4. CROP MANAGEMENT SYSTEMS IN RELATION T0 TILLAGE

The conservation of soil and water resources, in addition to tillage systems, is affected by the overall crop management systems in which the tillage systems are used. Crop management embraces several topics including management of planting materials, management of land before planting, seedbed preparation, planting, soil management, management of plant pests, and management of plant products (Sprague 1979). A subtopic related to several of these is cropping systems or sequences. This subtopic, which has a direct influence on soil and water conservation, will receive the major emphasis in this consideration of crop management. The discussion of cropping systems or sequences will involve continuous (or annual) cropping, crop rotations and multiple cropping (which includes intercropping and sequential cropping).

4.1 CONTINUOUS CROPPING

Continuous (or annual) cropping for this report involves the production of a given crop on the same land each year. The growing season for the crop may be entirely within a year (e.g. maize, cotton, spring wheat, etc.), within parts of two years (e.g. winter wheat, other winter crops), or cover several years (e.g. sugarcane, some forage crops, tree crops). In regions where conditions for crop growth. are sufficiently long, two or more crops may be grown on the same land each year. Although the emphasis is on the same crop each year, this restriction does not preclude the use of a cover crop, provided the main crop is still grown during the appropriate growing season. It also does not preclude the production of two or more crops by the same farmer, provided each crop is grown on its own area each year.

Probably the greatest advantage of continuous cropping is the potential for obtaining the greatest production of the most desirable crops. For a given locale, one or a few crops are usually most desirable because of yield levels, ease of production, available markets, farmer preferences, etc. Consequently, the largest possible area is devoted to the crop which enhances the potential for greatest yields or economic returns to the producer (Tables 26, 35, 67 and 69), unless pests, limited water, or other factors limit yields. A favourable economic return increases the potential that the farmer will invest in suitable soil and water conservation practices. In one example (Table 26), continuous wheat yields on the harvested area were lower because of lower soil water contents than on the fallowed area, but yields were higher for continuous wheat on a total-area basis. Fallowing is further discussed in Section 4.2

An advantage of continuous cropping from an economical viewpoint is the relatively low capital investment for equipment, especially where production is limited to only one crop or possibly a few similar crops that can be produced with the same equipment. As more types of crops are produced, either in rotation or continuously on separate areas; the complexity of accoutrements required generally increases. While tillage for all crops can probably be accomplished with the same equipment, seeding appliances or components of the equipment will differ (for example, drills vs. row-type planters, plates for different types of seed, etc.). Likewise, different types of crops require different types of harvesting equipment (for example, root crops, grains, cotton, sugarcane, etc.), all of which result in a need for greater capital expenditures for equipment.

The influence of continuous cropping on soil and water conservation is related to the type of crop grown. As a rule, continuous production of high-residue crops aids soil and water conservation whereas continuous production of low-residue crops is detrimental to soil and water conservation.

Continuous cropping of small grains is one of the most effective soil and water conservation practices, especially when supplemented with residue-based tillage practices (Papendick and Miller 1977) and when the crop is growing during the major period of erosion. An example of the latter is winter wheat in the Great Plains and Pacific Northwest (USA). Wheat is planted in the autumn and usually provides good ground cover during winter and early spring when the potentials for erosion by wind (Great Plains) and water (Pacific Northwest) are greatest. Because tillage and natural weathering destroy residues, the potential for erosion is usually higher in a crop-fallow system than with continuous cropping. Soil losses in a fallow system may be 10 to 15 times greater than with continuous cropping whereas adequate surface residues with continuous cropping reduce runoff (Papendick and Miller 1977). Runoff is further reduced because the soil is generally drier with continuous cropping. On fallowed land, stored soil water makes further water infiltration difficult late in the fallow period (Papendick and Miller 1977; Johnson and Davis 1980).

Continuous growing of crops that produce relatively small amounts of residue or where residues are removed for other purposes or destroyed by insects (Barber et al. 1980) often results in major soil and water losses. Residue production is generally low for all dryland crops in semi-arid and arid regions, and sometimes even in subhumid regions, especially for crops such as soybeans, cotton and groundnut. Where residue amounts are inadequate for effective management to conserve water and soil resources, other supporting practices may be required (see Section 5).

An advantage of continuous cropping related to crop residues is the maintenance of soil N and C (organic matter) contents at generally higher levels than with alternate crop-fallow systems. Examples from Haas et al. (1957) are shown in Table 71. Similar results were reported by Johnson and Davis (1972) and Unger (1968). More N was lost with row crops than with small grains, and usually more with crop-fallow than with a continuous cropping system. Trends for C were similar to those for N, but the magnitude of losses was greater for C (Haas et al. 1957). Greater losses with row crops result from more plant materials being removed at harvest, severe erosion and increased aeration due to cultivation (Brengle 1982).

