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THE NEW ORGANIC GROWER

A Master's Manual of Tools and Techniques for the Home and Market Gardener

REVISED AND EXPANDED EDITION

ELIOT COLEMAN

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CROP ROTATION

MOST DEPENDABLE AGRICULTURAL PRACTICES ARE AGES OLD. CROP ROTATION is a good example. Descriptions of the benefits of rotating crops can be found in the earliest Roman agricultural writings. The Greeks and, before them, the Chinese were also well acquainted with the principles of crop rotation. From his experience as a researcher at Rutgers, Firmin Bear stated that well-thought-out crop rotation is worth 75 percent of everything else that might be done, including fertilization, tillage, and pest control. In fact, I think this is a conservative estimate. Rarely are the principles of crop rotation applied as thoroughly as they might be in order to garner all of their potential benefits. To my mind, crop rotation is the single most important practice in a multiple-cropping program.*

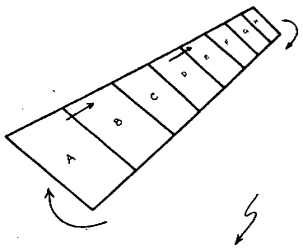
**The most complete bibliography of studies on all aspects of crop rotations up through 1975 is collected in "Bibliografia Sull Avvicendamento delle Colture" by G. Toderi in* Rivista di Agronomia, *9 (1975), pp. 434–68.*

In a word, crop rotation means variety, and variety gives stability to biological systems. By definition, crop rotation is the practice of changing the crop each year on the same piece of ground. Ideally, these different crops are not related botanically. Ideally, two successive crops do not make the same demands on the soil for nutrients, nor do they share diseases or insect pests. Legumes will be alternated with non-legumes. A longer rotation before the same crop is grown again is better than a shorter rotation. And, ideally, as many factors as possible will be taken into account in setting up the sequence.

Space and Time

The key to visualizing crop rotations is to understand that two things are going on at once. Rotations are both spatial (crops move) and temporal (time moves). With both crop sequence and time to consider, there may be some initial confusion when considering complicated rotations. Hang in there.

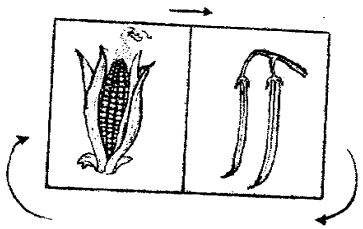
A graphic representation of an eight-year crop rotation would look like the following. There are eight sections with a different crop growing in each section. Now, let's say we want to rotate these eight crops so that A follows B, B follows C, and so on. Adding arrows to the picture indicates the direction of rotation. In each case the letters represent where the crop grows this year. The picture for the next year would follow the arrows one space over and have A growing where B



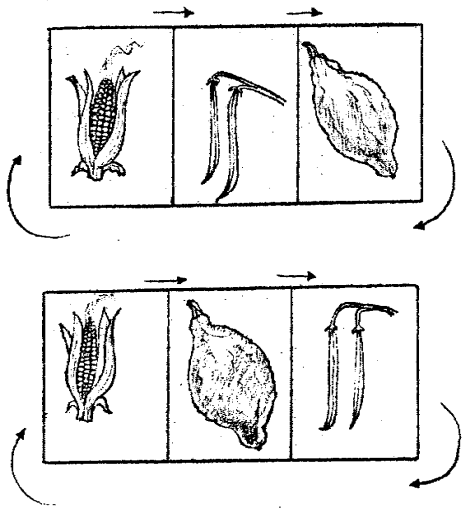
Graphic representation of an eight-year crop rotation.

grows this year, with H growing in A's old place. The following year would have A growing where C grows this year, and so on.

When planning rotations I use 3" x 5" index cards with the crop names written on them. Some of you may wish to use a computer to display your planning options. I move the cards around as I try to determine the ideal sequence for the number of crops involved. Let's see how that works. With two crops, there is no problem. Take corn and beans. Corn is growing this year where beans will be next year and beans are growing this year where corn will be next year.



