Intensive Home Vegetable Production

In 1976-1977, Hilde Maingay did research at the New Alchemy Institute In East Falmouth, MA to grow a maximum amount of nutritious vegetables on a limited amount of land. The garden produced a wide range of vegetables using organic methods on raised beds, hand tools (no machinery), and non-toxic pest control.

The goal was to produce food to eat fresh in the growing season, and additional food to preserve for winter. The yield of vegetables was weighed and calculated as the number of edible portions of each vegetable. The vegetables were divided into --

-- raw salad vegetables (23 kinds of vegetables)
-- cooked root vegetables (10 kinds of vegetables)
-- cooked green vegetables (24 kinds of vegetables)

In 1976-1977, 1/10 acre of garden was formed into 20 beds and 20 paths. The number of hours were measured for soil preparation, planting, weeding/mulching, and watering.

The outcome was that garden space of 1/10 acre can provide a year's worth of vegetables for more than 10 people, providing 3 servings of vegetables daily (raw salad vegetable, cooked root vegetable, cooked green vegetable).

LABOR

In a home vegetable garden, a person exchanges gardening work for fresh vegetables. In the intensive-production research garden, the work of growing the vegetables, (not including harvesting labor), averaged over the whole growing season, each minute of labor produced about 1 portion of vegetables.

Gardening work over the growing season requiries almost daily care. It is a sequence of preparing the soil, planting, weeding, watering and harvesting, .

Labor for the 1/10 acre research garden required one person to work --

4 hours/wk in April
8 hours / wk in May
15-20 hours / week in June
20 hours / week in July
3-8 hours/week in August

These hours do not include harvesting time, which is also required throughout the season. These hours do not include time for preserving any of the food. They do include raising 3000 seedlings in a small solar greenhouse.

Finally, a year's supply of vegetables is not all the food a person needs. To get enough protein and calories for good health, other, additional food (and land) would be needed.

The information above is from 2 articles by Hilde Maingay :

“Intensive Vegetable Production” Journal of the New Alchemists 4 pp. 47-55. 1977.

"A Study of the Energy Efficiency of Intensive Vegetable Production” Journal of the New Alchemists 5 pp. 62-68 1979. ,

For more info, google "Green Center New Alchemy"

Following are excerpts from :
"Intensive Vegetable Production" Journal of the New Alchemists 4 pp. 47-55. 1977.
"A Study of the Energy Efficiency of Intensive Vegetable Production"
Journal of the New Alchemists 5 pp. 62-68 1979. ,
plus additional photos.

A Study of the Energy Efficiency of Intensive Vegetable Production

- Hilde Maingay

Preparation of the Raised Beds

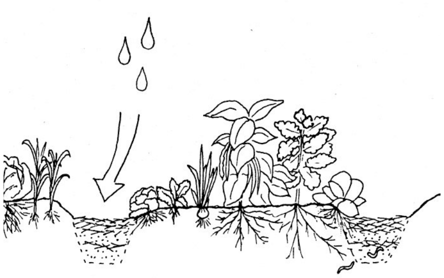
To prepare the beds in the New Alchemy gardens for intensive cultivation, a strip of soil one foot wide was dug to a depth of six to twelve inches. The soil was spread over an area four to five feet in width to form a planting bed. The strips that had been dug out became the pathways between successive raised beds. Twenty such beds were made, each approximately forty to forty-five feet long.

Tools: The garden tools used were a shovel to build the beds and dig the paths and a rake to smooth the surface. Auxiliary tools included a pitchfork to spread leaves, seaweed and other organic matter, a posthole digger for the bean posts, a trowel to set out the seedlings and string as a guide in making straight lines.

Labor: It took one woman of average size and strength two days to build these twenty beds.

Sheet Compost in the Pathways

Sheet composting differs from a standard compost pile in that thin layers of organic materials are spread over the soil, rather than being piled in one heap. It has an advantage in that gathering and spreading can be done at any time whereas a regular compost pile must have all the material within a one or two day period. When possible a layer of manure was added after two layers of green matter. Our manure is mainly from stable horses bedded on woodchips. The rest of the organic materials consisted of dry leaves, unwashed seaweed, garden wastes like weeds, vegetable parts and flowers, and once a few loads of straw from the local county fair with an exotic selection of elephant, tiger and goat manures.



As the season progressed, the pathways were filled, deterring the weeds and keeping the sides of the beds covered and cool. There were additional unanticipated advantages:

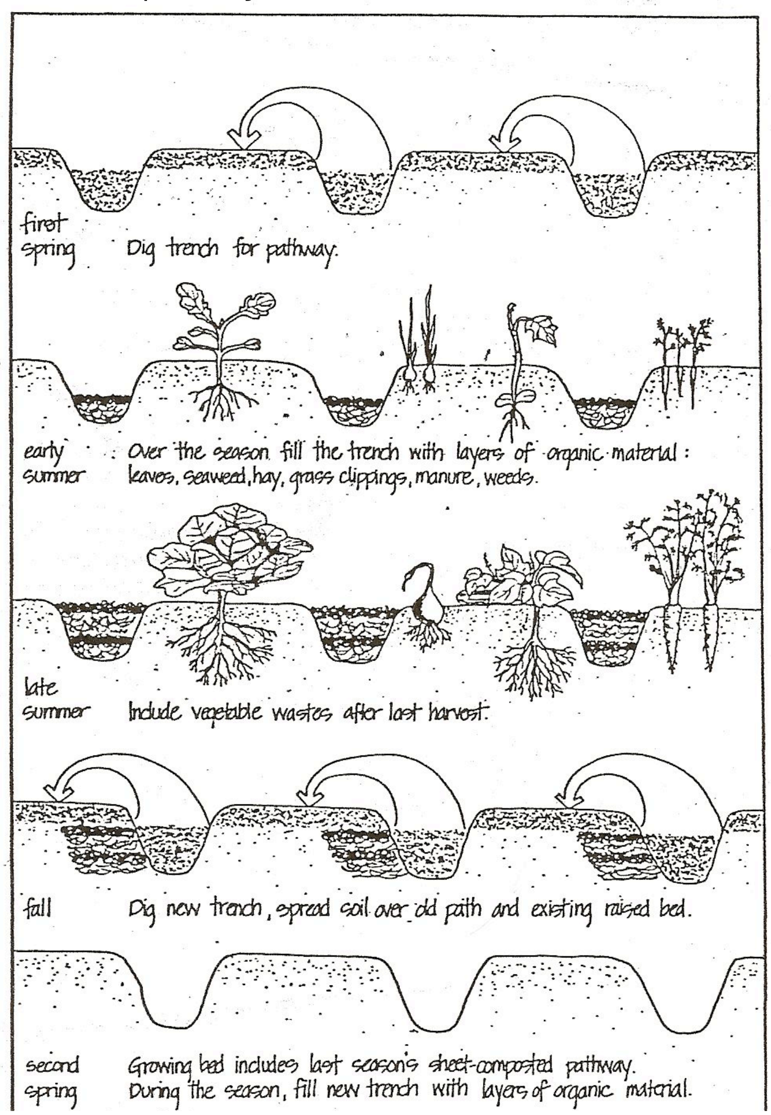
- Running back and forth with weeds and garden wastes was eliminated
- Improved absorption and retention of water in the beds

