Energy Inputs for Cantaloupe Production in San Joaquin Valley, California

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ABSTRACT

Concerns of consumers have increased the pressure on companies to become more responsible toward the environment. Wal-mart for example is pilot studying the possibility of introducing an 'energy' label on their products. This paper studies the energy inputs on cantaloupe production in San Joaquin Valley (SJV), California. To estimate the energy required to produce a kilogram of cantaloupe information was collected on the operations and various inputs such as fertilizer and irrigation used by farmers in the cantaloupe capital of the world. The energy required to manufacture fertilizers and pesticides, to produce and use the farm machinery and energy consumed during irrigation was calculated using appropriate energy equivalents from the literature. The total energy input was calculated to be 910kJ kg^{-1} or 35.3 MJ ha^{-1}. Fertilizer is the major energy input followed by irrigation and fuel. This number is relatively lower than estimates in the previous available data from 1980, and may be indicative of the adoption and advancement in drip irrigation techniques used by many growers in the SJV, and the improvement in cantaloupe cultivars better suited for the region.

Keywords energy input, cantaloupe production, fertilizer, irrigation, San Joaquin Valley

1. INTRODUCTION

High oil prices, climate change concerns and the desire of many consumers to address sustainable development issues have increased the pressure of companies to become environmentally 'friendly'. For example, in September 2007, Wal-Mart Stores Inc. announced an initiative to measure the amount of energy used to create products throughout its supply chain, including the procurement, manufacturing and distribution process (Wal-Mart, 2007). In the pilot project, Wal-Mart identified seven product categories- DVD's, toothpaste, soap, milk, beer, vacuum cleaners and soda- based on the classification that these products are commonly used by consumers. The fact that milk was included among the products would imply that there is an interest in the commodities from the agricultural sector. Assuming that similar energy inventories would be conducted in the future, either by Wal-Mart Inc. or by other commercial companies and regulatory agencies, then, there is a need to determine the energy inputs in the production of as many agricultural livestock and crop products as possible. Hence, as an initial step in filling this information gap for commercially produced crops, this paper examines the energy inputs in cantaloupe grown in the San Joaquin Valley (SJV), California (CA).

Cantaloupe (*Cucumis melo L.*) produced in the SJV was chosen for this study for two reasons. Firstly, the SJV, generally referred to as the "food basket of the world" contributes to California's ranking as the number one producer of cantaloupes in the country. For example, in

2007, cantaloupe production in CA accounted for 55% of total U.S. production and the produce was worth 149 million dollars (California Agricultural Statistics, 2008). Overall, California's agricultural abundance includes approximately 400 different commodities. Among these, the state produces about half of U.S.-grown fruits, nuts, and vegetables and many crops are solely produced in the state. In 2007, California's 75,000 farms and ranches received $36.6 billion for their output with six of the top ten counties being located within the SJV and accounting for more than $21.1 billion US dollars in cash receipts (USDA, California Agricultural Statistics, 2008). Of the six counties, Fresno continued to be the leader with an agricultural production with a value of $5.34 billion, representing an increase of 4.4 percent from the 2005 value (USDA, California Agricultural Statistics, 2008). If ranked separately, the value of agricultural commodities in Fresno county would rank it ahead of 22 other States in the United States.

Secondly, the latest energy inputs estimates for cantaloupes available in the scientific literature was conducted more than two decades ago by Johnson and Chancellor (1980). In the 1980 study, energy inputs were determined for the Imperial and San Joaquin Valley counties to be 84,364 and 103,896 MJ per ha, respectively. Energy inputs were computed for items such as machinery, gasoline and diesel, electricity, fertilizers, irrigation, pesticides transportation, beehive pollination and packing of melons. In 2006, the Imperial and SJV counties continue to be the two primary cantaloupes production areas in CA, accounting for 19,830 ha (49,000 acres) with average yields of 25.3 T/ha (11.3 tons/acre) at a gross value of $4,650 (US) per acre (Hartz el al., 2008). However, over the past two decades CA cantaloupe growers have been faced with rising costs of land, fertilizer, water, labor, and fuel, among other inputs. In response, these farmers continue to look for best management practices (BMPs) which optimize their yields and mitigate adverse environmental impacts while still being practical and economically viable to implement. For example, in an effort to improve water use efficiency and optimize vegetable yields on salt affected soils, an increasing number of SJV farmers are now using drip irrigation systems instead of furrow (flood) irrigation throughout the growing season (Hanson and May, 2007).

