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FARMING IN LAND PLANNING: AN EXPLORATORY SURVEY

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ABSTRACT

Land planning must take account of the functional relationships between land use components, the ways these components aggregate into land use types, and the relationships between aggregates and their sites. Farming is a land use, defined as the relatively intense terrestrial production of plant crops. This paper synthesizes available literature to provide a systemic model of farming that can apply to many technological and site contexts of land planning. The selection of plants to be grown determines the planting, pollination (in some cases), and harvesting practices that control the plants' productive cycle, and all the practices that influence the plants' environment. The environment consists of mechanical support, water, air, nutrients, heat, light, competition, disease, predation and continuation of the above over time. Any combination of farming practices would constitute a farming system of some sort. The compositions and intensities of farming systems have important implications for land planning.

Land planning is the systemic adaptation of land use to land. It must take account of the functional relationships between land use components, the ways these components aggregate into land use types, and the relationships between aggregates and their sites. There are many technological subsystems woven into any land use, just as there are many natural and man-made sybsystems woven into any site. The land planner is therefore interested in a broad range of technological sciences, but only those aspects of each science that are relevant at the systemic level [1].

Many fields of planning are extending from their traditional urban background into rural concerns [2]. Farming is an important rural land use in terms of spatial occupation and economic and environmental impacts: about 48 per cent of all United States land is in cropland and pasture [3]. Farming is a

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particularly important land use in times of declining resource supplies: farming is one of the land uses on which the welfare of all people depends [4]. Many efforts are already underway to preserve farming land, farming practices, or farming production [5].

Farming is defined as the relatively intense terrestrial production of plant crops. Farming includes a broad range of sub-uses, including cropland, feeding operation, grove, orchard, horticultural operation, pasture, range, and others [6]. It can occur on the same land with other land uses [7]. It is distinguished from aquaculture, forestry, hydroponics, and wildlife management, although analogous objectives and practices occur in these land uses [8–11]. It is also distinguished from agriculture, which is a broader term including the administrative and industrial processes that provide many services and inputs to farming [12].

This paper synthesizes available literature to provide a generic model of farming that can apply to land planning in many technological and site contexts. It describes what tangibly happens on the land. In contrast, a resource or socio-economic planner, who is interested possibly in eutrophication or the effect of a land use on employment, may look at farming as a "black box" of which only the inputs and outputs are relevant [13]. No previous attempt at modeling farming for physical land planning is known, although implicit definitions of farming have been used in many planning reports and ensuing programs [14, 15].

The speed and even superficiality with which the following survey relates a mass of farming technologies will dismay most agronomists, but are inherent in the broad view that any planner must take. Although this paper is designed for use by land planners, a comprehensive understanding of the farming process may incidentally help agronomists in the much-needed development of new, integrated farming systems [16].

The selection of plants to be grown and combinations of farming practices for growing them varies with the climate, the soil, the economic context (including both supply of inputs and demand for outputs), the available technology, the objectives of the farm, and the ways in which other objectives such as sewage disposal, energy conservation or land reclamation are fulfilled [12]. Some of these influences are well within the expertise of land planning, others are not. The interests of land planning and other planning and design fields overlap considerably, and one should seldom be performed without the benefit of the others. Many considerations besides the tangible aspects of farming will occur in any rural comprehensive planning project but they are beyond the scope of this paper.

FARMING PLANTS

Farming plants can include any terrestrial plants that are worth growing for their food, fiber, sap, or other products. The selection of plants to be grown determines the planting, pollination (in some cases), and harvesting practices that control the plants' productive cycle, and all the practices that influence the plants' environment. Plant breeders attempt to design plants for resistance to hazards, adaptibility to different environments, concentration of plant growth into the plant part desired for harvest, amenability and responsiveness to expected types and intensities of farming practices, length of growing season, and a number of nonfarming objectives such as storability and consumer acceptance of the product [17–19].

Different plants can influence each other either positively or negatively through pest repellence or harborance, nutrient effects such as nitrogen fixation, shading and other environmental factors [20]. Different plants can be grown on the same land simultaneously ("interplantation" or "companion planting"), in succession ("succession planting" or "double cropping," placing or releasing to full growth a second crop at the harvest of the first), or in "rotation" (cyclically placing a second crop of a different type sometime after the harvest of the first) [21, 22].

Plants can be placed in the farmed area by sowing seeds or by transplanting young plants which were started in trays or nurseries by sowing, budding, grafting or other means. The location and timing of sowing relative to weather and other farming practices creates the environment of potential seed germination. Transplantation might be done to control the seedlings' environment in another, more concentrated space, or to conserve space in the field for only the strongest seedlings. The effect on the plant of the changing environment during and after transplanting can be minimized by cutting back the top, retaining roots such as by growing plants in individual containers, retaining a ball of original soil around the roots, and "heeling in" to soil or otherwise retaining root moisture during storage or transportation [23, 24].

If the plant crop is a grain, fruit, nut, or otherwise depends on reproduction, pollinating agents may be encouraged or introduced at the proper time. These can include insects, birds, wind, water and manual labor. Their encouragement would include creating hospitable habitats for birds or insects; this may influence other farming practices such as the application of pesticides [23].