Table 71 PERCENTAGE CHANGE IN NITROGEN AND CARBON OF SURFACE SOILS UNDER CONTINUOUS AND ALTERNATE CROPPING WITH SMALL GRAINS AND ROW CROPS (from Haas et al. 1957)

Location	Years cropped	Small grains				Row crops			
		Continuous cropping		Alternate fallow		Continuous cropping		Alternate fallow	
		%N	%C	%N	%C	%N	%C	%N	%C
Mandan, ND	30	-18	-22	-27	-28	-36	-38	-40	-44
Archer, WY	34	-26	-35	-34	-43	-41	-52	-41	-52
Colby, KS	30	- 9	-21	-25	-28	-30	-40	-25	-44

The skills required of a farmer are related to the complexity of the cropping systems employed. Although some one-crop systems require a relatively high level of management, the level required for continuous cropping is usually less than for systems involving more than one crop, either in rotations or when grown on separate areas. The lower level required with continuous cropping results from the relatively few operations involved for tillage, planting, pest control and harvest. With rotations or more crops, the above operations may be different for each crop, thus resulting in a more complex management system.

The disadvantage of continuous cropping with respect to soil and water conservation has been discussed. Other disadvantages include the potential for greater pest problems (weeds, insects, diseases), poor use of soil water and nutrients, and a greater risk of crop failure.

Some pests cause greater problems with continuous cropping than with other systems because the pests are compatible with or favoured by the crop being grown. For example, weeds may have similar life cycles or be physiologically similar to the crop. Even though of similar life cycle, weeds that are physiologically different from the crop can sometimes be controlled with herbicides. Some examples of weed pests in this category include henbit and tansy mustard in winter wheat, pigweed in sorghum and maize, and annual grasses in cotton and soybean[1] . However, when weeds and crops are similar physiologically and with respect to life cycle, control with herbicides or by cultural techniques is difficult. Examples include barnyard grass, foxtail, fall panicum, crabgrass and sandbur in sorghum and maize; cocklebur and pigweed in soybean and cotton; and cheatgrass, hairy chess and downy brome in winter wheat and other winter small grains. Volunteer crop plants may be especially troublesome in succeeding years when crops are grown continuously (Unger and McCalla 1980).

As for annual weeds, perennial weeds also tend to increase with continuous cropping when the weeds and crops have similar growth periods and physiological characteristics. Some troublesome perennial weeds in the USA include Johnson grass, quackgrass, nutsedge, field bindweed, leafy spurge, perennial sow thistle, Bermuda grass, Canada thistle, horse nettle, silverleaf nightshade, Russian knapweed and woollyleaf bursage (Wiese and Staniforth 1973[1] .

When such weeds are present and cannot be effectively controlled by tillage or herbicides in a continuous cropping system, then a rotation involving crops of different growth cycles or physiological characteristics may be the most effective and economical control method available. Fields with summer annual weed problems can be rotated to winter grain crops. Weeds can then be controlled with tillage or herbicides during the period between crops. Conversely, fields with winter weeds can be rotated to spring or summer-planted crops. Rotations permit the selection of the most competitive crops against the most troublesome weeds (Wiese and Staniforth 1973). A crop rotation or even a crop-fallow system and use of intensive weed control measures during the period between crops may be necessary to reduce or eliminate a severe infestation of troublesome weeds (Unger and McCalla 1980).

The effect of crop arrangement in time and space (continuous cropping, rotations, etc.) on pests is illustrated in Fig. 68 (Section 3.2.4.i). In general, continuous cropping of one species is more conducive to pest problems than rotations. Pest problems (insects, diseases, etc.) can be controlled by using sequences of crops having the fewest number of pests in common. The best control is usually obtained when botanically unrelated crops follow one another (Litsinger and Moody 1976).

Depth of water use from soil profiles varies with crops grown and soil conditions. For example, sorghum for grain extracted water to a depth of only about 1.2 m in a Pullman clay loam in Texas (USA) (Musick and Sletten 1966; Unger and Wiese 1979), but to about a depth of 2.0 m in

1 See Appendix 6 for scientific names of weecds.

Richtield silty clay loam in Kansas (Musick and ,Sletten 1966). Consequently, where sorghum was grown continuously, some water and possibly nutrients remained deep in the soil profile and eventually percolated through the profile, especially in the Pullman soil. Some of the water and nutrients could be salvaged by growing deeper-rooted crops in rotation with sorghum. On Pullman clay loam, for example, sunflower grown after sorghum extracted water from depths of about 1.8-3.0 m (Jones 1978; Unger 1978c, 1982d), winter wheat extracted water to a depth of about 1.8 m (Johnson and Davis 1980), and alfalfa extracted water and N from a depth of about 4.5 m (Mathers et al. 1975b). Growing crops that have the potential to extract water and nutrients from different depths in a rotation results in more efficient water and nutrient use. It also increases the potential to store more water subsequently in the soil.

A disadvantage of continuous cropping, especially for dryland crops in arid to semi-arid regions, is the increased likelihood of crop failure due to inadequate soil water or precipitation to support a harvestable or economical crop yield. At Bushland, Texas, for example, winter wheat yielded less than 340 kg/ha of grain nine times between 1942 and 1969 with continuous cropping, but only six times with a wheat-fallow sequence (Johnson and Davis 1972). The 340 kg/ha was arbitrarily chosen as the level for crop failure. Even such yields, however, may be harvestable at some locations. The potential for crop failure may also be greater with continuous cropping due to insect, disease and other pest problems.

