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Mulching Practices and Innovations for Warm Season Vegetables in Virginia and Neighboring States

1. an informal survey of growers

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Introduction

The Virginia Association for Biological Farming (VABF) is conducting a comparative study of different mulching systems for warm-season vegetables. Organic mulches such as hay add valuable organic matter but can delay maturity of heat-loving crops by keeping the soil cool. Black plastic blocks weed growth and promotes earlier yields, but does not add organic matter, and must be disposed at the end of the season. Mulches that replenish the soil while supporting adequate and timely crop yields are needed for sustainable vegetable production.

Choice of mulching system is farm-specific, and depends on climate, soil, crops grown, availability and cost of mulching materials, labor and machinery, market opportunities and constraints, and the grower's farming philosophy. Therefore, the goal of this project is to assist farmers and gardeners in making this choice by providing information on the effects of different mulches on crop performance, weed control, soil conditions, pests and diseases, and other benefits and costs including environmental impacts. This information was gathered from three sources: growers' experience, on-farm field experiments, and relevant literature.

During 1993-94, we surveyed 72 vegetable growers to learn about current mulching practices, perceived advantages and disadvantages of different systems, farmers' innovations, and priorities for research. The following report summarizes the knowledge and ideas these growers shared. Results of on-farm field experiments are given in a companion report (Schonbeck, 1995).

Methods of the Survey

Survey participants were recruited at the annual Virginia Sustainable Agriculture Conference in 1993 and 1994, through a marketing directory of biological growers (VABF, 1992), and through referrals from research and extension specialists in vegetable production. Our objective was not to obtain a random sample, but to engage experienced and innovative growers in a collaborative research and information exchange effort. Therefore, results reported here are not presented as a statistical estimate of mulching practices in this region, but are offered as a summary of the combined wisdom of 72 farmers and gardeners with experience in the use of various mulches on summer vegetables.

Because small to medium sized farms serving local markets have received insufficient technical support in the past, the survey focused primarily on such farms. Several large, mechanized operations were included to obtain a broader perspective on considerations that affect mulching decisions. Fifteen participating growers have less than one acre in horticultural crops (vegetables, small and tree fruit, herbs, flowers); 38 have one to 10 acres, 12 have 10 to 50 acres, and seven have 100 to 4,000 acres.

Participants were interviewed in person or by telephone, or filled out a four-page questionnaire, which was usually supplemented by a follow-up phone call. Questions focused on mulching practices used for warm-season crops in the solanaceous or nightshade family (tomatoes, sweet and hot peppers, and eggplant) and the cucurbit family (summer and winter squash, pumpkins, cucumbers and melons). Growers were asked to list benefits, costs (dollar, labor and other) and problems they have observed with mulch(es) used. Questions were asked about soil, growing season, farm size, mechanization and marketing channels to

establish the context of growers' mulching practices. Participants were encouraged to elaborate on mulches they tried in the past and why they no longer use them, new practices they would like to try, and problems they would like research to address.

Responses were tabulated as numbers of participants who reported using each mulching material, and who cited specific advantages or disadvantages for each mulch. Growers' estimates of application rates, labor and other costs are expressed on a per-acre basis, and also in terms of row length, assuming a spacing of five feet between rows.

Mulching Materials Used for Warm Season Vegetables

Participants in the survey most often use hay and/or grain straw, plastics, or cover crop-based mulching systems for warm-season vegetables (Table 1). A few regularly apply other organic mulches (leaves, sawdust, livestock bedding, etc.) or paper (most commonly newspaper), and a larger number have experimented with them. (**Note**: the term *organic* is used here to indicate biodegradable plant or animal residues, and has no bearing on whether crops or mulches were organically grown. *Applied organic mulches* are organic materials that are brought onto the field and spread, as opposed to cover crops).

Table 1. Mulching materials used for warm-season vegetables on 72 farms in survey.

	----------Number of Farms----------			
Mulching materials	Using regularly	Experimental or limited use	Used in past	Would like to try
Hay	23	8	5	3
Grain Straw	20	9	3	1
Tree leaves	4	5	2	5
Other applied organic mulches	10	10	12	6
Cover crops	14	11	3	21
Plastic	18	9	22	9
Paper	7	11	6	12
No mulch	12	10		

Many growers use different materials for different crops or plantings, and some integrate two systems within a single field, e.g. plastic in the crop row with hay or cover crop in alleys. More than half of those using paper spread hay, straw or sawdust on top of the paper, whereas only three growers reported spreading organic materials onto plastic. About one-

third of participants grow some of their solanaceous and cucurbit crops in bare soil, but only three indicated that they use no mulches on any of these crops.

Over one quarter of participants have tried plastic mulches in the past but discontinued their use because of environmental concerns or disappointing results (Table 1). In contrast, few have stopped using hay, straw or cover crop-based mulches, while moderate numbers have discontinued other organic materials or paper. Many of those not already using living or killed cover crops as mulches want to try them in the future. There was also considerable interest in trying various paper, plastic and organic mulches other than hay and straw.

Small to medium farms (up to 50 acres in vegetables and other horticultural crops) use hay or straw more often than plastic, whereas larger farms (150 to 4,000 acres) use either plastic, cover crops or no mulch (Table 2). Paper and applied organic mulches *other* than hay or straw are used primarily on small farms with less than 10 acres of horticultural crops.

Table 2. Frequency of mulching practices[a] related to farm size.

	Number of Farms			
Mulching practice	< 1 acre[b]	1 to 10 acres	10 to 50 acres	>100 acres
Hay and/or straw	9	28	7	0
Other applied organic mulches[c]	9	15	1	0
Cover crops	2	17	4	2
Plastic	2	17	4	5
Paper	3	13	2	0
No mulch	4	10	4	4
Total number of farms	15	38	12	7

[a] Currently in use on one or more crops.
[b] Area in horticultural crops (vegetables, fruits, herbs, flowers).
[c] Includes tree leaves, grass clippings, sawdust, livestock bedding, etc.

Well over half of participants who grow tomatoes, peppers, eggplants, cucumbers or melons use applied organic mulches, plastic or paper on these crops (Table 3). Squash and pumpkins, which are generally less intensively managed, are more often grown in mowed or strip-tilled cover crops, or in bare soil. One-third of those who grow melons or eggplant use plastic mulch for these heat-loving crops, whereas the proportion is lower for the other crops. Several use plastic for early plantings of some vegetables, and hay, straw or bare soil for later plantings.