Harvesting is intended to garner the full yield of the field without damaging the crop or collecting extraneous material, and to treat the crop in some way such as drying to prevent spoilage, threshing, hulling, or dirt removal. Harvesting can be done manually, mechanically, or by grazing animals. Some harvesting is intended to store animal feed for use later on or elsewhere. Mechanical methods for most crops are technologically feasible, including those that do not destroy the plant and that pick selectively [25].

PLANT ENVIRONMENT

Given particular species and varieties of plants to be grown, farming aims to manage the environmental conditions that influence plant growth, including

Table 1. Typical Effects of Selected Cover Types on Erosion of Soil by Water [27]

Cover Type	*Erosion (Per Cent)*
Bare	100
Row Crop	40
Small Grain	10
Meadow	0.6

mechanical support, water, air, nutrients, heat, light, competition, disease, predation, and continuation of the above over time [12, 20, 26]. Such management is necessary because of imperfections in preexisting environments, the needs of plants, and the effects of other farming practices such as the removal of nutrients by harvesting. As illustrated in Table 1, crop selection is the first step in managing most environmental variables.

As shown in Figures 1 and 2, the environmental needs of plants vary, and for many environmental variables there is a range of most beneficial environment surrounded by ranges of less desirable effect. For other environmental variables such as predation the effect on plants is presumably more linear.

Some characteristics of the preexisting environment vary only geographically; climatic variables and associated conditions such as soil moisture vary geographically, seasonally and by probability of occurrence [31]. Practices might therefore be applied structurally, regularly with the cropping cycle, or occasionally as need is perceived.

MECHANICAL SUPPORT

Mechanical support involves the prevention of mechanical injuries to plants and the provision of soil that is loose enough to allow root extension and cohesive enough to hold together.

Potential mechanical injuries include those from the environment, which are discussed under "Continuation Over Time," and those from farming practices. Those from farming practices can be controlled through the selection of crops and practices, and the dimensions of farming geometry relative to farming practices.

Soil cohesion can be increased by increasing the soil's content of organic matter or moisture. Soil can be loosened by tillage and a variety of other methods.

"Tillage" is the operation of implements through the soil [32]; it includes "plowing" which is the cutting loose and inverting of slices of earth, "subsoiling"

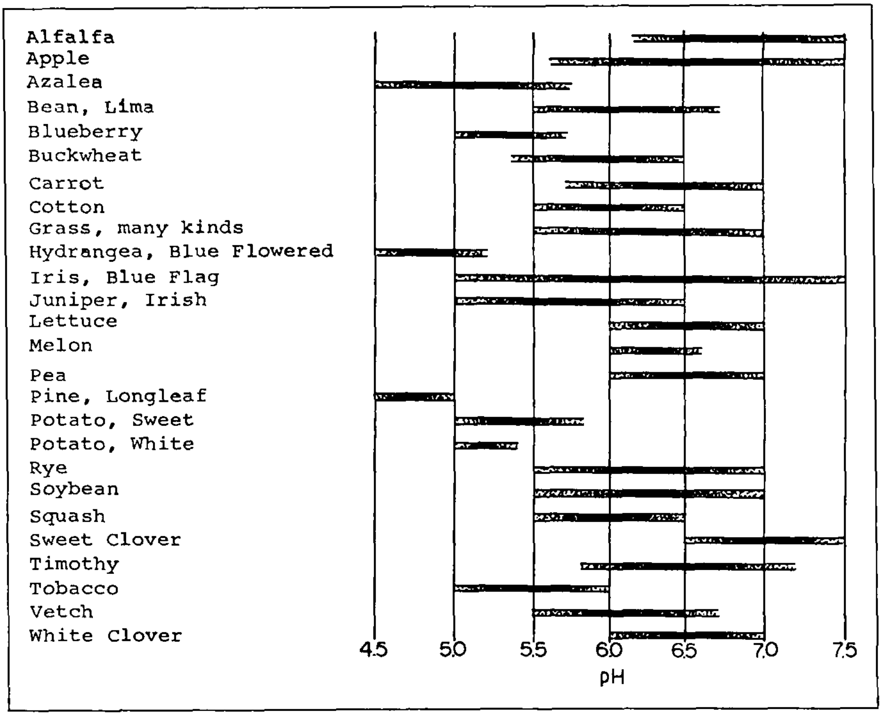

Figure 1. Effects of varying soil pH on the growth of selected plants. Darker shading implies faster and fuller growth. Each plant has a range of most beneficial pH, surrounded by ranges of less growth [28, 29]. As shown in Figure 2, this concept can be extended to many environmental variables.

which is deep plowing to shatter compact sublayers, and a variety of less common means of soil disturbance [33]. Tillage can be counter productive because it tends to compact the layer just below the depth of operation ("tillage pan" or "plow pan"), to degranulate and cohere soil that is not at a suitable moisture content, and to leave the surface bare and susceptible to crusting by weather [34].

