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TECHNICAL NOTE

The optimum energy harvest efficiency of nitrogen fixing hydrophyte: *Azolla pinnata*

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Abstract—Azolla is a nitrogen fixing hydrophyte that can be cultivated in absence of nitrogenous fertilizer. It is found that when biomass is continuously harvested from a culture of Azolla, solar energy can be converted at an optimum efficiency of 1.1%

INTRODUCTION

One of the best ways of capturing solar energy is green plant photosynthesis. Numerous studies indicate the feasibility of utilizing special plant products or biomass as a whole for the purpose of energy generation [1–5]. The suitability of a plant species as an energy crop depends on photosynthetic efficiency, irrigation and fertilizer requirements, harvestability and the nature of processing needed to extract energy. A good energy crop must have high photosynthetic energy storage capability and investment for all the other processes must be minimum. Recently we suggested that the most ideal energy crop should admit continuous biomass (energy) extraction while maintaining quasistatic equilibrium with the growth process [6, 7]. This idea also enabled us to define a parameter termed optimum energy harvest efficiency (OEHE), which is a measure of the suitability of a species as an energy crop. The OEHE of a plant species can be defined as follows: a large number of biological growth kinetics, including the growth of a plant community approximates to the logistic law. That is, if N is the weight of biomass produced per unit area in a time t, the rate of change of N is described by the differential equation [6, 7]:

$$\frac{\mathrm{d}N}{\mathrm{d}t} = kN - aN^2 \tag{1}$$

where k = rate constant, a = the coefficient of interspecific interaction. Suppose biomass is harvested continuously at a rate C, eq. (1) takes the form

$$\frac{\mathrm{d}N}{\mathrm{d}t} = kN - aN^2 - C. \tag{2}$$

Biomass can be extracted keeping the system in quasistatic equilibrium if,

$$C = kN - aN^2 \tag{3}$$

and C has a maximum value $C_{\max} = k^2/4a$ when $N = k/2a$. If b is the energy stored in biomass per unit weight and I is the intensity of solar radiation (i.e. light energy incident per unit area per unit time). OEHE can be expressed in the form

$$\eta_{\max} = \frac{k^2 b}{4aI} = \frac{KN_s b}{2I} \tag{4}$$

where N_s = the value of N at the saturation.

The expression (4) depends on measurable parameters k, a, b and I of which k, a and b are characteristics of the species. Continuous biomass extraction requires rapid propagation of plants without irreversible changes. Plants that distribute vegetatively and do not require intermittent inoculations satisfy the above conditions. Free-floating aquatic plants approximate to the above situation as they undergo rapid vegetative reproduction and distribute themselves without the need of an artificial assistance. In our earlier studies we have measured the OEHE of aquatic plants *Lemna major* and *Salvinia molesta* [7, 8]. In this work we report the measurement of OEHE for *Azolla pinnata*. Azolla could have advantage as an energy crop because its cultivation does not require nitrogeneous (Anabaena) symbiotically [8, 9]. The major nutrient requirement of Azolla is phosphate [8] and many countries not possessing fossil fuel resources for nitrogeneous fertilizer production have large deposits of rock phosphate.

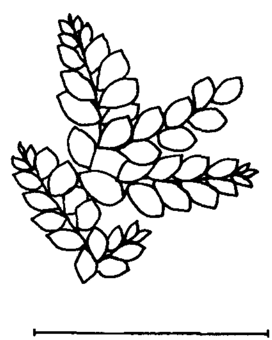

Fig. 1. *Azolla pinnata*.

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EXPERIMENTAL

Azolla is an aquatic fern native to Asia, Africa and the Americas. Several varieties of Azolla are cultivated extensively in China, Vietnam and other countries in South East Asia as a nitrogen supplier to the rice fields. The variety used in the present experiment is *Azolla pinnata* (Fig. 1). Our experiment for the determination of OEHE was carried out by inoculating a known weight of Azolla fronds to six glass walled tanks of cross-sectional area $\simeq 90\,cm^2$ (outside surface painted black to minimize the growth of algae and other photosynthetic organisms). Distilled water was used to prepare the culture solution to which all nutrients (Table 1) excluding nitrogen were added. The intensity of solar radiation was continuously monitored using a pyranometer and intergrator (EKO Industries Models Mp-20 and MS-801 respectively). At different stages of growth (two day intervals) the fronds of Azolla were removed from tanks, water blotted out, quickly weighed and transferred back to the tanks. The mean of six measurements were taken to calculate

