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Energy structure and energy-conserving efficiency of two crop systems

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ABSTRACT

Net energy conversion rate and energy-conserving efficiency have been studied in maize and wheat, two cropland ecosystems. The calorific values of the wheat crop are greater than those of the maize crop, while the calorific values of the weeds of the wheat field are less than those of the weeds of the maize field. The energy content of the above ground standing crop gradually increased from the time of emergence to harvesting in both crops. There is a positive correlation between biomass and biocontent. Net energy-conversion rate and energy-conserving efficiency (%) of crop plants and weeds follow the same trends as shown by productivity. The average energy-conserving efficiency of maize plants (8·3%) is lower than that of wheat plants (10·26%). This indicates a more efficient use of solar energy by the wheat cropland ecosystem.

INTRODUCTION

The demand on the world's natural resources is increasing rapidly with population growth and higher living standards. A scientific appraisal of primary productivity and its maximization in natural and man-modified ecosystems is required. The rate of biomass accumulation and the efficiency with which energy is trapped, accumulated and dissipated at different trophic levels in ecosystems are important. The potential productivity of different ecosystems depends largely on the efficiency with which green plants accumulate energy as net primary production. This energy is the main source of the energy available to animals and man.

Besides the environmental factors which affect the energy capture by plants, competition between plants can influence the distribution pattern of assimilates. To study the effect of weed competition on energy use by crop plants, this study of the ecological energetics of two agricultural ecosystems (wheat and maize) was undertaken.

AGROCLIMATIC CONDITIONS

Meerut, a part of the Indo-gangetic plain of Western Uttar Pradesh, lies between 28° 33′ and 29° 18′ N latitudes and 77° 07′ and 78° 12′ E longitudes. It has a semi-arid climate with air temperature ranging between 5·5°C and 45°C. The average annual rainfall is 804 mm, most of which is received during the period of July to September. During 1979, the minimum monthly rainfall was noted in December (1·1 mm) and the maximum in July (192·9 mm), with no rainfall in November. The soil of the experimental site is sandy clay loam, with about 36% sand, 29% silt and 35% clay. The water holding capacity of the soil is 24·15%. It is acidic (pH 5·5) with poor inorganic constituents. The percentage of N, P, K, Na, Ca, and organic carbon is low. Five fields each of wheat and maize (about 2 acres each) were selected for the present study on Meerut University Agricultural Farm. Wheat is a *rabee* (spring) crop sown in early December and harvested in April. Maize is a *khareef* (autumn) crop sown in July and harvested in October.

METHODOLOGY

Sampling was done by using quadrats of 1 m^2 area (Tripathi & Mishra 1971). Five quadrats were sampled randomly from each field. All plants in each quadrat were clipped at the base. The harvest was separated into two groups, crop plants and weeds. It was dried in an oven at 60°C for 48 h. The above ground biomass was obtained by weighing the oven dried material. Sample powders of the biomass were prepared at 10-day intervals till the harvesting of the crop.

DETERMINATION OF CALORIFIC VALUES

Three pellets of about 1 g each were prepared from each powdered sample and dried in a desiccator. The calorific values were determined by igniting the pellets in an oxygen bomb calorimeter. They were expressed in kcal g^{-1} dry weight (Leith 1968).

Energy structure

The energy content of the above-ground standing crop was obtained by multiplying the biomass by the appropriate calorific value and expressed as kcal m^{-2}.

NET ENERGY CONVERSION RATE

Net energy conversion rate (NECR), the change in energy content per unit time and space (kcal m^{-2} day^{-1}) was calculated by the following formula:

$$\text{NECR (kcal}^{-2}\,\text{day}^{-1}) = \frac{\text{Cal}_2 - \text{Cal}_1}{t_2 - t_1}$$

where Cal_1 and Cal_2 are the standing state of energy per unit of ground area at time t_1 and t_2 respectively.

Energy-conserving efficiency

The energy conserving efficiency (%) was determined using the following formula:

$$\text{ECE (\%)} = \frac{\text{Energy captured by the net dry matter m}^{-2} \times t}{\frac{1}{2}\ \text{total solar radiation m}^{-2} \times t} \times 100 \quad .$$

Data on total solar radiation $day^{-1} cm^{-2}$ were obtained from the Regional Meterological Centre, New Delhi. Only half of the solar radiation was considered to be photosynthetically active radiation (PhAR) for computing the energy conserving efficiency.

RESULTS AND DISCUSSION

Tables 1 and 2 give the calorific values for both crops and their associated weed species. It will be seen that the values vary with the age of the plants. The greatest calorific values of the crop and the weeds of the maize fields were recorded on the 45th day after sowing, while for the wheat crop it was the 100th day and for the weeds on the 40th day. Variations in the calorific values with age have also been reported by Ovington & Heitkamp (1960) for forest plantations, Dwivedi (1970) for *Dichanthium annulatum*, Gupta (1972) and Singh & Ambasht (1975) for grasslands and Singh (1975) for rice.