Of the other methods for loosening or maintaining the looseness of soil, mulching reduces crusting by insulating the surface from the weather. Increasing the soil's organic matter content tends to granulate and open the soil. Digging animals such as earthworms can be introduced or encouraged such as by thermal insulation and increasing organic matter. Soil compaction can be reduced by planting in blocks, which tends to distinguish growing zones from traffic zones and to reduce the number and area of traffic zones; and any combination of practices that reduces the weight of farming equipment (tillage tends to require the heaviest equipment) and the frequency of its passes over the field [22, 28, 35].

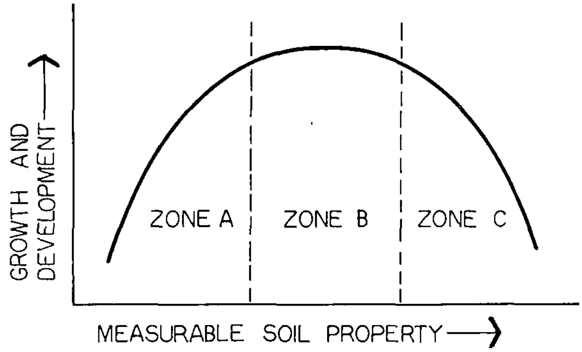

Figure 2. Schematic diagram of the effect of many kinds of environmental variables on tree growth and development. In Zone A, increasing the variable increases tree growth; in Zone B it has negligible effect; in Zone C, it decreases growth [30]. As shown in Figure 1, this concept can be extended to many kinds of plants.

WATER

The non-solid portion of the soil volume is occupied by water and air; to increase one tends to decrease the other. To increase water available to plants, precipitation or soil moisture can be conserved or used more intensely, or additional water can be supplied from some external source.

Precipitation can be used more intensely by increasing infiltration into the root zone through contouring, terracing, and maintaining soil looseness. Moisture in some soil sublayer can be used more intensely by lowering rows or larger farmed areas relative to the layer. Evaporation of soil moisture can be reduced by mulching, which is the application of any material (such as plant residues, straw, stone, plastic sheeting, etc.; closely-spaced crop plants are called "living mulch") to shade or seal the soil surface. Mulching also tends to insulate heat, control weeds, and reduce erosion [28]. Organic mulches add organic matter to the soil, but may harbor pests [16]; dark-colored mulches heat up quickly in the spring. Evaporation can also be reduced by rotating through a low-water-use crop such as a seasonal fallow, in which the soil profile stores the water for use by the next crop; and by windbreaks [36].

The supply of water from an external source is "irrigation." Irrigation facilities tend to include water supply, conveyances, method of application, waste water disposal, soil and plant management, and control of the timing and amount of water [37]. Conveyances can include open, graded channels or dikes, possibly with siphons to feed water to the plants; or gravity-flow or pressurized pipes on or below the soil surface. Evaporation and seepage losses from open conveyances may be large, and can result in field waterlogging and salt accumulation [38]. A variation of open conveyance is the distribution and retention of natural flood water over the farmed area [39].

AIR

Aeration tends to be necessary in poorly drained or compacted soil. It can be done by reducing soil water or loosening the soil [28].

Water can be prevented from entering the farmed area by "intercepting drainage," in which an updrainage surface or subsurface drain is located to divert incoming surface or groundwater. Surface (open) drains can be ditches or swales; sursurface (closed) drains can be buried tiles or pipes, or soil tunnels formed by bullet-shaped "mole" plows. Infiltration can be reduced by grading a flat or bowl-shaped area to direct water to an outlet. Water already in the soil can be conveyed away by channels or pipes spaced throughout the farmed area, or it can be reduced in importance by grading the rows or larger farmed units to raise them above water-rich elevations [37]. Its evaporation can be increased by inducing rapid plant growth, spacing or pruning the crop for maximum total evapotranspiration, or removing surrounding windbreaks [36].

Methods of loosening the soil are discussed under "Mechanical Support." Loosening the soil eases the exchange of air between the soil and the atmosphere.

NUTRIENTS

Nutrients vary in their supply (amount), chemical availability to the plant (form) and location in the soil profile. An oversupply of a nutrient may become toxic. Therefore nutrients may have to be added, changed, removed, or relocated [19].

The elements absorbed by plants in the largest amounts are carbon, hydrogen and oxygen; these are supplied in the form of air and water, which were discussed above. Of the remaining nutrients, nitrogen, phosphorus, and potassium are the "primary" nutrients that are supplied in most fertilizers; of these nitrogen is plentiful in the air, but it must be "fixed" to be available to plants, and it often must be replenished to the root zone in large amounts because it tends to return to a gaseous form and escape. The "secondary" nutrients are calcium, magnesium, and sulfur, of which calcium and magnesium are the functional components of "lime." At least eight additional "micronutrients" are absorbed by plants in very small amounts [28].

The addition of nutrients to the soil is "fertilization." [32] Synthetic fertilizers tend to be designed for nutrient type, nutrient content, immediate or timed availability, and ease of application. Because of their intensity, the rate and timing of their application must be planned relative to the plant's growth stage and the weather to get their nutrients into the crop without leaching into the groundwater or other losses.