A three-year rotation expands that concept. Once there are more than two crops, a new factor is involved: order. There are now two possible sequences. The index cards can be placed: corn/beans/squash or corn/squash/beans.



Notice that we are not concerned with the number of ways in which three items can be ordered (of which there are six), but rather with the possible sequences. If we go to a four-year rotation, there are six possible sequences. An eight-year rotation offers 5,040 sequences.

Why Bother?

Decisions, decisions. Why bother with crop rotation? Because there are so many benefits to the grower from setting up a rotational sequence that exploits every possible advantage. Corn, beans, squash, and other crops all take different nutrients out of the soil. All respond to diverse fertilization patterns. All are amenable to specific cultivation practices. All may affect or be affected by the preceding or

succeeding crop. Whenever the crop or cultural practices of the current year can be chosen to benefit a future crop, there is reason for bothering. In fact, whenever there is a choice between one or more ways of doing a job, one of them is usually the best way. The determined grower will take the time to think things through to optimize every aspect of his production.

Time spent planning a rotation is never wasted. Not only will you learn a great deal about important biological balances on the farm, but the results will be so effective in halting problems before they occur that you may sometimes have to remind yourself that a lot is happening. Very often farmers fail to take full advantage of a well-planned rotation, because rotations don't have any computable costs and because they work so well at preventing problems that farmers are not aware of all the benefits. Those benefits are, in a sense, invisible.

Insect, Disease, and Weed Control

Rotations improve insect and disease control by managing the system to benefit the crop. Monoculture encourages many pest problems, because the pest organisms specific to a crop can multiply out of all proportion when that crop is grown in the same place year after year. Pests are most easily kept in balance when the soil grows different crops over a number of years. A good rotation spaces susceptible crops at intervals sufficient to hinder the buildup of their specific pest organisms.

Rotations affect weed control in a similar way. The characteristics of a crop and the cultivation methods used to grow it may inadvertently allow certain weeds to find a favorable niche. A smart crop rotation will incorporate a successor crop that eradicates those weeds. Furthermore, some crops can work as "cleaning crops" because of the style of cultivation used on them. Potatoes and winter squash fit into this category because of the hilling practiced on the former and the long period of cultivation that is possible prior to vining for the latter.

Plant Nutrition

Rotations can make nutrients more available in a biological farming system. Some plants are more effective than others in using the less soluble forms of plant nutrients. The residues of these nutrient-extracting plants will make the minerals more available to later, less effective plants in the next sequence of the rotation.

In general, plants of a lower order of evolution have been shown to be better feeders on less soluble nutrient sources than those of a higher order of develop-

ment. Lowly plants—evolutionarily speaking—such as alfalfa, clovers, and cabbages, are more aggressive at extracting nutrients than more highly developed plants such as lettuce or cucumbers (see note on page 103). Lettuce and cucumbers, I've found, don't feed well on less soluble mineral nutrients. Thus, in my rotations, the choicest spot and the finest compost is always saved for the lettuce and cucumber crops, and their exceptional quality has always repaid that care.

Manure

Rotations encourage the best use of organic soil amendments. Some crops (squash, corn, peas, and beans, for example) grow best when manure or compost is applied every year. Others (cabbages, tomatoes, root crops, and potatoes) seem to grow better on ground that was manured the previous year. Greens are in the former category, with the caveat that the compost should be well decomposed. Obviously, a rotation that alternates manured crops with nonmanured crops will allow a grower to take these preferences into account.

Soil Structure

Rotations preserve and improve the soil structure. Different crops send roots to various depths, are cultivated with different techniques, and respond to either deeper or shallower soil preparation. By changing crops each year, the grower can make use of the full depth of the soil and slowly deepen the topsoil in the process.

