features are examined in greater detail. At the Angualasto site, pebbles were scraped into mounds (50–70 cm wide and 5–10 cm high) or raked into elongated ridges, 20–50 cm across, with alternating bare and pebble-paved soil.⁶¹ These features may have been used to grow maize and/or to increase valley runoff.⁶²

⁴⁵ F. Engel, 'New facts about pre-Columbian life in the Andean Lomas', *Current Anthropology*, 14, 1973, pp 271–80; R. A. Benfer, G. H. Weir, and B. O. Enriquez, 'Early water management technology on the Peruvian coast', in D. L. Browman, ed., *Arid Land Use Strategies and Risk Management in the Andes*, Westview Press, 1987, pp 195–206.

⁴⁶ Engel, 'New facts about pre-Columbian life', p 277.

⁴⁷ *Ibid.*, pp 275–77.

⁴⁸ Benfer et al., 'Early water management', p 199.

⁴⁹ *Ibid.*, p 199.

⁵⁰ Hillel, *Negev: Land, Water, and Life*, p 136; National Academy of Sciences, *More Water for Arid Lands: Promising Technologies and Research Opportunities*, National Academy of Sciences, 1974, p 68.

⁵¹ C. Field, 'A reconnaissance of southern Andean agricultural terracing', unpublished Ph D thesis, University of California, Los Angeles, 1966, p 512.

⁵² Engel, 'New facts about pre-Columbian life', pp 275–77.

⁵³ Benfer et al., 'Early water management', p 199.

⁵⁴ Field, 'Reconnaissance of southern Andean agricultural terracing', pp 263–401.

⁵⁵ R. A. Donkin, *Agricultural Terracing in the Aboriginal New World*, Viking Fund Publications in Anthropology No 56, University of Arizona Press, 1979; W. C. Bennett, E. F. Bleiler, and F. H. Sommer, *Northwest Argentine Archaeology*, Yale UP, 1948.

⁵⁶ Bennett et al., *Northwest Argentine Archaeology*, pp 18, 38–43, 90–98, 112–19.

⁵⁷ Field, 'Reconnaissance of southern Andean agricultural terracing', pp 393, 401, 512–13.

⁵⁸ *Ibid.*, pp 393–99.

⁵⁹ *Ibid.*, pp 372–74, 512.

⁶⁰ *Ibid.*, p 362.

⁶¹ *Ibid.*, pp 263–64.

⁶² *Ibid.*, pp 263–64, 512.

5. Southern (Hohokam) Arizona

As many as 42,000 rock mounds, in more than 100 different loci, were piled onto bajadas, talus slopes, and upper flood-plain terraces in the Phoenix-Tucson region of southern Arizona.⁶³ These features range in size from small clusters with a few fist-sized cobbles to large mounds several metres in diameter, but most are one to two metres in diameter and rarely exceed 75 cm in height.⁶⁴ The rock piles occur in clusters, and sometimes in alignments creating more or less rectangular areas; they are most dense around cobbly surfaces where the soil is more than 20 cm deep.⁶⁵ All these mounds are associated with the Hohokam culture and were built during the period AD 850–1300.⁶⁶

Some scholars suggest that these mounds were piled up when stones were cleared to increase runoff to canals and fields

below,⁶⁷ but this is unlikely as most of the mounds are on gently sloping to flat surfaces.⁶⁸ Other researchers have speculated that they were built to clear fields so that crops could be planted between the mounds⁶⁹ and to control the diversion of water over these planted fields.⁷⁰ Still others see no agricultural function to the piles at all, believing that they were used to support upright posts.⁷¹

In support of the LMA hypothesis, researchers have found clear evidence that these rockpiles were built and used for growing agave (used as a source of both food and fibre).⁷² Remains of charred agave have been found in nearby roasting pits, and many steep-edged core tools and knives, similar to Southwest Indian agave and mescal knives, have been found scattered across many of the rockpile fields.⁷³

6. Northern (Sinagua) Arizona

Nineteen ash ridges, twenty-five ash/cinder mounds, and several adjacent rockpiles, collectively covering an area greater than 4 ha, may have been used to grow crops in the volcanically-altered Sunset Crater region northeast of Flagstaff, Arizona.⁷⁴ These features were built and

⁶³ P R Fish and S K Fish, 'Agricultural maximization in the Sacred Mountain Basin, Central Arizona', in S K Fish and P R Fish, eds, *Prehistoric Agricultural Strategies in the Southwest*, Arizona State University Anthropological Research Papers No 33, Arizona State University, 1984, pp 147–59; S K Fish, P R Fish, C Miksicek, and J Madsen, 'Prehistoric agave cultivation in southern Arizona', *Desert Plants*, 7, 1985, pp 107–12; S K Fish, P R Fish, and J H Madsen, 'Analyzing regional agriculture: a Hohokam example', in S K Fish and S A Kowaleski, eds, *The Archaeology of Regions: A Case for Full-Coverage Survey*, Smithsonian Institution Press, 1990, pp 189–218; W B Masse, 'An intensive survey of prehistoric dry farming systems near Tumamoc Hill in Tucson, Arizona', *The Kiva*, 45, 1979, pp 141–86; J S Czaplicki and A G Rankin, *A Supplemental Class III Archaeological Survey of the Phase A, Reach 3 Corridor, Tucson Aqueduct, Central Arizona Project*, Supplement to Archaeological Series No. 165, University of Arizona Press, 1984; W H Doelle, 'Hohokam use of nonriverine resources', in P Grebinger, ed, *Discovering Past Behavior: Experiments in the Archaeology of the American Southwest*, Gordon and Breach, 1978, pp 245–74.

⁶⁴ Masse, 'An intensive survey of prehistoric dry farming systems', pp 164–66; Fish et al, 'Analyzing regional agriculture', p 202.