Fertilizers in the form of organic matter such as plant residues, manure or sewage sludge tend to contain a wide variety of nutrients at relatively low concentrations. They also tend to increase the soil's granulation, which has important effects discussed elsewhere, and the soil's ability to exchange available nutrients with plant roots ("cation exchange capacity"). Fresh organic matter can be added on top of the soil, counting on its limited area of contact to prevent soil nitrate depression resulting from the metabolism of initial decomposition; or it can be plowed into the soil a substantial time before the crop is placed [28]. Organic matter can also be decomposed into "compost" [32], in piles, windrows, bins, or mixers, before delivery to the farmed area.

Fertilization can occur through the management of biologic processes, in addition to the introduction of external substances. Leguminous plants can fix nitrogen from the air into the soil. Legumes can be selected as crop plants, or interplanted or rotated with desired plants. Young leguminous plants can be turned directly into the field where they grew ("green manuring") with relatively small danger of soil nitrate depression, although their growth tends to reduce moisture stored in the soil. Also, the periodic burning or decaying of previous successional vegetation on the farmed area can fertilize the soil, particularly where the successional vegetation is the major natural nutrient reservoir, as on lateritic soils [20].

Nutrients that are already present in the environment can be conserved through erosion control, sediment retention, and recycling. Naturally present soil nutrients are the products of the weathering of underlying or upstream parent materials; they can be conserved by controlling soil erosion or maintaining nutrient removal within their generation rate. Where flood irrigation is practiced, the deposited flood sediment may be retained as a nutrient bank; this might be considered more a form of mining of upstream soil than of conservation [40]. Nutrients used in plant growth can be recycled by replacing plant residues or crop wastes, either freshly or as compost.

Nutrient availability can be controlled by managing soil pH and oxidation/reduction relations. The pH can be lowered by adding certain chemicals such as ferrous sulfate or certain kinds of organic matter such as pine needles; it can be raised by adding lime. The availabilities of different nutrients vary differently with pH. The oxidation/reduction relation can be altered through soil drainage and aeration, both of which were discussed above. Dry, aerated conditions tend to create oxidized nutrient forms, which are relatively unavailable; wet conditions tend to create reduced forms, which are relatively available.

Toxic concentrations of particular nutrients can be controlled by changing their forms and/or removing them. An example from arid regions is the conrol of soil salts: they can be converted to soluble form by adding gypsum and flushed into the groundwater with a large dose of irrigation; then further concentrations can be prevented by controlling evaporation and consequent precipitation near the soil surface [28].

The movement into the root zone of nutrients added at the soil surface may have to be speeded. This can be done by placing the fertilizer at the correct depth with spikes, by tilling concentrated nutrient layers into the soil, by the downward leaching of water, or by the digging of animals [41].

HEAT

Heat may have to be added to, removed from, or retained in the soil or plants.

Heat can be added by exposing the soil or plant to the sun or relatively warm air, or by introducing heat from some external source. Exposure to the sun includes dark colors and lack of shading; soil color is influenced by mulching and the mineral, organic, and moisture contents of the soil. Heat can be introduced via buried pipes or wires, decomposing organic matter, induced mixing of upper and lower atmospheric layers, and warm irrigation water. The opposite practices tend to remove heat.

An existing temperature can be maintained such as to prevent autumn frosts by soil mulching; relatively temporary bags, hoods, or sheets over plants or plant parts; relatively permanent controlled environments such as "coldframes," "hotbeds," and "greenhouses"; and with high thermal capacities such as those of moist soil, stone mulch, and nearby stone walls. The opposite practices tend to allow rapid movement of heat between the soil or plant and the surrounding environment, such as to speed planting or germination in the spring [32, 42, 43].

LIGHT

The amount, type, and timing of light reaching the plants can be controlled.

The exposure of plants to natural sunlight can be controlled with other plants (interplanted or successively planted) for shade, or with structural shading or reflecting devices. Young plants can be shaded by mulch.

Time of lighting can be extended with artificial lighting [41].

COMPETITION

Weed plants tend to compete with crop plants for water, air, nutrients, and light. A few weeds also are parasitic or secrete harmful residues into the soil. Weeds can be suppressed by cultural, physical, chemical, or biological means.

Cultural, or habitat, means are implemented by managing either the plant environment or the competitiveness of the crop plant. Environmental controls include drainage, liming, mulching or any other farming practices that can be directed against the physiology of particular weed species in consideration of the physiology of the crop [20]. A specialized example is the saturated mud in rice fields, where rice is one of the few plants that can survive because it delivers oxygen to its roots from its superstructure [28]. Competition by crop plants can be encouraged by selecting plants for characteristics such as growth rate or leaf spread, placing plants closely to shade out competitors such as with block planting [35], or controlling the behavior of growing plants such as by fertilization or pruning. Where less competitive plants are desired as crops, they can be rotated with more competitive plants for temporary suppression.

An important class of physical means includes the pulling, grubbing, chopping up or burying of weeds by hand, hoe, or mechanical implements. Plowing before crop placement buries weeds and their seeds; "cultivation," the breaking of the soil surface, after crop placement undercuts weed plants but can damage shallow roots of crop plants. Another physical means is controlled fire.