- Beds moister and cooler than with mulch. The composting materials absorbed more rainwater and run-off water from the beds than the same amount of materials in a compost pile would have. No additional water was necessary to decompose the materials. If irrigating is done by flooding the pathway ditches, the plants receive water enriched with leached out nutrients from the sheet compost and the decomposition of materials is hastened. We noted a large population of earthworms under the strips.

During the relatively slow decomposition process, CO_2 is given off. Insufficient CO_2 is one major limiting factor in plant growth. In pathway sheet composting, CO_2 is released slowly and constantly. Later, when the compost is buried, the CO_2 remaining is released into the ground, beneath the plants. With all these advantages, sheet composting still does not completely replace the regular compost pile. In a well-built, balanced pile, the heat created during the first decomposition process can kill grubs, eggs and some pathogenic organisms.

Rotation of the Raised Beds

At the end of the growing season, all the beds were moved a third of their width by digging up part of the beds and putting dirt on top of the sheet compost filled pathways. At the same time new pathways were created.



Incorporating Organic Matter: All the organic materials were buried beneath a layer of top soil where further decomposition occurred over the winter, forming the growing medium for the next year's plants. Over a period of three years, a new layer of humus approximately six inches thick will have been placed under about six inches of top soil. Last spring, due to lack of snow in the winter and rain in the spring, the previous year's layer had not decomposed properly and a residual mat of dry leaves under the soil concerned us. It was decided to plant non-root crops like broccoli, brussels sprouts, eggplant and soybeans there and to seed carrots in plain dirt. All grew well. The leaves and the other organic material under the dirt decomposed fully over the summer.

Stimulating Soil Organisms: To maintain soil health, periodic addition of organic matter has proved to stimulate soil organisms. Earthworms play an important role in this process by stabilizing and even increasing soil fertility. Their numbers, appearance and vigor are good indicators of fertility. They improve the physical structure of the soil and produce nutritive materials for growing plants as well as being in themselves a food for a large variety of birds. Earthworms break down large quantities of leaves and other litter. They contribute to the nitrogen content of the soil as well as to its aeration.

Weed Control:

Cultivation
Using the intensive raised bed method, we found little or none of the usual cultivation necessary.

Mulch - Where and whenever possible, a mulch consisting in the main of a mixture of seaweeds and eelgrass was applied between the plants. Mulch helps retain moisture in the soil and helps prevent weed germination.

Intensive Planting - All plants in the beds were grown as close together as healthy growth would allow. The canopy of leaves produced once the plants have begun to grow shades out undesirable competitors and creates a beneficial microclimate for the plants themselves.

Fertilization:

In our raised beds we used four methods of adding nutrients to the soil.

Compost: Several compost piles were built. Some were slow decomposing piles left over winter, others were quicker and decomposed fully in a few weeks. The same proportions of two to one of green and animal manures as in the sheet compost method were used. The finished material was used as a fertilizer, sprinkled around the base of each plant.

Mulch: Most of our mulch consisted of dry leaves gathered during the previous fall and piled up over winter or seaweed collected from the local beaches during the growing season. The seaweed is left unwashed to avoid leaching of nutrients. There is considerable precedence for this as a gardening practice. No tests have been done as yet to establish the salt content of our soil or the possible increase of salinity over the last five years. Depending on the time in the season as well as the year, our mulch consists on the average of 85% eelgrass which is not a seaweed and 15% a mixture of codium and other seaweed species. In the fall it is dug in or covered over by top soil to trigger decomposition.

Rock Minerals: Small amounts of commercial rock minerals were used including glauconite greensand which is an iron potassium silicate and an undersea deposit. Dolomite was applied to raise the pH of the soil.

Sheet Compost: See previous discussion.

Irrigation:

Rain :To achieve maximum plant growth, water should be available constantly to plant roots. A heavy rainfall can saturate the soil, but even when it fulfills the moisture requirements of the plants it is not consistently available. Most of the water drains away below the root zone or evaporates into the air, making it necessary to replenish water between rainfalls.

Hose Sprinkling: Most of our watering was done by hand with a garden hose and tap water. Each bed received three minutes for a light watering and five minutes for a heavy watering. Hand irrigation has many drawbacks including the expense of tap water, and the application of chlorine and other possible additives with adverse side effects. It is time-consuming. It is also inefficient use of water in that distribution is uneven. There is loss through evaporation and high water pressure requirements. To alleviate some of these problems the following system was tried.

Flooding the Pathways: Because soils with a high percentage of organic matter and good water holding capabilities have a profile of underground water seepage that extends horizontally before it drains down, we hoped that by flooding the pathways with water a significant percentage would penetrate the beds. This proved true. Up to one foot on each side of the paths was replenished with water in this way.
Two wooden boxes, 4' x 4' x 4' in size, were placed at the end of the beds. Each was filled with tap water and left to stand for at least 24 hours to release the chlorine. Flexible black plastic tubing 1 1/2" in diameter and 20' in length was attached to the bottom of the box. The tubing was placed along the pathway. In five to ten minutes the contents of the box drained into the pathway. Slowly the water soaked into the beds as well as draining into the ground. We were pleased that the soil had the capacity to hold the water for long enough to fill the 40' pathway ditch and to retain it for a

while. We found this watering system to be quite satisfactory. The plastic tubing was moved easily from one path to another. The low pressure, gravity-fed application is gentle and evenly distributed. Loss by evaporation is kept to a minimum. In late summer when the paths became increasingly filled with mulch, the need for irrigation lessened.

