increase in the Latin population of South Florida has created a local market of considerable size, and further increases are likely. Miami should emerge as a major center of Caribbean, Central and South American trade (which may eventually include Cuba) and could offer a local alternative to the distant New Orleans and Houston export centers.

Experience has shown that a rice growing operation should be fully vertically integrated, controlling the means of production, drying, storage and selling the crop. In addition, if rice is marketed locally, some milling facilities will be needed. This offers potential for additional income, since milling more than doubles the price of rice.

In the Everglades it is probably best to let rice germinate in moist soil and then flood (9). Rice is not a full aquatic. Rice fields in this region will be very level and there will be little water flow. The water becomes warm, low in oxygen, and contaminated with algae. This decreases root systems and tillering. After rice is tall enough to shade the water, growth is enhanced by flooding. Thus, rice has a lower water requirement early in its growth. This fits in with the water supply pattern in the Everglades (Table 5). The rainy season begins in late May or June, and average rainfall exceeds pan evaporation from June through September. It may be necessary to pump water into the fields in excess of evapotranspirational usage. One study in the Everglades showed that seepage losses were twice as great as those by evapotranspiration (5).

Rice production, whether for grain or cover crop, may help farmers with their water management problems. Concern is mounting over releasing farm drainage into public waters. It has been suggested that farmers may have to set aside a portion of their land to receive water drained from the remainder. Perhaps rice lands could both produce income and be a reservoir for farm drainage.

Table 5. Average summer rainfall and pan evaporation for the years 1924-76 at the Agricultural Research and Education Center, Belle Glade.[z]

| Month | Rainfall | Pan evaporation | Rainfall—pan |
|---|---|---|---|
| | (inches) | | |
| April | 2.93 | 6.41 | −3.48 |
| May | 4.76 | 6.94 | −2.18 |
| June | 9.18 | 6.09 | +3.09 |
| July | 8.29 | 6.23 | +2.06 |
| August | 8.05 | 6.01 | +2.04 |
| September | 8.63 | 5.13 | +3.50 |

[z]Source: AREC-Belle Glade weather records.

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# ENERGY ANALYSIS OF THE USE OF FULL-BED PLASTIC MULCH ON VEGETABLES


RICHARD C. FLUCK AND LAWRANCE N. SHAW
*Frazier Rogers Hall,*
*IFAS, Agricultural Engineering Department,*
*University of Florida,*
*Gainesville, FL 32611*

PAUL H. EVERETT
*IFAS Agricultural Research Center,*
*University of Florida,*
*Immokalee, FL 33934*


*Additional index words.* Energy conservation.

*Abstract.* **The effects of production practices on energy consumption are growing in importance due to the increasing costs and decreasing availability of energy. The effects of the use of full-bed plastic on the total energy consumed in staked tomato production were investigated. Increases in energy consumption compared with no-mulch production are due to the energy sequestered in the plastic mulch, the soil fumigant, increased fertilization and increased irrigation. Decreases in energy consumption are due to fewer cultivations and elimination of the pre-emergence herbicide. The net effect is a 58% increase per unit area in total energy requirements for production and harvesting using plastic mulch. However, since production is also much greater with plastic mulch, the net effect is that energy productivity, the quantity of product per unit of energy, is slightly increased.**

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There is recent widespread increased awareness of the importance, and, indeed, necessity, of energy as an input to industrialized agricultural systems. The energetics of alternative systems are likely to assume a position of increased importance in selecting a system for producing a product. We performed an energy analysis of the use of full-bed plastic mulch on tomatoes as an example of energy analysis and because the energetics of this system have already been the subject of some interest (10, 11). Two currently used systems for Florida tomato production, plastic mulch and no-mulch, were compared to estimate differences in their energy consumption per unit area and productivity per unit of energy input. The plastic mulch system is a more intensive tomato production system, with increased energy consuming inputs; however, the plastic mulch system also produces an increased yield. An important question is which system has greater energy productivity.

*Increased energy consumption.* The use of plastic mulch in producing tomatoes with current Florida practices requires additional energy in several different ways:

1. Energy for manufacturing the plastic and moving it through the distribution system to the grower.
2. Energy for applying the plastic mulch.
3. Energy sequestered in fertilizer applied at higher rates.
4. Energy required for greater amounts of irrigation.
5. Energy required for producing fumigant used under plastic.
6. Energy required for herbicide used in alleys between beds.
7. Energy required for removing plastic mulch after harvest.
8. Energy required for picking additional production.