The calorific values of the wheat crop were higher than those of the maize crop. This may be due to seasonal differences as Long (1934) has also reported that variation in the calorific values correspond to season. The greater winter values may be due to a higher percentage of fats and proteins produced in that season since fat is synthesized at low temperatures (McNair 1945; Mayer & Anderson 1952). According to Trukhin & Milkryakova (1969), in extreme high temperature and light intensity, the relative rates of protein and lipid synthesis decrease. Furthermore, the reduced water contents in plants during summer may also reduce protein content by blocking glycolysis, Kreb cycle and amination (Shah & Loomis 1965). This may explain the lesser calorific values of maize compared to those of wheat. Weed competition also seems to be important in explaining the smaller calorific values of maize. There is a high incidence of weeds in maize fields. This is because the low sowing density of maize plants provides space and light for the weeds to grow and flourish. The high weed competition in maize fields may lower calorific values. In wheat fields the higher density of wheat plants does not allow a profuse development of weeds. Hence weed competition is relatively small and results in high calorific values of the wheat crop.

Ovington *et al.* (1963) reported that the calorific values for maize fields, prairie savannah and oakwood ecosystems were 4·5, 4·8 and 4·6 kcal cm^{-1} dry weight respectively. Leith (1968) observed that the calorific values of *Helianthus annuus, Zea mays* and the mixed forest were 4·3, 4·2 and 4·7–4·9 kcal g^{-1} respectively. Golley (1961) recorded the calorific values of *Andropogon viriginalis* as 4·2–4·3 kcal g^{-1}. The calorific values for grasslands at Gyanpur and Varanasi were 3·82–3·97 and 3·8–4·8 kcal g^{-1} respectively (Gupta 1972; Singh & Ambasht 1975). The average energy content of the maize crop observed in this study (3·4 kcal g^{-1}) is lower than the values reported by Ovington *et al.* (1963) and Leith (1968). The energy content of weeds of the maize and wheat fields (4·8 kcal g^{-1} and 4·1 kcal g^{-1} respectively) is close to the values obtained by Singh & Ambasht (1975) for grasslands. The energy content of wheat crop (4·7 kcal g^{-1}) is close to the mixed forest as reported by Leith (1968).

The percentage energy-conserving efficiency of maize fields has been reported as 0·35% (Ovington & Lawrence 1967), that of an old field broomsedge community as 0·3–0·4% (Singh & Ambasht 1975), while six rice varieties averaged 10·4% (Singh 1975).

Table 1. Ecological energetics of a maize crop and its weeds at different periods of growth of the crop

Age of the crop in days	Caloric values kcal g^{-1} dry weight			Above-ground standing crop kcal m^{-2}		NECR kcal m^{-2} day^{-1}			ECE %		
	Crop	Weeds	t	Crop	Weeds	Crop	Weeds	t	Crop	Weeds	t
15	3·256 ±0·10	4·032 ±0·20	3·61*	52·09 ±0·35	85·47 ±0·27	3·47 ±0·12	5·69 ±0·10	24·63**	1·50 ±0·08	3·11 ±0·10	21·84**
25	3·504 ±0·20	4·512 ±0·10	4·70**	99·23 ±0·25	175·71 ±0·36	4·71 ±0·14	8·82 ±0·16	33·52**	1·72 ±0·11	24·85 ±0·17	198·20**
35	3·857 ±0·04	5·319 ±0·15	4·61**	123·42 ±0·22	391·47 ±0·27	2·41 ±0·09	21·77 ±0·20	153·16**	0·88 ±0·05	7·94 ±0·12	14·60**
45	4·068 ±0·06	5·380 ±0·22	9·11**	650·88 ±0·38	365·84 ±0·34	52·74 ±0·18	−2·56 ±0·07	450·04**	19·25** ±0·26	−1·14 ±0·06	764·10**
55	3·136 ±0·13	5·082 ±0·17	15·76**	815·36 ±0·46	898·49 ±0·39	16·44 ±0·21	53·26 ±0·26	190·87**	7·34 ±0·14	23·77 ±0·24	639·20**
65	3·110 ±0·11	4·884 ±0·14	17·29**	1244·00 ±0·29	791·20 ±0·39	42·86 ±0·23	−10·72 ±0·14	206·95**	19·13 ±0·22	−4·78 ±0·12	99·30**
Average	3·448 ±0·35	4·860 ±0·53	5·29**	–	–	20·43 ±20·19	22·38 ±18·80	00·16	8·30 ±7·98	14·92 ±9·40	1·16

*Significant at 0·05 level. **Significant at 0·01 level. NECR = net energy conversion ratio, ECE = energy-conserving efficiency.