In this paper, we adopt an analytical approach similar to that used by Johnson and Chancellor (1980), Kallivroussis et al (2002) and others to estimate energy inputs for various items used in cantaloupe production. Energy inputs were estimated for cantaloupe production starting from primary cultivation to harvesting. Post harvest activities were not included in this study. The primary objective was to determine the energy inputs on a per hectare basis for a cantaloupe operation, in Fresno county.

2. MATERIALS AND METHODS

The average farm size in California in 2006 was 141 hectares (349 acres) (California Agricultural Statistics, 2008). The size of the field examined for the analysis in this study was around 405 hectares (1000 acres), which is considered medium to small sized for the area. The farm was located in Mendota, in Fresno county (36°45′22″N;120°22′56″W). Mendota with a population of 8,656 located 35 miles west of downtown Fresno, and with its unique climatic conditions suited for cantaloupe production, calls itself the Cantaloupe Capital of the World (Westlands Water District, 2006). Production practices, tractors and equipment used are considered typical for the area which is one the most advanced technologically in the country.

2.1 Overview of Cantaloupe Production in Fresno County

Production techniques data were collected from interviews with three different vegetable growers in the area while the actual field data and equipment used were gathered from one grower. Table 1 lists the field operations and the approximate timeline, which are typically carried out for cantaloupe production in Fresno county.

Table 1. Approximate timeline for cantaloupe operations in Fresno county

Cultivating operations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bed preparation												
Cultivating												
Weeding												
Fertilization												
Irrigation												
Harvesting												

In the SJV cantaloupes are planted in raised beds. Fields are worked into one or two meter wide beds (40 or 80 inches), with a single seed line planted per bed (Hartz et al, 2008). Fields are irrigated and in Fresno county the percentage of drip irrigated fields is increasing. After harvest the grower will cultivate the field using stubble disk (2 times). Sometimes, this operation is followed by one pass with a deep ripper. After any subsoiling the field is cultivated with a stubble disk twice. Then a land plane is used to grade the land in one pass. Dry fertilizer will be applied during a one pass disking operation. Listing of beds will take place afterwards only to be followed by pipe laying for the sprinklers. Pre-irrigation will take place to allow for cultivating operations such as lilliston, harrows and planting. After planting a couple of disking operations will take place. Harvesting will take place using packing machines, which for the largest producers are custom made.

2.2 Estimating Energy Inputs

The energy required for the production of cantaloupe was divided into direct and indirect categories. Direct energy inputs included those quantities that were consumed during actual production operations. For example the amount of energy contained in the fuel used. Indirect energy inputs were those required to manufacture and maintain durable goods, such as tractors and other farm equipment and machinery, as well as other materials used for crop production (Kallivrousis et al., 2002).

A first step in calculating the energy inputs for various implements used in the production of cantaloupes is to estimate their work rate, by using the width, speed, and field efficiency (Table 2). These values were provided by the farmer based on his extensive experience and data recorded over the years. The data were cross checked with the recommendations of the ASABE standard D497.5 Agricultural Machinery Management Data summarized in Table 3 (ASABE D497.5. 2006).