Pest and Disease Control:

Insects Observed: The following is a list of the most significant insect pests observed in the intensive gardens, the problems they represented and what was done about them: *Pests* White Flies, Aphids, Flea Beetles: no significant damage Cabbage Worms, Squash Borers: hand picked, minimal damage Corn Borers: no picking or other control, damage in about 1/3 of the ears, limited mostly to tips Cucumber Beetles: no control, resulting in cucumber wilt which killed at least 75% of the plants Mexican Bean Beetles: decreased production, all plants eventually killed, extensive hand picking done

Beneficial Animals Observed
larva and adult of Lady Bird Beetle
praying mantis
toads: created cool, muddy places to attract them, but they found their own favorite places elsewhere between the vegetables
birds: many types of bird houses tried, as well as fences and posts, and sunflowers as a food source

Cultivation Methods: Traditional methods were used.

Planting Schemes: \

Plant varieties were chosen for disease and pest resistance. When possible they were grown from purchased seeds produced in climatic conditions similar to ours, without chemical fertilizers and pesticides. A wide range of seed varieties was used for each type of vegetable.

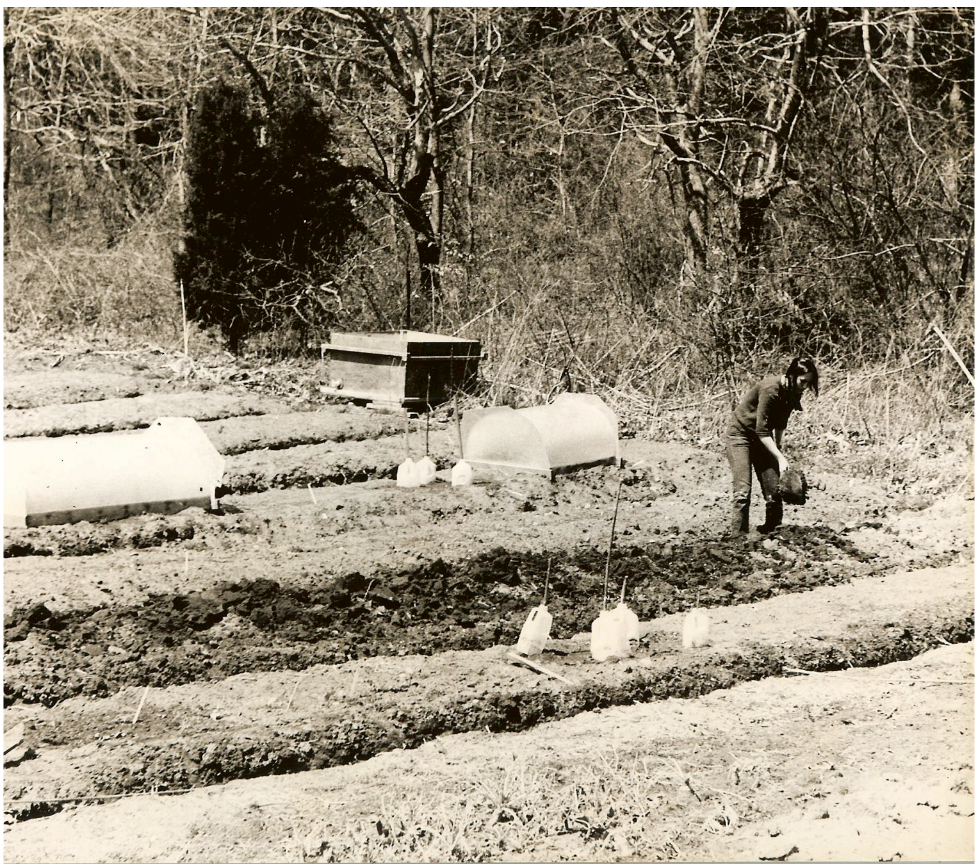
Companion Planting: This was used extensively to optimize space in relation to incoming sunlight and available nutrients and water. Many combinations of plants have been suggested as beneficial in pest control because of their ability to attract or repel certain insects by color, taste, smell or by chemical excretions from the roots. Most companion planting is not scientifically documented but is based on the collective experience of gardeners over many years. Even less well documented are the ratios in which companion plants should be grown together. One study has shown that planting one onion to every five or ten cabbages promoted growth in cabbages, but that more onions inhibited growth. The aromatic powers of the food and companion plants have to be synchronized for effectiveness. Other flowers particularly those of the Compositae family, like the sunflower and many herbs, are helpful in pest control by providing shelter and nectar for predators or pests. We used them for this purpose.

Biological Sprays: In general, our focus has been on improving the soil rather than experimenting with home-made or commercial biological sprays. I nsecticides were avoided in the intensive beds although rotenone was used elsewhere in the gardens.

CLOCHES

Extending the growing season is an efficient way to utilize the sun's energy. As our last killing frosts of the season on the Cape are in mid-May and our first often in mid-September, the growing season for many plants is considerably shorter than six months.

A cloche may be defined as a bell-shaped glass cover which is placed over a plant to protect it from frost and to force its growth. A modern plastic version is on the market under the brand name "Hot Caps." These are expensive and do not last longer than a season.



To maximize our growing period, we made modified cloches. They consisted of simple covers for the plants made from left-over pieces of Kalwall, the fiberglass material used on our greenhouse structures. In size and appearance they fall between a cloche and a greenhouse.

A rectangular frame of 2 x 4's was made for the base. Kalwall fiberglass was curved to form an arc and attached to the wood base. Doors were attached to the ends leaving space for free air flow and eliminating overheating problems.

The difference in growth was striking. A month after setting out, the plants under the cloche were two to three times as big as the controls. Two months after the planting date, the first broccoli was harvested. The plants kept producing until the second week of October. The cabbages were ready for harvest by the last week of July. Vegetables planted a month early and placed under the protective cover of a cloche were mature a month earlier than had a cloche not been used.