Table 3. Mulching practices used for different vegetable crops on 72 participating farms.

Mulching practice	Tomato	Pepper	Eggplant	Cucumber
Plastic	19	13	8	8
Applied organic mulch	34	22	11	13
Cover crops	7	6	3	4
Paper or paper + organic	7	1	0	1
Unmulched	5	9	2	12
Total number of farms growing each crop	67	49	24	36

Mulching practice	Summer Squash	Winter Squash	Pumpkin	Melon
Plastic	6	0	2	9
Applied organic mulch	12	2	5	4
Cover crops	9	10	4	5
Paper or paper + organic	0	0	0	2
Unmulched	16	8	5	3
Total number of farms growing each crop	41	19	16	23

Mulching Systems and their Advantages and Disadvantages

Hay and Straw

About half of the 44 participants who mulch with hay or straw produce these materials on their farms; others purchase them or obtain them free at nearby farms. Old, low-quality or spoiled hay, and straw produced as a grain byproduct are most often used, but some farmers cut rye, other cereal grains or hay at early heading for clean, seedless mulch.

Growers generally apply hay or straw by manually breaking square bales apart and spreading the mulch at the desired thickness, or by unrolling large (500 to 800 lb) round bales between crop rows. Some growers apply hay or straw to summer vegetables at planting, but many wait several weeks to let the soil warm up, hoe emerging weeds, then spread the mulch.

Estimated rates of application on 22 farms averaged 12.2 tons per acre (range 3.6 to 27.2 tons), or roughly 700 square bales. (One 35-lb square bale per 62 square feet = eight bales per 100 feet of row = 12.2 tons per acre; however bale weight can vary from 25 to 60 lb). Growers estimated mulch depth of 3 to 12 inches at application, settling to 1 to 4 inches, but depth and settling are affected by application method, traffic and soil biological activity.

Participants use hay and straw mulches because they suppress weeds, conserve soil moisture, contribute organic matter and nutrients, provide habitat for beneficial organisms, improve soil conditions, and offer other benefits (Table 4). Some reported dramatic soil improvements after several years of mulching. A few expressed concern that the mulch may tie up soil nitrogen or make the soil more acid, but others found that hay, especially legume hay, provides significant amounts of nitrogen. Several growers said that hay or straw mulch saved their vegetable crops during the extremely hot, dry summer of 1993, and two cited penetration by rain and overhead irrigation as an advantage over plastic films.

Only one grower specifically mentioned increased vegetable yields as an advantage of hay or straw. Ten cited lower soil temperatures and delayed crop maturity as a disadvantage, and several mentioned pest or disease problems (Table 4). Melons seem particularly sensitive to cool soil, and one grower noted that "melons don't do well" in hay. Soil cooling during hot weather was considered beneficial, especially for tomatoes which prefer moderately warm temperatures and may suffer stress in plastic or bare soil during hot weather.

The most frequently noted problems with hay and straw are weed growth, often from seeds present in the mulch itself, and high labor and other costs (Table 4). Yet many felt that more time was saved on weed control than was spent mulching. Labor estimates by 17 survey participants for spreading hay or straw ranged from 36 to 218 person-hours per acre, averaging 90 hours (one hour per 100 feet of row). Round bales are more time-efficient if several people work together and crop row spacing allows the bale to be rolled out between rows.

Several found that spoiled hay can be difficult to spread because it is wet and heavy, and a few reported biohazards such as molds causing allergies, poison ivy, thorny weeds and bees' nests in round bales. Fresh materials, particularly grain straw may be easier to spread than old hay. The mulch was generally easy to turn under in fall, but sometimes caused problems for rotary tillers. Disking seems to work better, and one grower finds that a single pass can break up the mulch and incorporate cover crop seed (broadcast before disking).

Another constraint on mulching with hay or straw is that the farmer must either produce them on farm or obtain them nearby at an affordable price. Two farmers estimated on-farm production costs for rye straw at about $0.75 to $1.00 per square bale, and a third quoted $1.50 to $2.00 for hay. Growers who purchase mulch from nearby farms quoted prices of $0.60 to $2.50 per bale for straw (average $1.66), and $0.25 to $3.25 for hay (average $1.19; lower prices for old hay). The large, round bales (equivalent to about 15 square bales) may be more economical, as they sell for $5 (spoiled) to $20 (fresh).

Table 4. Advantages and Disadvantages of Applied Organic Mulches

	Number of growers:	
Advantages:	Hay or straw	Other
Weed suppression	28	8
Adds organic matter and/or nutrients	23	12
Conserves soil moisture	23	7
Net labor savings	14	1
Habitat for beneficials; fewer pests	8	4
Soil cooling -- desirable in summer	8	1
Easy to till into soil at end of season	8	2
Improves soil tilth	6	5
Readily available; free or cheap	6	3
Enhances soil life	6	2
Cleaner fruit; less disease and rotting	5	1
Less foliar disease	4	1
Disadvantages:		
Mulch carries weed seed	21	2
Labor intensive	16	6
Cools soil, delays crop maturity	10	1
Inadequate weed control	10	1
Purchase and hauling costs	10	
Harbors certain pests	8	3
Difficult to obtain	5	3
Decomposes too fast; need to reapply	5	
Too moist, mats down, doesn't breathe	5	5
Difficult or hazardous to spread	5	3
Aggravates disease problems	3	4
Does not add nutrients/binds N	4	
Capital equipment needed for on-farm production	3	
Hard to till in at end of season	3	
Total number of farms in survey using organic mulches	44	26

On-farm production requires land and capital equipment (tractor, mower, baler) which may not be available to small-scale market gardeners. One grower reported that good hayland produces about 200 square bales per acre annually, and several estimated that three to seven acres of hayland are needed to provide mulch for one acre of vegetables,. Annual hay yields average 2.4 tons per acre (Virginia Agricultural Statistics, 1993); at this rate, five acres of hay would mulch an acre of vegetables at the average use rate of 12 tons per acre. Yields for grain straw are generally similar, but one participant reported needing six acres in rye to produce 250 bales of straw for about 0.4 acre of vegetables.