Chemical means include all chemical herbicides which on contact with plants or by being absorbed into plant systems kill them or alter their growth. They can be applied from the air or from the ground. Timing of application relative to crop placement or germination is important to avoid damage to the crop.

Biological means include the introduction or provision of habitat for natural parasites, predators or pathogens of weed species. An example is the reduction of the Prickly pear (*Opuntia* species) in Australia by the introduction of the moth borer (*Actoblastic cactorum*) from Argentina [20].

DISEASE AND PREDATION

Pathogens tend to be micro-organisms such as bacteria or fungi that result in plant disease; predators tend to be larger animals such as birds and rodents that result in crop damage. The distinction between pathogen and predator is unclear, such as in some insect-plant relationships. The methods for controlling both have much in common, and are conveniently discussed together. Like weeds, pathogens and predators are biological, so the means of controlling them fall into the same categories: cultural, physical, chemical, and biological.

Cultural means are implemented through controlling either the field environment or the crop plant. Environmental controls can include the selective elimination of infested plants or plant parts; the elimination of infested plant residues such as by plowing; the introduction of pest-repelling sounds, smells, objects, or chemicals; and other farming practices such as drainage and liming that can be directed against a pest in consideration of the physiology of the crop [20]. Resistance can be induced in a growing plant such as by fertilization or pruning [17].

Physical means include barriers and a variety of physical means of elimination. Barriers (fences or screens) can be applied to entire farmed areas, to individual plants such as by trunk collars, or to plant parts such as by bags over fruits [20]. Elimination can be by trapping (including in a "trap crop" that emerges before the harvest crop and to which a concentrated elimination program is applied), by shooting, manually, and by steam sterilization of soil [23].

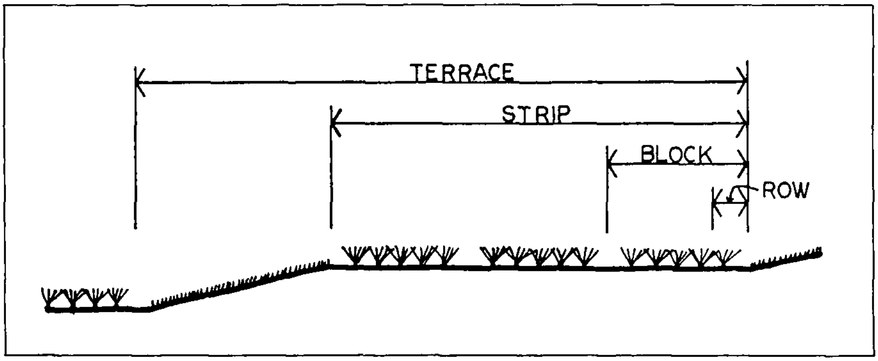

Figure 3. Schematic cross-section showing the relationships of row, block, strip, and terrace when they are practiced together.

Chemical means include all chemical pesticides, which can be applied from the air or ground to the plant, plant parts, or soil. Pesticides vary widely in their form, composition, degradability and selectivity. Pests can acquire resistance to some pesticides.

Biological means include a variety of manipulations of the natural competition between organisms, such as introducing or providing habitat for parasites, pathogens, or predators; and a variety of subtle measures such as introducing large numbers of sterilized males [20].

CONTINUATION OVER TIME

Stable farming must occur in a more or less stable general environment. Stabilization practices are addressed to the relatively gradual phenomena of soil erosion by wind and water, and relatively short-lived phenomena such as fire and flood.

Erosion control methods include those applied to the soil surface and those applied to the geometry of farming operations.

Surface treatments include mulching and wetting the soil to increase cohesion, and including a good cover type in crop rotation; its organic matter or plant residues accumulate and continue to act during other stages in the rotation [39].

Geometric methods of erosion control (see Figure 3) are possible because farming operations tend to occur in linear rows, or blocks that contain the equivalent of more than one row. Rows or blocks may be in furrows, raised beds or mounds. Blocks may be structurally isolated from traffic areas by pavements or walls; their edges can then contain work stations. The spacing of plants is usually intended to be as close as possible consistent with the needs of the plant or interplanted crops in order to use the farmed area and travel

Table 2. Suggested Widths of Crop Strips for Decreasing Erosion of Soil by Water [28]

Slope Gradient (Per Cent)	*Suggested Width (Feet)*
2 – 7	88 – 100
7 – 12	74 – 88
12 – 18	60 – 74
18 – 24	50 – 60

distance efficiently and to intensify soil cover. Ways to achieve a high density of strong plants include sowing seed at excessive density and later removing the weaker seedlings, or transplanting selected seedlings at the final density [24].

Geometric erosion control methods (see Figure 3) include "contouring," "strip cropping," and "terracing."

Contouring is the performance of any linear farming operations such as tillage and harvesting more or less parallel to the topographic contours. The resulting furrows, wheel tracks, and crop rows or blocks then act as miniature dams, channels, and reservoirs which control the flow of runoff, thereby controlling water erosion. The orientation of the rows may be modified in relatively arid regions to control wind erosion.