Table 2. Implements used and values of parameters for various operations for cantaloupe production

Field operation	Width	Speed[1]	Field efficiency[1]	Work rate
	m	km h^{-1}	%	ha hr^{-1}
Stubble disk	5.5	8.0	85	3.74
Subsoiler	3.7	6.0[2]	85	1.89
Tooth harrow	6.10	11.0	85	5.70
Planting machine	6.10	9.0	65	3.56
Light cultivator	6.10	7.0	85	3.63
Land planer	6.10	8.0[2]	85	4.15
Lilliston	6.10	11.0	85	5.70
Lister	6.10	8.0	80	3.90
Spaying	25	10	80	20
Lay/remove pipe				6.5
Lay/remove tape				8.10
Harvesting[2] (Packing machine)	18	0.45	90	0.81
Moving to/from field		15[2]		0.50

[1] from ASAE standard D497.5 FEB 2006
[2] from farmer data/observation

Table 3. Energy coefficients used to calculate energy inputs from farm machinery. Data were obtained from Nebraska tests, actual weight of the equipment and ASABE standard D497.5 (2006)

Item	Mass	Life	Energy coefficient
	kg	h	MJ h^{-1}
Tractor 8400T	12397	16000	111
MT835 Challenger	22441	16000	201
JD 4630	7370	16000	66
Stubble disk	5600	2000	401
Ripper	2400	2000	172
Light cultivator	2100	2000	150
Planting	1050	1500	76
Harrow	800	2000	77
Land plane	3200	2000	230
Lister	780	2000	56
Sprayer	10400	12000[1]	124
Harvester	3600	4000[2]	129
Harvesting wagon	1000	3000	48
Lilliston	1100	2000	79
Trailer (with pipes and tape)	2700	3000	129
Transportation[3]	13775	16000	123

[1] From farmer's data; [2] (from Johnson and Chancellor, 1980);
[3] Different tractors used for transportation of materials. The mass is the average of the mass of the equipment used.

2.2.1 Energy Input from Machinery

The amount of energy sequestrated in a machine consists of the energy used to manufacture raw materials, the energy required during the manufacturing process, energy for repair and maintenance and energy required to transport it form the factory to the consumer (Bowers, 1992). The energy to manufacture the farm machinery was estimated to be 86.77 MJ kg^{-1} (Pimentel, 1973).

The energy for repair and maintenance was estimated to be 0.55 times the energy to manufacture the machine (Fluck, 1985). The energy sequestered for transportation and distribution was estimated to be 8.8 MJ kg^{-1} (Lower et al., 1977). The total energy sequestered in the farm machinery will be 143.2 MJ kg^{-1}. Table 3 shows machinery parameters and energy coefficients for the implements used during cantaloupe production.

The distance from the shop to the field as well as the distance to transport fertilizers and seeds from the storage facility to the field was estimated to be 10 km. The tractor speed during these operations was estimated at 15 km/hr. It was assumed that on average one tractor move corresponded to 20 hectares cultivated based on data supplied by the farmer.

2.2.2 Energy Input from Fertilizers

The energy contained in fertilizers was calculated as the sum of the energy for manufacturing the fertilizer, packing, transporting and distributing the material. The energy embodied in the main mineral fertilizers is shown in Table 4.

Cantaloupe has moderate nutrient needs. According to Hartz et al (2008), typical fertilizer applications rates are 90 to 168 kg ha^{-1} (80 to 150 pounds per acre) of nitrogen (N) and 45 to 225 kg ha^{-1} (40 to 200 pounds per acre) of P_2O_5. The farmers surveyed in the area apply approximately 123.3 kg ha^{-1} (110 pounds per acre) of nitrogen and 168.1 kg ha^{-1} (150 pounds per acre) of P_2O_5. Most of the fertilizer was applied as dry (during a disking operation) or liquid using the irrigation system.

Table 4. Energy embedded in main fertilizers (adopted from Mudahar and Hignett, 1987)

Fertilizer	Production	Packaging, transporting and application	Total of sequested energy	Total energy per hectare
	MJ kg^{-1}	MJ kg^{-1}	MJ kg^{-1}	MJ ha^{-1}
N	69.5	8.6	78.1	9,630 (78%)
P_2O_5	7.6	9.8	17.4	2,925 (22%)
Total				12555 (100)

2.2.3 Energy input from pesticides

The energy inputs from the pesticides include the energy required for production, formulation, packaging and transportation. It should be noted that the term pesticide is a general term that includes insecticides, fungicides and other materials used for pest control. Green (1987) calculated the energy embodied in various pesticides. However, data for the pesticides used in cantaloupe production (Table 5) are not included in his study and therefore the energy was assumed to be the average of the energy contained in the pesticides listed by Green (268 MJ/Kg of active ingredient). The farmers would spray their field an average of three times during the season.