⁶⁵ Masse, 'An intensive survey of prehistoric dry farming systems', pp 164–66.

⁶⁶ Fish et al, 'Prehistoric agave cultivation', p 110; Fish et al, 'Analyzing regional agriculture', p 195; V Canouts, *An Archaeological Survey of the Onne Reservoir*, Report to the Arizona Archaeological Center, University of Arizona Press, 1975, p 284; J S Wood, 'Second foundation: settlement patterns and agriculture in the northeastern Hohokam periphery, central Arizona', in Fish and Fish, *Prehistoric Agricultural Strategies*, pp 271–89; K Rozen, *The Archaeological Survey of the Northern Tucson 138 kV Transmission Line System: The Northern Tucson Basin and Lower Santa Cruz Valley, Arizona*, Archaeological Series No 132, University of Arizona Press, 1979, p 64; P H Stein, *Archaeological Investigations Along the Salt-Gila Aqueduct*, Arizona Projects Office Technical Report, United States Bureau of Reclamation, 1979, p 78.

⁶⁷ Doelle, 'Hohokam use of resources', p 266; Canouts, *Archaeological Survey of the Onne Reservoir*, pp 83, 285; Wood, 'Second foundation', p 272; Stein, *Archaeological Investigations Along the Salt-Gila Aqueduct*, p 120.

⁶⁸ Fish et al, 'Analyzing regional agriculture', p 203; Masse, 'An intensive survey of prehistoric dry farming systems', p 166.

⁶⁹ Rozen, *The Archaeological Survey of the Northern Tucson*, pp 59–60, 64.

⁷⁰ S K Fish, P R Fish, and J H Madsen, 'A preliminary analysis of Hohokam settlement and agriculture in the northern Tucson Basin', in A E Dittert and D E Dove, eds, *Proceedings of the 1983 Hohokam Symposium, Part 1*, Arizona Archaeological Society, 1985, p 92.

⁷¹ L S Teague and P L Crown, *Hohokam Archaeology Along the Salt-Gila Aqueduct Central Arizona Project*, Archaeological Series No 150, University of Arizona Press, 1982, p 109.

⁷² Fish et al, 'Prehistoric agave cultivation', pp 107–12; Fish et al, 'Analyzing regional agriculture', pp 205, 208; Czaplicki and Rankin, *Supplemental Class III Archaeological Survey*, p 5.

⁷³ Fish et al, 'Prehistoric agave cultivation', p 107.

⁷⁴ G L Berlin, J R Ambler, R H Hevly, and G G Schaber, 'Identification of a Sinagua agricultural field by aerial thermography, soil chemistry, pollen/plant analysis, and archaeology', *American Antiquity*, 42, 1977, pp 588–600; G L Berlin, D E Salas, and P R Geib, 'A prehistoric Sinagua agricultural site in the ashfall zone of Sunset Crater, Arizona', *J Field Archaeology*, 17, 1990, pp 1–16.

used by the Sinagua people during the years AD 1150–1250, and possibly as early as AD 1100.⁷⁵ At one site, ridges and swales average 265 m in length, 3–4 m in width, and 10–30 cm in height; at an adjacent site the largest ridge is 150 × 20 m and the smallest is 25 × 9 m.⁷⁶ All ridges are oriented at an oblique angle to the prevailing wind. The mounds are 10–24 m in diameter and 17–42 cm in height/depth.⁷⁷

One theory maintains that these mounds and ridges represent the piles of ash and cinder cleared from agricultural fields, following the eruption of Sunset Crater in AD 1064–67, in order to replant maize in the soil beneath the fresh layer of ejecta.⁷⁸ This view is based on the recovery of maize pollen from soil between ridges. A more recent study counters that this pollen was taken from underneath the ash-mulched features and that it pre-dates the eruption of AD 1064.⁷⁹ These scholars have found a different assortment of pollen within the ash/cinder ridges and mounds, leading them to believe that weedy plants, such as *amaranthus* and *chenopodium*, were double-cropped with spring and summer greens and other domesticates.⁸⁰

Wind-borne ejecta were spread over an area far larger than the 4 ha covered by ash ridges and mounds. Many other reports discuss farming in this wide-spread ash cover,⁸¹ but do not discuss the raking or surface loading of ash or cinder to build up a mulch.

7. Northern (Anasazi) New Mexico

Extensive areas of terrace and mesa tops are covered by hundreds (perhaps thousands) of pebble mulch gardens around prehistoric Anasazi Pueblo sites in northern New Mexico.⁸² Most are believed to have been built and then abandoned within the century spanning AD 1350–1450, with a few possibly in use a decade or two earlier and few decades later.⁸³ Most of the mulched gardens, covering at least 70,000 m² were built around a dozen different pueblos in the lower Chama and Ojo Caliente valleys, northwest of Santa Fe.⁸⁴ A further 102 pebble mulch gardens, covering another 41,000 m², are found south of Santa Fe, in the Galisteo Basin, around the pueblos of San Marcos (96 gardens) and San Lazaro (6 gardens).⁸⁵ At present, only the Galisteo pebble mulch gardens have been completely surveyed. The full extent of gardens in the Chama-

⁷⁵ Berlin *et al.*, 'A prehistoric Sinagua agricultural site', pp 13–14.

⁷⁶ *Ibid.*, pp 1–2, 5.

⁷⁷ *Ibid.*, pp 2, 5.

⁷⁸ G G Schaber and G J Gumerman, 'Infrared scanning images: an archaeological application', *Science*, 164, 1969, pp 712–13.

⁷⁹ Berlin *et al.*, 'A prehistoric Sinagua agricultural site', p 2.

