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The Energy Cost of Protected Cropping: A Comparison of Six Systems of Tomato Production*

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Estimates are presented of the energy sequestered in the production of tomatoes by 6 different cropping systems, 5 of them practised with varying degrees of environmental protection in Mediterranean climatic regions, and one in heated glasshouses in a more northern region. Within the 6 systems considered, the total non-solar energy inputs ranged from 72 to 29286 GJ ha^{-1}, the yield of edible, metabolic energy from 46 to 196 GJ ha^{-1} and the fossil fuel energy invested per unit yield from 1·4 to 137 MJ kg^{-1}. For these 3 quantities the minimum value was for extensive, mechanized, unprotected field production in California and the maximum for early crop production in heated glasshouses in England. For unheated crops, amortization of the protective structures and other fixed equipment represents an increasingly significant fraction of the total energy requirement as the degree of environmental control increases, reaching over half of the total when protection is afforded by glass. There is a sharp reduction in the proportional, although not the absolute size of this indirect energy investment for crops grown in artificially heated and ventilated glasshouses. The difference in energy costs of production between protected, heated crops in northern Europe and unheated crops in the Mediterranean region approximately equals the energy cost of transporting the fruit by air. Finally and very briefly, some implications of the expected increase in fossil fuel costs to protected cropping systems in the Mediterranean region are considered.

1. Introduction

Enoch[1] has recently outlined a conceptual framework within which the energy costs and yield returns of protected cropping can be compared for different climatic regions and with alternative sources of supply, i.e. from cold storage or by transport of produce grown in regions with a more favourable climate.

In order to quantify comparisons of this type, information is required on both the direct and indirect energy requirements for protected cropping systems. Some information has been published on the direct energy requirements for a few heated glasshouse crops produced in the traditional centres of northern Europe,[2,3] but there is very little data available on the indirect energy costs represented by the protective structures themselves, or for the new and rapidly expanding systems of protected cropping practised in regions with Mediterranean climates, where the production of out-of-season export crops is of considerable importance.

The purpose of this paper is to present such data for some of the more widely used production systems employed for tomato, the most important protected food crop.

2. Methods of production and analysis

The tomato is the major protected food crop produced in Israel during the first 4 months of the year. Some 35 hectares of unheated glasshouses are used for this crop, nearly all in the southern coastal strip between 31° and 31°30′N. The glasshouses are either of the Venlo type (aluminium

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steel structures, 3·8 m to the ridges and 3·0 m to the eaves, with bays 3·2 m wide), or are of greater volume (single span structures 8 m wide and 5 m to the ridge), with side walls of plastic which can be rolled up for natural ventilation.

A small area, approximately 10 ha, of winter tomatoes is protected by walk-in polyethylene film tunnels, 2·5 m high and 4·5 m wide. A larger area of spring tomatoes, some 450 ha, is covered by low plastic tunnels, 0·45 m high and 0·9 m wide. With both types of tunnel the plastic film is supported by simple galvanized iron arches.

A very much larger area, approximately 700 ha, is used to produce tomatoes during the winter months in the open field; over half this area is in the same region as the glasshouse crop. The unprotected crop is produced on the single trellis row system. A small proportion of the open field crop receives some protection from hail, sand and rainstorms by an open-mesh, plastic-net roof supported 2·5 m above the soil surface by light metal posts and plastic cord. Windbreak rows of trees afford some additional protection throughout the region.

The proportion of fruit suitable for export to Europe varies from an average of 50% for the glasshouse crop to 20% for the open field crop.

In addition to the 4 production systems used in Israel outlined above, 2 very different systems of tomato cultivation used in California and England have been studied.

That from California represents an extensive, highly mechanized system of open field production in a Mediterranean climate. Approximately 12,000 ha of tomatoes are grown for the fresh fruit market, mainly during summer and autumn, supplying nearly three quarters of the total U.S.A. demand. Irrigation is by a low energy, gravity-feed furrow system in contrast to the pressurized, trickle irrigation system used for tomato production in Israel.

The sixth example of tomato production—the highly intensive system used in southern England to produce fruit from late March till October in heated glasshouses—represents the opposite extreme to the Californian system. The total area of heated glasshouses used for tomato production in the United Kingdom is more than 500 ha but not all of this area is as intensively managed as the system analysed in this study.