Neither watering nor weeding a cloche this size created a problem. The watering was done with a regular garden hose and an accurately regulated spray. As it was very light, the cloche was easily lifted and put aside for weeding.

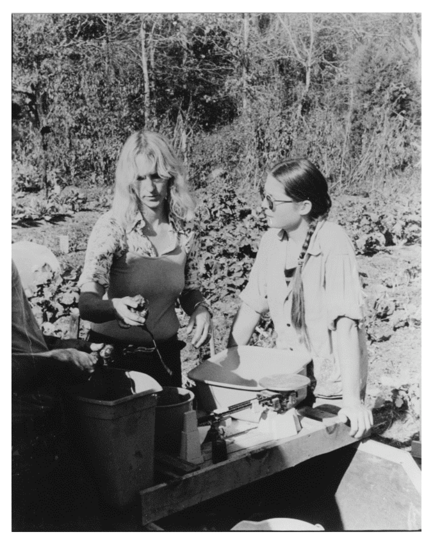
Cloche Without Frame:

Encouraged by our first success, a larger cloche was made. To avoid the storage problems of the previous model, this one was made to be disassembled. In late April, 1976, kohlrabi, eggplant, tomato, basil and Bibb lettuce seedlings as well as onion sets were planted under this cloche.

A Study of the Energy Efficiency of Intensive Vegetable Production

by Hilde Maingay. 1979.

Since the time of our first gardens, we have been addressing ourselves to the question of whether it is possible to achieve average or above-average yields without the use of chemicals and, if so, how much energy and labor would be required. In the spring of 1976, we began an experiment in small-scale food production without pesticides. The test garden plot was one-tenth of an acre, divided into twenty raised beds, as described in *Journal Four.* During the growing season, we collected data on human labor, irrigation water and productivity. Over-all the garden produced the equivalent of three daily servings of vegetables for more than ten people for 365 days,



Because weather could have been an unusually favorable or unfavorable variable the first year, it was decided to repeat the experiment the following year, 1977. Higher yields were expected as soil fertility had increased. In the planning stages, I began to ask myself, "Is it possible, for land under cultivation to produce average or above average yields without the use of chemicals? And, if so, how much energy and labor would this take?"

...

In the spring of 1977, we planted the same plot as the previous year, again dividing it into twenty raised beds. As before, data on human labor, water and productivity were collected. Cloches were used to extend the growing season. The cloche design, as described in the fourth journal, proved very successful. Over 3,000 seedlings from our small solar greenhouse, the Six-Pack, were transplanted into the garden.

We dug a separation ditch, to cut the roots of the trees on the edge of the woods that intrude into our gardens. We planted Jerusalem artichokes at the end of each bed as a buffer between the food plants and the woods. The previous summer, wild rabbits had raided the pea and bean plants, preventing the plants from reaching maturity. This year we shot the wild rabbits and a splendid spring garden resulted.

Although many people were involved in harvesting, weighing and recording the vegetables, three people guided all other aspects of the garden work. Two were summer volunteers and novices in the field, though they quickly demonstrated both their stamina and their sensitivity to the plants. The results of the '77 gardens were as we had hoped: more food was grown with less work and with less irrigation. (See Tables 1A, 1B, IC, 1D) It is safe to assume that these, gardens have not yet reached their, upper limits of productivity. Soil fertility increases noticeably each year. And, as our planting scheme improves, we anticipate a steady decline in the human labor needed as well.

Table 1A 1977 Productivity in Grams and Servings in Relation to 1976 Yield of Raw Salad Vegetables.

Raw Salad Vegetables	Total Edible Grams	Grams Per Portion	Total Portions per Crop 1977	1976
Cucumber	281,874	133	2119.3	307.7
Lettuce	103,322	77	1341.8	361.2
Beet Greens	8424	30	280.8	--
Collards	7147	30	238.2	--
Kale	9212	30	307	180.9
Spinach	4348	27	161	327.4
Swiss Chard	21,429	38.5	556.5	208.1
Cabbage	19,509	36.5	534.4	2340.3
Celery	16,370	60.5	270.5	141.8
Pepper	2944	38.5	76.4	14
Cauliflower	1672	30	55.7	108.8
Corn*				
Leek	500	35	14.2	184.9
Summer Squash	3396	50	67.9	133.2
Tomato	17,358	100	173.5	228.7
Celeriac	5272	36.5	144.4	--
Kohlrabi	5785	36.5	158.5	210.2
Ground Cherries				
Carrot	19,907	65	306.2	--
Onion	17,297	30	576.5	--
Garnish:				
Herb	--	--	--	--
Onion Top	9083	38.5	235.9	--
Parsley	--	--	--	--
Total No. Portions			7618.7	4747.2
Number of People - 1 Portion/Each Day of Year			20.8	13
			Increase - 60%	

Table 1B 1977 Productivity in Grams and Servings in Relation to 1976 Yield of Cooked Root Vegetables.

Cooked Root Vegetables	Total Edible Grams	Grams per Portion	Total Number of Portions per Crop 1977	1976
Jerusalem Artichokes	99,836	81.5	1224.9	--
Parsnip	7329	105.5	69.4	85.6
Potato	78,126	81.5	958.5	2052.9
Rutabaga	19,749	81.5	242.3	174.7
Turnip	15,427	98	157.4	133.9
Celeriac	10,544	98	107.5	--
Kohlrabi	11,570	98	118	156.6
Beet	22,002	90	244.4	204.2
Carrot	39,814	80	497.6	186.4
Onion	34,594	98.5	351.2	264.8
Total No. of Portions			3971.2	3259.1
Number of People - 1 Portion/Each Day of Year			10.8	8.9
			Increase - 21.3%	

Table 1C 1977 Productivity in Grams and Servings in Relation to 1976 Yield of Cooked Green Vegetables.