Some participants have chosen other mulching systems because of the high labor costs or other disadvantages of hay and straw. However, only a few who have used these materials in the past have discontinued them (Table 1), indicating a high level of satisfaction with the range of benefits derived.

Other Applied Organic Mulches

Small-scale market gardeners often mulch with a variety of organic materials, including tree leaves, pine needles, partially composted animal bedding, sawdust or wood chips, grass clippings, green chop (freshly cut forage crops), old silage and chickweed. Growers obtain these materials from municipal yard waste collections, their own farms or nearby farms, and spread them manually. Animal bedding is usually composted or aged in a windrow until it no longer heats up, then spread as mulch.

Several participants use the method of Ruth Stout (1973), in which a deep mulch (6 inches or more) is maintained year round, and pulled back from crop rows to plant seeds or seedlings without tillage. One gardener uses municipal leaves, while others use a mixture of materials.

Benefits most often cited include organic matter, nutrients, moisture conservation, weed suppression, improved soil tilth and reduced pest problems (Table 4). Two growers observed reduced erosion, and a few others found these materials less weedy than hay. Several growers noted that spreading these mulches is labor-intensive; one estimated two and one-half hours per 100 feet of row (200 hours per acre) for composted bedding. Leaves in bulk are particularly awkward to handle, while bagged leaves may be more convenient to pour out between crop rows. Several observed that leaves or grass clippings can mat down and/or become too wet, and a few others reported increased disease or pest problems.

Cover Crops

Some growers use cover crops as either a living mulch (growing simultaneously with the vegetable), or a grown-in-place dead mulch (killed by mowing or herbicides prior to planting the production crop). Living mulch is usually strip-tilled to produce a 12 to 40-inch wide competition-free zone for the vegetable crop. Living mulches include red, white or crimson clover overseeded into established vegetables, vetch or crimson clover sown in fall and strip-tilled in spring before vegetable planting, and clover or grass alleys between vegetable beds. The beds are mulched with plastic or paper + organic materials, overseeded with low-growing legumes once the vegetable is established, or cover cropped after harvest. In some cases, the position of tilled beds and clover/grass strips are alternated annually or every few years.

Winter cover crops such as rye, hairy vetch and crimson clover can usually be killed by mowing after they begin to flower in late spring, and 14 participants reported using this method to grow mulch in place for summer vegetables. (**Note:** *ryegrass*, often sold as "annual rye," cannot be killed by mowing, and is not suitable for this use). Rye + vetch is usually planted in early fall of the previous year at 45 to 60 lb rye and 25 to 40 lb vetch per acre (about 10 oz rye and 6 oz vetch per 500 square feet). Sometimes vetch or crimson clover (15 to 20 lb per acre) is planted alone.

The most often-cited benefits of cover crop-based mulching systems are organic matter contribution and related improvements in the soil, weed suppression, and labor efficiency (Table 5A). Some participants noted that legumes release more N than hay or straw, and that cover cropping combined with reduced tillage seems particularly beneficial to soil structure and life. Cover crops are more feasible than applied organic mulches for mechanized farms, and several of the largest farms in the survey are experimenting with them.

Table 5A. Advantages of Cover Crop Mulches

	Number of growers:	
Advantages:	Mowed cover	Living mulch/ strip till
Adds organic matter and/or nutrients	6	7
Weed suppression	5	4
More labor-efficient than applied organic mulches	4	3
Improves soil tilth	3	2
Prevents soil erosion		4
Attracts beneficials; fewer pests	1	4
Can get into field sooner in spring or after rain	2	2
Enhances soil life	3	1
Conserves soil moisture	2	1
Better crop yields	2	1
Reduces amount of hay or straw mulch needed	2	1
Total number of farms using cover crops	14	14

Weeds and cover crop regrowth are the main problems with this system (Table 5B). Mowed cover crops leave a relatively light mulch (one to four tons per acre) that may not suppress weeds sufficiently, especially later in the season. Several participants supplement the cover crop by adding hay, straw or green chop. Rye and vetch sometimes grow back and compete

with the vegetable crop, especially if the cover is mowed before flowering to accommodate early planting. Some growers plant into a tilled strip to reduce competition.

Several participants have found this system awkward to manage. Sometimes, the mowed cover crop must be pulled back from the planting row to allow soil warming. Heavy cover crops can be difficult to mow or strip-till, the residue can interfere with mechanical transplanting or cultivation, and timing of mowing or other operations can be tricky.

The growing cover crop removes moisture from the soil in spring. A few growers felt that this was an advantage, allowing field operations to begin sooner, but one participant found that tomato seedlings required extra watering because the cover crop had dried the soil too much.

Table 5B. Disadvantages of Cover Crop Mulches

	Number of growers:	
Disadvantages:	Mowed cover	Living mulch/ strip till
Inadequate weed control	8	1
Cover crop regrowth competition	5	3
Decomposes too fast	4	
Cools soil, delays crop maturity	3	1
Cover crop difficult to manage	3	
Difficult to get cover crop established		3
Complicates vegetable crop management	2	1
Labor intensive	2	

Plastic Mulches

Black polyethylene (PE) film is the most commonly used plastic mulch, followed by water-permeable materials such as woven polyester or landscape fabric. Growers usually use 1 to 2 mil thick PE films, although several use 4 or 5 mil black plastic. A few growers have experimented with transparent PE (usually as a pre-plant treatment to solarize the soil), white PE (when soil cooling is desired) or infrared-transmitting (IRT) film which heats the soil more than black PE while maintaining good weed control.

Growers generally purchase plastics from suppliers of agricultural inputs, but heavier grades of black PE are sometimes purchased or salvaged from the construction trade. Plastics are applied manually on small farms, and by tractor-drawn mulch layers on large, mechanized farms. Mulch layers tuck the entire edge of the plastic into the soil and some small scale growers do likewise with hand tools. Others place a shovelful of earth every several feet along the edge, which saves time and may be adequate in locations not subject to high winds.

The mulch is usually laid just before planting (sometimes a month before planting) in 3 to 5 ft wide strips centered on crop rows 4 to 10 ft apart, thus covering 40 to 100% (usually 60 to 75%) of the land area. In mechanized applications, drip irrigation tape, fertilizers and/or soil fumigants (for weed and disease control) are applied simultaneously with the plastic.