Deeper-rooting plants of both cash crops and green manures extract nutrients from layers of the soil not used by the shallow rooters. In doing so they open up the soil depths, leaving paths for the roots of other, less vigorous crops. Deep rooters also incorporate mineral nutrients from the lower strata into their structure, and eventually, when the residues of these plants decompose in the soil, those nutrients become available to the shallow rooters.

Yields

Rotations improve yields not only in the many ways discussed above but also in subtler ways. Some crops are helped and some hindered by the preceding crop. The University of Rhode Island conducted over 50 years of studies on the influence of the preceding crop on the yields of the following crop.* The possible reasons for this are numerous and even after extensive study there is no general agreement on what exactly are the processes involved. Some causes for the beneficial influence of preceding crops on subsequent crops are:

- Increase in soil nitrogen
- Improvement in the physical condition of the soil
- Increased bacterial activity
- Increased release of carbon dioxide
- Excretion of beneficial substances
- Control of weeds, insects, and disease

The injurious effects of preceding crops, which I aim to avoid by careful rotation planning, are produced by:

- Depletion of soil nutrients
- Excretion of toxic substances
- Increase in soil acidity
- Production of injurious substances resulting from the decomposition of plant residue
- Unfavorable physical condition of the soil due to a shallow-rooting crop
- Lack of proper soil aeration
- Removal of moisture
- Diseases passed to subsequent crops
- Influences of crops upon the soil flora and fauna

Patterns

Despite a lack of agreement among researchers, certain patterns emerge from the studies I have read on good and bad rotational effects, as well as from my own observations:

- Legumes are generally beneficial preceding crops.
- The onions, lettuces, and squashes are generally beneficial preceding crops.
- Potato yields best after corn.
- For potatoes, some preceding crops (peas, oats, and barley) increase the incidence of scab, whereas others (soybeans) decrease it significantly.
- Corn and beans are not greatly influenced in any detrimental way by the preceding crop.
- Liming and manuring ameliorate, but do not totally overcome, the negative effects of a preceding crop.
- Members of the chicory family (endive, radicchio, etc.) are beneficial to following crops.
- Onions often are not helped when they follow a leguminous green manure.
- Carrots, beets, and cabbages are generally detrimental to subsequent crops.

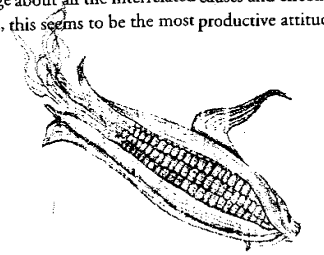
**The results of the University of Rhode Island crop-rotation experiments are reported in the following two studies: "A Half-Century of Crop-Rotation Experiments" by R. S. Bell, T. E. Odland, and A. L. Owens in* Bulletin No. 303, *and "The Influence of Crop Plants on Those Which Follow: V" by T. E. Odland, R. S. Bell, and J. B. Smith in* Bulletin No. 309 *(Kingston: Rhode Island Agricultural Experiment Station).*

These are merely patterns, not absolutes. Still, it is necessary to start somewhere. These patterns have been discerned through research on the influence of preceding crops on subsequent crops and from my own and other farmers' experience. Since these patterns may be soil- or climate-specific, they are offered mainly to indicate the kinds of influences to which alert growers should attune their senses. Whether universal or applicable only to a specific farm, these bits of wisdom can be valuable to the farmer who learns to apply them.

One Percenters

Whereas the rotation guidelines presented earlier in this chapter qualify under the category of standard crop rotation "rules," the patterns above belong more in the category of "suggestions, hints, and refinements." The effect of any of them on improved yield, growth, and vigor may only be 1 percent, an amount that may not seem worth considering to some. What must be understood is that a biological system can be constantly adjusted by a lot of small improvements. I call them "one percenters." *The importance of these one percenters is that they are cumulative.* If the grower pays attention to enough of them, the result will be substantial *overall* improvement. And, best of all, these one percenters are free. They are no-cost gains that arise from careful, intuitive management.