Cooked Green Vegetables	Total Edible Grams - 1977	Grams per Portion	Total Number of Portions per Crops 1977	1976	Total Edible Grams - 1977
Snap Beans	45,464	62.5	727.4	231.8	14,492
Broccoli	12,020	84	143	318.1	26,722
Br. Sprouts	7428	77.5	95.8	118.5	9189
Okra	7245	88.5	81.8	8.5	759
Peas	19,712	81.5	241.8	13	1065
Sw. Pod Peas	4006	81.5	49.1	--	--
Eggplant	9630	106.5	90.4	241.5	25,725
Winter Squash	28,197	122	231.1	23.8	2913
Beet Greens	16,848	95	177.3	--	--
Collards	14,292	95	150.4	--	--
Kale	18,424	95	193.9	114.2	10,857
Spinach	8696	100	86.9	176.8	17,680
Swiss Chard	42,858	95	451.1	168.7	16,028
Cabbage	39,018	73	534.4	2351.8	171,682
Celery	32,740	77	425.1	222.9	17,165
Pepper	5888	83.5	70.5	11.7	982
Cauliflower	3344	62.5	53.5	104.5	6532
Corn				75	(150 ears)
Leek	1000	68.5	11.2	48.7	4315
Summer Squash	6793	119	57	95.2	11,329
Tomato	34,716	119	291.7	384.3	45,742
Ground Cherries					
Dry Beans	1414	50	28.2	--	--
Wheat					
Total No. Portions			4191.6	4709.0	
Number of People - 1 Portion/Each Day of Year			11.4	12.9	
			10.9% decrease in production over 1976		

Table 1D Total Number of Portions in Each Category - 1976 and 1977.

Portions	1976	1977	
Raw Salad	4,747.2	7,618.7	60.4% increase
Cooked Roots	3,259.1	3,971.2	21.8% increase
Cooked Greens	4,709	4,191.6	10.9% decrease
Total	12,715.3	15,781.5	24.1% increase

Method of establishing the number of portions produced

In 1976, the total amount of edible grams of each variety of vegetable was divided in half. One-half was used fresh; dividing this half by given grams per portion, the total number of portions for that vegetable was found. The other half was considered a cooked vegetable and reckoned the same way. By, dividing the given grams per (cooked) portion, the total number of portions was found.

In 1977, we used the same method, changing the proportion between the raw and cooked. One-third of the total amount of edible grams produced was calculated as raw, the remaining two-thirds as cooked portions. It is our feeling that this is a more realistic reflection of our food habits. While many vegetables can be eaten fresh in season, most have to be canned, frozen, dried or put in a pit or root cellar, for later usage.

Corn: Almost one-and-one-half beds were seeded in corn but had to be reseeded two or three times, as the birds plucked all the soft sprouted seedlings as soon as they appeared above the ground. Interestingly enough, the only successful row was one that had been seeded adjacent to a row comprised of a mixture of broccoli, cauliflower and leek and, in that row, gennination was almost 100 per cent. Once the corn seedlings had grown beyond a size that attracts birds, many were transplanted to fill in empty spots. We had, in the meantime, started corn in flats, out of the reach of the birds. These seedlings filled the rest of the space designated for corn. Then, as if this rough start had not been enough, earwigs appeared in mid-season, causing damage to the tassels. Pollination was poor, although four rows may be insufficient for pollination. Beds of corn should probably be adjacent to each other. Finally, when the ears were almost ready for harvesting, the birds returned and stripped most of the ears, leaving little either for us or the corn borers.

New Zealand Spinach and Leeks were planted at the same time as the corn and close to it and were quickly shaded out. It was not until the third week in August, after the corn was harvested that they got a chance, but, as a result, produced relatively poorly in terms of edible grams.

Wbeat: A small test plot, approximately one-third of a bed, was seeded in spring wheat. Germination and growth were excellent. The heads were big and full by the end of the season. For a variety of reasons, I did not harvest them immediately, the main one being that I had planned to give Earle a sheaf of wheat for our wedding in September. For several weeks they stood in the garden, sturdy and full until the morning I came to pick them and was faced with total devastation. Birds again. Not a grain was left nor a stem unharmed.

Ground Cberries: Ground cherries have a sweet vegetable taste, like a cross between cherries and tomatoes. They are about the size of a small cherry and store easily. We put some in a bucket and left them on a cool back porch. We rediscovered them the following February and most of them were still in fine condition!

A row one foot wide and twenty feet long was planted with ground cherry seedlings that had been started in the small solar greenhouse. Germination and transplanting presented no problems and fruiting was abundant. Due to their novelty, however, few people were willing to put in the time to pick and weigh them or to think of ways to use them. To encourage consumption, reduce waste and lighten the burden of picking for those responsible for the experiment, the weighing ban was lifted. Still, hundreds were wasted on the ground. We are curious to see if any will germinate spontaneously in the garden next year.

Each year a few crops have an unusually hard time, which lowers our overall productivity and efficiency rates. In 1977 the crops mentioned above account for at least 10% failure in the garden. Several other vegetable.varieties produced a below average yield but were balanced by those which did extremely well.

Table 2 and Figure 1 give the human labor requirements for the various gardening tasks over the growing season. requirements between the 1976 and 1977 growing seasons.

Table 2 Human Labor Requirements for Different Garden Tasks and Total Labor Requirements of 1976 and 1977.

Human Labor	Soil Preparation in Beds Min.	Watering Min.	Weeds and Bugs Min.	Plant and Seed Min.	Total Amount of Labor 1977 Min.	1977 Hrs.	1976 Hrs.
April	300	81	--	273	654	11	18 1/2
May	361	407	265	783	1816	30 1/4	34
June	1053	189	515	1282	3039	50 1/2	78 1/2
July	1260	1747	1250	660	4917	82	86 1/4
August	370	707	510	295	1882	31 1/2	13
September	135	20	--	--	155	2 1/2	5
Total	3479	3151	2540	3293	12,463	207 3/4	235 1/4