The main benefits of plastic mulch appear to be excellent weed control (except for transparent or white plastic), soil warming, earlier and higher yields, less disease and fruit rotting, and soil moisture retention (Table 6A). Plastic mulches were reported to increase yields of all warm season crops, especially melons. One grower found that black PE warmed the soil just 1 to 2 degrees F, yet enhanced melon yields fourfold. However, seven participants saw no yield increase with plastic, four said that plastic overheated or "burned" some plants, and two add organic mulch in summer to prevent this. Apparent yield benefits may depend on crop, climate and the mulch to which plastic is compared. Tomatoes prefer moderately warm soil, and may yield more in a soil cooling mulch than in plastic if the weather is hot.

Table 6A. Advantages of Plastic Mulches

	Number of growers:	
Advantages:	Nonpermeable	Permeable
Weed control	20	3
Warms soil; gives earlier harvest	11	3
Better crop yields	11	1
Cleaner fruit, less disease and rotting	8	3
Conserves soil moisture	7	4
Durable, last several seasons	5	4
Precise moisture control w/ drip irrigation	4	
Excludes excess moisture	4	
Fewer pests	4	2
Cost-effective; inexpensive	3	
Labor-efficient	3	1
Total number of farms using plastic mulch	22	6

Plastic film retains soil moisture, and installing drip irrigation under the mulch allows precise regulation of soil moisture. Several growers expressed concern that films exclude rain or overhead irrigation, but others found plastic helpful in shedding *excessive* moisture. In one case, this resulted in sweeter cantaloupe, a crop which becomes watery and tasteless if overwatered. Another grower who mulches most crops with tree leaves controlled tomato fruit cracking by laying plastic underneath the leaves.

Water-permeable woven plastic mulches may be advantageous for growers without drip irrigation; however one grower found that even this material can hinder rain infiltration and aggravate transplant shock. On sandy soils, precisely positioned drip irrigation may be necessary for plastic mulch to give good results. However, moisture can move laterally through finer-textured soils (loam, silt loam or clay loam), and three growers found that plastic works well without drip on such soils provided it is laid while the soil is moist.

The main disadvantages of plastic mulch are that it becomes a nonrecyclable and nondegradable waste that must be disposed; application and pickup are labor intensive; the plastic may break up and leave persistent litter in the field; and it does not feed the soil (Table 6B). "Degradable" plastics break up into bits, creating a particularly severe litter problem. All five growers who tried these materials no longer use them, and several farmers are waiting for further technological improvements before trying degradable plastics on their farms. Some participants do not like plastic in the garden or field because it could adversely affect soil life, it contradicts the principle of biological farming, or it is simply unaesthetic. These concerns led many survey participants to stop using plastic (Table 1).

Table 6B. Disadvantages of Plastic Mulches

	Number of growers:	
Disadvantages:	Nonpermeable	Permeable
Creates non-reusable waste	18	
Labor-intensive to apply and pick up	13	
Leaves litter in field	12	
Plastic not wanted in garden/field	11	
Does not add organic matter	7	1
Does not increase yield	7	1
Purchase cost	6	2
Weed growth	5	
Consumes non-renewable resources	4	1
Pickup is nasty, hazardous work	4	
Blocks entry of rain or overhead irrigation	3	1
Too hot -- burns crops	3	1
Complicates disease management	1	3
Excessive tillage requirements	2	
Mechanical injury to seedlings	2	

Depending on row spacing, mulching with four foot wide, 1 mil PE consumes about 90 to 180 lb plastic per acre (1 to 2 lb per 100 feet of row), and creates a corresponding amount of waste. Although these materials usually last only one year, two growers reported that 1.25 mil embossed PE and IRT films are easier to retrieve intact than older agricultural plastics and may provide a second season of use. A few growers have developed rotations that allow them to use a single plastic application for two successive crops, e.g. annual strawberries before or after a summer vegetable. Several participants have found that the heavier materials, particularly permeable/woven plastics, are still good after 3 years, and are hoping to use them for 6 to 10 seasons. However, three expressed concern with carryover of disease organisms or copper and sulfur fungicides on these materials.

Some participants listed labor or purchase costs as disadvantages of plastic mulches, but others considered them cost effective. Nine growers paid an average of $135 per acre for 1.0 to 1.5-mil black PE. Heavier PE films run $200 to 600 per acre, and woven/permeable plastics cost $1,000 to 2,000 per acre, which could be amortized over the lifetime of the material. Estimates of labor to lay plastic by hand ranged from 12 to 158 person-hours per acre (average 82 hours = just under one hour per 100 feet of row). One grower noted that laying plastic takes about as long as hay. Mechanized application goes quickly (3 to 6 person-hours per acre), but requires specialized capital equipment. Pickup and disposal seem to entail only a fraction of the costs of purchase and application. However, two described pickup as nasty, dirty work, and two others reported hazards from black widow spiders or copperheads living under the plastic. One grower prefers manual application because he found that mulch layers bury edges so deeply that pickup is much more difficult.

Paper Mulches

Some participants have mulched with paper products, including shredded newspaper or cardboard, sheets of newspaper (two to 20 thicknesses), or Planters' Paper, a commercially available, black, recycled kraft paper mulch. (**Note**: mention of a product or trademark does not imply recommendation by the author or VABF of that product over others.) Two growers reported applying shredded newspaper at approximately 7.5 to 17.5 tons per acre (3 to 7 in depth). Often, organic materials such as hay, straw or sawdust are spread on top of two to four sheets of newspaper. The paper is usually obtained free as a waste product, although two growers have purchased bales of shredded newspaper or rolls of Planters' Paper.

Weed control, moisture conservation and improved soil conditions were most often mentioned as benefits of paper mulch used alone or with organic materials (Table 7). Laying newspaper prior to spreading organic mulch increases labor costs, but a few growers found that this practice enhances weed control or soil conditions compared to either material alone.

The most widespread concern with paper mulches is possible environmental hazards from heavy metals or other chemicals in inks and glues in used paper (Table 7). However, six participants noted that in recent years, newspapers and other publications are switching to much less toxic, soy-based inks, and one had a residue test done on newspaper which revealed no heavy metal residues. Some participants found paper mulches time-consuming to apply, while others felt they were labor-efficient. Two growers estimated 55 and 73 person-hours per acre for laying paper, and three others estimated 73 to 194 hours (average 137 hours = one and one-half hours per 100 feet of row) for a paper + organic mulch.