⁸⁰ *Ibid.*, p 12.

⁸¹ Colton, 'Sunset Crater: the effect of a volcanic eruption', and *Black Sand*; H S Colton, 'The prehistoric population of the Flagstaff area', *Plateau*, 22, 1949, pp 21–25; *idem* 'Experiments in raising corn in the Sunset Crater ashfall area east of Flagstaff, Arizona', *Plateau*, 37, 1965, pp 77–79; Pilles, *Volcanic Activity and Human Ecology*; D A Breternitz, 'The eruption(s) of Sunset Crater: dating and effects', *Plateau*, 40, 1967, pp 72–76; A P Sullivan, 'Sinagua agricultural strategies and Sunset Crater volcanism', in Fish and Fish, *Prehistoric Agricultural Strategies*, pp 85–100; S H Maule, 'Corn growing at Wupatki', *Plateau*, 36, 1963, pp 29–32.

⁸² D R Lightfoot, 'The landscape context of Anasazi pebble-mulched fields in the Galisteo Basin, northern New Mexico', *Geoarchaeology*, 8, 1993, pp 349–70; *idem*, 'The cultural ecology of Puebloan pebble mulch', *Human Ecology*, 21, 1993, pp 115–43; Lightfoot and Eddy, 'The agricultural utility of lithic-mulch gardens', pp 425–37; T D Maxwell and K F Anschuetz, 'The southwestern ethnographic record and prehistoric agricultural diversity', in T W Killion, ed, *Gardens of Prehistory: The Archaeology of Settlement Agriculture in Greater Mesoamerica*, University of Alabama Press, 1992, pp 35–68; L S Cordell, *Prehistory of the Southwest*, 1984; F C Hibben, *Excavation of the Riana Ruin and Chama Valley Survey*, University of New Mexico Anthropological Series Bulletin No 300, University of New Mexico Press, 1937; K F Anschuetz, T D Maxwell, and J A Ware, *Testing Report and Research Design for the Mendenales North Project, Rio Arriba County, New Mexico*, Laboratory of Anthropology Note No 347, Museum of New Mexico, 1985.

⁸³ Lightfoot, 'The cultural ecology of Puebloan pebble mulch', pp 130–31; R L Tjaden, 'Bordered garden plots and field houses near Sapawe, north central New Mexico: a dry farming strategy', unpublished M A Thesis, Arizona State University, Tempe, 1979, p 16; R W Lang, *A Prehistoric Pueblo Garden Plot on the Rio Ojo Caliente, Rio Arriba County, New Mexico: Ojo Caliente Site 7, Features 1–2*, Contract Archaeology Division Report No 065, School of American Research, 1981, p 40; Maxwell and Anschuetz, 'Southwestern ethnographic record', p 57.

⁸⁴ Maxwell and Anschuetz, 'Southwestern ethnographic record'; Cordell, *Prehistory of the Southwest*, pp 205–6; Anschuetz *et al.*, *Testing Report and Research Design*; J A Ware and M Mensel, *The Ojo Caliente Project: Archaeological Test Excavations and a Data Recovery Plan for Cultural Resources Along U.S. 285, Rio Arriba County, New Mexico*, Archaeology Notes No 99, Museum of New Mexico, 1992.

⁸⁵ Lightfoot, 'The cultural ecology of Puebloan pebble mulch', pp 122–24, and, 'The landscape context of Anasazi pebble-mulched fields', pp 351–53.

Ojo Caliente valleys has not yet been assessed.

Many of the mulched gardens are bordered and/or internally partitioned with fist-sized and larger stones. Some of these, found in the vicinity of non-mulched gardens, may have been incrementally constructed by adding a pebble mulch to more traditional bordered gardens. Others have no stone borders, or only incomplete borders, and are found far from bordered gardens.⁸⁶ Many of these gardens are surrounded by borrow pits, or shallow depressions dug into the surface of gravelly ridges and terraces (1–4 m in diameter and 0.2–1.7 m in depth).⁸⁷ Some researchers argue that these hollows served as growing pits.⁸⁸ Others have demonstrated that much of the gravel used as a mulch on the gardens was 'mined' from these borrow pits, suggesting that their use as growing pits was incidental, if valid at all.⁸⁹

Pebble mulch gardens appear to have been intentionally sited only in areas with a surface/near-surface deposit of gravel.⁹⁰ Pebbles were acquired from borrow pits and/or by scraping adjacent areas and raking pebbles into layers over a garden surface.⁹¹ The gardens are generally rectangular in shape and vary from a small size

of 2–3 m to large fields several tens to hundreds of metres on a side; most average 10 or 20 m in length and width.⁹² The mulch appears as a layer of pea- to plum-sized pebbles, 3–7 cm high (15 cm in extreme cases), mixed with aeolian sediments incorporated into the mulch layer through centuries of disuse.⁹³

Scholars once believed that these pebbled forms were the stone foundations of Pueblo communities.⁹⁴ The agricultural nature of these features has now been confirmed with the repeated recovery of maize pollen in soil samples taken from pebble mulch gardens.⁹⁵ Furthermore, only one incidence of maize pollen has been recovered from samples taken just off of the gardens, suggesting that maize was indeed grown on the gardens and not on the gravelly soil between gardens.⁹⁶ Two lithic hoes have also been recovered from pebble mulch gardens in the Galisteo Basin.⁹⁷ The limited natural rainfall of the area, and the great number of pot sherds scattered around many of the pebbled gardens, suggest that the maize was routinely

⁸⁶ Lightfoot and Eddy 'The agricultural utility of lithic-mulch gardens', p 426; Maxwell and Anschuetz, 'Southwestern ethnographic record'; D E Buge, 'Prehistoric subsistence strategies in the Ojo Caliente valley, New Mexico', in Fish and Fish, *Prehistoric Agricultural Strategies*, pp 27–34.