Table 2. Ecological energetics of a wheat crop and its weeds at different periods of growth of the crop

Age of the crop in days	Caloric values kcal g^{-1} dry weight			Above-ground standing crop kcal m^{-2}		NECR kcal m^{-2} day^{-1}			ECE %		
	Crop	Weeds	*t*	Crop	Weeds	Crop	Weeds	*t*	Crop	Weeds	*t*
30	4·889 ±0·15	4·012 ±0·10	8·52**	92·59 ±0·35	17·85 ±0·21	3·08 ±0·16	0·59 ±0·08	24·12**	5·56 ±0·17	1·07 ±0·09	40·48**
40	4·331 ±0·11	4·459 ±0·13	1·30	211·35 ±0·43	122·89 ±0·32	11·87 ±0·20	10·50 ±0·19	8·61**	5·82 ±0·20	5·14 ±0·16	4·60**
50	4·540 ±0·14	4·026 ±0·16	4·21*	544·80 ±0·47	354·24 ±0·26	33·34 ±0·18	23·13 ±0·22	62·25**	16·34 ±0·24	4·31 ±0·18	63·68**
60	4·840 ±0·12	3·980 ±0·11	9·15**	677·60 ±0·42	652·72 ±0·30	13·28 ±0·15	29·84 ±0·20	114·76**	5·30 ±0·12	14·63 ±0·26	50·47**
70	4·997 ±0·18	3·996 ±0·14	7·68**	995·40 ±0·49	832·86 ±0·36	31·78 ±0·24	18·01 ±0·16	82·70**	12·68 ±0·28	7·19 ±0·14	30·39**
80	5·015 ±0·21	4·389 ±0·13	4·39*	1303·90 ±0·50	905·18 ±0·34	30·85 ±0·21	7·12 ±0·12	169·98**	12·31 ±0·25	2·88 ±0·10	60·72**
90	4·265 ±0·15	3·825 ±0·09	4·27*	1447·04 ±0·55	800·61 ±0·33	14·31 ±0·17	−10·35 ±0·15	30·29**	4·75 ±0·16	−3·47 ±0·12	11·09**
100	5·080 ±0·19	4·229 ±0·14	6·25**	2032·00 ±0·62	934·60 ±0·41	58·59 ±0·30	3·04 ±0·10	304·38**	19·43 ±0·23	4·45 ±0·21	83·31**
Average	4·740 ±0·30	4·110 ±0·20	38·88**	—	—	24·63 ±16·51	10·23 ±9·78	2·14*	10·26 ±5·33	4·65 ±3·93	2·39*

*Significant at 0·05 level. **Significant at 0·01 level. NECR = net energy conversion rate, ECE = energy-conserving efficiency.

In the present study, the following percentage energy-conserving efficiencies were observed: maize plants—8·3%; weeds of maize crop—14·92%; wheat plants—10·26%; weeds of wheat crop—4·65%. Since Ovington & Lawrence (1967) used total incident solar radiation and Golley (1966) estimated gross production rather than net production, no direct comparison with their observations can be made. The values obtained in the present study are comparable to those of Singh & Ambasht (1975) and Singh (1975) since they determined net production for half of the total incident solar radiation.

This study indicates that the productive potential of the wheat cropland ecosystem is higher than that of maize cropland ecosystem.

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بنية الطاقة وكفاءة الحفاظ عليها في محصولي الذرة والقمح

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خلاصة

في هذا البحث ، تمت دراسة المعدل الصافي لتحويل الطاقة ، والنسبة المئوية لكفاءة الحفاظ على الطاقة في نظامين بيئيين زراعيين لحقلين للذرة والقمح .

ان محتوى محصول القمح من السعرات الحرارية اعلى من محتوى محصول الذرة ، بينما كان محتوى الحشائش البرية في حقل القمح من السعرات اقل من محتوى الحشائش النامية في حقل الذرة . واثبتت الدراسة ان محتوى كل من الذرة والقمح من الطاقة يزداد تدريجيا من مرحلة ظهور البادرات حتى مرحلة جني المحصول . كما ظهر ان هناك علاقة موجبة بين الكتلة الحية لكلا المحصولين ، ومحتواهما من الطاقة .

ان متوسط كفاءة الحفاظ على الطاقة يبلغ ٨,٣٪ في محصول الذرة ، و ١٠,٢٦٪ في محصول القمح ، مما يشير الى ان محصول القمح يستخدم الطاقة الشمسية بكفاءة اكبر .