*Decreased energy consumption.* On the other hand, there are some ways in which energy consumption is decreased with plastic mulch:

1. Less energy required for fewer cultivations.
2. Less energy required for fewer applications of fertilizer.
3. Less energy required for pre-emergence herbicide.

## Procedure

Energy inputs for the production system through harvesting were quantified based on the system as described in terms of costs by Brooke (3) for the 1975-76 season. The mean of the 2 staked tomato systems for Immokalee-Lee and Manatee-Ruskin served to describe the more prevalent plastic mulch system. From this we subtracted the energy inputs unique to the plastic mulch system and added those unique to the no-mulch system in order to estimate the total energy inputs of the latter.

Analyses were made to estimate the energy required for each of the inputs listed previously as unique to either system. Both process analysis and input-output analysis were used, depending upon the input. All energy inputs, direct and indirect, were included.

Table 1 presents the production energy requirements through harvesting for an acre of staked tomatoes grown on plastic mulch using current Florida practices. The estimated total energy requirements for growing and harvesting an acre of tomatoes, using this system, are 123,893,000 BTU (322,900 MJ/ha). Since the yield was a mean of 854 marketable units (30 lb. boxes) (4702 kg/ha), the energy productivity is 206.8 lb. of tomatoes per million BTU (0.0889 kg/MJ) consumed within the system.

The energy required for several inputs unique to the 2 systems was determined so that the energy requirements and energy productivity for the no-mulch system could be estimated. Table 2 serves as a summary and listing for the various inputs which are subsequently detailed.

*Fumigant.* The energy required to provide the fumigant used with the plastic mulch system was determined with input-output analysis using the procedure suggested by Bullard *et al.* (4). The product of the cost of Vorlex ($10.55/gal) and an application rate of 20 gal/acre was distributed as shown in Table 3 to arrive at an energy requirement of 23,573,000 BTU/acre (61,429 MJ/ha). The application of a fumigant could be a component of either system, but the use of fumigant did not become a common practice until the advent of mulch.

*Plastic mulch.* The energy requirements for making low density polyethylene film, used for mulch on tomatoes, have been determined using process analysis. Fossil fuels are used as a feedstock in making ethylene, which is the primary input to polyethylene production. Carbon black is added to polyethylene granules and polyethylene film is extruded. Hayes (7) listed 67,500 BTU/lb. (157.0 MJ/kg) as the energy requirements for polyethylene. Berry and Makino

Table 1. Energy requirements for staked tomatoes grown on plastic mulch.

| Item | Cost[z] $/acre | Energy intensity[y] BTU/$1975 | Energy consumed BTU/acre |
|---|---|---|---|
| Land rent | 44.90 | 19,066 | 856,000 |
| Seed | 89.45 | 37,038 | 3,313,000 |
| Fertilizer | 272.24 | 91,692 | 24,962,000 |
| Spray and dust | 305.76 | 80,541 | 24,626,000 |
| Cultural labor | 600.54 | 8,438[x] | 5,067,000 |
| Machine hire | 57.98 | 93,929[w] | 5,446,000 |
| Gas, oil and grease | 81.26 | 351,646[v] | 28,575,000 |
| Repair and maintenance | 119.28 | 28,810[u] | 3,436,000 |
| Depreciation | 82.18 | 49,182 | 4,042,000 |
| Licenses and insurance | 59.15 | 18,411 | 1,089,000 |
| Interest | 79.80 | 13,955 | 1,114,000 |
| Miscellaneous | 168.97 | 105,711[t] | 17,862,000 |
| Picking | 415.39 | 8,438[x] | 3,505,000 |
| Total growing and picking | 2,376.90 | | 123,893,000 |

[z]Mean of costs for Immokalee-Lee and Manatee-Ruskin areas (3).
[y]Most energy intensities taken from (4) and adjusted to 1975 cost levels using price deflators.
[x]Labor energy intensity taken as 18% of the average energy intensity for all goods and services in the gross national product, or 0.18 x 46,876 BTU/$ = 8438 BTU/$. The factor 18% is taken from a model of the energy sequestered in agricultural labor developed by the senior author.
[w]Based on an assumed division of machine hire into 30% labor, 40% farm machinery, 20% fuel, and 10% interest.
[v]Based on an assumed division of 50% gasoline and 50% diesel and prices of $0.57/gal and $0.39/gal respectively.
[u]Based on an assumed division of 50% farm machinery and 50% labor.
[t]Based on an assumed division of 70% plastic mulch, 18% stakes, 9% twine and 3% wire.