Table 5. Most common pesticides used in cantaloupes

Name	Active Ingredient	Energy per hectare
	kg ha^{-1} (Pounds/acre)	MJ ha^{-1}
Isopropyl Alcohol	0.018 (0.016)	4.8
Methoxyfenozide	1.167 (0.149)	312.7
Alpha-(Para-Nonylphenyl-Omega-Hydroxypoly (Oxyethylene)	0.102 (0.091)	27.4

Source: California Department of Pesticide Regulation, 2006.

2.2.4 Seeds

The energy sequestered in the seeds can be calculated in a variety of methods as listed by Heichel (1980). Singh and Mittal (1988) suggested that seed input was higher than the energy equivalent value of crop production output by 1 MJ kg^{-1}. Oskan et al. (2004) suggested that energy equivalents for seeds are similar to the energy equivalent of the product itself. For the current study, we used the approach of Johnson and Chancellor (1980), in which it was assumed that a value of 471 MJ ha^{-1} is representative of the energy input for cantaloupe seeds.

2.2.5 Energy input from irrigation

There is high competition for agricultural water in California, and more so in the SJV. Political, economic and hydro-ecologic parameters have created conditions where the water available for farming is limited and expensive. This has resulted in an accelerated change from the traditional furrow irrigated fields to drip irrigation where water efficiency is higher (Hanson and May, 2003). Hence, many of the large scale commercial cantaloupe growers in the SJV now utilize sprinkler irrigation systems to establish the crop, followed by sub surface drip irrigation during the remainder of the growing season. The energy input for these combined irrigation systems can be classified as being either direct or indirect (Table 6). The method of calculating the energy irrigation requirements are given in Appendix A.

Table 6. Irrigation energy requirements

Irrigation system	Total Dynamic Head	Total direct-energy requirement	Indirect energy	Total energy requirement
	m	GJ ha^{-1}	GJ ha^{-1}	GJ ha^{-1}
Drip	70	7.24	1.30	8.54
Sprinkler	72	1.86	0.33	2.19

Direct energy includes the energy consumption to lift or pressurize the overall rate of water required by the crop per hectare. This study considers the water direct energy requirement as the energy needed to irrigate the crop starting from the irrigation canal as the source of the water supply. The calculation does not include the energy needed to bring the water to the canal due to the complexity of the issue involving the political and other decision making processes by the respective irrigation districts. For the fields examined in the current study, the farmer used a sprinkler system to pre-irrigate the beds before seeding the crop. After seed emergence, the farmer switched to his buried drip irrigation system (Table 6).

Indirect energy includes raw materials, manufacturing and transportation of the different components. Fluck and Baird (1982) recommended a percentage of direct-use energy for various irrigation systems, with values ranging from as low as 18% for the traveling sprinkler system to as high as 375% for the surface with a run-off recovery system. In the current study, the authors selected 18% for both sprinkler and drip irrigation systems with the acknowledgement that, this number may be still be an overestimation because of the relatively greater proportion of subsurface drip irrigation, than sprinkler irrigation, used during the growing season (Table 6).

2.2.6 Energy from labor

Energy in labor is expended when workers carry out operations related to crop production. There are various methods of calculating energy from labor as summarized by Fluck and Baird (1982). For the purpose of this study, it was assumed that a farm laborer consumes 91.1 MJ in a 40 hour working week (Pimentel et al, 1973). A coefficient of 2.28 MJ h^{-1} was used to convert hours of labor to energy. The inverse values of work rate were multiplied by 2.28 MJ h^{-1} to obtain the energy cost of labor in h ha^{-1} (Table 7).