Table 7. Advantages and Disadvantages of Paper Mulches and Paper + Organic Mulches

	Number of growers:	
Advantages:	Paper alone	Paper + organic
Weed control	5	8
Conserves moisture	4	4
Labor efficient; easy to apply	4	1
Soil cooling in summer	2	2
Easy to till into soil at end of season or next spring	3	1
Improves soil tilth	2	1
Recycles waste product	2	1
Increased crop yields	2	
Prevents soil erosion		2
Enhances soil life	1	1
Cleaner fruit, less disease and rotting	1	1
Disadvantages:		
Concern about toxicity of inks & glues in waste paper	11	
Labor intensive	3	2
Materials blow away in strong wind	4	
Decomposes too slowly; difficult to till into soil	3	1
Harbors pests	3	1
Inadequate weed control	2	1
Cools soil, delays maturity or reduces yield	1	2
Keeps soil too wet	2	
Retards moisture penetration		2
Total number of farms using paper mulches	8	11

A few growers found that thick paper mulches can keep the soil too wet, or that paper + organic mulches can exclude moisture. Opinions differed on whether paper interferes with fall tillage (Table 7). Effects on soil moisture and rate of paper decomposition may be influenced by how much paper is applied, whether it is shredded, what other organic materials are added, and the biological activity of the soil.

Weed Suppression by Various Mulches

Black or IRT plastic films seem to give the best weed control, as only two of 20 growers using them had weed problems: weeds coming through planting holes, and bermudagrass (the heat-loving "wiregrass" of low elevations) penetrating the film itself. Three farmers had trouble with weeds growing under clear or white plastic and pushing it up off the soil surface.

Weed suppression was widely cited as a benefit of organic mulches, yet weeds sometimes broke through and necessitated manual weeding or additional mulch. Some participants considered this a minor problem, others found it serious. Improved soil tilth beneath the mulch can make weeds easier to pull, but pulling can take longer than hoeing, which cannot be done once the mulch is applied.

Seeds in the mulch itself can compromise weed control. Sixteen participants mentioned grass or weed seeds in hay and five others had volunteer grain from straw. Several growers said that composted livestock bedding or pine needles carry few or no weed seeds, but a few others have had noxious weeds carried in by manure. Some growers cut their own grain straw or hay at early heading to ensure seedless mulch. A few others found that allowing seedy hay to age for 1 to 2 years before use kills most of the seeds, especially when round bales are set on end to let rain penetrate.

The thickness of hay or straw needed for adequate weed suppression may depend on the crop being grown, weed species and populations in the field, seeds in the mulch itself, weed management prior to application, soil moisture and weather conditions. One participant reported good weed control with as little as four tons per acre(about three square bales per 100 feet of row), while several others had only partial weed suppression at seven to ten tons (five to seven bales per 100 feet of row). One farmer successfully controlled weeds with ten tons hay per acre even without hoeing before application, but severe weed problems developed when the rate was halved because of a shortage of hay. He suggested a quick test for adequate thickness: no soil should be visible when the newly-laid mulch is pressed down with the hand. A few participants found that two to four layers of newspaper beneath an organic mulch improves weed control and may reduce the amount of organic mulch required.

Mow-killed winter cover crops provide only one to four tons mulch per acre, but the minimum-tillage aspect of this system can reduce germination of annual weeds. A few growers have had severe weed problems in summer vegetables grown in mowed cover crops, but two others found that tomatoes and vining cucurbits are vigorous enough to tolerate late season weeds with no loss of yield or quality. Several participants address the weed problem by adding supplemental hay or straw, and find that less of these materials are needed than if the cover crop were turned under before planting vegetables.

Mulch Effects on Pests and Diseases

Several participants found that organic mulches or cover crops greatly reduced pest problems, and eight observed that hay or straw provide habitat for spiders and other beneficial organisms. Cover crops attract beneficials, especially when unmowed strips are allowed to grow and flower between or near vegetable beds. However hay, straw or paper can harbor a few specific pests, including slugs, field mice and squash bugs. One participant gathers and

composts straw mulch at the end of the season to control squash bugs. Although pine needles are more often used on strawberries or onions than on summer vegetables, two growers found this mulch effective in repelling slugs.

Few growers reported effects of plastic on pests or beneficials. White plastic was observed by two farmers to repel deer, squash bugs and aphids. Flea beetles seem to be deterred by dark colored mulches and attracted by light ones. On one farm, eggplants grown in *black* plastic had fewer flea beetles than unmulched plants, whereas the same crop in *white* plastic was severely damaged by this pest. Another grower reported that mulching with tree leaves reduced flea beetle numbers on eggplant.

Plastic can keep soil from splashing onto the plant and thus reduce diseases such as tomato late blight and other fruit rots. However, one farmer found that plastic did not reduce bacterial speck on tomatoes, and another saw more early blight in woven plastic than in mowed vetch.

Reports on organic mulch effects on crop diseases varied from "straw prevented disease problems even in the flood year of 1992" to "organic mulch is a disease habitat." The mulch prevents soil splash and may increase crop resistance by creating favorable growing conditions. However, a thick organic or newspaper mulch can get too moist and mat down, excluding air and encouraging fungal growth during wet weather. Several growers observed increased problems with early and late blights in tomatoes, and downy mildew or *Phytophthora* rot in pumpkins. A few noted that grain straw is generally cleaner and faster-draining than hay, and one had less rotting in cantaloupe with paper + hay than in hay alone.

Effects of Mulches on Soil Conditions

Many participants consider organic mulches good for the soil, and some found that they played a key role in regenerating compacted or worn-out soils on their farms. Soil "came alive" after several seasons of mulching with hay, straw, livestock bedding, leaves or aged hardwood sawdust. Earthworm numbers and organic matter increased, while tilth and moisture retention improved dramatically and erosion was curbed. Although these changes may not be measurable in a single season, research has confirmed that they accrue over time, even under relatively light mulches (Schonbeck, 1995). Growers observed similar benefits from cover crop mulches. Although cover crops add less organic matter than a thick applied mulch, the reduced tillage and the year-round presence of living plants enhance humus formation and minimize traffic-related soil compaction.