4,2 CROP ROTATIONS

Crop rotations are of two general types. In the first, an area is intensively cropped for one or a few years, then abandoned or fallowed for a longer period for soil fertility restoration, during which period other areas are cropped. This is the system of shifting cultivation described in Section 3.2.1, and it will not be further discussed. The crop rotations discussed in this section, the second type, involve the growing of one or more crops alternately with fallow or with each other (when more than one crop is involved). The entire area is not fallowed or abandoned, as with shifting cultivation.

Crop rotations may be simple such as the wheat-fallow system where one crop is produced in 2 years, or complex where several crops are grown in a system requiring five or more years for completion (Stewart et al. 1975). A detailed discussion of different rotations is not practical for this report. Hence, the major emphasis is on the advantages and disadvantages of crop rotations which have an influence on soil and water conservation. Crop rotations are used for a number of reasons, including soil conservation, water conservation, improved pest control, improved soil conditions, shifting of resources, and more reliable or improved crop yields.

Relatively high yields and possibly the greatest economic returns would be achieved if the most desirable crop could be grown continuously. However, because of water, pest, fertility or other- limitations, continuous cropping may not be possible. In addition, it may result in a high potential for wind or water erosion, especially for crops that produce small amounts of residue. In such cases, improved soil conservation can be achieved by growing low and high-residue producing crops in rotation. Some examples are rotations involving sorghum and wheat; peas and wheat; soybeans and wheat or maize; maize, wheat and meadow; cotton and sorghum; and maize and grasses. In each rotation, the first-mentioned crop normally produces residues that are less effective for controlling erosion, either by water or by wind, than the other crop. Consequently, a rotation involving crops that produce more residues results in at least part of the area being protected against erosion at least part of each cycle as compared with continuous cropping of only the erosion-susceptible crop.

The effect of crop rotations on potential soil losses due to water-erosion, as determined by the Universal Soil Loss Equation, is illustrated by the crop management factor, C (discussed in Section 3.2.l.iii Potential for soil erosion). In all cases where a high-residue crop is included in the rotation, the potential for soil loss is lower than where the low-residue crop is grown continuously. Crop management practices that affect the C values include tillage, rotations and residue management practices. When the potential for erosion at a given location cannot be reduced to acceptable levels by crop management, then other supporting practices must be used to control erosion. These are discussed in Section 5. Control of wind erosion is also aided by residues, as has been previously discussed. Alternate methods of controlling wind erosion where residues are not adequate or available have also been discussed.

Some advantages of crop rotations with respect to water conservation and improved water utilization were mentioned in the discussion of continuous cropping (Section 4.1). Rotations also improve water conservation and utilization through reduced runoff due to (a) improved crop cover which decreases soil dispersion, (b) use of plants that impede water flow across the surface (grasses, legumes, other close-growing crops), (c) use of crops that are growing during critical runoff and erosion periods, and (d) use of crops producing large amounts of residue that can be managed for runoff and erosion control. Effects of residues on runoff and water erosion are shown in Tables 8, 10, 11, 12, 21, 31, 32, 43, 46 and 47.

Rotations further aid water conservation by allowing the use of alternate crops, tillage methods and other practices to control weeds and other pests that use water directly or result in inefficient use of water by crop plants. Rotations are especially beneficial to control troublesome weeds which directly compete with plants for water and have a major-influence on crop yields (Tables 6 and 7). While rotations help to control pests, best control can be achieved by pest management which includes the use of pesticides, resistant varieties, natural enemies and cultural practices (Litsinger and Moody 1976).

Inclusion in a rotation of crops which produce large amounts of residue is beneficial for soil and water conservation when the residues are managed on the soil surface. Crops producing much residue also improve soil and water conservation through their influence on soil conditions when the residues decompose on the surface or when they are ploughed under. Decaying residues release substances that cement or bind soil particles together into secondary units or aggregates. If water stable, the aggregates are of special value for maintaining high water infiltration, good soil structure and good plant growth. Large stable surface aggregates are also important for controlling wind and water erosion (Unger and McCalla 1980).

Soil aggregation is also enhanced by substances secreted by soil organisms such as bacteria, fungi, actinomycetes (Donahue et al. 1977), and earthworms (Hopp and Slater 1961), which use crop residues as their food source. Earthworms are especially beneficial for improving soil structure and maintaining high water infiltration rates (Hopp and Slater- 1961).

Crop rotations that include grasses or legumes have long been known to increase soil aggregation and maintain organic matter contents at higher levels than do continuous row crops (Johnston et al. 1943; Mazurak et al. 1955; van Bavel and Schaller 1951; Wilson and Browning 1946). On Marshall silt loam in Iowa (USA), aggregates were largest with continuous bluegrass and successively smaller after red clover, oats and maize in a 10-year rotation, and after continuous maize. With continuous maize, organic matter content decreased from 3.39% in 1931 to 2.86% in 1942. The rotation maintained organic matter contents at levels similar to those with continuous bluegrrass. Less runoff and erosion were associated with the larger aggregates and higher organic matter contents. Yields of rotation and continuous maize were similar when water was limited, but higher with the rotation when water was adequate (Johnston et al. 1943). Similar results were reported by van Bavel and Schaller (1951) and Wilson and Browning (1946).