⁸⁷ Lightfoot, 'The cultural ecology of Puebloan pebble mulch', p 122; Maxwell and Anschuetz, 'Southwestern ethnographic record', p 60; R W Lang, *An Archaeological Survey Near the Confluence of the Chama and Ojo Caliente Rivers, Rio Arriba County, New Mexico*, Contract Archaeology Division Report No 065, School of American Research, 1979, p 19.

⁸⁸ Lang, *An Archaeological Survey Near the Confluence of the Chama and Ojo Caliente Rivers*, p 19; Buge, 'Prehistoric subsistence strategies', p 32.

⁸⁹ Lightfoot, 'The cultural ecology of Puebloan pebble mulch', p 122; Maxwell and Anschuetz, 'Southwestern ethnographic record', p 60; R A Luebben, 'Leaf Water site', in F Wendorf, ed, *Salvage Archaeology in the Chama Valley, New Mexico*, Monographs of the School of American Research No 17, School of American Research, 1953, p 16.

⁹⁰ Lightfoot, 'The landscape context of Anasazi pebble-mulched fields', pp 360–66.

⁹¹ Lightfoot, 'The cultural ecology of Puebloan pebble mulch', pp 120–21; Maxwell and Anschuetz, 'Southwestern ethnographic record'.

⁹² D R Lightfoot, 'The prehistoric pebble-mulched fields of the Galisteo Anasazi: agricultural innovation and adaptation to environment', unpublished PhD thesis, University of Colorado, Boulder, 1990, pp 150–52; Tjaden, 'Bordered garden plots and field houses', p 5; Buge, 'Prehistoric subsistence strategies', p 31.

⁹³ Lightfoot, 'The prehistoric pebble-mulched fields', pp 173–74; Cordell, *Prehistory of the Southwest*, p 205; R W Lang, *Archaeological Investigations at a Pueblo Agricultural Site, and Archaic and Puebloan Encampments on the Rio Ojo Caliente, Rio Arriba County, New Mexico*, Contract Archaeology Division Report No 007, School of American Research, 1980, pp 5, 17.

⁹⁴ E L Hewett, *Antiquities of the Jemez Plateau, New Mexico*, Bureau of American Ethnology Bulletin No 32, Smithsonian Institution, 1906, pp 32, 36; R Greenlee, *Archaeological Sites in the Chama Valley, and Report on Excavations at Tsama, 1929–1933*, Santa Fe Laboratory of Anthropology, nd, pp 10, 24; A B Reagan, 'The story of Jemez and Sia', *El Palacio*, 4, 1917, p 30.

⁹⁵ K Fiero, *Prehistoric Garden Plots along the Lower Rio Chama Valley: Archaeological Investigations at Sites LA 11830, LA 11831, and LA 11832, Rio Arriba County, New Mexico*, Laboratory of Anthropology Note IIIe, Museum of New Mexico, 1978; K H Clary, *Pollen Evidence for the Agricultural Utilization of Late Classic Period (AD 1350–1500) Puebloan Gravel Mulch Terrace Gardens, the Rio Chama, in the Vicinity of Medanales, New Mexico*, Castetter Laboratory for Ethnobotanical Studies Technical Series Report No 198, University of New Mexico Press, 1987.

⁹⁶ Clary, *Pollen Evidence*, p 19.

⁹⁷ Lightfoot, 'The cultural ecology of Puebloan pebble mulch', p 127.

pot-irrigated, at least during the hottest and driest part of the growing season.⁹⁸

8. (Maori) New Zealand

More than 400 ha of gravel-mulched fields, and many hundreds of stone piles, are found at scattered locations on both the North and South Islands of New Zealand.⁹⁹ These forms of LMA were used by the indigenous Maori sometime during the period AD 1200–1800, and perhaps a little earlier or later.¹⁰⁰

Most of these gravel fields and stone mounds were used to grow the 'kumara', or sweet potato.¹⁰¹ One ancient taro garden, uncovered in the Pelorus district, South Island, had its surface covered with small gravels carried from a nearby beach.¹⁰² One scholar has also suggested that maize might have been grown on some of the gravel-mulched fields.¹⁰³ The Maori were apparently able to fertilize the soil by burning tea trees (rich in phosphates, potash, and lime) and other wood, scrub, and vegetable matter on the surface of the gravel layer before working the ashes into the underlying soil.¹⁰⁴

Uniformly-spread gravel mulch was used on large fields, all on the South Island around the Waimea West-Nelson district,¹⁰⁵ Pelorus district,¹⁰⁶ and Kaiapoi

area,¹⁰⁷ by applying a 2–6 cm layer of homogeneous-sized gravel across the top of sandy loam soil.¹⁰⁸ Most of the gravel for these fields was obtained from borrow pits, which are scattered in hundreds all around these fields. A few pits are extremely large (2–3 m deep and covering 1–3 ha), but the more numerous pits are much smaller.¹⁰⁹ Once excavated, these pits (known locally as 'Maori holes' and 'kumara pits') may have been used as storage pits for the sweet potatoes grown on surrounding gravel fields, or perhaps they are just being confused with true kumara pits found elsewhere in New Zealand.¹¹⁰ One early researcher believed that the pits were Maori vapor baths, dwelling places, or defensive works.¹¹¹

A few gravel mounds were built on the South Island in the Kaiapoi area,¹¹² but the greatest number of gravel and stone heaps were piled around six different sites on the North Island.¹¹³ Remains are especially numerous around the Taranaki coast, Bay of Plenty, and the Auckland Isthmus.¹¹⁴ Stones were taken from the rocky soil in these areas and piled in large heaps, some up to 8 m in diameter and 1.8 m in height; some mounds have only 2–3 m separation, though most are several metres apart, and many were arranged in rows.¹¹⁵ All researchers agree that the gravel fields were used to grow crops, but the purpose of the stone mounds has been a subject of debate. At least one scholar has suggested that they are heaps of stone left over from clearing the ground for cultivation, with crops planted between the mounds.¹¹⁶ However, this still would not preclude their use as

⁹⁸ *Ibid.*, p 139; Lang, *Archaeological Investigations at a Pueblo Agricultural Site*, p 12.