2.2.7 Energy from fuel

The fuel requirements from the cantaloupe production were estimated taking into account the tractor and other equipment used for every operation by taking into consideration the specific fuel consumption as derived from the Nebraska tractor tests for the corresponding tractors (Table 8). For moving to and from the field the average tractor-implement weight was used (13775kg). The distance was considered to be 10 km per trip. The method used for calculating fuel requirements are given in Appendix A.

Table 7. Energy labor requirements

Operation	Work rate	Labor	No. of workers	No .of operations	Human energy inputs
	ha h^{-1}	h ha^{-1}			MJ ha^{-1}
Disking	3.74	0.27	1	2	1.23
Ripper	2.51	0.4	1	1	0.91
Disking	3.74	0.27	1	2	1.23
Land plane	4.15	0.24	1	1	0.55
Disking – Dry fertilizer	3.74	0.27	1	1	0.61
Lister	3.90	0.26	1	1	0.59
Light cultivator	3.63	0.27	1	1	0.62
Trailer (lay/pick up pipes)	6.50	0.15	5	2	3.42
Trailer (lay/pick up pipes)	8.10	0.12	3	2	1.64
Lilliston cultivator	5.70	0.17	1	2	0.78
Harrowing	5.70	0.17	1	1	0.39
Planting	3.56	0.28	1	1	0.64
Lay/pick up tape	8.10	0.12	3	2	1.64
Lilliston x 2	5.70	0.17	1	2	0.78
Spraying	20	0.05	1	3	0.34
Harvesting	0.81	1.23	20	15	841.3
Moving to/from field	0.50	2	1	1	4.56

Table 8. Energy requirement for each agricultural operation

Operation	Specific fuel consumption	Fuel consumption	Total energy per unit of land
	kg kW^{-1} h^{-1}	l ha^{-1}	MJ ha^{-1}
Disking	0.269	13.71	655.34
Ripper	0.276	34.25	1637.15
Disking	0.269	13.71	655.34
Land plane	0.269	12.35	590.33
Light disking – Dry fertilizer	0.343	8.74	417.77
Lister	0.269	13.15	628.57
Lilliston cultivator	0.343	5.56	211.28
Harrowing	0.343	5.56	211.28
Planting	0.382	7.08	338.42
Light cultivator	0.343	5.56	211.28
Lilliston	0.343	5.56	211.28
Spraying	0.215	2.32	110.90
Harvesting	0.516	20.2	965.56
Trailer with pipes	0.311	3.12	149.14
Trailer with tape	0.311	2.51	120.00
Moving to/from field	0.311	1.00	47.80

3. RESULTS AND DISCUSSION

The energy requirements for cantaloupe production in western Fresno county are shown in Table 9. The energy inputs were calculated after multiplying the energy coefficients of Table 3 by the number of hours that the implement or tractor was used for cantaloupe production per hectare. The largest energy input was the materials with 38% of the total energy inputs followed by irrigation with 30.4% and fuel with 25% (Table 9). Primary and secondary tillage sequestered 10% each.

Our analysis shows that the energy requirement for fertilizer in cantaloupe production is approximately 38% of total and the highest input. Moreover, almost 80% of the energy sequestered in fertilizer is due to the nitrogen fertilizer. Table 9 also indicates that energy input in the form of fuel counted for more that 24% of the total energy inputs, indicating that fuel usage is the third most important energy input contributor for cantaloupe production. Fertilizer and fuel usage and management are critical components of cantaloupe production and it is very difficult to imagine significant reduction in these commodities without significant decrease of crop yield. Furthermore, these two items are correlated with the fluctuations in crude oil and petroleum prices which are controlled at the state and national level in the U.S. Hence, the farmer must continue to seek out techniques in an effort to optimize the methods of using these two inputs in his or her cantaloupe production.