Soil aggregation and water infiltration decreased and erosion generally increased when row crops replaced sod crops (Adams 1974; Jensen and Sletten 1965; Mazurak and Ramig 1963; van Bavel and Schaller 1951). The residual effect on aggregation increased with age of sod before ploughing. Aggregation and water infiltration generally increased with the age of sod when grasses replaced grain crops (Mazurak and Conard 1959; Mazurak and Ramig 1962; Mazurak et al. 1960). About 4 years in sod were needed before substantial increases in water infiltration were measured (Mazurak et al. 1960) . However, in tropical regions, the first year of grass resulted in the acquisition of 80% of the resistance to erosion and only 15% the second year. Because of the rapid development of resistance to erosion and the rapid breakdown of organic materials, short periods of grasses and crops are recommended for tropical regions (Hudson N. 1981; Juo and Lal 1977). As a group, cool-season grasses affected aggregation and water infiltration more favourably than warm-season grasses (Mazurak and Conard 1959). Consequently, it is more difficult to maintain good aggregation and high water infiltration rates in warm tropical regions than in cooler regions by managing crops and their residues (Hudson N. 1981).

In addition to the effects of residues on soil physical conditions, residues also affect soil chemical conditions because they contain nutrients that are released for subsequent plant use when they decompose. This is especially true when the residues are from legumes which have lower C:N ratios than non-legumes (Lyon et al. 1952). The legumes provide more N for subsequent crops than non-legumes, both by N released by decay of above-ground residues and by N fixed on roots by soil bacteria. Some of the N fixed by bacteria is used by the host plant; the remainder remains in root tissues or sloughed nodules from which it is released by decay for subsequent use by other plants (Lyon et al. 1952). Crop rotations involving legumes are highly important, especially in regions where fertilizer N supplies are limited and expensive, as in many developing countries or any other cropping situation where capital is limited.

Crops differ with respect to soil physical requirements for optimum growth and yield (Larson and Allmaras 1971; Taylor et al. 1966). Consequently, each crop in a rotation may require a different tillage practice. Use of a rotation which requires different depths and types of tillage for different crops may, therefore, prevent the development of soil crusts, plough pans, or other dense layers which could cause problems of seedling emergence, soil aeration, root penetration, or root proliferation.

Where tillage for one crop results in an unfavourable condition, another type of tillage for a different crop may alleviate the problem. In addition, the different crop itself may remedy the adverse conditions (Hudson N. 1981). The rotation of tillage methods and crops combined with the resultant improved soil conditions should lead to improved soil and water conservation. This would result from better plant growth, which provides more plant materials for direct protection against erosion, and more residues for possible management, improved soil conditions for greater water infiltration, and improved soil aggregation which results in a lower potential for erosion.

In contrast to continuous cropping, rotations involving two or more crops permit the shifting of input and output resources for more efficient use of available land and water resources. Shifting of resources allows operations such as tillage, planting, cultivation, irrigation and harvest of a particular crop to be performed in a more timely manner because a smaller area is devoted to any given crop. In a one-crop system, only a limited area can, for example, be planted at the optimum time with available equipment and labour, and yields generally are lower when the crop is planted at a suboptimum time (Hoeft et al. 1975). By growing crops that require operations at different times, equipment and labour resources are used more effectively throughout the year.

In addition to more effective use of equipment and labour, shifting of resources results in expenses being incurred and income being derived at different times. Income may be in the form of food gathered for direct consumption, trading of products for other goods, or sale of crop products for cash. Finally, rotations involving fallow or two or more crops minimize the chances of complete crop failure due to unexpected adverse conditions, such as inclement weather (drought, excess rainfall, frost, etc.), insects and plant diseases. Many farmers with small holdings and a few resources cannot afford to lose a crop. If the crop fails, there is no food. Consequently, a rotation that minimizes the risk of complete failure is especially important (Wright 1977). For market-oriented enterprises, crop rotations minimize the possibility of major financial losses due to complete dependence on one crop for which poor prices may prevail at market time.

Rotations have variable effects on crop yields. With adequate water-, nutrients and other input resources, combined yields for all crops grown continuously on separate areas are usually not too different and may be higher than when the same crops are grown in rotation (Constantinesco 1976; Jones 1975; Unger 1972).

However, when the rotation permits better overall utilization of water, nutrients, etc., and one crop provides improved conditions for the other crop or crops, then there are usually yield increases with the rotation system (Amemiya 1977; Constantinesco 1976; Hudson N. 1981; El Fakhry and Sultan 1980; Stallings 1957; Van Doren et al. 1977).