Note: 69 minutes/day over a 6-month's period

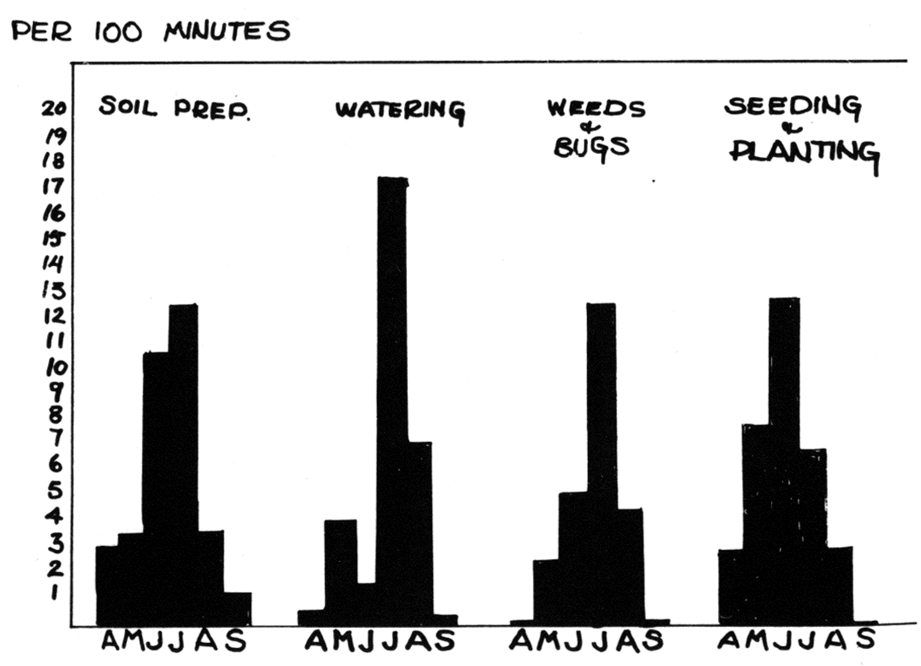


Fig. 1

Figure 2 shows the difference in total human labor

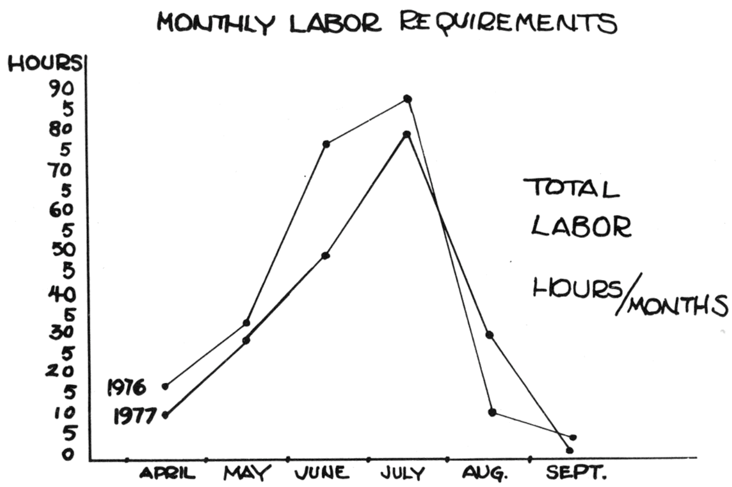


Fig. 2.

Table 3 shows the relation between the amount of water used and productivity in portions of vegetables. In 1977 it took less than one gallon of water to produce one portion of vegetables.

Table 3 Water Requirement/Portion.

	1976	1977	
Water in Minutes	3,640	3,151	13.43% decrease of labor required for watering
Water in Gallons	14,560	12,604	13.43% decrease of water required for total production
Amount of Portions Per Gallon Water	0.87	1.25	43.9% increase of water efficiency per portion

Note: It took 1 gallon of water to produce 1¼ servings of vegetables.

Table 4 shows the relation between the amount of human labor required and productivity in portions of vegetables. In 1977 it took less than one minute of labor to produce one portion of vegetables.

Table 4 Labor Requirement/Portion.

	1976	1977	
No. of Portions	12,715.3	15,781.5	24.1% increase in productivity
Labor in Minutes	14,115.0	12,436.0	11.89% decrease in labor
Amount of Portions Per Minute	.90	1.26	41.0% increase of labor efficiency per portion

Note: It takes 1 minute to grow 1¼ portions of vegetables or it takes less than a minute to grow 1 portion of vegetables.

THE ENERGY RATIO OF OUR EXPERIMENTAL PLOT:

As interest in agricultural energetics is relatively recent, information on the relation between energy and agriculture is still somewhat sparse. In his study, *Energy and Food Production,* G. Leach provided most of the information for performing a preliminary study on the energetics of our experimental garden plot. Garden-sized plots achieve productivity by virtue of inherent small scale and labor intensiveness, which allow for intercropping and succession cropping, thus utilizing soil and radiant energy more fully than is possible with monocrop farming. As mechanization has made intensive inter-cropping less efficient, more space is required to grow a single crop. Three times as much land would be necessary to produce the same amount of food by industrial methods as we grew in our garden. Further, in addition to the economic cost of dependence on chemical fertilizers, insensitive treatment of the soil results in heavy losses of topsoil. The U. S. D. A. expects an annual loss of topsoil of up to one inch in shallow soils and up to five inches in deep soils.

The joule (J) is the energy unit used to facilitate the comparison of the different kinds of energy inputs such as labor, machinery, fertilizers and pesticides with **each** other and with the final energy output in the form of edible food. The joule is a very small quantity. MJ stands for megajoule or 106j. The following conversions should give an idea of the meaning of these quantities:

10 MJ = equivalent to 2,400 kcal, the amount of calories of nutrition needed by an average adult per day.

3.6 MJ = equivalent to 1 kilowatt hour (kwh), a lightbulb of 100 w burning for 10 hours. 59 MJ = equivalent to one gallon of gasoline which can move a car approximately 20 miles.

The Energy Ratio (Er) can be found by dividing the edible energy output by the total amount of energy input.

In a comparable study to that in Table 4 done on 600 suburban garden plots in London, England, energy inputs in the form of fossil fuels were considered negligible if they represented less than 10 per cent of the total.

Human Labor: Human labor requires approximately .19 MJ/hr for resting, .29 MJ/hr for small activities, .5 MJ/hr for light work to 1.0 MJ/hr for heavy work. Whereas new gardens with poor soil require a high percentage of heavy work, our established gardens only needed light to moderate labor at .6 MJ/hr.

journal Four discusses the types of activities included in total human labor requirements, amounting in all to 207 hours over the 1977 growing season. We decided to double this number to account for such activities as working with the spring seedlings, trucking organic matter, harvesting and digging the beds in the fall. Thus, we spent 414 hours of work in the garden; one hour and 22 minutes per day. This is equivalent to 2 5 per cent of a typical 40-h our work week (414/1714) over a ten-month period.