Table 2. Energy requirement differences for staked tomatoes grown without mulch.

| Item | Energy consumed BTU/acre | Energy productivity Pounds/million BTU's |
|---|---|---|
| Total energy requirements for plastic mulch system | 123,893,000 | 206.8 |
| Subtract if plastic not used: | | |
| Fumigant | 23,573,000 | |
| Plastic | 15,232,000 | |
| Less fertilizer | 4,231,000 | |
| Less irrigation | 2,233,000 | |
| Herbicide | 447,000 | |
| Removal of plastic | 422,000 | |
| Application of fumigant and plastic | 466,000 | |
| Less picking | 1,453,000 | |
| Add if plastic not used: | | |
| More cultivations | 1,264,000 | |
| More applications of fertilizer | 253,000 | |
| Pre-emergence herbicide | 1,025,000 | |
| Total energy requirements for no-mulch system | 78,378,000 | 191.4 |

Table 3. Energy requirement for fumigant.

| Item | % | Allocated share of cost $1975 | Energy intensity BTU/$1975 | Total energy BTU/acre |
|---|---|---|---|---|
| Agricultural chemicals | 88 | 185.68 | 122,645 | 22,773,000 |
| Railroad | 1 | 2.11 | 64,394 | 136,000 |
| Motor freight transport | 1 | 2.11 | 45,715 | 96,000 |
| Wholesale trade | 9 | 18.99 | 26,389 | 501,000 |
| Retail trade | 1 | 2.11 | 27,209 | 57,000 |
| | 100 | 211.00 | | 23,563,000 |

(1) stated 68,840 BTU/lb (160.1 MJ/kg) with an additional 4710 BTU/lb. (10.95 MJ/kg) for extrusion. Hayes' (7) energy requirement for ethylene of 43,722 BTU/lb (101.7 MJ/kg) can be used in conjunction with Smith's (9) polyethylene processing energy requirement to obtain a total polyethylene energy requirement of 64,388 BTU/lb. (149.9 MJ/kg) or with those described by Hydrocarbon Processing (8). An average described process, when added to the ethylene feedstock energy requirement, results in 51,966 BTU/lb. (120.9 MJ/kg). In this analysis we assumed an energy requirement for 0.95 specific gravity polyethylene mulch of 68,000 BTU/lb. (158.2 MJ/kg) and a 1 1/4 mil (0.032 mm) thickness applied in a 60 inch (1.52 m) roll to rows on 72 inch (1.83 m) centers for a total of 224 lb./acre (25.1 kg/ha) or a plastic mulch energy requirement of 15,232,000 BTU/acre (39,705 MJ/ha).

*Fertilizer.* Though the current trend is toward less fertilizer, growers typically apply nitrogen at higher rates with plastic mulch. It was assumed that 325 lb. N/acre (364 kg/ha) was applied with plastic mulch, or 150 lb./acre (168 kg/ha) more than with no mulch. Blouin and Davis (2) is one of many sources of energy requirements for fertilizers, and we used 28,209 BTU/lb. (65.6 MJ/kg) based on their analysis for ammonium nitrate. The increased energy requirement due to the increased level of nitrogen application is 4,231,000 BTU/acre (11,028 MJ/ha).

*Irrigation.* Growers also typically apply more irrigation with plastic mulch. We assumed a total of 75 inches (191 cm) with plastic or 25 inches (64 cm) more than with no mulch. Also assumed was a 50 ft (15 m) head and a typical diesel powered pump. Gilley and Watts' (6) procedure produced an energy requirement for the additional 25 inches (64 cm) of irrigation of 2,233,000 BTU/acre (5814 MJ/ha).

*Herbicide.* With plastic, a herbicide is typically applied to the alleys between rows. One pint of Paraquat costing $4.00 will treat an acre. By an analysis similar to that for the fumigant, the herbicide was estimated to require 447,000 BTU/acre (1165 MJ/ha).