Use of rotations involving fallow (for example, a wheat-fallow system wherein one crop was produced in 2 years) resulted in lower crop yields than continuous cropping (Johnson 1950; Johnson and Davis 1972; Johnson et al. 1974; Jones 1975; Unger 1972) because part of the land was not cropped and, therefore, yields on a total-area basis were relatively low. Even under such conditions, a rotation involving fallow may be desirable because it minimizes the possibility of crop failure (Black et al. 1974; Johnson et al. 1974; Leggett et al. 1974). Also, yields in a fallow system (wheat-fallow in Turkey) needed to be only about 50 percent greater than with continuous cropping to result in an economic advantage for the farmer (Wright 1977) because of less frequent planting, harvesting, etc. At other locations, the economic breakeven point may be different, but rarely would a doubling of yields be required of the crop-fallow system.

At three locations in the central Great Plains (USA), long-term average winter wheat yields were 650 kg/ha in a continuous cropping system and 1 630 kg/ha in a wheat-fallow system. The more than doubling of yields was a definite economic advantage for the rotation system and wind erosion was effectively controlled by establishing and maintaining a vegetative cover on land during the fallow and cropping periods (Greb et al. 1974). Wheat yields were also more than doubled by fallowing as compared with continuous cropping at some locations in the northwest USA (Leggett et al. 1974). The same authors, however, considered fallowing to be generally non-essential because good yields were possible with annual cropping and because fallowing promoted (1) inefficient use of total precipitation, (2) erosion, (3) destruction of soil organic matter and loss of nutrients, and (4) formation of seepage and salty areas (saline seeps) in the fields. Increased formation of saline seeps in the northern USA was also attributed to fallowing (Black et al. 1974).

Some of the disadvantages of some rotations, namely, the hazard of greater erosion, lower total yields and development of saline seeps, were discussed with the advantages of rotations in the preceding paragraphs. Other potential disadvantages include the need for more equipment, for greater skill in management and the lower production of high value crops.

The increased equipment requirement with crop rotations as compared with continuous cropping is mentioned in Section 4.1. Whereas the subsistence or low capital input farmer may accomplish all production and harvesting operations with the same equipment, regardless of cropping system, a greater variety of equipment is usually required in mechanized agriculture for crop rotations than for continuous cropping, especially when rotations involving two or more crops are used. The greater variety of equipment with multiple-crop systems results from specific equipment needs for certain crops for tillage, planting, cultivating and harvesting and, therefore, adds to overall production costs. However, soil and water conservation can be enhanced when a wide array of equipment is available and used wisely. This entails using the equipment that provides the required or desired conditions for a given crop, but still conserves soil and water resources. This may be no-tillage for some crops and clean tillage for others, even at the same location. By having more types of equipment to select from, the requirements of a particular crop can be met more readily.

A shift from continuous cropping to crop rotations usually results in a shift to a more complex crop production operation and, consequently, the need for greater managerial skill by the farm operator. Greater skill is required because different crops may have different requirements for tillage, planting, pest control and harvesting. Although some one-crop systems require a relatively high level of management, an even greater level is often required when another crop is added to a system.

A relatively constant supply of a variety of foods is usually the goal of a subsistence farmer. However, in a market-oriented system, one or a few crops are considered desirable because of ease of production, good yields, established markets, and profitable prices. Consequently, the producer strives to produce more of these crops. Where rotations involving other than only the most economically desirable crops are involved, they may result in an economic disadvantage for the producer, especially on a short-term basis. However, if soil and water resources are conserved, a long-term economic benefit may be achieved by use of the rotation.

4.3 MULTIPLE CROPPING

Multiple cropping systems are similar to crop rotations involving more than one crop in that different crops may occupy the land at different times. However, whereas crop rotations involve a complete shift to another crop, both in time and space, multiple cropping involves growing two or more crops closely together in time and space. Included under multiple cropping are sequential cropping and intercropping. These terms, and those of some subsystems, are given and defined in Table 72 (Andrews and Kassam 1976).

Multiple cropping, as a rule, results in more intensive use of land than is achieved with continuous cropping and crop rotations. Whereas usually only one crop per year is obtained with continuous cropping or rotations, two or more crops per year are obtained with multiple cropping, except in arid areas where only one crop can be grown every 2 years because of water limitations (Table 72). Such systems as the latter are synonymous with a crop-fallow rotation as discussed in Section 4.2

Sequential cropping is adaptable to any type of cultivation system (shifting, labour intensive, animal and small tractor, and modern high-

Table 72 DEFINITIONS OF THE PRINCIPLE MULTIPLE CROPPING PATTERNS (from Andrews and Kassam 1976)

MULTIPLE CROPPING: The intensification of cropping in time and space dimensions. Growing two or more crops on the same field in a year.

l. SEQUENTIAL CROPPING: Growing two or more crops in sequence on the same field per year[1] . The succeeding crop is planted after the preceding crop has been harvested. Crop intensification is only in the time dimension. There is no intercrop competition. Farmers manage only one crop at a time in the same field.

1.1	Double cropping	Growing two crops a year in sequence.
1.2	Triple croppping	Growing three crops a year in sequence.
1.3	Quadruple cropping	Growing four crops a year in sequence.
1.4	Rattoon cropping	The cultivation of crop regrowth after harvest, although not necessarily for grain.

2. INTERCROPPING: Growing two or more crops simultaneouslv on the same field. Crop intensification is in both time and space dimensions. There is intercrop competition during all or part of crop growth. Farmers manage more than one crop at a time in the same field.