⁹⁹ E Best, *Maori Agriculture*, A R Shearer, 1976; T Rigg and J A Bruce, 'The Maori gravel soil of Waimea West, Nelson, New Zealand', *J Polynesian Society*, 32, 1923, pp 85–93; H Conway, 'Maori horticulture', in W A Pullar, ed, *Soils and Agriculture of the Gisborne Plains*, New Zealand Soil Bureau Bulletin No 20, R E Owen, 1962, pp 62–65.

¹⁰⁰ Best, *Maori Agriculture*, pp 24–25, 240–41; Rigg and Bruce, 'Maori gravel soil', pp 85–93; J Rutland, 'Traces of ancient human occupation in the Pelorus district, Middle Island, New Zealand', *J Polynesian Society*, 3, 1894, pp 220–32.

¹⁰¹ Best, *Maori Agriculture*, pp 23–28, 121–25, 240–41; Rigg and Bruce, 'Maori gravel soil', pp 85, 87, 90–92; Rutland, 'Traces of ancient human occupation', p 221.

¹⁰² Rutland, 'Traces of ancient human occupation', p 231.

¹⁰³ Best, *Maori Agriculture*, pp 24–25.

¹⁰⁴ Rigg and Bruce, 'Maori gravel soil', p 92.

¹⁰⁵ Best, *Maori Agriculture*, pp 121–24; Rigg and Bruce, 'Maori gravel soil', pp 85–93; Rutland, 'Traces of ancient human occupation', pp 220–32.

¹⁰⁶ Rutland, 'Traces of ancient human occupation', pp 22c–32.

¹⁰⁷ Best, *Maori Agriculture*, p 23.

¹⁰⁸ Rutland, 'Traces of ancient human occupation', pp 221, 232.

¹⁰⁹ Best, *Maori Agriculture*, pp 122–23.

¹¹⁰ Rigg and Bruce, 'Maori gravel soil', pp 85–93.

¹¹¹ Rutland, 'Traces of ancient human occupation', pp 222, 232.

¹¹² Best, *Maori Agriculture*, p 23.

¹¹³ *Ibid.*, pp 26, 124–25, 223; Conway, *Soils and Agriculture of the Gisborne Plains*, pp 62–65.

¹¹⁴ Best, *Maori Agriculture*, p 26.

¹¹⁵ *Ibid.*, pp 122–25.

¹¹⁶ *Ibid.*, pp 26, 124–25, 223.

mulched kumara beds, excepting the largest mounds, where the gravel or stone layer is probably too deep.

9. Lanzarote, Canary Islands

Most of the 400 km² of cultivated fields on the arid island of Lanzarote, in the Canary Islands, are covered with an ash and lapilli (gravel-sized cinder) mulch.¹¹⁷ Crops have been planted in the moist soil underneath the mulch since 1740, when a volcanic eruption blanketed parts of the island with cinder and ash.¹¹⁸ These mulched fields are still used to grow onions and carrots,¹¹⁹ watermelons,¹²⁰ lentils, chick peas, beans, maize, grapes and figs.¹²¹

In some places the crops are grown using *in-situ* ash that has not been modified in depth or areal extent. Across most of the island, however, ash and lapilli deposits have been thinned out, raked and piled deeper, or otherwise altered in order to create a mulch layer suited to the needs of various crops. Most of the fields are farmed with a mulch 10–15 cm thick.¹²² Lithic-mulched forms on the island include mostly ash ('picon') fields and lapilli ('arena negra') fields.¹²³ Lapilli-covered terraces have also been built on some of the mountain slopes.¹²⁴ After several generations, some of the farmers who had neither ash nor lapilli on their fields began to transport this material from nearby volcanoes and spread it as a mulch over their land, so that 'one

hardly ever sees a Lanzarote field with soil showing'.¹²⁵

In places, where the lapilli cover is especially deep (1 m or greater), pits have been excavated into the cinders, and grapes or figs are planted in the underlying soil.¹²⁶ Grape vines planted in cinder pits are especially common around La Geria and near the El Penon mountain.¹²⁷ A semi-circular wall of lava rocks is commonly built around the rim of these pits – especially on the northeast rim – which reduces whirlwinds in the pits; grape and fig yields in pits with stone rims average 10 per cent higher than in pits without rims.¹²⁸

10. Lanzhou, China

Pebble-mulched fields have been used to grow cantaloupes, watermelons, vegetables, and cotton near river channels in the Lanzhou area of central China.¹²⁹ Rainfall is at a minimum for crop production in this region, and pebbles in old river beds are easily obtainable. Farmers carried the pebbles, mixed with sand, from nearby streambeds and spread them on level to gently sloping fields in a layer 10–15 cm in depth.¹³⁰ Old fields were re-mulched every 20–50 years, or new fields incrementally built, as gardens began to lose their fertility. Local farmers understood both the short-term benefits and long-term problems with pebble mulching, explaining that 'the grandfather works hard [to apply the mulch], the son becomes rich [from the increased yield these fields bring], and the grandson becomes poor [as the fields become old]'.¹³¹

¹¹⁷ Aschmann, 'Historical development of agriculture', p 98; S Dinkins, 'Lanzarote: the strangest Canary', *National Geographic*, 135, 1969, pp 117–39.