Strip cropping is the placement of different kinds of crops in adjacent strips. The strips can be more or less parallel to the topographic contours where water erosion is the primary concern, or perpendicular to an erosive wind. Suggested dimensions of strips for control of water erosion are listed in Table 2. Strip cropping can be coordinated with contouring by making the width of each strip equal to some number of rows or blocks. It can be coordinated with crop rotation by using the strips as units of rotation and cycling the crop sequence through the array of strips [39].

Terracing is the relative leveling of land areas larger than individual furrows or wheel tracks, more or less parallel to the topographic contours to divert or retain runoff. Terraces vary in their spacing, cross-section, and methods of handling water. An entire slope may be graded into a series of terraces, or terraces may be installed only at intervals. The relatively steep face between level areas may be farmed or retained by a cover crop or wall. Terraces may divert water (and associated sediment) from flowing downslope, slow it down as it passes across them, or retain all of it. The dimensions of terraces vary according to complicated equations [37], with their cross-sectional shape, their intended effect on runoff, and the slope gradient and soil to which they are applied. Terraces may be coordinated with other means of erosion control by making the width of each terrace equal to some number of rows, blocks or strips.

Relatively short-lived phenomena that can endanger a crop (apart from short-lived instances of biological hazards, which are discussed under "Disease and Predation") can include uncontrolled fire, flood, hail, wind, and any other events that are harmful to the crop. Control measures vary with the type of event, but can be generally classified as hazard reduction, emergency preparedness, detection, and suppression of an event once it has started. Hazard reduction can include a variety of structural measures or farming practices such as firebreaks, shelterbelts, or crop selection [20].

FARMING SYSTEMS

Any combination of farming practices that results in a plant product could constitute a farming system of some sort, and any conceivable system might be applicable to some combination of the world's wide variety of plants, soils, climates, local skills, and other influencing factors.

Although individual practices tend to be simple, the systems into which they aggregate and their relationships to their environments tend to be complex. A practice seldom affects only one aspect of the environment; there are interactions between practices; there are interactions between environmental factors; and there are feedbacks from plants to their environments such as that of increased plant growth on water withdrawal. Although some practices tend to work individually toward opposite effects, they are not necessarily incompatible; they may have attractive synergistic results, such as the common Midwestern combination of terraces to retain water with subdrains to remove the resulting excess [44].

Different farming systems may coexist on the same land [45]; a land unit on which a relatively homogeneous system or combination of systems is applied is a "field." An ownership unit might contain a variety of farming systems in order to make complementary use of the holding [12].

The broad classification of four general farming system types in Table 3 can be useful in the early, general stages of rural land planning projects. It describes cover types that can be strongly related to and thereby distributed over land environments. Crop selection, types of farming practices, and intensity of application can vary to some extent within each type of system according to the needs of the particular case. The less intense applications of each type are transitional to forestry, wildlife management, and other types of land use.

The important implications for land planning and related concerns of the design of particular farming systems within each type are illustrated by a comparison of three well-spaced temperate-climate "tillage" systems. Their essential practices are summarized in Figure 4.

"Clean tillage" formerly tended to be applied to any soils in temperate climates, but is now tending to be limited to relatively heavy, poorly drained soils where aeration is a concern. It generally starts with a pre-planting plow to

Table 3. General Types of Farming Systems, and Examples of Their Applications by Intensity and Climate [45]

	General Farming Type							
	Tree Crops		*Tillage With or Without Livestock*		*Alternating Tillage with Grass, Bush or Forest*		*Grassland or Grazing of Land Consistently in Indigenous or Man-Made Pasture*	
Intensity	*Temperate*	*Tropical*	*Temperate*	*Tropical*	*Temperate*	*Tropical*	*Temperate*	*Tropical*
Very Extensive	Cork collection from Marquis in southern France	Collection from wild trees, e.g., shea butter	(None)	(None)	Shifting cultivation in Negev Desert, Israel	Shifting cultivation in Zambiz	Reindeer herding in Lapland; Nomadic pastoralism in Afghanistan	Camel-herding in Arabia and Somalia
Extensive	Self-sown or planted blueberries in the north-east of the U.S.A.	Self-sown oil palms in West Africa	Cereal growing in Interior Plains of North America, pampas of South America, in unirrigated areas, e.g., Syria	Unirrigated cereals in central Sudan	?	Shifting cultivation in the more arid parts of Africa in U.S	Wool-growing in Australia; Hill sheep in the U.K. (Sheep in Iceland); Cattle ranching in in U.S.A.	Nomadic cattle-herding in East and West Africa; Llamas in South America
Semi-Intensive	Cider apple orchards in the U.S. Some vineyards in France	Cocoa in West Africa; Coffee in Brazil	Dry cereal farming in Israel or Texas	Continuous cropping in congested areas of Africa; Rice in S.E. Asia	Cotton or tobacco with livestock in the south-east of the U.S.A.; Wheat with leys and sheep in Australia	Shifting cultivation in much of tropical Africa	Upland sheep country in North Island, New Zealand	Cattle and buffaloes in mixed farming in India and Africa
Intensive	Citrus in California or Israel	Rubber in S.E. Asia. Tea in India and Ceylon	Corn Belt of the U.S.A. Continuous barley growing in the U.K.	Rice and vegetable growing in south China; Sugar-cane planatations throughout tropics	Irrigated rice and grass beef farms in Australia; much of the east and south of the U.K., the Netherlands, northern France, Denmark, southern Sweden	Experiment stations and scattered settlement schemes	Parts of the Netherlands, New Zealand, and England	Dairying in Kenya and Rhodesia highlands