2.1	Mixed intercropping	Growing two or more crops simultaneously with no distinct row arrangement.
2.2	Row intercropping	Growing two or more crops simultaneously where one or more crops are planted in rows.
2.3	Strip intercropping	Growing two or more crops simultaneously in different strips wide enough to permit independent cultivation but narrow enough for the crops to interact agronomically.
2.4	Relay intercropping	Growing two or more crops simultaneously during part of the life cycle of each. A second crop is planted after the first crop has reached its reproductive stage of growth but before it is ready for harvest.

1 The farming year is 12 months except in arid areas where only one crop can be grown every 2 years due to water limitations. In these areas sequential cropping involved growing two or more crops every 2 years.

technology) (Andrews and Kassam 1976). It is merely an intensification of crop production in the time dimension where water and other resources (labour, equipment, capital, etc.) are adequate. Sequential cropping affords an opportunity to use land and water resources effectively throughout the period that is favourable to growing crops. By having a crop on the land for most or all of the year, the potential for erosion is also decreased.

In warm, humid regions, year-round crop production is possible with sequential cropping, provided adequate water is available. In temperate regions, the length of growing season may be limited by low temperature and low solar radiation in winter months. Where either water or temperature limits the growing season, a rapid change from one crop to the next is usually desirable so that each crop has adequate time to reach its potential yield under the prevailing conditions.

Strategies for intensifying sequential croppinq include using short-maturity cultivars, growing rattoon crops, harvesting crops in the immature state, transplanting slow growing crops, and using minimum or no-tillage systems (Allen et al. 1975; Bradfield 1969; Hoeft et al. 1975). No-tillage planting has been particularly beneficial for establishing the second crop in a double cropping system where the growing season fnr the second crop is limited (Allen et al. 1975; Hoeft et al. 1975; Jeffers et al.1973; McKibben and Oldham 1973; McKibben and Pendleton 1968), mainly because of more timely planting of the second crop, time saved in establishing it, and water conserved by not disturbing the soil.

In contrast to sequential cropping, which is generally adaptable to all cultivation systems, intercropping is adaptable mainly to the shifting, labour intensive, and animal and small tractor cultivation systems. Inter-cropping is seldom adaptable to modern high-technology cultivation systems because the crops are grown in close proximity to each other which results in intercrop competition during at least a part of the growth period and makes use of modern technology (large equipment, herbicides, etc.) impractical or impossible. Some intercropping, however, is practised in modern high-technology systems by seeding a second crop (e.g. soybeans) in skipped rows within a field of the primary crop (wheat). Average yields for-each crop are approximately 65-80% of the yields obtained without inter-cropping (D.M. Van Doren, Wooster, Ohio, personal communication).

Although use of mechanized equipment is possible when a row or strip intercropping system is used, intercropping is essentially a labour-intensive crop production system. Through intensive cropping, some exceptionally high yields were obtained at some tropical and subtropical locations where a year-round growing season and adequate precipitation prevailed. Examples of some intensive cropping systems are given in Section 3.2.2.ii.c. Crop production practices included intercropping, trans-planting, rattooning, etc. Use of these practices is, however, not restricted to tropical or subtropical locations, but can be used anywhere. The overall goal is to have one or more crops actively growing whenever conditions for plant growth are favourable. Such practice usually results in most efficient use of water because it is used by crops soon after it is received and, therefore, evaporation from soil is reduced. In addition, use of soil water by plants increases the potential for storage of subsequent rainfall, thus decreasing the potential for runoff and erosion. Also, the plant cover provides further protection against erosion.

In the examples given in Section 3.2.2.ii.c, water supplies and temperatures were favourable for year-round crop production. At other locations, limited water supplies or unfavourable temperatures may restrict crop production to certain periods of the year. Other factors such as light, radiation, daylength, etc. also affect crop production and must be considered in the development of intensive cropping systems for a given location. However, the following examples emphasize only the effects of seasonal water supplies and temperature on intensive production of annual crops. It is assumed that crops grown in the systems are compatible with respect to their light, space, nutrient, etc. requirements, and that soil conditions, pest control, etc. are adequate for the crops.

Case I Water supplies and temperature favourable throuqhout the year

The examples given in Section 3.2.2.ii.c pertained to crop production where water and temperature conditions were favourable throughout the year. Potential yields are highest under these conditions.

Case 2 Adequate water, seasonally cool (or hot) temperatures

In this case, year-round crop production is possible if crops are available which tolerate cool (or hot) temperatures. Crops such as cereal grains, grasses and some legumes tolerate relatively low temperatures and can be grown during the cool season. Other crops such as sorghum, millet, cotton, etc. tolerate relatively high temperatures. Therefore, these crops should be the basic crops during the cool or hot seasons, respectively. Then, as temperatures moderate, other adaptable crops can be established by any of the different subtypes of intercropping to assure continued crop growth when the basic crop reaches maturity.