The terminology and units used for the energy analysis follow the recommendations of the IFIAS workshop.[4] All production inputs, apart from human labour, were converted to energy units by multiplying the mass or volume used by its Gross Energy Requirement, GER. This represents the energy used to produce and transport each production input, plus its gross enthalpy of combustion. Whenever possible local GER values were used for the three production areas examined, i.e. California, England and Israel.

The convention adopted to account for the energy input in human labour, an unresolved methodological problem, was to include this as the total energy metabolized during the hours of work, the procedure adopted by Leach.[2] His value for the rate of energy metabolization by workers in intensive horticultural production systems, 0·7 MJ h^{-1}, was used here.

The accuracy of the estimates presented is unknown. In the one production system for which 2 independent estimates could be made the total values of GER agreed within 20%.

3. Results and discussion

Inputs into the 6 production systems are listed in Table I together with their energy equivalents. References are given therein to the sources of information used to obtain both the inputs and their GER's.

The energy costs of producing tomatoes by the different systems are summarized in Table II in which the data listed in Table I are combined into direct and indirect inputs. Direct inputs include those required to fertilize, irrigate the crop and heat the glasshouse, etc., whereas the indirect requirements include the energy sequestered in the amortization of the protective structures, and the irrigation and other equipment. By analogy to financial accounting, the direct requirements represent the annual running costs and the indirect requirements the fixed capital costs of production, both given in energy terms.

TABLE I

Material and energy inputs into 6 tomato production systems
(A) Extensive mechanized production—open field, predominantly summer and autumn, California

Inputs		*GJ ha*$^{-1}$
Fertilizers N	240 kg × 64 MJ kg^{-1}	15·37
P_2O_5	410 kg × 2 MJ kg^{-1}	0·82
K_2O	50 kg × 2 MJ kg^{-1}	0·10
Irrigation water	6835 m^3 × 1·12 MJ m^{-3}	7·65
Mechanized operations	Diesel oil 305 l × 35 MJ l^{-1}	10·67
	Gasoline 400 l × 38 MJ l^{-1}	15·20
	Depreciation and repairs	4·05
Pesticides	Insecticides 42 kg, fungicides 60 kg, both × 100 MJ kg^{-1}	10·20
Labour	Hours 1070 × 0·7 MJ h^{-1}	0·35
Miscellaneous	Plants, overheads, etc.	7·89
TOTAL		72·30

Sources
Basic data on inputs and GER taken from two sources, Cervinka *et al.*[5] and F.E.A.,[6] whose totals differ from 59·87 GJ ha^{-1} [5] to 75·26 GJ ha^{-1}.[6] Additional data on labour and fertilizer requirements from ORNL.[7] Mechanized operations include distribution of fertilizers, pesticides and irrigation water. Miscellaneous items calculated as difference from total. Depreciation and repairs of machinery also calculated as difference of fuel items from total

(B) Labour-intensive open field production, autumn–winter, southern coast, Israel

Inputs		*GJ ha*$^{-1}$
Fertilizers N	930 kg × 63 MJ kg^{-1}	58·96
P_2O_5	430 kg × 7 MJ kg^{-1}	3·12
K_2O	1045 kg × 7 MJ kg^{-1}	7·20
Irrigation water	4850 m^3 × 11·2 MJ m^{-3}	54·32
Mechanized operations	5 tractor hours, basic cultivations, sprays, transport	4·48
	Depreciation and repairs	1·80
Pesticides	Fungicides 120 kg × 100 MJ kg^{-1}	12·00
	Soil sterilants 500 kg × 66·8 MJ kg^{-1}	33·40
Labour	Hours 6250 × 0·7 MJ h^{-1}	4·38
Irrigation equipment	Solid set trickle system with liquid fertilizer injector	
	Polyethylene 415 kg × 122 MJ kg^{-1} over 5 years	10·13
	Steel fertilizer tank etc. 400 kg × 90 MJ kg^{-1}/5 yr	7·20
Trellis row support	2050 wooden stakes 4000 kg × 18 MJ kg^{-1}/3 yr	24·00
	62 km steel wire 1000 kg × 24 MJ kg^{-1}/3 yr	8·00
Miscellaneous	Plants, overheads, etc.	7·89
TOTAL		236·88