One percenters may not always provide measurable results, but they have a definite influence. I have learned to pay attention and try to make use of them. Sir George Stapleton, an English grassland specialist, referred to this approach as "competent ignorance." He was always aware of how much he did not know and how much science always misses, but he did not want that to limit his ability to act. I think that attitude is wise. Rather than not acting because we can't be certain, I suggest we try instead to apply what we hope we know. The grower should try to take as many intelligent actions as possible to incrementally improve his crops and then be attentive to what happens. Given our limited knowledge about all the interrelated causes and effects operating in the biological world, this seems to be the most productive attitude.



I am presently studying ecological succession to find patterns for devising ever better crop rotation sequences. I am curious about the mechanisms of natural succession in disturbed ecosystems. I want to know the guidelines determining what follows what after fires or landslides or clearcuts and so forth. Is this just a case of the availability of sun and shade, or are there progressive changes in the soil that dictate succession and, if so, how do they proceed? Are the pioneer crops merely opportunistic, do they just add organic matter, or are there other biological, chemical, or structural modifications that improve the soil's suitability to the needs of another crop? In other words, are there patterns, and can I replicate them? Because if there are identifiable patterns, I can employ similarities in the effect of vegetable or green manure crops on the soil to create crop rotations that mimic natural laws. I suspect many of the observations made by growers over the centuries have picked up on a lot of this. But I also suspect there are endless incremental improvements to be made through further study.

A Sample Rotation

Before deciding what crops the As, Bs, and Cs of those earlier illustrations stand for, we must first collect a good deal of information. Toward that end, let's set up a sample rotation for our 5-acre vegetable farm. The following factors need to be considered:

Number of Sections. A crop rotation works best if the rotational sections are all the same size. That goal is not always easy to achieve on the large farm, where whole fields are involved, but it should be manageable with 5 acres of vegetables. For this discussion let us assume that we will be using 5 acres of land divided into 10 half-acre sections.

Number of Years. Just as two dozen crops don't necessarily mean a 24-year rotation, you should realize that ten sections don't have to mean a ten-year rotation. Each section can be divided into two, three, or more separate and shorter rotational cropping plans. Possibly a legume-grass pasture could be included for a number of years in rotation. Each grower makes these decisions to suit his or her own situation. For now, let's say that the ten sections will be managed as a ten-year rotation.

Number of Crops. In the example we are working with at the moment, 24 major crops will be grown. To begin to plan where to grow each crop in the rotational sequence, we need to divide the crops, first by botanical classification.

Poaceae
Corn

Liliaceae
Onion

Chenopodiaceae
Beet
Chard
Spinach

Cucurbitaceae
Squash, winter
Squash, summer
Cucumber

Brassicaceae
Rutabaga
Kale
Broccoli
Cauliflower
Cabbage
Brussels sprouts
Radish

Fabaceae
Pea
Bean

Apiaceae
Carrot
Parsley
Celery
Parsnip

Solanaceae
Potato
Tomato
Pepper

Asteraceae
Lettuce

The reason for this division by vegetable families is based on one of the first principles of crop rotation—not growing the same crop or a closely related crop in the same spot in successive years. Our list is a good start, but more information is needed. It might help to divide up the crops according to more general gardening categories:

Root Crops
Beet
Carrot
Onion
Parsnip
Potato
Rutabaga
Radish

Legumes
Pea
Bean

Vine Crops
Squash
Cucumber

Grain Crops
Corn

Fruit Crops
Tomato
Pepper

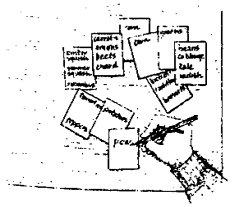
Brassica Crops
Broccoli
Cauliflower
Cabbage
Brussels sprouts

Greens
Lettuce
Spinach
Chard
Parsley
Celery
Kale

Although this categorization mixes up the botanical divisions, it adds valuable new information. Since more than one crop will be growing in some sections, it helps to decide which crops have similar cultural requirements or which, such as greens, might need to be harvested together for a specific market.