To intensify crop production where winter temperatures are too low for crop survival, crops should be established as soon as temperatures moderate sufficiently. Since the soil temperature requirement for germination may be higher than that for plant survival, plants can be started in sheltered areas or indoors, then transplanted to the field when conditions become favourable. This is practial for limited areas and extends the growing season. Other adaptable crops can then be planted throughout the period when conditions are propitious. Toward the end of the warm season, crops can be grown which tolerate relatively cool temperatures and for which the edible part is produced in the soil where it is protected against low temperatures. Crops in the latter group include carrots and some radishes.

Case 3 Seasonal water supply, favourable temperatures

Several opportunities are available to intensify crop production through intercropping at locations where distinct wet and dry seasons prevail. One method is to dry-plant seeds before the onset of the rainy season, thus permitting germination as soon as rainfall is adequate to wet the soil. Such practice, however, may be risky, especially if initial rainfall is limited and not reliable. The seed may germinate, but the seedlings fail to survive if additional rainfall is delayed. In other cases, germination and emergence may be erratic. These problems can sometimes be overcome by conserving water from the last rainy season or occasional rainfall during the dry season by appropriate conservation measures. Mulches of crop residues or other materials, or even of dry soil, may conserve adequate water for early crop establishment (see Sections 3.2.4.iii and 3.2.5).

Crop establishment early in the rainy season is possible by transplanting in a field plants started elsewhere. This may be practical for limited areas. Then other crops can be established as appropriate throughout the rainy season, provided soil conditions permit such activity. Toward the end of the rainy season, crops can be grown which are capable of extracting adequate soil water for completing their life cycle. Forage crops may be especially appropriate for late in the rainy season because they can be harvested at any growth stage or the residues could be managed during the dry season to aid erosion control and to conserve water from scattered rains that may occur during the dry season.

Case 4 Seasonal water supply, seasonal temperatures

Crop production where water supplies and temperatures are favourable during the same season is essentially the same as when one or the other limits production during a given season. In such situations, early establishment of adapted crops followed by intercropping of other crops at appropriate times leads to potentially high production. When water supplies and favourable temperatures do not occur in the same season, then water conservation is extremely important and the crops should be established as soon as practical when temperatures become low enough to reduce losses of water due to evaporation. Intercropping may have limited potential in this situation because the soil may contain only enough water for one or- possible two crops.

Most regions of the world have periods of low and high rainfall at different times of the year, as covered by Cases 3 and 4. Of these, the situation covered by Case 3 is probably most common with respect to intensive multiple cropping. Therefore, some representative cropping sequences are given to illustrate the variety of crops and complexity of systems used in certain countries.

In Cameroon, intercropping of perennial and annual crops involves coffee, plantains or bananas, maize, cocoyams, drawf bears and local vegetables. Where the cropping period is followed by a fallow period, root crops (yams or cocoyams) start the sequence and are intercropped with cereals such as maize. Legumes are used toward the end of the rainy seasor, and cassava is planted at the end of the dry season and continues during the second year, after which the land is followed. In other parts of Cameroon, typical intercropped species are: (1) maize, cocoyam, Colocasia, yam and vegetables, and (2) potato, maize and local vegetables. Sorghum and cotton or sorghum and groundnuts may be sequentially cropped (Lyonga 1980).

Farmers in southern Nigeria intercrop maize, cassava, vegetables and cocoyam where little or no tillage is performed (Agboola 1980). Where ridges or mounds are constructed, yams may be planted on the mound; maize, okra, melon and cassava at lower parts of the mound; and rice between the mounds (Figs. 57, 58). The vast diversity of crop combinations used at different locations in Africa is given in Table 73. Other typical icter-cropping examples are maize and beans in Central America and tropical South America, and rice and melons followed by rice, cabbage and maize in Taiwan (Agboola 1980).

The foregoing examples illustrate the advantage of multiple croppirg (sequential cropping or intercropping) systems with respect to their- potential for growing a large variety of foods. This potential plus that for obtaining high total yields were also demonstrated and discussed ic Section 3.2.2.ii.c. Multiple cropping systems have another potential: minimizing soil erosion as compared with conventional cropping systems (Siddoway and Barnett (1976). Grasses and other close-growing crops, when included in the intercropping system, are especially effective for minimizing soil erosion, but other crops do the same through ircreased vegetative cover during critical erosion periods. Multiple cropping, especially intercropping, is most efficacious for controlling erosion at locations where year-round crop production is possible, provided an adequate vegetative cover is maintained. Where crop productior is limited to various seasons because of water-, temperature or other limitations, multiple cropping may enhance erosion control during the growirg perriod, but may have no particular value for other seasocs unless more residue is produced and then managed for erosioc coctrol. The same prirciples of erosion control that have been discussed ir other sections for convertioral systems are applicable for multiple cropping systems where residue supplies are limited.