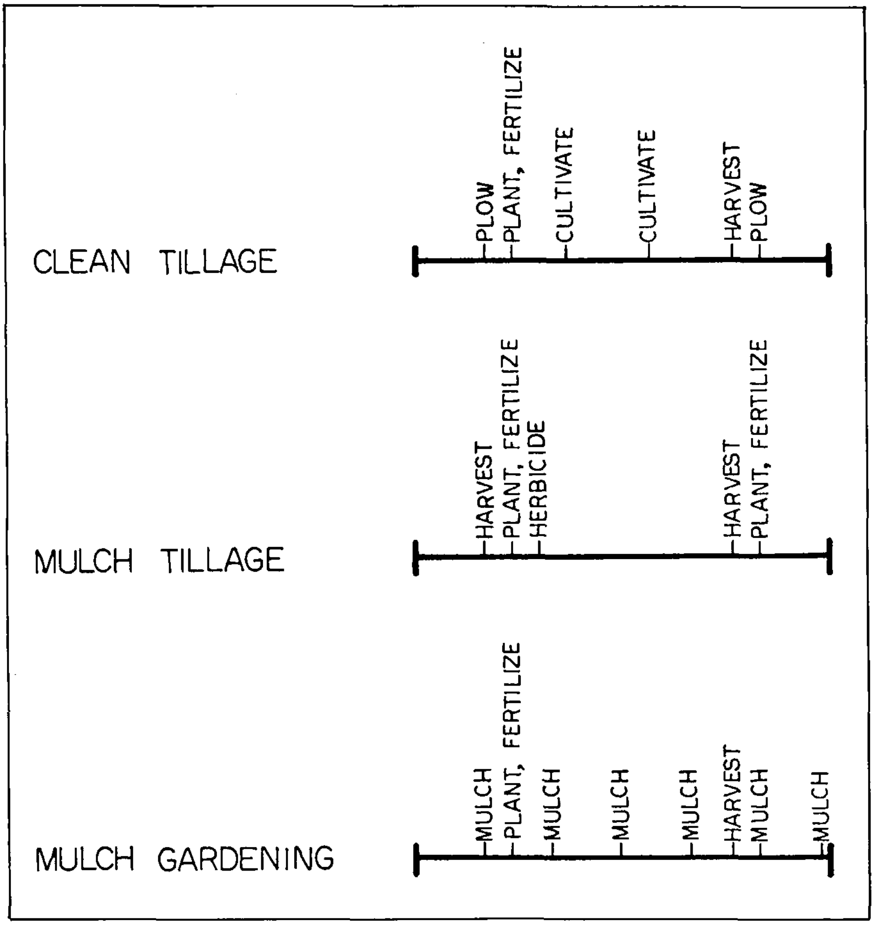

Figure 4. Summary of essential practices in typical applications of three tillage farming systems. Each line is a time scale representing a calendar year, with the temperate-climate growing season in the middle.

suppress weeds and to loosen the soil for root growth and aeration. During the growing season some number of cultivations between rows kill weeds and break up the surface crust to aerate and irrigate the soil. A post-harvest autumn plowing might mix plant residues into the soil with time for them to decompose before the next planting. This method's intense tillage tends to be effective in controlling weeds and aerating the soil, and it may help in controlling disease and predation. However, the same practices tend to aggravate runoff and erosion, to leave a bare soil that is subject to crusting by weather and invasion by weeds, to degranulate the soil, to form "plowpans" and to oxidize organic matter. Also, repeated runs over the field with equipment compact the soil and cost energy and money [34, 46].

"Mulch tillage" tends to be applicable to (create relatively high yields on) well-drained, light soils. Plowing and cultivation are limited to once every few years or are eliminated entirely, depending on aeration needs. Plant residues are left in place (tending to be about one to four tons per acre immediately after harvest) as mulches and earthworm environments. Seeding is performed by slicing or spiking through the layer of residues. Weed control in addition to the mulch is by maintenance of an interplanted cover crop (such as sod with corn), dense planting, and/or application of a chemical contact herbicide just after planting. This combination of practices is effective in controlling weeds, minimizing erosion and runoff, maintaining soil structure and organic matter, and, when practiced on suitable soils, aerating the soil. The few annual runs with equipment tend to minimize soil compaction and costs of energy and money. It may be amenable to aerial operations [22, 46].