Space for Each Crop. The fact that 24 crops will be grown in a ten-section rotation indicates that some of the crops do not need as much growing area to meet market demand as others. And that leads to one of the most interesting of the rotation-planning puzzles: how to meet the different needs of the market and still fit all of these disparate crops into a systematic crop rotation. The best place to begin is by deciding how much space or what percentage of the total cultivated area each crop needs in order to produce the right amount for market. We can determine those space requirements by creating six different categories, from the largest space needs to the smallest. From my experience, divisions for our 24 crops would look like this:

More Space ←					→ Less Space
6	5	4	3	2	1
Corn		Potato	Tomato	Lettuce	Onion
		Pea	Cauliflower	Pepper	Beet
		Winter squash	Broccoli	Carrot	Chard
				Summer squash	Parsley
				Bean	Celery
				Cabbage	Parsnip
				Spinach	Rutabaga
					Kale
					Radish
					Brussels sprouts
					Cucumber

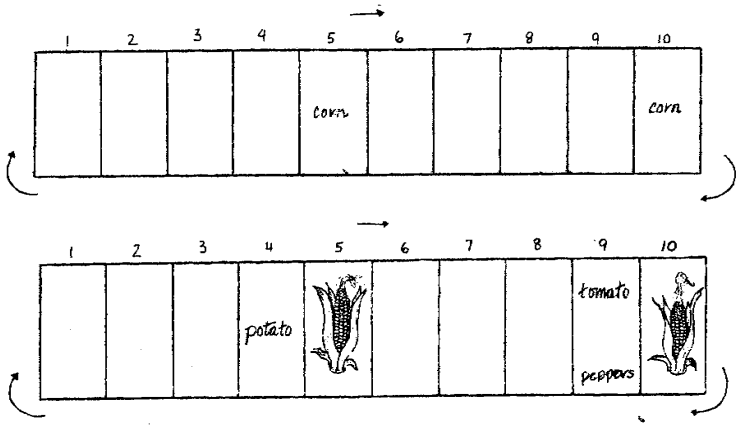


Now the index cards come into play. Each card will represent a section of the rotation. Write each of the names of the left-hand crops (those requiring the most space) on a separate card (or two cards, in the case of larger crops like corn). Take a pair of scissors and cut up proportional sections of other cards to represent the smaller areas needed by the right-hand crops. More than one of the smaller-space crops will occupy the same rotational section. Next, tape a number of them together in the space of one card. Whenever possible, put crops that are in the same family or require similar cultivation conditions together.

The Crop Rotation Game

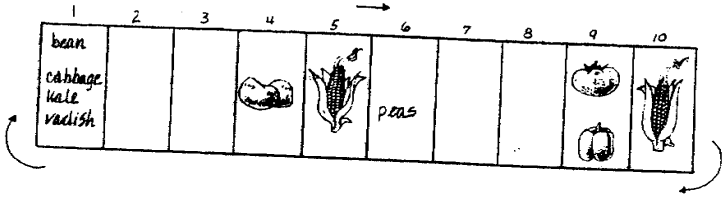
At this stage, the arrangement and rearrangement of the cards is something like a board game. The rotation principles and patterns discussed earlier are the "rules." New rules are added as the grower becomes aware of them through experience, reading, and suggestions from other growers. The game begins by placing the cards on a flat surface and adjusting their positions to make up one rotational sequence or another. The aim is to determine if it is possible to grow all the crops desired on the land available and in the quantities necessary, while at the same time satisfying all the rules. The winner is the sequence that comes closest to the ideal pattern, one that optimizes as many of the beneficial aspects of a crop rotation as can be achieved with these specific crops.

So let's give it a try. The two corn crops should not be side by side. Put one in the middle of the rotation and one at the end, thus placing the corn crops as far from each other as they can be in a ten-year rotation. We know that potatoes yield best after corn, so put the potatoes in Section 4. That naturally suggests a place for the tomatoes and peppers in order to create distance between them and the related potatoes.