As a rule, multiple cropping in space and time is more conducive to controlling weed, insect, disease and other- pests thac continuous cropping (Fig. 68) (Constarticesco 1976; Litsiccger ard Moodv 1976· nrn··i

Table 73 CROP COMBINATIONS IN DIFFERENT LOCATIONS IN AFRICA IN 100 m^2 SAMPLE PLOTS IN RELATION TO SEEDBED PREPARATION (from Agboola 1980)

Crop	Location and seedbed preparation[1]											
	1	2	3	4	5	6	7	8	9	10	11	Percentage frequency
Dioscorea rotundata	X	X	X		X	X	X	X	X	X		82
D. rotundata (Abi)		X		X								18
D. dumetorum						X		X	X	X		36
D. bulbifera					X	X						18
D. alata			X		X	X		X				36
D. cayenensis sp.								X				9
Cassava (*Manihot* sp.)		X		X	X	X		X	X	X	X	64
Cocoyam (*Xanthosoma*)			X	X			X	X	X			45
Cocoyam (*Colocasia*)			X		X			X	X			36
Sweet potato			X									9
Musa sp.				X			X		X			27
Maize (*Zea* sp.)	X	X	X	X	X	X	X	X	X	X	X	100
Cowpea (*Vigna* sp.)			X		X							18
Groundnuts (*Arachis* sp.)					X	X	X					27
Voandzeia sp.					X							9
Sphenostylis sp.								X				9
Solanum sp.	X		X									9
Capsicum sp.									X			18
Okra (*Hibiscus* sp.)	X	X	X		X	X	X	X	X			73
Pumpkin (*Cucurbita* sp.)	X	X						X				27
Melon (*Colocynthis* sp.)	X	X	X	X		X	X					55
Telfairia sp.					X				X			18
Lagenaria sp.					X	X						18
Amaranthus sp.	X		X	X								27
Corchorus sp.	X		X	X			X		X			45
Bitter leaf (*Verooria* sp.)									X			9
Talinum triangulare							X	X				18
Castor bean (*Ricinus* sp.)	X		X	X	X							36
Sugarcane (*Saccharum* sp.)								X				9
No. of species per sample	9	7	13	9	13	10	9	13	12	4	2	

[1] Locations and types of seedbeds were: 1 - Ogidi (mound), 2 - Abagana (mound), 3 - Umuleri (mound), 4 - Awka (mound), 5 - Ezillo (mound), 6 - Abakaliki (mound), 7 - Ikom (mound), 8 - Oron (flat), 9 - Ibam Ekpe (flat), 10 - Onne 1 (flat), and 11 - Onne 2 (flat).

1974) . While weeds are major problems in multiple cropping systems, especially in warm, humid regions, and are a major reason for using shifting cultivation (Moody 1974; Ofori 1974), weed control in these regions is usually better with multiple cropping than with continuos cropping. The improved control with multiple cropping results from the various crop and weed species having different growth habits, light requirements and abilities to compete for space, water and nutrients (Litsinger and Moody 1976; Moody 1974; Ofori 1974). Undoubtedly, closer management by the farmer, especially on small farms, results in weeds being controlled on a more timely basis in a multiple cropping than in a continuous cropping system, thus reducing the overall weed problems.

As for weeds, multiple cropping may result in fewer and less severe insect, disease and other pest problems than continuous cropping. Factors responsible include use of shorter maturing varieties, greater crop diversity (plant types, heights, leaf density, cover, etc.), use of resistant cultivars, growing of crops at a time nut of phase with the time of greatest potential for the pest, presence of effective parasites or predators, chemicals (odours, exudates, etc.) produced by certain plants, and greater distances between susceptible cultivars (Litsinqer and Moody 1976; Ofori 1974).

Although weed problems tend to he less in multiple than in continuous cropping systems, as previously discussed, weed control may be more difficult in multiple cropping (especially intercropping) systems because major tillage or herbicides often cannot be used. Major tillage, such as that with animals or tractors, may not be possible because the crops are interplanted, have overlapping growing seasons, and may be broadcast planted (not in a pattern suitable for weed control with tillage) (Litsinger and Moody 1976; Moody 1974). Even where the crops are planted in rows, inter-row cultivation does not control weeds in the row and, there-fore, may require weeding by hand. Sequential cropping should not interfere with major tillage per se for weed control and other purposes such as seedbed preparation, water conservation, erosion control, etc. However, time may be limited for tillage when a rapid shift to another crop is desired. Where tillage is performed by hand, intercropping could restrict tillage, but not necessarily weed control with a hoe or cutlass, or by pulling.

Use of multiple copping systems definitely limits the control of weeds with herbicides. Because of the variety of crops grown, most herbi-cides cannot be used without harming some crop in the system. This is especially a problem with intercropping, and may be a problem with sequential cropping because of the residual effects of herbicides on subsequent crops (Moody 1974). As for herbicides, residues from insecticide applications to a preceding crop may also linger in the soil and adversely affect the next crop by contaminating the edible plant parts or by phytotoxic action. The residual action may, however, control other insect pests (Litsinger and Moody 1976).

The limited opportunities for tillage and for applying herbicides to control weeds are the primary reasons why multiple cropping systems, especially intercropping systems, are labour-intensive systems. Being labour-intensive may or may not be a disadvantage. It is a disadvantage where the labour supply is limited. It is usually an advantage where labour is plentiful. Farm work may be difficult and unappealing to many people. However, it provides an opportunity for employment where the labour supply is plentiful and where there are limited opportunities for employment in industry and other occupations.