Table 9. Energy input in cantaloupe production

Operation		Energy consumption, MJ ha^{-1} Machinery	Tractor	Labor	Fuel	Material	Irrigation	MJ ha^{-1}	%
Primary tillage	Disk x 2	215	108	1.23	1311			1635	4.63
	Subsoiler	59	91	0.91	1637			1788	5.06
Total								3423	9.69
Secondary tillage	Disk x 2	215	108	1.23	1311			1635	4.63
	Land plane	55	27	0.55	590			673	1.91
	Light cultivator/ dry fertilizer	41	31	0.62	211			284	0.80
	Lister	14	29	0.59	629			673	1.91
	Lilliston	14	12	0.78	211			238	0.67
	Harrow	12	14	0.39	211			237	0.67
Total								3740	10.59
Crop planting etc	Planting	19	21	0.64	338			379	1.07
	Spraying	19		1.02	333			353	1.00
	Cultivator light	41	18	0.62	211			271	0.77
	Lilliston	14	12	0.78	211			238	0.67
Total								1241	3.51
Harvesting	Harvester	218	81	841	966			2106	5.96
Total								2106	5.96
Transportation			6.15	4.6	48			59	0.17
Total								59	0.17
Irrigation	Trailer (pipe)	39.6	19.8	3.42	298			361	1.02
	Trailer (tape)	31.8	16.2	1.64	240			290	0.82
	Pre-irrigation						2190	2190	6.20
	Drip irrig.						8540	8540	24.18
Total							10730	1381	32.22
Material	Pesticides					345		345	0.98
	Fertilizer					12,555		12,555	35.55
	Seeds					471		471	1.33
Total								13371	37.86
Grand total		1007	594	860	8756	13371	10730	35321	
%		2.85	1.68	2.44	24.79	37.86	30.38		

Irrigation is the second largest energy contributor to the cantaloupe production. Irrigation systems used in the area are very efficient and although the farmers are continuously seeking for further improvements and even more efficient techniques, it is not expected to achieve significant improvements in the near future. Positive results from research aimed at optimizing nutrient and water use efficiency by aerating the water delivered during sub surface irrigation may provide a viable alternative for cantaloupe producers in the SJV (Goorahoo et al., 2008; Bhattarai et al., 2005 & 2004).

Although harvesting is a labor intensive operation, the actual energy input contribution is minimal with only 6 percent of the total energy input. Primary and secondary tillage sequestered 10% each. Tractor, agricultural equipment and labor contribute with approximately 7% of the total energy input. Although the amount of energy sequestered in transportation of fertilizers and seeds from the storage facility to the field, is included in the total energy consumption, the amount of energy for transportation of the production to the freezer is not included.

Johnson and Chancellor (1980) in a similar work for cantaloupes in San Joaquin Valley, calculated that the energy input from fertilizers was 17. 6 GJ ha^{-1} while the energy sequestered in irrigation was 20.75 GJ ha^{-1}. In our current study energy input from fertilizers was 12.55 GJ ha^{-1} (almost 29% less than in the Johnson and Chancellor study), while energy inputs from irrigation was found to be 10.73 GJ ha^{-1} (almost 48% less). The reduced energy inputs could be due to the improvement on the application rates of fertilizer with improved efficiency and the significant advances in irrigation techniques. For example, over the past two decades, cantaloupe growers have witnessed the introduction of sub-surface drip irrigation techniques and related technological advancements which have greatly improved water and fertilizer use efficiency.

Cantaloupe yield in the SJV is estimated to be approximately 38.82 tons per hectare (15 tons per acre) (Fresno County report 2007). By using the values obtained the current study it can be deduced that the amount of energy required to produce one kg of cantaloupe is 910 kJ kg^{-1}.

4. CONCLUSION

Cantaloupe production in SJV has become more efficient over the last twenty years, due primarily to the introduction and advancement of drip irrigation and the availability of improved seed varieties. The main energy input categories remain fertilizer, irrigation and fuel. Our study indicates that, excluding the energy required for packing and handling the melons, it takes around 910 kJ of energy to produce one kilogram of cantaloupe in the SJV.