Several participants raised concerns about negative effects of plastic on the soil. In one case, plastic seriously aggravated erosion on sloping land by channeling and concentrating rain runoff; in another, a slight increase in soil compaction was noted. Two others expressed concern about the amount of tillage needed to create the smooth and level seedbed required for laying plastic. Several growers remedy the lack of organic matter input by growing cover crops or laying hay in alleys between plastic-mulched beds.

Benefits and Costs of Different Mulching Systems: is it worth it?

Organic Mulches

Although hay and straw mulches entail relatively high materials and labor costs, they can easily pay for themselves in yield increases, especially for growers who direct-market their produce at retail prices. Assuming that mulch is produced or obtained at $1.50 per 35-lb bale and application requires 90 hours of labor at $6 per hour, the cost of mulching an acre with 700 bales (the average rate quoted by survey participants) would be about $1,600. Two estimates by growers for total mulching costs with materials produced on farm were $1,500 per acre for rye straw spread at about 900 bales per acre, and $2,100 for hay at about the same rate. These cost estimates are equivalent to about $17 to $24 per 100 feet of crop row.

On-farm field experiments and other research indicate that, in most circumstances, organic mulches might increase tomato yields by about 5 tons per acre (115 lb per 100 feet of row) compared to unmulched tomatoes (Schonbeck, 1995). Larger yield increases would be expected during hot summers, whereas cool weather may be less favorable for hay-mulched summer vegetables, especially eggplant or melons. At wholesale prices of $0.33 per pound (Virginia Agricultural Statistics, 1993), a five-ton increase in tomato yield would give a net return on mulching of $1,200 to 1,800 per acre. However, many smaller scale growers market tomatoes directly at retail prices of about $1.00 per pound, for a net return of about $8,000, or $92 per 100 feet of row.

In addition to yield benefits, organic mulches help replenish the soil and reduce weed control costs. Environmental costs are that several acres of land are required to produce mulch for one acre of vegetables, and that fossil fuel is expended in production and hauling. Care should be taken to ensure that hay fields are managed and harvested sustainably and that their soil fertility is maintained. Specific measures might include applying manure, other amendments, or biodynamic preparations; seeding legumes to increase nitrogen fixation, and leaving one hay cutting in the field each year to replenish organic matter.

Cover crops

Sowing cover crops requires much less labor than laying hay, plastic or paper. Seeds cost about $0.10 to 0.20 per pound for rye, and $1.00 per pound for vetch or crimson clover, or about $35 per acre for a rye + vetch cover crop, and $20 per acre for crimson clover. Perennial clover seeds cost about twice as much as crimson, but are sown at 5 to 15 lb per acre. Adopting a cover crop mulch entails both savings (less tillage and cultivation) and costs (special soil preparation and planting equipment, more labor needed for planting or for controlling cover crop regrowth) for which quantitative estimates were not obtained. However, one participant who maintains permanent grass-clover strips between tilled beds in a six acre market garden estimated $260 per acre annually (33 person-hours plus $60 in other costs) to keep the strips mowed.

Growers reported varied effects of mowed cover crops on vegetable yields, ranging from significant reductions to large increases, and researchers have had similar results (Schonbeck, 1995). Further experimentation by growers and researchers is needed to understand and optimize the effects of cover crop mulches on yields. Cover crops offer many

of the same benefits to the soil as applied organic mulches, but do not entail removing nutrients and organic matter from several acres of hayland to feed one acre of garden.

Plastic Mulches

Assuming a purchase cost of $135 per acre plus 82 hours labor, a manual application of lightweight black PE without drip irrigation would cost about $630 per acre. Two large-scale farmers reported total costs of $800 to 1,000 per acre for application of fertilizer and/or fumigant, drip tape and plastic mulch, plus end-of-season disposal.

Plastic mulches enhance tomato yields compared to unmulched crops, especially in cooler climates (Schonbeck, 1995). A small grower realizing a five ton per acre yield increase from plastic mulch would obtain a net return of $9,400 per acre ($108 per 100 feet of row) for direct-marketed tomatoes. Because drip irrigation enhances the yield effect of plastic, a mechanized farm could realize substantial returns even at wholesale prices, e.g. $5,600 per acre for a ten ton increase. Melons, cucumbers and eggplant, which like higher soil temperatures than tomatoes do, may show more dramatic yield responses to plastic. However, plastic raises environmental concerns discussed earlier, and does not add organic matter. Long term soil tilth and fertility may suffer unless alleys are cover cropped or mulched with organic materials, and beds are cover cropped in winter.

Paper Mulches

Field trial results indicate that tomato yield responses to paper may be smaller than for other mulches (Schonbeck, 1995). However, where a usable paper waste is available free (e.g. end rolls from a newspaper publisher), a paper mulch could pay for itself with as little as a one ton per acre yield benefit. A paper + organic mulch requires more labor to spread than either one alone, but the combination may enhance weed control or other benefits. Recycling paper waste onto the land also reduces waste burdens at landfills, and recent trends toward less toxic inks and bleaching processes will help to make this practice more environmentally safe.

Growers' Research Priorities and Information Needs

Participants most often wanted more information on the effects of mulches on crop diseases and insect pests, on planting into mowed cover crops or living mulches, and on paper mulches (Table 8). Growers were especially interested in the possible role of organic mulch or cover crops as habitat for beneficials, and in reducing disease problems. Three mentioned soil solarization with clear plastic for disease or weed control. A few wanted more information on dealing with problems that mulch could aggravate, including squash bugs and certain fungal diseases in hay or straw, and pest nematodes in clover living mulch.

Specific cover crop questions include low-growing legume living mulches that do not compete with the production crop, equipment and methods for no-till planting and weed control in mowed cover crop, and how much legumes could reduce the need for applied nitrogen fertilizers. One grower suggested developing a region-specific cover crop handbook, as has been done by Rodale Research Center for the Northeast.