Sources
Basic data on inputs from Sagiv Bar-Yosef and Mini[8] and from H. Geisenberg, Irena Rylski, A. Sagi and B. Sagiv (personal communications—see Acknowledgements). Gross Energy Requirement for fertilizers and irrigation water are average local values,[9] that for soil sterilants—methyl bromide—from U.S.A. value (10),[2] that for plastic in irrigation dripper and main water lines are the mean of U.K., U.S.A. and Netherlands values.[11] Values for steel for U.K. from References (12) or (2), higher value for tank and fittings, lower value for wire crop supports. Miscellaneous items taken as for system A

The results in Table II show that the indirect energy term increased from a minimum of 4% of the total GER for production in unprotected extensively managed field crops, to 31% for early spring crops grown under low plastic tunnels, to a maximum of 59% for winter crops grown in unheated glasshouses. For crops produced in heated glasshouses, the indirect energy component represented only 4% of the total GER, although absolutely the indirect requirement was more than double that for unheated glasshouse production.

(C) Labour-intensive production—open field, protected by plastic net roof, autumn–winter, southern coast, Israel

Inputs		*GJ ha*$^{-1}$
Fertilizers N	930 kg × 63 MJ kg^{-1}	58·96
P_2O_5	430 kg × 7 MJ kg^{-1}	3·12
K_2O	1045 kg × 7 MJ kg^{-1}	7·20
Irrigation water	4850 m^3 × 11·2 MJ m^{-3}	54·32
Mechanized operations	5 tractor hours, basic cultivation, spray, transport	4·48
	Depreciation and repairs	1·80
Pesticides	Fungicides 120 kg × 100 MJ kg^{-1}	12·00
	Soil sterilants 500 kg × 66·8 MJ kg^{-1}	33·40
Labour	Hours 7825 × 0·7 MJ h^{-1}	5·48
Irrigation equipment	Solid set trickle system with liquid fertilizer injection	
	Polyethylene 510 kg × 122 MJ kg^{-1}/5 years	12·44
	Steel fertilizer tank etc., 400 kg × 90 MJ kg^{-1}/5 years	7·20
Trellis row support	2560 wooden stakes, 5000 kg × 18 MJ kg^{-1}/3 years	30·00
	78 km steel wire, 1250 kg × 24 MJ kg^{-1}/3 years	10·00
Plastic net roof and support	Polyethylene 550 kg × 122 MJ kg^{-1}/3 years	22·36
	620 Metal purlins, 4525 kg × 90 MJ kg^{-1}/10 years	40·73
	10 km wire support, 550 kg × 24 MJ kg^{-1}/10 years	1·32
Miscellaneous	Plants, overheads	7·89
TOTAL		312·70

Sources
Basic data for inputs and Gross Energy Requirements as for system B. Inputs of labour, irrigation equipment and trellis row supports greater because of greater number of rows, 1·3 m apart under net-roof, compared with 1·6 m apart for unprotected crops

(D) Semi-intensive production protected by low plastic tunnels, winter–spring, central coast, Israel

Inputs		*GJ ha*$^{-1}$
Farmyard manure	50 m^3 × 5·80 GJ m^{-3}	290·00
Fertilizers N	250 kg × 63 MJ kg^{-1}	15·75
Irrigation water	4000 m^3 × 11·2 MJ m^{-3}	44·80
Mechanized operations	5 tractor hours, basic cultivation, spray and transport	4·48
	Depreciation and repairs	1·80
Pesticides	Fungicides 100 kg × 100 MJ kg^{-1}	10·00
Labour	Hours 4480 × 0·7 MJ h^{-1}	3·14
Irrigation equipment	Solid set trickle system, 415 kg polyethelyne × 122 MJ kg^{-1}, over 5 years	10·13
Plastic tunnels	Polyethylene, 1300 kg × 122 MJ kg^{-1}, 1 year only	158·50
	Galvanized steel supports, 225 kg × 24 MJ kg^{-1}, over 7 years	0·77
Miscellaneous	Plants, overheads, etc.	7·89
TOTAL		547·36

Sources
Inputs and GER as for Systems B and C, GER of Farmyard Manure as for horse manure—including enthalpy and support energy partitioned between work and manure, transport, density of 0·6—totals 9·65 MJ kg^{-1}.[13] Low plastic tunnels of 0·07 mm polyethylene film supported by 4 mm diameter galvanized supports. Semi-intensive cultivation does not include soil sterilization, liquid fertilization or plant support