¹¹⁸ Aschmann, 'Historical development of agriculture', p 98; Dinkins, 'Lanzarote', pp 117, 122.

¹¹⁹ J J Parsons, 'The Canary Islands search for stability', *Focus*, 35, 1985, p 26.

¹²⁰ Dinkins, 'Lanzarote', p 127.

¹²¹ Aschmann, 'Historical development of agriculture', p 98.

¹²² *Ibid.*, p 98; Dinkins, 'Lanzarote', pp 126–28.

¹²³ Dinkins, 'Lanzarote', pp 120–28; Parsons, 'The Canary Islands', pp 26, 28; W H Isom and G F Worker, 'Crop management in semi-arid environments', in A E Hall, G H Cannell, and H W Lawton, eds, *Agriculture in Semi-Arid Environments*, Springer-Verlag, 1979, p 205.

¹²⁴ Aschmann, 'Historical development of agriculture', p 98.

¹²⁵ Dinkins, 'Lanzarote', p 127.

¹²⁶ Aschmann, 'Historical development of agriculture', p 98.

¹²⁷ Dinkins, 'Lanzarote', p 127.

¹²⁸ *Ibid.*, pp 127–28.

¹²⁹ T C Tsiang, 'China', in *Soil Conservation: An International Study*, FAO Agricultural Studies No 4, UNFAO, 1948, pp 81–85; W C Lowdermilk, 'China fights erosion with U.S. aid', *National Geographic*, 87, 1945, pp 641–80; J L Buck, *Land Utilization in China*, University of Chicago Press, 1937, pp 7, 52, 115.

¹³⁰ Tsiang, 'China', p 84; Lowdermilk, 'China fights erosion', p 662; Buck, *Land Utilization in China*, p 52.

¹³¹ Tsiang, 'China', p 84.

Pebble mulch was used in China at least during the years 1800–1950, and possibly much earlier. One writer vaguely describes such finds as 'old'.¹³² Another implies that they have been used at least since 1800–1850, but could be older still.¹³³ Chinese pebble mulch gardens were reportedly in use as recently as 1948,¹³⁴ when they were still being repaired and maintained.

III

In addition to the prehistoric/recent historic cases of lithic mulch agriculture outlined above, there are many more places where, even in the latter part of this century, stone and gravel mulch has been applied on a limited horticultural basis (that is not for large-scale, commercial agriculture), or studied for its suitability to contemporary agriculture (Fig 4).

Rock mulch was used on farms in Monroe, New York and Pluckemin, New Jersey in the 1930s and 1940s.¹³⁵ It was used on farms in northern Ohio and in gardens in New York City in the 1960s and 1970s.¹³⁶ Rock mulching has been known for years to apple growers in the Pennsylvania Poconos, although they may never have called it 'rock mulching'.¹³⁷ Rocks piled around tree trunks have been used to improve the growth of pecan trees in Texas, and fruit trees in Ohio, Kansas, Michigan, Florida, Oregon, and

California.¹³⁸ Rock and gravel mulch has also been used to grow berries in California and Washington.¹³⁹

Agriculturally useless land was brought into production using stone-mulch strips in a 5 ha market garden outside Johannesburg, South Africa; this field was used in the 1950s to grow a variety of vegetables.¹⁴⁰ Vegetables have been grown in between rows of stone strips in Bavaria.¹⁴¹ Stone mulch has been used to grow potatoes and other vegetables in Sweden,¹⁴² and has been applied to vineyards in France and Mexico.¹⁴³ Olive trees south of Aleppo, Syria, are today planted with a large pile of coarsely-crushed limestone around their trunks. This is done both to reduce soil acidity and to increase soil moisture under the mounds. In other parts of the Near East, stone and pebble mounds are still used around fruit trees and grape vines.¹⁴⁴ The integrity of this list is limited by relatively sparse reporting on the use of lithic mulches. Other contemporary cases surely exist, where LMA has been applied but has not been formally researched, and is therefore not yet part of the academic literature.

Although lithic mulch agriculture has been used only on a limited basis in both historic and recent times, controlled agronomic/horticultural experiments with various forms and depths of lithic mulch have demonstrated the potential for expanding this method today. Gravel mulch has been shown to improve the yield of corn, sorghum, tomatoes, and soybeans in studies

¹³² Lowdermilk, 'China fights erosion', p 662.

¹³³ Tsiang, 'China', p 84. The extensive volume on Chinese agriculture assembled by F Bray (vol 6 of J Needham, ed, *Science and Civilisation in China*, 1984,) discusses contemporary agriculture and summarizes many private and state commissioned monographs and treatises on Chinese agriculture c AD 535, 1273, 1313, 1600, and 1742, yet never mentions the practice of pebble mulching and so fails to shed light on its origins.

¹³⁴ *Ibid*, p 84.

¹³⁵ Rodale, *Stone Mulching in the Garden*, pp 54, 62.

¹³⁶ E H Faulkner, 'Miscellaneous mulches: gravel', in *Handbook on Mulches*, special printing of *Plants and Gardens*, 13, 1970, p 48; A Sutcliffe, 'The Brooklyn Botanic Garden', also in *Handbook on Mulches*, pp 34–35.

¹³⁷ Rodale, *Stone Mulching in the Garden*, p 97.

¹³⁸ *Ibid*, pp 39–55, 106–37; J I Rodale, 'Rock mulches', *Organic Gardening*, 7, 1945, pp 4–7; *idem*, 'Decorative rock mulches', *Organic Gardening*, 7, 1945, pp 7–10.

¹³⁹ Rodale, *Stone Mulching in the Garden*, pp 54–55, 124–26.