Table 8. Research Priorities of Growers Participating in Survey

Research Topic	Number of Growers
Effect of mulches on incidence of crop diseases	9
Role of mulches as beneficial habitat in biological pest control	8
Mowed or strip-tilled winter annual cover crops	8
Legume living mulches	6
Waste paper derived mulches	6
Mechanized hay application	5
Plastic mulches other than black PE	5
Oiled paper as alternative to plastic	4
Cost-benefit analysis of plastic mulch, including environmental	4
Labor costs of mulching	4
Effect of leaves on soil	3
Paper + organic mulches	2
Effects of plastic *vs* organic mulches on soil	2

Dr. Ronald Morse and coworkers at Virginia Tech have developed a subsurface tiller-transplanter which improves seedling establishment and minimizes soil disturbance when transplanting vegetables into killed cover crops (Morse, 1993). They have also found that rye + vetch can sometimes be killed mechanically by rolling it down, and that no-till planting is easier after rolling than after mowing. Dr. Morse welcomes calls from growers who would like to try these strategies for no-till, no-herbicide vegetable production (tel. 703-231-6724).

A number of participants wanted more information on woven, infrared-transmitting, colored or degradable plastic mulches and various paper mulches (Table 8), and wanted to try these materials themselves (Table 1). Specific questions include: returning paper wastes to the land via mulching, shredded newspaper or end-rolls as labor efficient alternatives to newspaper sheets, and oiled paper as a biodegradable, soil-warming alternative to plastic. Four growers wanted an in-depth cost-benefit analysis of plastic mulch including environmental impacts, and two wanted to evaluate its effects on soil health in comparison with organic mulches.

Reducing labor costs of mulching is another priority. Five growers wanted to explore mechanized hay or straw mulching, and noted that tractor drawn bale choppers, shredders and blowers are available that might be adapted for this use. Other topics include labor-efficient methods for small, manual operations, and returns on labor invested in mulching.

Some Mulching Innovations and Success Stories

Manually applied organic mulches on medium-sized farms

Carol Eagle of September Morn Organic Farm, in Highland County, VA grows 38 acres of vegetables which are planted, mulched and harvested manually after initial tillage and bed forming is done by tractor. A crew of six farmworkers spreads about six to 12 inches of oat or rye straw on the growing beds just after transplanting tomatoes, leaving a two-inch space around the stems. The straw is either produced on farm and aged one year before use (oats) or obtained from a nearby farm (rye). Tomatoes are planted relatively late when the soil has warmed up, and Carol has seen no problems resulting from cooler temperatures under the thick mulch. Aged hardwood sawdust (mostly oak) from a nearby mill is applied in the alleys.

Carol has chosen oat straw after several years experimenting with various materials, because it "seems to have something that plants like." Tomatoes in this mulch had no disease, even in the flood year of 1992 when unmulched tomatoes showed severe disease symptoms. She has also noticed that sawdust holds moisture better than straw, and seems to enrich and loosen the soil in the paths as it decomposes. Sawdust aged two or three years is most beneficial. Peppers yielded more in aged sawdust than in straw. She now rotates the position of beds and walkways each year to take advantage of these benefits.

Mulching the tomatoes requires about six person-days per acre, but Carol reckons that mulching saves over 20 person-days in weed control. She also found that using aged straw makes the job go faster, as fresh straw is stiffer and harder to handle.

Potomac Vegetable Farms, which includes 50 acres of vegetables in Fairfax County, VA and 19 more in Loudoun County, grows winter rye specifically for mulching about seven acres of tomatoes and other solanaceous crops. Rye is planted in fall, cut and baled in May at early heading before it produces viable seed. The straw is either applied fresh or after one year dry storage, at about 16 tons per acre. Ellen Polishuk, who manages the Loudoun County acreage, finds rye straw much easier to spread than spoiled hay, and has had very good results especially with tomatoes. The straw is cleaner and less likely than old hay to promote fruit rot. She has also observed improved soil structure, increased earthworm activity and higher yields in greens and other crops grown the year after straw-mulched tomatoes. Although manual application is labor intensive, growers at both sites feel that their efforts are well repaid in weed control and soil health.

Hay as earthworm food

We have a 1/4 acre vegetable garden at Windswept Farm in Floyd County, VA which has an unusually fertile clay loam soil full of earthworms. However, the soil can crust badly if exposed to hot sun and summer downpours for more than a couple of weeks, so we try to keep it covered at all times except during seedling establishment. Once the crop is established and the soil is warm, we add several inches of either freshly cut or old hay.

The first thing we noticed is that the mulch disappears remarkably fast, and a second application is usually needed in midsummer. On closer observation, we found that earthworms, particularly the large nightcrawlers, pull the mulch down into their burrows to

eat. The second thing we noticed is that this process keeps the soil in excellent condition so that it requires very little tillage before planting the next crop. Essentially the worms are composting the organic residues and tilling the soil for us, as long as we keep them fed. Maintaining even an inch of mulch will accomplish this. Oats sown in August and allowed to winterkill produce just enough cover to promote ideal conditions for early spring plantings.

During prolonged wet weather, we have noticed that a thicker mulch can aggravate slug problems and cause some waterlogging of our heavy soil. There is evidence that compacted or inadequately aerated soil can release substances that attract slugs (Luebben, 1994). Therefore we loosen the soil to a depth of 10 inches with a fork once a year, and adjust mulch thickness according to weather conditions.

A diversity of mulches -- all produced on-farm

Kip and Odette Mortenson manage Mountain Spirit Farms, a diversified farm in Pendleton County, West Virginia that produces grains, beef, vegetables and berries. They mulch some of their vegetables with oat, wheat or rye straw, second cutting alfalfa hay, or a hairy vetch + yellow sweet clover mix grown specifically for mulch. The vetch + sweetclover are planted in the fall and harvested late the next spring, when vetch has climbed the tall sweetclover and a large biomass has been produced. Kip prefers the legume mulches, and finds the alfalfa weed-free and easier to spread than straw because of its short stalks.

Tomatoes and cucurbits are planted in strips tilled on the contour through white clover, either with a tractor tiller (seven feet wide) or a walk-behind tiller (22 inches wide). After crop establishment, they reseed the clover. The living mulch reduces the amount of hay or straw mulch needed.

Paper + organic mulch gives added benefits

After trying a variety of mulches on his 1.5 acre market garden, Andy Bradshaw of James City County, Virginia concluded that newspaper + straw or leaves is the best system for his scale of production. Solanaceous and cucurbit crops are mulched about four weeks after planting, and tomatoes are caged just before the mulch is laid. In 1993 he used four thicknesses of newspaper sheets followed by straw at about 8.5 tons per acre, purchased at $1.50 per square bale. In 1994, he rolled out two thicknesses of newsprint end rolls (remnants 100 to 300 feet long which are a byproduct of newspaper printing, but are themselves free of inks), followed by bagged leaves delivered by the county. This is a more cost-efficient system because the materials are available free, and require less labor for application.