In Table III the various sources of energy used in the 6 production systems have been tabulated. These include solar energy, calculated as the global radiant energy incident on the crop during the growing season after allowing for transmission losses caused by the protective structures. On the basis of a series of measurements during the growing season[16] a transmissivity of 0·65 was used for Venlo glasshouses, both heated and unheated. Measurements by A. Sagi[17] indicate a transmissivity of 0·85 for the open-mesh plastic net roof and a similar value was adopted for low plastic tunnels based on laboratory measurements of the absorptivity of polyethylene film,

(E) **Intensive production in unheated glasshouse, winter–spring, southern coast, Israel**

Inputs		*GJ ha⁻¹*
Fertilizers N	1620 kg: 2600 kg ammonium nitrate, 200 kg potassium nitrate	
P_2O_5	940 kg: 2200 kg superphosphate, 390 kg ammonium phosphate	
K_2O	1920 kg: 900 kg potassium sulphate	
Mixed, etc.	200 kg mixed liquid fertilizers, 1800 kg magnesium sulphate	
Sub-total		119·20
Irrigation water	6000 $m^3 \times 11{\cdot}2$ MJ m^{-5}	67·20
Mechanized operations	Cultivation and transport	4·28
	Machinery depreciation and repairs	1·71
Pesticides	Fungicides 150 kg, insecticides etc. 30 kg both × 100 MJ kg^{-1}	18·00
	Soil sterilant 800 kg × 66·8 MJ kg^{-1}	53·44
Labour	Hours 10,000 × 0·7 MJ h^{-1}	7·00
Irrigation equipment	Trickle system with liquid fertilizer injection	
	Polyethelyne 657 kg × 122 MJ kg^{-1}/7 years	11·76
	Steel fertilizer tanks, etc. 400 kg × 90 MJ kg^{-1}/7 years	5·14
Plant support	Polystyrene string 100 kg × 165 MJ kg^{-1}	1·65
	Steel wire 230 kg × 24 MJ kg^{-1}/10 years	0·55
Venlo steel–aluminium glasshouse	Glass, 120 tonnes × 23·2 MJ kg^{-1}/25 years	129·60
	Aluminium, 20 tonnes × 254 MJ kg^{-1}/25 years	203·20
	Steel, 7 tonnes × 90 MJ kg^{-1}/25 years	25·20
	Construction Labour, tractor, sand, cement/25 years	1·29
	Repairs at 1 % of glass per year	27·84
Miscellaneous	Plants, overheads	15·78
TOTAL		692·84

Sources
Input data from final report of Survey and Planning Group, Southern Project,[14] plus data as in system B. GER of individual fertilizers from major local manufacturer (private communication[9]), also for glass (private communication—see Acknowledgements). GER of aluminium taken as mean of U.K., U.S.A. and The Netherlands value.[11] Miscellaneous sub-total approximate estimate allowing for intensive plant propagation and production system

doubled to allow for the effects of deterioration with age, dirt deposits and condensation during the early morning hours.

The results show that the efficiency of solar energy fixation in fruit yield is negatively correlated with the incident solar energy; the efficiency in the case of the heated glasshouse crop during the early part of the year in northern Europe being nearly 8 times greater than that of the summer field crop grown in California.

The non-solar energy inputs listed in Table III have been divided into those of non-renewable fossil fuel origin and those of renewable, biological origin such as human labour and organic matter soil dressings. When expressed as fossil fuel energy input per weight tomato produced the 6 systems of production show a hundredfold range in energy intensities.

Values in Israel varied from 2·3 MJ kg^{-1} for open field production to 3·4 MJ kg^{-1} for production in unheated glasshouses, reaching 5·1 MJ kg^{-1} for spring crops protected by low plastic tunnels.

The energy intensity per unit crop from unprotected, extensive mechanized open-field production in California averages 1·4 MJ kg^{-1}, only 62 % that for the labour-intensive open field production in Israel.

By contrast, crop production in heated glasshouses in southern England required 137·1 MJ kg^{-1}, or nearly 40 times the fossil fuel requirement for production in unheated glasshouses in Israel.