¹⁴⁰ Chilwell, 'Stone mulches increase productivity of soil'; Jacks *et al*, *Mulching*.

¹⁴¹ Joseph A. Cocannouer, *Trampling Out the Vintage*, University of Oklahoma Press, 1945, p 118; Rodale, *Stone Mulching in the Garden*, p 64; Rodale, 'Rock Mulches', pp 4–5.

¹⁴² Rodale, *Stone Mulching in the Garden*, p 53.

¹⁴³ Jacks *et al*, *Mulching*, p 12.

¹⁴⁴ Spencer and Hale, 'The origin, nature, and distribution of agricultural terracing', pp 21–22.

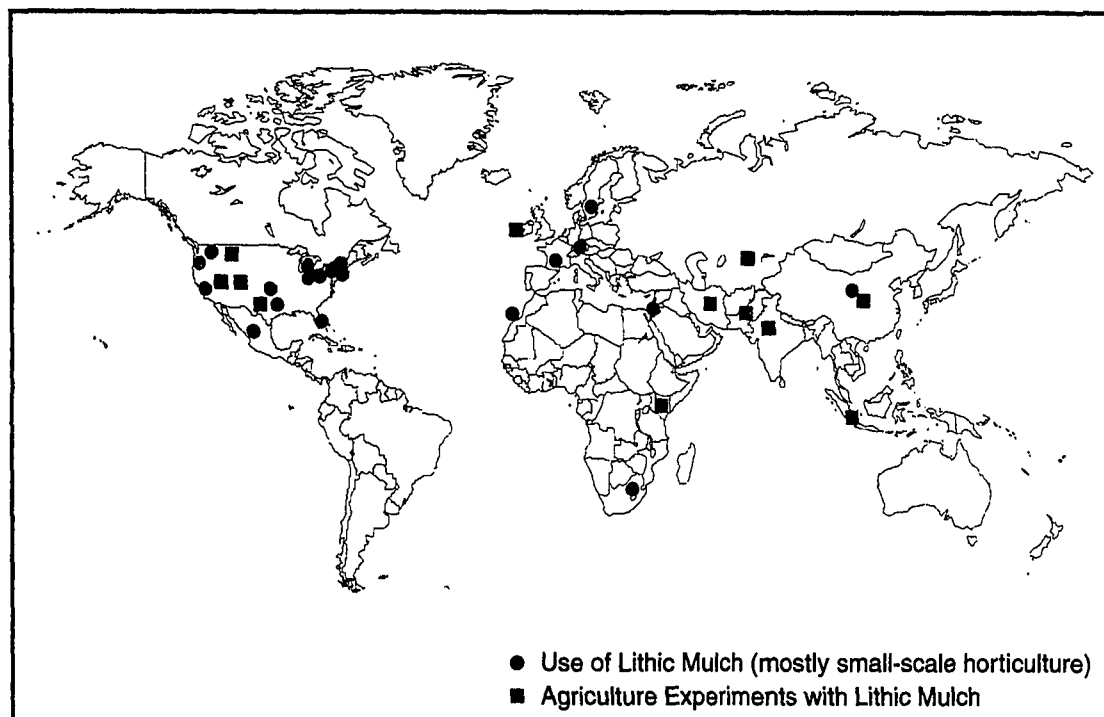


FIGURE 4

Contemporary use of lithic mulch (post-1900) and agricultural experiments with lithic mulch.

conducted in Colorado.¹⁴⁵ A gravel mulch improved the yield of grain sorghum in a three-year study in Texas.¹⁴⁶ Rock and gravel mulches can increase the total production of dryland wheat, according to field trials in Utah,¹⁴⁷ and a four-year study in Montana.¹⁴⁸ Young shade trees responded well to a ground cover of gravel mulch in another study in Tennessee.¹⁴⁹

Experiments conducted around the world have produced similar results. Stone mulching improved the growth of apple trees in a drought-prone area of Russia.¹⁵⁰ Sand and gravel mulches have been shown to improve the growth of lumber, orna-

mental, and fruit trees in experiments conducted in Pakistan, India, and Indonesia.¹⁵¹ Gravel mulch has significantly increased corn yield under arid and semi-arid conditions in Iran.¹⁵² The stem diameter, yield, and total biomass of tea plants significantly increased with the use of a stone mulch in Kenya.¹⁵³ Gooseberries and strawberries have been experimentally grown using a gravel mulch in Ireland.¹⁵⁴ In one Israeli

¹⁴⁵ Fairbourn, 'Effect of gravel mulch on crop yields'.

¹⁴⁶ Adams, 'Effect of mulches', and 'Influence of mulches'.

¹⁴⁷ A T Bleak and W Keller, 'Crested wheatgrass yields as influenced by water conservation practices', *Agronomy J.*, 66, 1974, pp 326-28.

¹⁴⁸ Choriki *et al.*, 'Rock and gravel mulch'.

¹⁴⁹ H van de Werken, 'Fertilization and other factors enhancing the growth of young shade trees', *J Arboriculture*, 7, 1981, pp 33-37.

¹⁵⁰ V Botaniki, 'The effect of a stone mulch on the water regime of apple trees growing on gravelly soil', *Referativnyi Zhurnal*, 1974, pp 330-36.

¹⁵¹ M I Sheikh, 'Eucalyptus Camaldulensis grows much better than Ceratonia Siliqua and Zizyphus Mauritiana', *Pakistan J. Forestry*, 32, 1982, pp 70-71; D W Seckler and K G Tejwani, 'Effect of sand and gravel mulching on moisture conservation for tree saplings', *J Tree Sciences*, 2, 1983, pp 20-23; B Singh, G N Gupta, and K G Prasad, 'Use of mulches in establishment and growth of tree species on dry lands', *Indian Forester*, 114, 1988, pp 307-16; A P Tampubolon and Z Hamzah, 'Effect of water conservation measures on the growth of teak (*Tectona Grandis*) seedlings in a low-rainfall zone', *Buletin Penelitian Hutan*, 496, 1988, pp 1-15.