These mulches keep the soil cool and moist, an important benefit during the hot summers of coastal Virginia. Furthermore, Andy found that the paper + organic mulch controlled weeds better than hay alone, and virtually eliminated soil compaction. The soil was "very soft" under paper + straw, whereas it became slightly compacted under straw alone.

Jake Kawatski and Pam Dawling, who manage the four-acre food garden at Twin Oaks Community in Louisa County, Virginia, and Beth Eder who manages a six-acre Community Supported Agriculture (CSA) farm in Maryland, also use newspaper + straw or hay for

summer crops. They like this system because it enhances soil organic matter, feeds soil life, retains moisture, moderates temperature and reduces compaction. Jake observed that the paper slows the breakdown of hay and thereby helps prevent fruit rotting in cantaloupe.

Mowed cover crops reduce pests and disease, increase production

Pam Bramhill, who has a three-acre CSA in the Chesapeake Bay region of Maryland, and Norma Wilson who farms in Loudoun County, VA have participated in on-farm research with Dr. Aref Abdul-Baki (USDA, Beltsville) on mowed hairy vetch as an in-place mulch. Pam mowed strips through a heavy stand of vetch and transplanted melons, summer squash, peppers and eggplant. Although weeds broke through the mulch six weeks after planting, the crops gave high yields without applied fertilizer. The unmowed strips of vetch flowered, attracted lady beetles, and seemed to promote biological pest control. Pam observed far fewer cucumber beetles than in previous years without a vetch cover crop, and *no* squash vine borers or squash bugs, which allowed the summer squash to produce for two months.

Over three seasons, Norma observed higher yields in tomatoes grown in mowed vetch or rye + vetch than tomatoes in hay mulch or weed cloth (a woven plastic mulch). She attributes this partly to nitrogen released by vetch residues. When early blight broke out in 1994, tomatoes in the cover crop mulch had less blight and produced longer than tomatoes in plastic. Blight severity in hay was between vetch and plastic. Summer squash grown in mowed vetch also seemed to thrive, although vine borers were still a problem. Norma plans to use mowed vetch + rye as her primary mulching method in the future.

Strip tillage and mulching conserve soil and water on sloping land

Dick Austin of Chestnut Ridge Farm grows peppers and raspberries on a sloping field in Scott County in southwest Virginia. The field is planted in perennial ryegrass + clover, through which rows four feet apart are tilled on the contour with a 24-inch rototiller. Peppers are mulched on the day of planting with two layers of newspaper plus four inches of hardwood sawdust obtained from a nearby sawmill. The ryegrass + clover strips between the crop rows are mowed regularly, and the position of the cropped rows is alternated each year. In addition to organic matter input and excellent weed control, Dick observes that this mulch "catches water flow down the hill and holds moisture well. Even in extremely heavy rain we can detect no erosion in the field."

Growing the mulch right next to the vegetables

David and Ronnie Boyer have a small diversified farm in Patrick County, VA, where squash, tomatoes and other vegetables are grown on four foot wide, mulched beds alternating with four foot wide permanent grass-clover walkways. In the first year, they used two pigs in a moveable pen to break the existing sod. The pigs thoroughly turned the soil as they dug for edible roots, and the pen was moved daily to create tilled, terraced beds on the contour.

Beds are kept mulched throughout the season with fresh clippings collected from the walkways and from a field of orchardgrass + ladino clover with a 42-inch bagging mower. The

Boyers mow whenever the grass + clover reach a height of six inches, as this encourages clover growth and provides a continuous supply of clippings. The mulch is maintained about three to four inches deep. In addition to good weed suppression and moisture retention, the Boyers have noticed a dramatic increase in soil humus and earthworm populations.

Initially, David estimated that up to 20 square feet of grass + clover were needed to provide mulch for one square foot of vegetable beds, but he hopes eventually to provide most of the mulch needed from the walkways. He now plants hairy vetch in the beds about a month before fall frost, mows it the following May and plants tomatoes and other crops without tillage. The vetch mulch is then supplemented with clippings during the summer.

Beverly Eggleston raises free range beef on a 160 acre farm in Washington County, VA, and is now diversifying into tomatoes, salad greens and other vegetables. He uses hairy vetch, rye, soybean, sudangrass and other cover crops to build up the soil for one to two years, then turns the cover crop under and plants vegetables. He has experimented with woven black plastic and straw mulches for tomatoes, but found that both had drawbacks. He is now planning to implement a modification of the Boyers' mulching strategy. With plentiful land available, Bev plans to establish crop beds on the contour, separated by 20 to 30 foot wide strips of hay or cover crop. Vetch + rye in the beds will be mowed and strip-tilled just before planting cucurbits and other summer crops. Hay will be cut and windrowed in the strips, then moved into the vegetable beds after crops are established and the soil is warm. This system would eliminate baling and hauling, and would minimize soil erosion on his sloping fields.

Making the best use of plastic mulches

Rick Hall, who grows 1,700 acres of vegetables in Accomac County on the Delmarva Peninsula, routinely uses plastic mulches with drip irrigation for solanaceous and cucurbit crops. Black PE is used for March plantings, and white-painted black PE (shades out weeds yet reflects excess heat away from soil) for June tomato plantings. Even though he uses 1.0 to 1.5 mil films, Rick found that he can get two years' use out of them by leaving them in the field after harvesting tomatoes, and rotating to cucumbers or summer squash the second year.

Chip and Susan Planck grow 45 acres of vegetables in Loudoun County. They mulch with straw or hay to control weeds, provide beneficial habitat, prevent soil splash and thereby reduce fruit rots and other diseases. However, black PE mulch and sometimes polyethylene tunnels are used for early plantings of tomatoes, eggplant and cucurbits to warm the soil and growing environment. About four weeks after planting, alleys are cultivated then mulched with hay. In this way, the crops are managed for earliness yet the benefits of organic matter input and habitat for insect predators are also realized. This approach also saves labor, as plastic is laid and alleys are cultivated by tractor drawn implements, and hay-mulching just the alleys goes much faster than tucking hay around each plant.

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