Fertilizer: We used small quantities of lime and greensand as fertilizers. Extensive soil tests done at the close of the 1977 growing season indicated no further fertilizers would be needed in 1978.

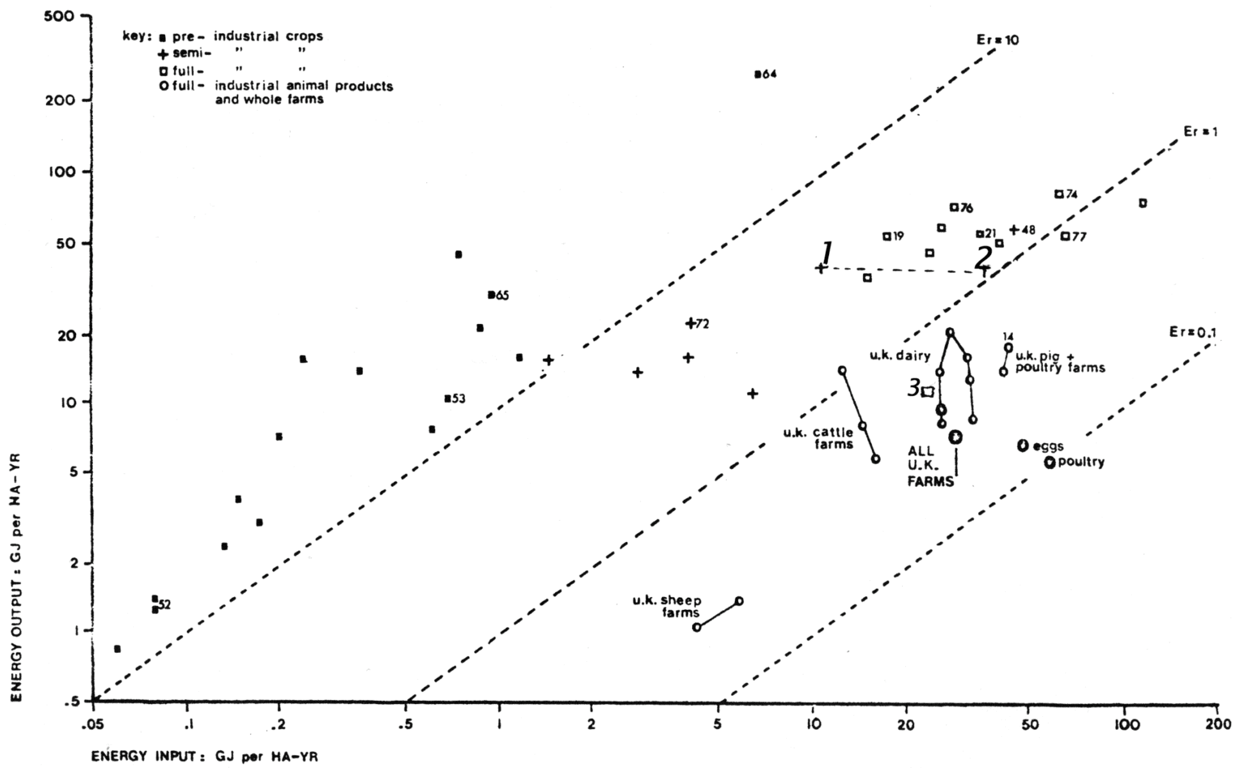
The truck: The truck was the one exception to the exclusive use of such handtools as the shovel, rake, hoe and trowel in working the experimental plot. It was used to pick up organic materials, mainly seaweed and manure, with which we filled in the ditches or pathways between the beds to create strips of sheet compost within the garden. Over the growing season, we made about twenty trips in the truck. Initially, we assumed the proportion of gas to be insignificant in comparison with our total labor input. Some simple calculations proved otherwise. The energy consumed by the truck on forays within a one-kilometer-radius of the fann was equivalent to ten months of human labor.

Table 9 Energy Analysis of New Alchemy Experimental Plot.

	MJ/1/10 acre/year
INPUT:	
Labor, 2 x 207 hours at 0.6 MJ/hr.	248.4
Fertilizers, Lime and Greensand, 2 MJ/kg - Light Application of 50 kg each/1/10 acre	200.0
Machinery and Equipment Negligible	--
Total	448.4
OUTPUT:	
35 Vegetables of Total Edible Weight of 1253 kilograms	
Energy Output (Edible Portions)	1672.1
Protein Output (Edible Portions)	22.8 kgP
RATIOS:	
Energy In/Protein	19.6 MJ/kgP
Energy Out/In	Er 3.72

FIG. 3

Energy Inputs and Outputs per Unit of Land Area in Food Production – World



52 New Guinea	- taro, yam, sugar, sweet potato	19 UK	- wheat
53 India	- rice, cattle, milk	21 UK	- potato
65 Mexico	- corn by hand	48 UK	- garden plots - vegetables & 40% potatoes
64 China	- rice and beans	76 USA	- corn 1970
72 Philippines	- rice	74 USA	- intensive rice
1 .... 2 NAI	- vegetables	77 Hong Kong	- rice and vegetables
		3 USA (est.aver.)	- vegetables

Energy Output:

We refer here to output of food ready for direct human consumption.

Calories: On 1/10th of an acre, the 1977 garden plot produced the equivalent of about half the energy needs of one person for a year at 10 Mj /day or 2,400 kcal/day. The energy ratio for this production is Er = 3.7 if truck use is not included. Er = 1.0 if the truck is used 20 times for a 6-mile or 10-kilometer round-trip.

Protein: Protein is included in the table. The garden produced the equivalent of all the protein needs for one person for 14 months at 54 gr/day. The energy used to produce this amount of protein was 4 to 16 times less, depending again on the extent to which the truck was used, than the energy used to produce the same amount of protein with industrial farming methods. This difference can be accounted for by the fact that protein derived from industrial farming is mainly from animals, whereas our protein is exclusively from vegetables. It is generally agreed that it takes 9 times as much land to produce a given quantity of protein from animals as it does the same quantity of vegetable protein.