¹⁵² Hakimi and Kachru, 'Silage corn responses to different mulch tillage treatments'.

¹⁵³ C O Othieno, 'Soil temperature and the growth of the tea plant', *Tea in East Africa*, 16, 1976, pp 1-2; Othieno and Ahn, 'Effects of mulches on soil temperature and growth of tea plants'.

¹⁵⁴ An Foras Taluntais, 'Small fruits', in *Horticulture Research Report 1977*, An Foras Taluntais, 1977.

experiment, the soil surface of test plots was treated mechanically and chemically to create a surface layer of water-resistant dirt clods, which emulated a lithic mulch by increasing infiltration and reducing evaporation of soil moisture.¹⁵⁵

IV

Many scholars are quick to assert that the diffusion of ideas and technology best explains similarities in agricultural forms and adaptive strategies across wide regions of the earth. With few exceptions, however, cultural diffusion does not adequately account for the historic use of lithic mulch agriculture.

It is possible that Roman colonizers found the Nabatean stone mounds and adapted this technology to their own vineyards and orchards on the Italian Peninsula. It is also possible that Sinagua farmers knew of the Hohokam agave mounds or that rumors of the success of Sinagua ash fields led Anasazi gardeners to experiment with pebble mulching. However, the discontinuity and apparant randomness of LMA across most of the world make it far more likely that LMA was independently invented. Each of these peoples, given similar environments, would surely have noticed the natural effects of stony-ashy surfaces on plant growth and could then improve upon nature by crafting similar forms to enhance their crops.

It is possible that LMA did diffuse more widely, and that these data are incomplete. Perhaps there are other cases of LMA that have yet to be recovered; many other stone piles or gravel surfaces around the world hitherto attributed to something other than agriculture, or assumed to be wholly natural, may have been ignored. It is the intention of this paper to alert scholars to the

possibility that LMA may be found at other sites, if we are aware of the historic-environmental context of lithic mulch agriculture, and the likelihood of its use in rocky drylands. Ground-level fieldwork, with an eye to LMA forms, may yet turn up more cases of historic LMA. Large-scale aerial photography (especially colour infra-red) of stony and gravelly surfaces around settlements would be particularly helpful to identify geometric patterns which are not easily discernable from the ground.

Lithic mulch agriculture may be little-known, and thus rarely mentioned in the literature, for various reasons: remains may have been obliterated by later construction; lithic-mulched plots may have mixed with aeolian sediments and blended into the surrounding landscape; while archaeologically-viable plots remain at many more sites, LMA may have been overlooked by fieldworkers unaware of this form of agriculture; and finally LMA was rarely used, and always remained a variant strategy peripheral to any cultural core. In every historic case, LMA was adopted to mitigate subsistence risk in dry environments.¹⁵⁶ While it could be used to such ends in arid and semi-arid lands today, its impact on food production would remain, as in the past, minimal compared to irrigated agriculture.

This technique will reduce soil erosion by shielding the soil from raindrop splash, reduce runoff from fields, and slow the velocity of potentially erosive wind across the mulched surface. The storage of soil moisture will increase because the mulch aids infiltration by reducing soil-crust formation and reduces evaporation. A lithic mulch will improve germination and extend the growing season by moderating diurnal extremes in soil temperature and slightly raising the average temperature. The cumulative effect of these benefits will be an increase in the production of plant

¹⁵⁵ D Hillel, 'A new method of water conservation in arid zone soils', in Y Mundlak and S F Singer, eds, *Arid Zone Development: Potentialities and Problems*, Ballinger Publishing Company, 1977, pp 99-108.

¹⁵⁶ D R Lightfoot, 'Morphology and ecology of lithic mulch agriculture', *Geog Rev*, 84, 1994, pp 172-85.

biomass, an improvement in the development of plant roots, and an increase in crop yield.

A solid layer of lithic mulch may limit the recycling of essential nutrients or inhibit the application of fertilizer. It would be possible to remove the mulch each year and till the crop compost/fertilizer into the soil before re-applying the mulch. However, because of the amount of labour involved, this is not likely to be done. This is why Chinese pebble-mulch gardeners did not re-mulch until their gardens began to get 'old' and less productive than non-mulched soil.¹⁵⁷ One alternative would be to leave stone-free strips between mulched rows to receive crop waste or fertilizer. Lithic-mulched strips or mounds are still effective at soil and water conservation but

avoid the barriers to sustainable crop production inherent in a solidly-mulched field. Lithic mulch has been applied as strips or mounds in the Negev desert of Israel, northwest Argentina, the Hohokam and Sinagua regions of Arizona, South Africa, Bavaria, and eastern North America.¹⁵⁸

This study underscores the importance of historic-comparative agricultural research and the need to modify our paradigms as we learn more about the diversity of past agricultural activities. Scholars should be prepared to view lithic mulch agriculture as a taxonomically discrete agricultural form and to consider the possibility of its existence at other historic sites.

¹⁵⁷ Tsiang, 'China', p 84.

¹⁵⁸ Evenari *et al*, *The Negev*; Field, 'A reconnaissance of southern Andean agricultural terracing'; Fish *et al*, 'Prehistoric agave cultivation'; Berlin *et al*, 'A prehistoric Sinagua agricultural site'; Chilwell, 'Stone mulches increase productivity of soil'; Cocannouer, *Trampling Out the Vintage*, p 118; Rodale, *Stone Mulching in the Garden*, pp 39-107.