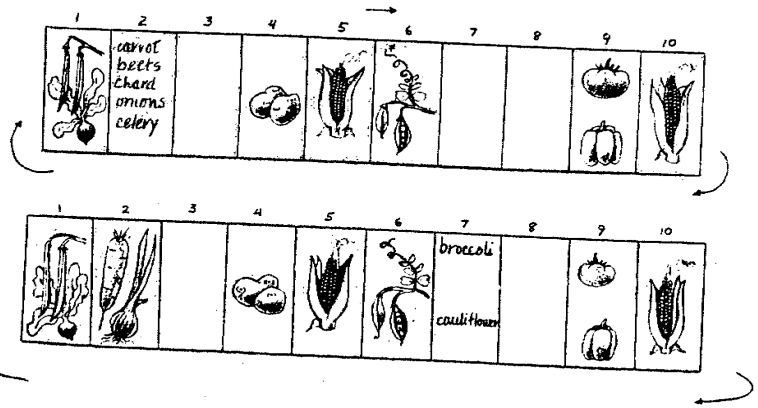


Since grain crops (corn) traditionally do well after legume crops (peas and beans), what if we precede the corn with the two legumes? Granted, there are the cabbage family crops sharing the bean section (and one of our patterns suggests

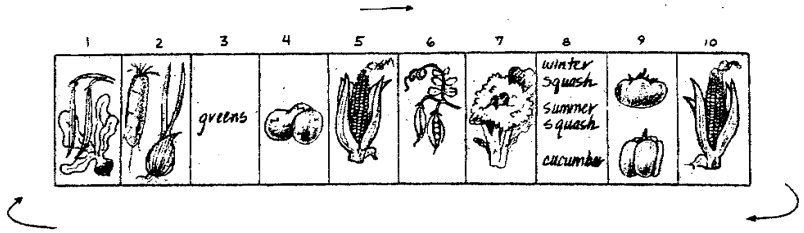
that cabbages are negative preceding crops), but corn has been found to be the least affected by a preceding detrimental crop. Further, the corn field will likely be manured, helping to offset any negative effects.



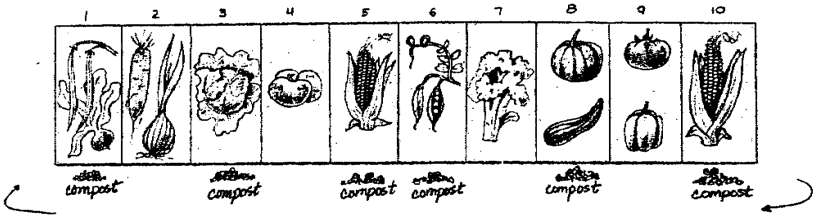
Since beans are not affected too much by the preceding crop, let's put the often detrimental roots (carrots and beets) in front of them. Now a nuance can be considered. Onions have been shown to be a very beneficial crop before the cabbage family. We aren't growing enough onions to take advantage of that in whole sections, but they can still be effective depending upon where the crops are placed in a section. In this case we can grow the carrots and beets where they will be followed by the beans, and grow the onions, as much as possible, where they will be followed by the cabbage family. What the heck? They have to grow somewhere, so it might as well be where they have a chance of doing some good. And since those cabbage family crops are in the bean section, the other brassicas ought to be set apart from them. Section 7 would seem to be ideal.



Now for the final two sections. Squash is a generally beneficial preceding crop, and it is well suited to growing with an undersown leguminous green manure (see Chapter 8). Since that green manure would be excellent before the broccoli-cauliflower section, let's put the squash card in section 8. By default, the greens go to Section 3.



Now let's see if this fits in with some of the rules we haven't considered yet. What about the crops that most benefit from manure or compost the same year it is applied? The ideal situation has those crops alternating with the others. Not bad at all.