Other data for tomato production in heated glasshouses show similar very high energy intensities. For example, data for tomato production in Ohio, the main area for such production in the

(F) Intensive production in heated Venlo glasshouse, spring–summer, southern coast, England

Inputs		*GJ ha^{-1}*
Organic soil conditioner	Peat 95 $m^3 \times 8{\cdot}37$ GJ m^{-3}	79·55
Fertilizers N	1214 kg: ammonium nitrate, potassium nitrate	
P_2O_5	150 kg: triple superphosphate	
K_2O	3255 kg: potassium sulphate	
Others	Kisserite	
Fertilizer sub-total		127·20
Lime	10,000 kg $\times$ 2 MJ kg^{-1}	20·00
Irrigation water	11,045 $m^3 \times 9{\cdot}1$ MJ m^{-3}	100·51
Mechanized operations	Cultivation and transport	6·00
	Depreciation and repairs	2·40
Pesticides	Fungicides 150 kg, insecticides etc. 30 kg, both $\times$100 MJ kg^{-1}	18·00
Labour	19,275 h $\times$ 0·7 MJ h^{-1}	13·49
Heating	Oil 505,800 l $\times$ 46·6 MJ l^{-1}	23,570·28
Soil sterilization	Oil 56,200 l $\times$ 46·6 MJ l^{-1}	2,618·92
Ventilation	Electricity 74·130 kWh $\times$ 14·4 MJ kWh^{-1}	1,067·47
CO_2 enrichment	Propane 9·67 t $\times$ 56·7 MJ kg^{-1}	548·06
Irrigation equipment	Trickle irrigation with liquid fertilizer injection plus overhead sprinklers	
	Polyethylene 724 kg $\times$ 106 MJ kg^{-1}/7 years	10·96
	Steel fertilizer tank etc. 400 kg $\times$ 90 MJ kg^{-1}/7 years	5·14
	Aluminium 372 kg $\times$ 253 MJ kg^{-1}/10 years	9·41
Plant support	Polypropylene string 100 kg $\times$ 149 MJ kg^{-1}	1·49
	Steel wire 230 kg $\times$ 24 MJ kg^{-1}/10 years	0·55
Venlo steel aluminium glasshouse	As system E plus heating and ventilation.	
	Amortization of glass, aluminium and steel plus construction and repairs	386·93
	Amortization of heating system 100 tonne steel $\times$ 90 MJ kg^{-1}/15 years	600·00
Miscellaneous	Plants, overheads	100·00
		29,286·36

Sources
Inputs for early, full season heated crop from U.K. Tomato Manual.[15] GER for peat represents enthalpy and transport, density at 0·1. Those of individual fertilizers and other inputs from U.K. sources.[2, 11, 12] In the absence of quantitative inputs for pesticides assumed similar to system E. Miscellaneous subtotal approximate estimate allowing for sophisticated plant propogation system,[15, 2] plus overheads associated with capital and labour intensive enterprise

U.S.A., give an energy requirement of 155·6 MJ kg^{-1} [18] and the late, March-planted tomato crop grown in heated glasshouses in Hamburg, Germany, has an energy requirement of 84·8 MJ kg^{-1}.[3]

Taking the mean of the 3 figures quoted, 125 MJ kg^{-1}, it can be seen that tomatoes grown in heated glasshouses are one of the most energy intensive plant products consumed. Their energy conversion efficiency, in terms of metabolic energy produced per unit non-solar input, is less than 1 %. This efficiency is very low in comparison with other agricultural products.[2]

The main reason for the high fossil fuel energy requirement for early tomato production in northern latitudes glasshouses is of course the need to supplement with artificial heat the prevailing low levels of insolation then available for solar heating. By comparison, the winter levels of insolation in the south eastern Mediterranean region are sufficiently high to obviate this need.

In December, daily insolation in southern England averages 1·9 MJ m^{-2}, and during the same month in southern Israel averages 11·7 MJ m^{-2} per day. During the four winter months, December to March, insolation averages 4·4 MJ m^{-2} per day in southern England and 14·5 MJ m^{-2} per day in southern Israel. Annual values show some what smaller differences, global radiation totalling 3·76 GJ m^{-2} and 7·41 GJ m^{-2}, respectively.