*Removal of Plastic.* At the end of the season the plastic mulch must be removed from the field. Hand labor for the typical removal costs approximate $50/acre ($20/ha). At an energy intensity of 8438 BTU/$ (8.90 MJ/$) an estimated 422,000 BTU/acre (1095 MJ/ha) is required.

*Application of fumigant and plastic.* Application of the plastic mulch to the bed is performed simultaneously with fumigant application. The energy costs of a 40 PTO hp tractor for this operation are indicated in Table 4. The application speed is 3 mph (4.8 km/hr) with a field efficiency of 70% for an application rate of 1.53 acres/hr (0.62 ha/hr). The energy costs of the fumigant and plastic mulch application equipment were estimated from a total initial cost of $1000 for fumigant and plastic mulch applicators depreciated over a 5-year life when used on 100 acres/year (40.5 ha/year) and an energy intensity of 46,965 BTU/$ (49.55 MJ/$) to be 93,930 BTU/acre (244.9 MJ/ha). The energy

Table 4. Energy requirements for 40 PTO Hp. diesel tractor.

| Item | Cost $/hr | Energy intensity BTU/$1975 | Energy consumed BTU/hr |
|---|---|---|---|
| Depreciation | 1.500[z] | 46,965 | 70,448 |
| Interest | 0.075[y] | 12,892 | 967 |
| Housing | 0.112 | 38,169 | 4,275 |
| Property taxes | 0.150 | 75,845 | 11,377 |
| Insurance | 0.038 | 18,411 | 700 |
| Repairs and maintenance | 0.484 | 28,810 | 13,944 |
| Lubricants | 0.145 | 71,920 | 10,428 |
| Fuel | 0.966[x] | 438,918 | 423,995 |
| Operator's labor | 4.000 | 8,438 | 33,752 |
| | 8.145 | | 569,886 |

[z]Assumed 500 hr/yr use for 10 yr, initial cost $7500, straight line depreciation to zero salvage.
[y]Assumed 10% interest rate.
[x]2.30 gal/hr x $0.39/gal.

cost of the tractor is 569,886 BTU/hr (601.2 MJ/hr) ÷ 1.53 acres/hr (0.62 ha/hr) or 372,475 BTU/acre (971.0 MJ/ha). The total is therefore 466,000 BTU/acre (1216 MJ/ha).

*Picking expense.* Picking expense for the no-mulch system is linearly decreased from that of the plastic mulch system. Since the no-mulch system assumes 500 marketable units (30 lb) and the plastic mulch system assumes 854 marketable units, the picking energy required for the no-mulch system would be reduced by 1,453,000 BTU/acre (3788 MJ/ha).

*Cultivations.* If plastic mulch is not used, several additional cultivations are performed for weed control. It is assumed a 23 PTO hp gasoline tractor is used for 5 cultivations at 2.5 mph (4.0 km/hr) and 80% field efficiency or at 1.45 acres/hr (0.59 ha/hr). By an analysis similar to that of Table 4, the energy requirements for the tractor are determined to be 344,652 BTU/hr (363.6 MJ/ha). The energy required for the tractor is therefore 1,188,455 BTU/acre (3098.3 MJ/ha). The cultivator is assumed to cost $800 and is depreciated over a 5 year life and used on 100 acres/year (40.5 ha/year) with an energy intensity of 46,965 BTU/$ (49.55 MJ/$) for an energy requirement of 75,144 BTU/acre (195.5 MJ/ha). The total energy requirement for the additional 5 cultivations with no-mulch is 1,264,000 BTU/acre (3294 MJ/ha).

*Fertilizer applications.* If no mulch is used, fertilizer must be applied several times during the growing season. It is assumed the 23 PTO hp gasoline tractor is used with a two row fertilizer distributor for 3 fertilizations at 5 mph (8.05 km/hr) and 80% field efficiency or at 5.82 acres/hr (2.36 ha/hr). The energy required for the tractor is therefore 177,656 BTU/acre (463.2 MJ/ha). The fertilizer distributor is assumed to cost $800 and is depreciated over a 5 year life and used on 100 acres/year (40.5 ha/year) with an energy intensity of 46,965 BTU/$ (49.55 MJ/$) for an energy requirement of 75,144 BTU/acre (195.5 MJ/ha). The total energy requirement for the three fertilizer applications with no mulch is 253,000 BTU/acre (660 MJ/ha). If any fertilizer applications were combined with cultivations, the combined energy requirements would be reduced.