"Mulch gardening" (or "no-dig gardening") has been tried by home gardeners. As in "mulch tillage" soil inversion is limited or absent; it therefore probably tends to be applicable on light, well-drained soils. Its application is further limited to sites where an external source of organic matter is available, and to the growing of relatively well-spaced crops such as vegetables. For weed suppression and earthworm habitat it relies on very heavy applications of mulch in the form of in-situ compost (six to eight inches deep organic material, or about eight to ten tons per acre, replaced continuously as it decomposes). Crop placement is in pockets selectively cleared of mulch; the mulch is replaced where the plant has overtopped it. Mulch gardening is effective in controlling some types of weeds, minimizing erosion and runoff, maintaining soil structure and organic matter, and, when practiced on suitable soils, aerating the soil. It probably involves low energy and money expenditures. However, it tends to insulate the soil against warming up in spring, does not control all weeds, and may not be amenable to mechanization [41, 47].

Some general effects of these three alternatives are summarized in Table 4. Similar analyses of other farming systems and their relationships to the sites for which they are proposed can aid the competent distribution of land uses.

Farming systems tend to imply intensity of application. Some general implications of intensity are illustrated in Figure 5. In this case a doubling of yield was associated with an approximately tenfold increase in fertilizers, pesticides, and power. Recently devised systems such as mulch tillage are probably generating new points to the lower right of this graph [22]. To help continue the trend of efficiency and productivity on proposed farming sites is certainly one of the tasks of land planners.

Table 4. Selected Typical Effects of the Three Farming Systems Shown in Figure 4.

Farming System	*Runoff (Inches)*	*Soil Erosion by Water (Tons/Acre)*	*Soil Erosion by Wind (Tons/Acre)*	*Soil Organic Matter Maintenance (% Content) After 4 Years)*	*Soil Moisture Maintenance*	*Labor Cost (Hour/Acre/Year)*	*Money Cost ($/Acre/Year)*	*Energy Cost (Horsepower/ Acre/Year)*	*Applicable Soil*
Clean Tillage	1.8	16.5	84	1.3	Low	4.9	23	27	Heavy, poorly-drained
Mulch Tillage	1.4	3.6	15	1.6	High	2.0	19	1.2	Light, well-drained
Mulch Gardening	Low	Low	Low	High	High	Moderate	Low (depending on compost source)	Low	Light-well-drained
Test Location	Ohio	Ohio	Wisconsin	South Carolina	Estimated	Single crop of corn in Midwest, 1969	Single crop of corn in Midwest, 1969	Single crop in Midwest, 1969	Estimated
Source	Table 3-5, Phillips and Young, 1973 [22]	Table 3-5, Phillips and Young, 1973 [22]	Table 4-4, Phillips and Young, 1973 [22]	Table 3-15, Phillips and Young, 1973 [22]	Hayes, 1971 [46]	Table 8-2, Phillips and Young, 1973 [22]	Table 8-1 Phillips and Young, 1973 [22]	Table 9-2, Phillips and Young, 1973 [22]	Hayes, 1971 [46] Rodale, 1975 [41]

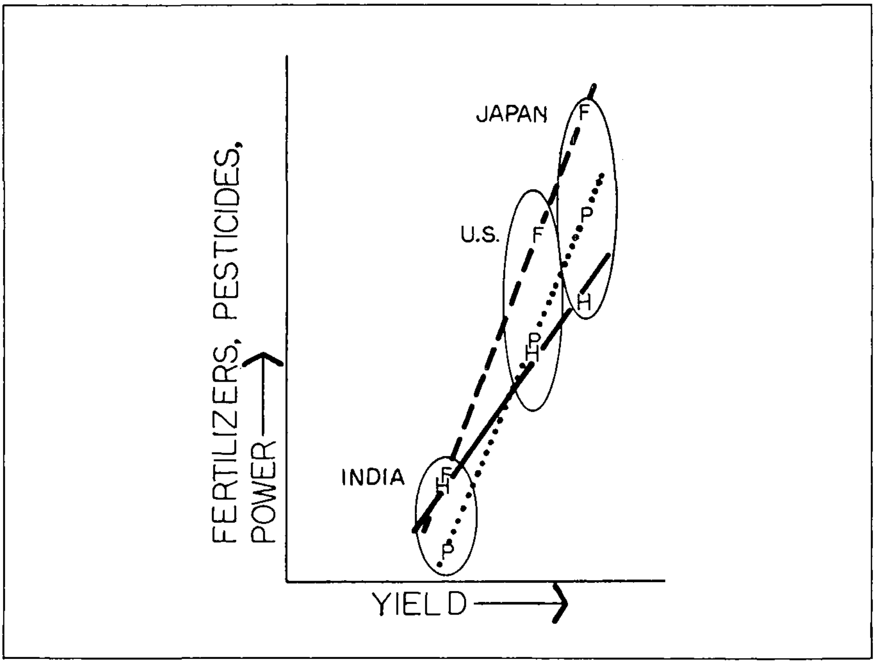

Figure 5. Relationships between average crop yield (in units such as kg/ha), fertilizers (F, in units such as kg/ha), pesticides (P, in units such as kg/ha) and power (H, in units such as H/ha) in three countries in 1963 [48].

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