Appendix A: Calculations

Work rate

The work rate was calculated by:

$C = buE_f$

Where:
b = operation width
u = speed
E_f = field efficiency of implement

Fuel

The fuel consumption per operation was calculated as follows:

$G_D = q\ P_S$

q = specific fuel consumption, kg kW^{-1} h^{-1} (from corresponding Nebraska tractor test)
P_S = Power at the gear selected, kW (from corresponding Nebraska tractor test)
G_D = fuel consumption per hour, kg h^{-1}

$G_f = G_D\ W_S$

G_f = Fuel consumption, l h^{-1}
W_S = fuel weight per liter, kg l^{-1} (from corresponding Nebraska tractor test)

$G = G_f / C$

G = fuel consumption per land unit, l ha^{-1}

Direct energy from irrigation

The needs on cantaloupe on western Fresno county are around 1510 – 1890 mm (2 -2.5 feet acre) per season. The farmer was using drip irrigation with an electric motor. He was also using 377 mm (0.5 feet acre) for pre-irrigation applied by sprinkler a common practice in the area. The area irrigated was 121.4 hectares (300 acres).

Direct energy can be expressed by following equation (Ortiz-Canavate and Hernanz, 1999):

$$DE = \frac{\delta g H Q}{n_1 n_0}$$

Where:
DE = direct-use energy in Joules per hectare

δ = water density, 1000 kg/m^3
H = total dynamic head in meters, 70 meters for the drip irrigation, 72 for the sprinkler pre-irrigation system
g = acceleration of gravity, 9.81 m s^{-2}
Q = overall rate of water in m^3 per hectare, 1507 m^3 ha^{-1} for the drip irrigation and 377 m^3 ha^{-1} for the sprinkler pre-irrigation
n_1 = is the pump efficiency, 0.65 for the centrifugal used by the farmer
n_0 = efficiency of the electric motor used, 0.22 (Ortiz-Canavate and Hernanz, 1999)

For the drip irrigation the direct energy requirement is:

$$DE = \frac{1000 \cdot 9.81 \cdot 70 \cdot 1507}{0.22 \cdot 0.65} = 7237 \frac{MJ}{ha}$$

For the sprinkler irrigation the direct energy is:

$$DE = \frac{1000 \cdot 9.81 \cdot 72 \cdot 377}{0.22 \cdot 0.65} = 1862 \frac{MJ}{ha}$$

5. REFERENCES

ASABE. 2006. D497.5. Agricultural Machinery Management Data. Michigan: ASABE.

Bhattarai, S., S. Huber, and D.J. Midmore. 2004. Aerated subsurface irrigation water gives growth and yield benefits to zucchini, vegetable soybean and cotton in heavy clay soils. *Annuals of Applied Biology*. 144: 285-298.

Bhattarai S.P., N. Su and D. J. Midmore. 2005. Oxygation unlocks yield potentials of crops in oxygen limited soil environments. *Advances in Agronomy*. 88: 313-337.

Bowers, W. 1992. Agricultural field equipment. Energy in farm production. *Energy in World Agriculture*, Vol. 6, ed. Fluck R. C., 117-129. Amsterdam: Elsevier.

Brouwer, C., Prins, K. and Heibloem, M. 1989. FAO Irrigation Water Management: Irrigation Scheduling. *Training Manual*, No. 4. Rome, Italy.

California Department of Pesticide Regulation. 2006. *Annual Pesticide Use Report Data Indexed by Commodity*. Sacramento, California.

Fluck R. C. 1985. Energy sequestered in repairs and maintenance of agricultural machinery. *Transactions of the ASAE*, 28: 738–744.

Fluck R. C. and C. D. Baird. 1982. *Agricultural Energetics*, 87-120. Westport, Connecticut: AVI.

Fresno County. 2007. *Annual Agricultural Report*. Retrieved from http://www.co.fresno.ca.us/DepartmentPage.aspx?id=23215.

Goorahoo D., D. Adhikari, F. Zoldoske, S. Cassel, A. Mazzei, and R. Fanucchi. 2008. Potential for AirJection® Irrigation in Strawberry Production. 2007. Eds. Takeda, F., D.T. Handley, and E.B. Poling *In Proc. North American Strawberry Symposium. North American Strawberry Growers Association*, 152-155. Kemptville, Canada.