Energy and protein outputs differ considerably with the mixture of vegetables. With the exception of our small crop of potatoes, our vegetable varieties were among the lowest in both calories and protein. Figure 1, again taken from Leach, shows the relationships between different agricultural systems with regard to energy input and output. This graph was used to determine our position in the world food production Considering the crops we grew, our position is quite remarkable. None of the other agricultural systems included vegetables. I added the approximate position of industrial vegetable production (o3), which ranks as low in efficiency as cattle and milk production. Vegetables grown in greenhouses, such as greenhouse lettuce with an Er = 0.002, have such a poor energy ratio that they cannot be placed on the chart.

DESIGNING FOR A FUTURE SMALL-SCALE FOOD PRODUCING SYSTEM:

Our goal at New Alchemy is to minimize the amount of land needed and to use fossil fuels as wisely and efficiently as possible. An ideal system would be complex in terms of technique as in crop rotation, crop succession and companion planting, but simple in skills and tools. It would have chickens, goats, geese and fish to provide eggs, milk and other forms of animal protein. We plan to concentrate on growing foods which require neither freezing nor canning for winter storage.

Solar greenhouses should prove economical for fresh vegetables. A small family structure could provide the greens for the fall, winter and spring without recourse to fossil fuels. It also provides the space to grow all the seedlings needed for a tenth of an acre garden plot. It would function as an auxiliary heat source when attached to a house.

Land Requirements:

Many new crops will be grown in the '78 season. By using average U. S. -yield figures, we can estimate the amount of land required and hope that, as with the other crops, our yields will exceed those grown on a large scale. Table 5 lists the grains which can be grown to meet dietetic needs and the space required.

Table 5 Grains.

	General Information on U.S. Grains.				Food Value of Grains.		Reflection on N.A.I.'s Proposed Diet.				
	Bu./Acre	Bu./1/200th Acre Bed	Lbs./Bu.	Lbs./1/200th Acre Bed	Gr. Protein/ 100 gr.	Cal./100 gr.	Lbs. per/ Year	Gr. per/ Day	Gr. Protein per/Day	Cal. per/ Day	Beds per/ Year
Field Corn	80	0.4	56	22.4	8.9	348	56	69	6.3	248	1
Wheat	30	0.15	60	9	12.3	330	81	100	12.3	330	9
Soybean	25	0.1	60	7.5	34.1	403	40	50	17	201	5.4
Oats	45	0.2	32	7.2	14.2	390	7.2	9			1
Barley	44	0.2	48	10.5	8.2	349	8.2	13			1
Rye	26	0.1	56	5.6	12.1	334	5.6	7	6	348	1
Buckwheat	33	0.16	50	8.2	11.7	335	8.2	10			1
Gr. Sorghum	48	0.2	50	12	11	332	12	15			1
Navy Bean	1156 lb.	--	--	5.7	22.3	340	5.7	7			1
Field Pea	1120 lb.	--	--	8.6	24.1	340	8.6	11			1
Sw. Corn	40	0.2	56	11.2	35	96	11.2	14	4.5	285	1
Popcorn	40	0.2	56	11.2	11.9	362	11.2	14			1
Cane Sorghum	48	0.2	50	12	11	332					
Cane Syrup	400 gal.	2 gal.	--	20 lbs.	--	257	40	50	--	128	2
Potato	20,500 lb.	--	--	102	2.1	76	102	125	2.6	95	1
Alfalfa Seed	--	--	--	--	--	--	--	--	--	--	--
Total							396.9	494	48.7	1635	27.4

Table 6 reflects the amount of feed that needs to be grown for a lactating goat. Apart from browse, a goat eats one-half pound of mixture of grains per day and another half pound for each pound of mild she produces. The goat is asssumed to produce an averae of five pounds of milk per day over a nine-month period. The last describes the land requirements, apart form pasture, for an average of two cups or one pound of mik per person per day.

Table 6 Goat Milk.

	Annual Feed and Land Required for Average Goat Lactating Nine Months per Year Not Including Pasture or Browse*			Land Required for Producing One Pound of Goat's Milk per Day** per Year
	Pounds per Year	Grams per Day	1/200th Acre Bed per Year	Number of 1/200th Acre Beds per Person per Year
Field Corn	400	493	17.8	4.6
Oats	400	493	55.5	14.6
Wheat	200	246	22.2	5.8
Soybeans	100	123	13.3	3.5
Molasses	75	92	$***	--
Total	1175	1147	108.8	28.5

* Producing average of five pounds milk per day during lactation.

** One pound goat milk contains 16 grams protein and 260 calories.

*** $ indicates item purchased.

Table 7 reflects the amount of feed that needs to be grown for a laying hen. A hen is assumed to produce 273 eggs per year. Two chickens per person are included in hypothetical diet calculations. The land requirements for an average of one egg per day per person are shown in the last column of this table.

Table 7 Eggs.

	Annual Feed and Land Required for Average Hen Producing 273 Eggs per Year			Land Required for Producing One Egg per Day per Year*
	Pounds per Year	Grams per Day	1/200th Acre Beds per Year	Number of 1/200th Acre Beds per Person per Year
Field Corn	44	54	1.9	2.0
Wheat	7	8	0.7	0.9
Soybeans	9	11	1.2	1.6
Mix (alfalfa, bonemeal, meat-scraps, oyster shell, salt)	10	13	$**	--
Total	70	86	3.8	4.5

* One egg contains 6 grams protein and 80 calories.

** $ indicates items purchased.

Based on our vegetable growing experience, we can conclude that two beds will yield a more than ample supply of raw and cooked vegetables for any individual. Producing honey does not require land. A good hive will produce approximately 40 pounds of honey, or 50 grams a day a person. Space is given for fruit as well. The estimate is rough, but a piece of land the size of two beds should support at least a good-sized apple tree and several grape vines. We have computed all this information into Table 8. It is obvious that changes in diet will have an enormous impact on land requirements. Our proposed diet would require 3/10ths of an acre per person.

Table 8 Land Required for Year's Food Supply with Hypothetical Local Diet.

Food Groups	Grams of Protein Per Person Per Day	Calories Per Person Per Day	1/200th Acre Beds Required
Vegetables	8.0	80	2.0
Grain	48.7	1635	27.4
Goat Milk	16.0	260	28.5
Eggs	9.0	120	6.8
Honey	0.1	150	--
Fruit	0.2	58	2.0
Total	82.0	2303	66.7