*Pre-emergence herbicide.* If no mulch is used, a pre-emergence herbicide such as Diphenamid is applied for weed control. It is assumed that 3 lb./acre (3.4 kg/ha) costing $3/lb. ($6.60/kg) are applied. The herbicide's energy requirement was determined to be 1,025,000 BTU/acre (2672 MJ/ha) by an analysis similar to that for the fumigant. It was assumed that the tractor and equipment energy for the pre-emergence herbicide used with no-mulch and for the herbicide used with plastic mulch are equal and have no effect on energy requirement differences between the systems.

### Results

The plastic mulch system is both more energy intensive and more productive. The total energy requirements for plastic mulch grown staked tomatoes were estimated to be 123,893,000 BTU/acre (332,990 MJ/ha) whereas the no-mulch staked tomato system was estimated to require 78,378,000 BTU/acre (204,332 MJ/ha). The plastic mulch system therefore requires about 58% more energy per unit production area.

Energy productivity is approximately the same with the two systems. The plastic mulch system, assuming 854 marketable units/acre, produces tomatoes at an energy productivity of 206.8 lb./million BTU (0.0889 kg/MJ). The no-mulch system, assuming 500 marketable units/acre, produces tomatoes at 191.4 lb./million BTU (0.0823 kg/MJ), or about 7% less efficiently in terms of the total energy inputs. Within the error limits of this analysis, it could not be said that the energy productivities of the 2 alternative systems are different.

### Discussion

The plastic mulch tomato production system, though much more energy intensive per unit land area, is no more energy intensive per unit of production than the no-mulch system. In fact, it may be slightly less energy intensive per unit of production (8% greater energy productivity was indicated). The plastic mulch system does conserve land resources, but not at the expense of increased energy consumption per unit of production.

Two of the most important energy consuming inputs in the plastic mulch tomato production system are the fumigant, which accounts for 52% of the net difference, and the polyethylene, which accounts for 33% of the net difference. Any potential reduction in the energy requirements for either of these inputs, such as a reduction in fumigant application rate or a reduction in polyethylene thickness, would result in decreased total energy consumption and, unless production were concurrently reduced, increased energy productivity. The 2 next most important energy consuming inputs are due to the different rates of fertilizer and irrigation application, accounting for 9 and 5%, respectively, of the net difference. The remaining energy *consuming inputs* unique to the two systems are essentially inconsequential in comparison.

This analysis of the energy requirements of 2 production systems for tomatoes has demonstrated that the plastic mulch system is more energy intensive per unit area but is likely no more energy intensive per unit of product. Such a situation may hold true for other production systems also.

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# PEPPER PRODUCTION EFFICIENCY USING THE GRADIENT-MULCH CONCEPT[1]

C. M. GERALDSON
*IFAS, University of Florida,*
*Agricultural Research & Education Center,*
*5007 60th St. E, Bradenton, Florida 33508*

*Additional index words. Capsicum annum,* bell peppers.

*Abstract.* **Over a span of more than 50 years, including the 1971-72 season, average pepper production in Florida had ranged from 200 to 400 marketable units per acre (30 lb. bushels).[2] In the last 6 years cultural procedures centering around the use of a full bed mulch was associated with an increasing production. By 1975-76 the average yields reached 550 bu/acre with about 50% of the growers using procedures which include a full bed mulch. A few growers have obtained yields of 2 to 3 times that average. Since 1960 a number of intensively grown crops have been evaluated at the Bradenton Agricultural Research and Education Center in the development of the gradient-mulch concept. More recently a precision combination of selected components have been associated with consistent pepper yields that ranged from above 1000 to 1500 bu/acre. By approaching the maximum potential of a production system (using essentially the same components), unit production costs can be markedly decreased which, in turn, favors a maximum return per dollar invested. This also favors maximum efficiency per unit of energy, fertilizer, water and other contributing components. In this paper the more critical variations of contributory components will be evaluated with relevance to maximum efficiency.**

Over a span of more than 50 years, including the 1971-72 season, average pepper production in Florida has fluctuated

[1]Florida Agricultural Experiment Stations Journal Series No. 848.
[2]For metric conversions see Table near the front of this Volume. Ed.