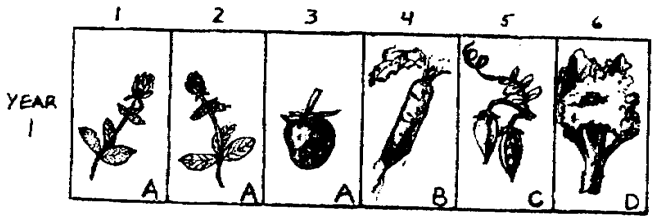


I would suggest that the manure for the corn in section 5 could be omitted, since the pea crop will be finished early enough, even in my short season (120 frost-free days), to allow a leguminous green manure to be seeded and get well established by the end of the growing season. When tilled under the following spring, the green manure should provide more than adequate nourishment for the corn crop to follow.

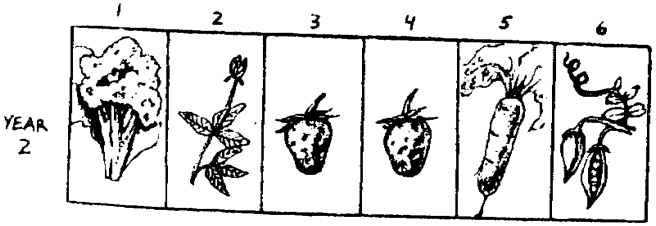
If manure and compost are in short supply, some selective decisions will have to be made. It would be nice to aim for a manure application at least one year in three, but even that isn't vital. Instead, the grower has recourse to another management practice, the undersown green manures mentioned earlier. Those techniques will be discussed in the next chapter.

Multi-Year Crops

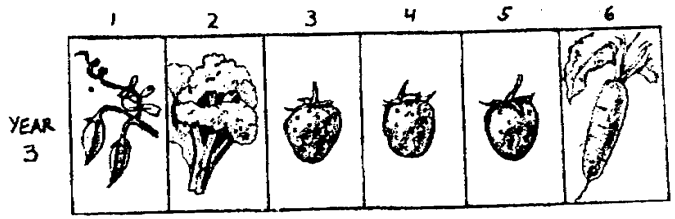
There is no problem including in the rotation those crops that need to remain in the ground for more than one year. They are assigned as many sections as the number of years they are to grow. A six-year rotation for four crops would look like this in Year 1:



Let's say crop A is strawberries. In Year 1, only Section 3 would be planted to strawberries. The other sections could grow green manure or any other crop unrelated to B, C, or D. In Year 2, Section 4 would be planted to strawberries.



The strawberries in Section 3 are now in their second year and cropping. Section 2 can be treated again as in Year 1. Then, in Year 3, the rotation is off and running.



The strawberries in Section 3 will give a second crop this year before being turned under. The Section 4 berries are in their first year of cropping, and the Section 5 berries have just been planted.

The sequence continues in future years. If the "As" were a pasture or hay crop, the same system would prevail. One new section would be seeded each year and one old section would be tilled up and readied for the following crop. In fact this would be an excellent way to use a perennial deep-rooting legume like alfalfa or a legume-grass mixture (red clover/alsike clover/timothy, for example), to include some serious soil fertility improvement in a rotation. The perennial soil-improving crops have been found to achieve optimum benefit to soil structure and produce increased organic matter if they can be left for three years. The virtues of alfalfa and many other green manure crops are discussed in the next chapter.

Short Rotations

Not surprisingly, the reality is often not as perfect as the ideal. When there is no way to run a long rotation, you have to make the best of things. If a single crop dominates a large part of the production program, it may be necessary to repeat it every other year—or, as in the case of some greenhouse lettuce production, even twice a year. In these short-rotation situations, changes should be introduced at every opportunity. That even includes changing the variety of the crop. Any slight genetic difference should be exploited if it adds diversity to the cropping program. A succession crop sown after the main crop can help. A green manure can follow or be undersown (see Chapter 8). Mustard or rape, traditional cleansing crops for sick soil because they stimulate soil microorganisms, can be very effective so long as the dominant crop is not a fellow brassica.