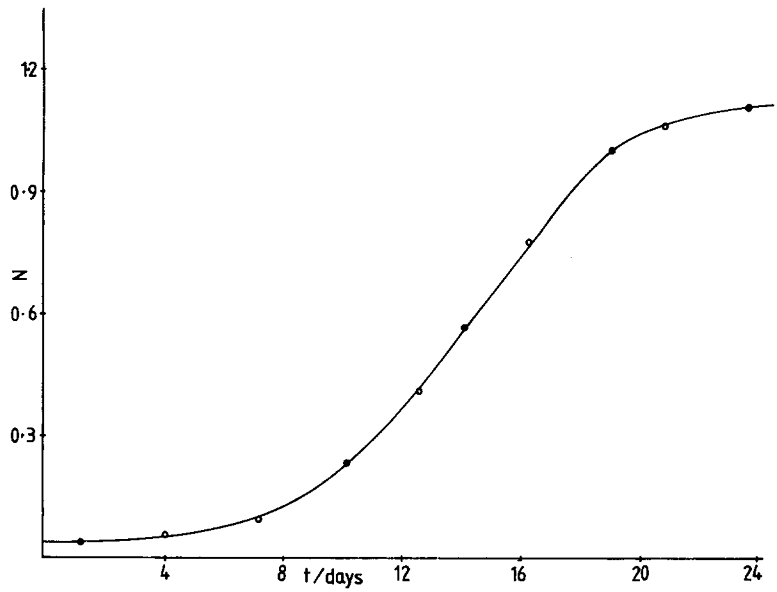

Fig. 2. The growth curve for *Azolla pinnata* (N = biomass wet wt./m^2).

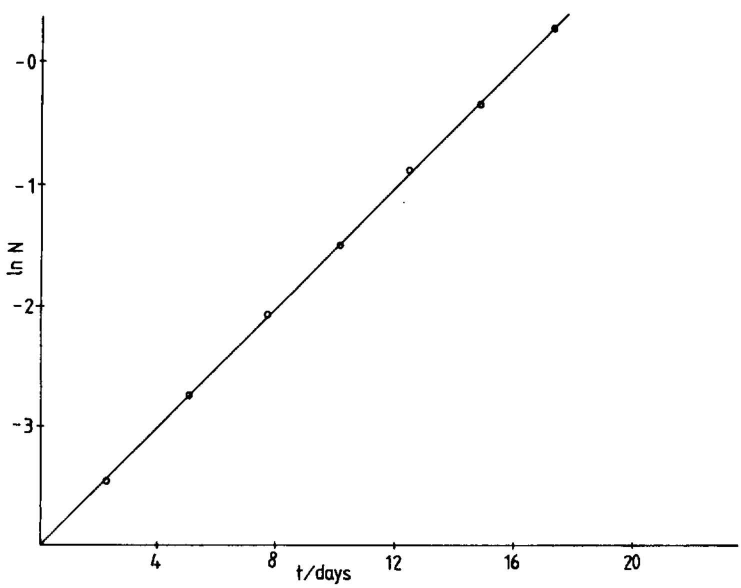

Fig. 3. The plot of ln N vs t for the initial phase of growth.

Table 1. The concentration of nutrients in the culture solution

Nutrient	g/l^{-1}
K_2SO_4	0.09
$CaCl_2$	0.10
$MgSO_4$	0.20
NaH_2PO_4	0.70
Ferric citrate	0.01

N. The mean temperature ($\sim 27°C$) and the relative humidity (average $\sim 76\%$) were also recorded. From the growth curve (Fig. 2) it is seen that an equilibrium biomass of 1.1 kg m^{-2} is approached in about 25 days. Samples of biomass removed from the tanks at this stage were dried in an oven at 105°C, the dry weight per wet weight was found to be 5.1%. Dried biomass grounded and the caloric value was determined by bomb calorimetry (Shimadzu Auto-calculating Bomb calorimeter CA-4P).

RESULTS AND DISCUSSION

The variation of the biomass yield with time is presented in Fig. 2. Clearly the curve has the logistic shape expected from eq. (1) and the saturation biomass yield is 1.1 kg m^{-2}. At initial stages of growth the interspecific competition becomes negligible and the plot of ln N vs t is approximately linear. The rate constant obtained from such a curve (Fig. 3) is 0.25 day^{-1} (i.e. the doubling time $= k^{-1} \ln 2 \simeq 2.7$ days). The caloric value (b) determined as the average of five measurements is 4583 cal g^{-1} dry wt. and the mean value of I during the period of measurement was 1.28×10^4 kJ day^{-1} m^{-2}. From above data we obtain $\eta_{max} = 1.1\%$. OEHE previously determined for two other aquatic weeds *Lemna major* and *Salvinia molesta* [7] are somewhat larger. However, as Azolla does not require nitrogenous fertilizer, biomass conversion system based on this plant could have higher potential. Azolla is known to contain 3.5% by dry wt. of nitrogen. Thus the above measurements also shows that an Azolla based biomass conversion system could fix atmospheric nitrogen at a rate 2.5 kg ha^{-1} day^{-1}.

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