Green, M.B. 1987. Energy in pesticide manufacture, distribution and the use. Energy in Plant Nutrition and Pest Control. *Energy in World Agriculture* (2): 165-195, ed. Helsel, Z. R. Amsterdam: Elsevier.

Hanson, B. and D. May. 2003. Drip irrigation increases tomato yields in salt-affected soil of San Joaquin Valley. *California Agriculture* 57 (4): 132–137.

Hanson, B. and D. May. 2007. The effect of drip line placement on yield and quality of drip-irrigated processing tomatoes. *Irrigation Drainage Systems* 21: 109–118. Online Publication: DOI 10.1007/s10795-007-9023-5

Hartz T., M. Cantwell, J. Mickler, S. Mueller, S. Stoddard, and T. Turini. 2008. Cantaloupe production in California. *University of California, Division of agriculture and natural resources*, Publication 7218.

Heichel G. H. 1980. Assessing the fossil energy costs of propagating agricultural crops. In *Handbook of Energy Utilization in Agriculture*, ed. D. Pimentel, 27–33. Boca Raton, FL: CRC Press.

Johnson H. and Chancellor W. J. 1980. Cantaloupes. In *Handbook of Energy Utilization in Agriculture*, ed. D. Pimental, 209–217. Boca Raton, FL: CRC Press.

Kallivroussis, L., A. Natsis and G. Papadakis. 2002. The Energy Balance of Sunflower Production for Biodiesel in Greece. *Biosystems Engineering*. 81 (3): 347–354.

Lower, O.J., G. Benock, N. Gay, E. M. Smith, S. Burgess, L. G. Wells, T. C. Bridges, L. Springate, J. A. Boling, G. Bradford and D. Debertin. 1977. BEEF: Production of beef with minimum grain and fossil energy inputs, I, II, III. *Report to National Science Foundation*, Washington, DC.

Mudahar M. S. and T. P. Hignett. 1987. Energy in Plant Nutrition and Pest Control. *Energy in World Agriculture*, 2: 25-61, ed. Z. R. Helsel,. Amsterdam: Elsevier.

Nebraska Tractor Test Laboratory. 1972. *Test 1113*-S*ummary 263 John Deere 4630 Power Shift Diesel*. University of Nebraska, Lincoln, Nebraska.

Nebraska Tractor Test Laboratory. 1998. *Test 1747-Summary 263 John Deere 8400T Diesel 16 speed*. University of Nebraska, Lincoln, Nebraska.

Nebraska Tractor Test Laboratory. 2003. *Test 1823-Summary 400 Challenger MT835 Diesel 16 speed*. University of Nebraska, Lincoln, Nebraska.

Ortiz-Cañavate, J. and J. L. Hernanz. 1999. Energy & Biomass Engineering. In *CIGR Handbook of Agricultural Engineering* Vol V:13-24 ed. CIGR – The International Commission of Agricultural Engineering. American Society of Agricultural Engineers.

Ozkan, B., H. Akcaoz and C. Fert. 2004. Energy input–output analysis in Turkish agriculture. *Renewable Energy* 29: 39–51.

Pimentel, D., L. E. Hurd, A. C. Belloti, M. J. Forster, J. N. Oka, O. D. Sholes and R. J. Whitman. 1973. Food production and the energy crisis. *Science*, 182: 443-449.

Singh, S. and J.P. Mittal. 1992. *Energy in production agriculture*. NewDelhi, India: Mittal Publications.

USDA's *National Agricultural Statistics Service*, California Field Office. 2008. California Agricultural Statistics, 2007 Crop Year.

Wal-Mart Stores Inc. Retrieved from http://www.walmartfacts.com/articles/5307.aspx.

Westlands Water District. 2006. Focus on Mendota- Cantaloupe Capital of the World. *Annual Report 2004 / 2005 compiled by Board of Directors of Westlands Water District.* Retrieved from http://www.westlandswater.org/long/200601/annual_report_2004_2005.pdf?title=2004-2005&cwide=1024.