TABLE II

Gross energy requirements for tomato production systems, GJ ha^{-1}

Production system / *Site:*	*A* Extensive mechanized open field / *California*	*B* Labour intensive open field / *S. Israel*	*C* As B protected plastic net / *S. Israel*	*D* As B protected by low plastic tunnels / *C. Israel*	*E* Unheated glasshouse / *S. Israel*	*F* Heated glasshouse / *S. England*
Direct inputs						
Chemical fertilizer	16·3	69·3	69·3	15·8	119·2	147·2
Organic soil dressings	0	0	0	290·0	0	79·6
Soil sterilants	0	33·4	33·4	0	53·4	2618·9
Cultivation and transport	27·9	5·3	5·3	5·3	5·2	7·2
Irrigation-water	7·7	54·3	54·3	44·8	67·2	100·5
Pesticides	10·2	12·0	12·0	10·0	18·0	18·0
Heating	0	0	0	0	0	23570·3
Ventilation	0	0	0	0	0	1067·5
CO_2 enrichment	0	0	0	0	0	548·1
Plants	0·9	0·9	1·0	0·9	5·8	25·0
Labour	0·4	4·4	5·5	3·1	7·0	13·5
Overheads, etc.	6·0	6·0	6·0	6·0	9·0	46·9
Sub-total	69·4	185·6	186·8	375·9	284·8	28242·7
Indirect inputs						
Machinery	2·0	1·0	1·0	1·0	0·8	1·2
Irrigation	0	17·3	19·6	10·1	16·9	25·5
Plant support	0	32·0	40·0	0	2·2	2·0
Protective structures	0	0	64·4	159·4	387·1	386·9
Heating, ventilation	0	0	0	0	0	625·0
Miscellaneous	0·9	1·0	0·9	1·0	1·0	3·1
Sub-total	2·9	51·3	125·9	171·5	408·0	1043·7
TOTAL	72·3	236·9	312·7	547·4	692·8	29286·4

It should be emphasized here that the values for GER of early tomato production presented do not include the large quantities involved in marketing such high value and short-lived crops—i.e. for their packaging and transport.

The following calculation suggests that, in energetic terms, the difference between the cost of producing early tomatoes in northern Europe and southern Israel approximately equals the energy costs of transporting the fruit by air freight.

Thus, if all the energy costs of producing tomatoes in Israel during the first four months of the year are allocated to the fruit that is exported, then the costs vary between 55 MJ kg^{-1} for the plastic-tunnel protected spring crop to 7 MJ kg^{-1} for the crop produced during the same period in unheated glasshouses. Allowing for the greater volume of the latter form of production for export gives an approximate, average energy requirement for export production in Israel of 23 MJ kg^{-1}. Early crop production in northern Europe requires 137 MJ kg^{-1}, giving a difference of 114 MJ kg^{-1}.

The energy cost of air freighting fruit from Israel to London is 109 MJ kg^{-1} based on a local estimate of 26·4 kJ per kg km[19] which allows for the largely empty return flight, U.S. estimates of the energy costs of air freight, 103·7 kJ per kg km,[20] would almost double the energy cost of transport even without any allowance for the return flight.

TABLE III

Energy sources and efficiencies of tomato production systems

Production system	*A* *California*	*B* *S. Israel*	*C* *S. Israel*	*D* *C. Israel*	*E* *S. Israel*	*F* *S. England*
Inputs per hectare per growing season						
Solar incident on crop TJ	43·29	28·11	23·89	30·31	24·49	22·56
Non-solar:						
non-renewable-fossil fuel GJ	71·9	232·5	307·2	254·2	685·8	29193·5
renewable-labour and organic matter GJ	0·35	4·38	5·48	293·1	7·0	93·0
Outputs per hectare per growing season						
Metabolic, GJ	46	92	110	46	184	196
Yield, t	50	100	120	50	200	213
Efficiencies						
Metabolic output/ solar input	0·001$_1$	0·003$_3$	0·004$_6$	0·001$_5$	0·007$_5$	0·008$_7$
Metabolic output/ non-solar input	0·64	0·39	0·35	0·08	0·27	0·00$_7$
Metabolic output/ fossil fuel input	0·64	0·39	0·36	0·18	0·27	0·00$_7$
Intensities						
Fossil fuel input/ yield, MJ kg^{-1}	1·44	2·33	2·79	5·08	3·43	137·06
Labour input/yield, minutes kg^{-1}	1·3	3·8	3·9	5·4	3·0	5·4