In other words, aim for as great a variety of unrelated crops as possible in the span between related crops. Some growers advocate growing two consecutive crops (of, say, lettuce) followed by a longer break instead of alternating the crop with shorter breaks. I have not found that to be better, but I encourage a trial if the idea seems appealing. Other growers suggest that the more intensive the cropping, the more care must be taken to optimize all the growing conditions, especially by using extra soil-improving organic amendments like compost. I agree fully with that suggestion.

In some cases, no rotation at all is recommended. Many old-time growers insist that tomatoes do best if planted every year in the same spot. They even recommend fertilizing them with compost made from the decayed remains of their predecessors. I once grew tomatoes that way for eight years in a greenhouse. In truth, they were excellent, and they got better every year. I do not grow field tomatoes that way now and cannot really defend my decision except to say that it is more convenient when they are part of the rotation. It could be that I am just uncomfortable about breaking the rules I have found to work so well with other crops. It could also be that I am unnecessarily limiting my options. I suggest that you try growing tomatoes (or any crop, for that matter) without rotation. Nothing is as stifling to success in agriculture as inflexible adherence to someone else's rules. With a little daring and imagination whole new vistas may open up. Remember, the aim of this farming system is independence, reliability, and sustainability. Any practices and attitudes that contribute to that goal should become part of the rule book.

A Tried-and-True Rotation

The ten-year rotation we just developed was meant as a teaching exercise. It may need refining for your operation. The eight-year rotation presented below is a good one to conclude with because it is one I have followed since 1982. It has been well tested. I have thought about modifying it countless times but never have. Its virtues always seem to outweigh its defects, although that isn't to say it can't be improved. I'm sure it can. But it has been a dependable producer, and I offer it here as a tried-and-true example of a successful rotational sequence that incorporates many crop benefits.

The goal of this particular rotation was to grow 32 vegetable crops in adequate quantities to feed for a year the community of 60-some people who eat daily in the Mountain School dining hall (see page 290). Since we have found that we can feed 40 people per acre, the rotation below represents 1½ acres of land. The salad crops not included here were grown in a separate small salad garden close to the kitchen.

Potatoes follow sweet corn in this rotation because research has shown corn to be one of the preceding crops that most benefit the yield of potatoes.

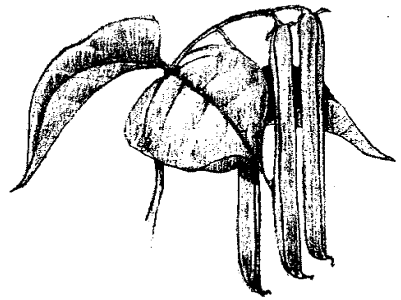
Sweet Corn follows the cabbage family because, in contrast to many other crops, corn shows no yield decline when following a crop of brassicas. Secondly, the cabbage family can be undersown to a leguminous green manure which, when turned under the following spring, provides the most ideal growing conditions for sweet corn.

The Cabbage Family follows peas because the pea crop is finished and the ground cleared by August 1, allowing a vigorous winter green manure crop to be established.

Peas follow tomatoes because they need an early seedbed, and tomatoes can be undersown to a non-winter-hardy green manure crop that provides soil protection over winter with no decomposition and regrowth problems in the spring.

Tomatoes follow beans in the rotation because this places them four years away from their close cousin, the potato.

Beans follow root crops because they are not known to be subject to the detrimental effect that certain root crops such as carrots and beets may exert in the following year.



Root Crops follow squash (and potatoes) because those two are both good "cleaning" crops (they can be kept weed-free relatively easily); thus there are fewer weeds to contend with in the root crops, which are among the most difficult to keep cleanly cultivated. Also, squash has been shown to be a beneficial preceding crop for roots.

Squash is grown after potatoes in order to have the two "cleaning" crops back to back prior to the root crops, thus reducing weed problems in the root crops.