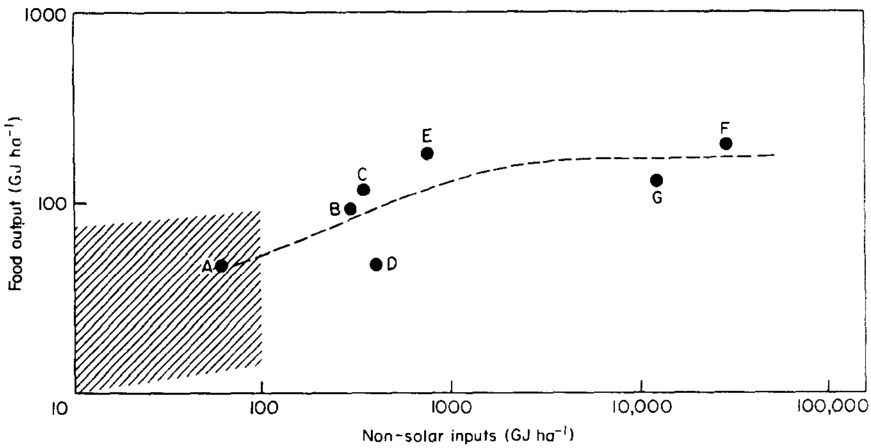

Fig. 1. Relationship between food yield output and non-solar inputs for 7 different tomato production systems in energy terms, GJ ha^{-1} *per crop (log scale). Production systems (see Table I for details):* A, *extensive, mechanized open field, California;* B, *intensive, hand-labour open field, Israel;* C, *as* B, *with open-mesh plastic net roof covering, Israel;* D, *low polyethylene tunnels, Israel;* E, *unheated Venlo glasshouse, Israel;* F, *heated glasshouse, early crop, England;* G, *heated glasshouse, late crop, Germany.*[3] *The shaded area encloses points representing all 17 fully industrialized cropping systems detailed by Leach*[2]

Within the range of production systems examined, a number are clearly less economical in their use of non-solar energy than others. For example, in Israel the doubling of energy inputs associated with production in low plastic tunnels to prolong the winter cropping season, as compared with unprotected field crops, is accompanied by a 50% reduction of the yield (*cf.* points B and D, *Fig. 1*). In northern Europe, the 3-fold increase in the gross energy requirements for the early heated glasshouse crop compared with the later, less-intensively cultivated summer crop, is accompanied by a 50% increase in yield (*cf.* points F and G, *Fig. 1*).

Clearly for tomato production, as for modern agriculture in general,[2,10 21] increased production per unit area and time is usually associated with increases in the use of inputs which depend either directly or indirectly on non-renewable, fossil fuel. Moreover, the relationship between yield output and non-solar inputs (*Fig. 1*) is such that the production processes become increasingly less energetically efficient as the output rises and harvests are advanced.

The fact that the market for the winter tomato crop is still expanding, despite increasing fuel prices, emphasizes the large gap that still exists between the results of energy and money accounting. As an extreme example, in 1977 the cost of oil for heating and sterilizing one hectare of early crop glasshouse tomatoes in southern England was approximately equal to that of labour, respectively 28% and 23% of the total production costs.[15] The energy analysis of the same production system presented in Table I(F) shows that the oil represented 89% of the gross energy requirements, whereas labour represented less than 1%.

The peaking of world oil production expected to occur within the next 20 years will almost certainly lead to further increases in the relative cost of energy and this will presumably reduce the gap between the results of energy and financial analyses. If this occurs it will have important implications for the future of protected cropping systems, both in the Mediterranean area and elsewhere.

Most of these are obvious from the above discussion, but nevertheless they may be worth restating in view of the frequency with which an increase of sophisticated protected cropping is advocated as a contribution to the world's food and even energy supply in the future.

It would appear unwise to expand energy intensive forms of protected cropping which require large annual energy inputs, whether direct—e.g. heating fuel, or indirect, e.g. polyethylene film. Future development should rather seek to increase the exploitation of the natural advantages of the region, i.e. high winter solar radiation and plentiful human labour. For instance, the development of new tomato varieties tolerant of minimal protection and low-energy transport modes, and yet acceptable to the northern European market, would appear more rewarding than attempts to achieve even greater yields through the use of more sophisticated and complete control of the environment.

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