

THE OCCURRENCE OF *AZOLLA PINNATA* IN SRI LANKA

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ABSTRACT

Early records have indicated the species *Azolla pinnata* as indigenous to Sri Lanka. This study located a number of natural habitats of *Azolla* in Sri Lanka which differed widely in rainfall, temperature and elevation.

All natural habitats of *Azolla* were confined to locations that were wet at most times of the year. The survival of *Azolla* during dry periods seemed to be through spores that are produced abundantly under natural conditions. Although the flood water in rice fields where natural habitats of *Azolla* were located had very low concentrations of phosphorus, *Azolla* was seen to grow well and showed indications of having a considerable ability to fix atmospheric nitrogen.

An environment favourable to *Azolla* seems to be very rare in nature; it is confined to specific locations, occupying a very small niche.

INTRODUCTION

Until recent times the tiny water fern *Azolla* has not been of much interest to many agricultural scientists although it had been a botanical curiosity since the early part of this century owing to its unique symbiotic relationship with the nitrogen fixing cyanobacterium *Anabaena azollae* (Moore, 1959; Ashton and Walmsley, 1976; Lumpkin and Plucknett, 1982). The fuel crisis of the early 1970s caused an escalation in costs of chemical fertilizers, necessitating agriculturists to seek alternate sources of plant nutrients. Consequently scientific interest developed on *Azolla* as a possible source of nitrogen and organic matter to rice soils. This interest was further enhanced by the long history of use of the *Azolla* plant as a green manure for rice in some parts of the Far East (Lumpkin and Plucknett, 1982).

A considerable amount of research has been carried out during the last decade on various aspects of *Azolla* in many countries including Sri Lanka, using successfully cultured *Azolla* plants from greenhouses and field plots. Encouraging results have been obtained to prove its agronomic potential although some problems exist that need to be solved before *Azolla* could be successfully fitted into the rice farming system (Moore, 1969; Lumpkin and Plucknett, 1982).

Of the six species of *Azolla* found in the world today, *Azolla pinnata* R. Br. is reported to be the species that occurs in tropical Asia (Moore, 1969; Kulasooriya *et al*, 1980; Lumpkin and Plucknett, 1982). One of the earliest records stating *Azolla pinnata* R. Br. as a plant found in Sri Lanka was in 1902 (Moore, 1969). Willis (1911) listed *A. pinnata* under the plant family Salviniaceae.

Of all recorded information on *Azolla*, very little is available on its natural existence. A study of the environmental conditions under which *Azolla* grows in its natural habitat as a wild plant is likely to provide a sound understanding about the growth of this plant and assist in its possible future exploitation. This paper identifies some of the natural habitats of *A. pinnata* in Sri Lanka and describes the environmental conditions affecting its natural existence.

MATERIALS AND METHODS

Information regarding locations where *Azolla* occurred naturally was obtained from the Extension staff of the Department of Agriculture. These locations were visited several times to study the life cycle of the plant and the environmental conditions of the habitat. People living close to each location were questioned in regard to the presence of *Azolla*, especially to find out whether the plant had been recently introduced. A habitat was considered natural if *Azolla* was known to have been present there for a period of at least fifty years. Fresh *Azolla* plants, soil and flood water samples were collected from habitats that were located in rice fields, for chemical analysis in the laboratory. The plants were washed carefully to remove soil particles and algae entangled with roots, dried to constant weight at 60°C and analysed for nitrogen, phosphorus, potassium and carbon by conventional methods. Soil samples were analysed for pH,

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available phosphorus (Olsen) and organic matter (Walkley-Black). Flood water samples were first evaporated until the volume was reduced sixfold and then analysed for phosphorus.

RESULTS AND DISCUSSION

The natural habitats of *Azolla* investigated are shown in Table 1 and their distribution in Figure 1. *Azolla* is found at a number of locations ranging from water bodies in the dry zone to rice fields at elevations of over 1000 metres, thus illustrating its ability to grow under diverse conditions of temperature, rainfall and elevation. Apart from its presence at Sigiriya, Debokkawa and Tissamaharama irrigation reservoirs, *Azolla* found at other locations was only in flood water of rice fields.

The morphological features of *Azolla* plants found at each of the locations reported here were similar and closely resembled those described by Lumpkin and Plucknett (1982) as of the species *Azolla pinnata*. Each small *Azolla* plant (about 1 cm in frond diameter) consisted of a multibranched, prostrate floating stem which bore deeply bilobed tiny leaves and an adventitious root system that hung down into the water. The frond of these plants exhibited the typical triangular shape of the species *A. pinnata*.

The growth of *Azolla* in rice fields having a rice-rice cropping system, a rice-vegetable cropping system and its presence in irrigation reservoirs are described below.

Azolla in fields having a rice-rice cropping system

Rice fields with a rice-rice cropping system where *Azolla* was found (Table 1) are often terraced and situated on steep to gently sloping landscape of inland valleys surrounded by high rising mountains. Rice cultivation in these areas is mainly rainfed. The surrounding mountains serve as reservoirs of water to the rice fields. Their abundant and continuous supply creates perennial springs in some rice tracts. The portions of rice tracts that are supplied by perennial springs are commonly referred to by farmers as "Ulpath Kumbura" or "Wagala" due to their year-round wetness. *Azolla* is usually found in the vicinity of these springs. The importance of a continuous supply of water for the growth and multiplication of *Azolla* is borne out by the fact that it is confined to specific areas of large rice tracts

that are always wet, while it is not present in the rest of the rice fields although the latter receive the same rainfall. The word *Azolla* has been derived from the conjugation of two Greek words with the meaning "killed by drought" (Lumpkin and Plucknett, 1980). The association of *Azolla* with water is also evident in Sri Lanka from the names "diya mal", "mada mal", "diya pasanam" and "parsa" given to the plant by the people of the localities where it is growing naturally.

The growth, multiplication and decline of the *Azolla* population followed a similar pattern at all locations and is diagrammatically shown in Figure 2. The first appearance of *Azolla* often occurred in the flood water just prior to transplanting rice. Following transplanting of rice, *Azolla* multiplies and grows along with the rice crop and 4—6 weeks later, patches of dense green *Azolla* covers could be seen on the surface of the flood water under the rice canopy. This is the stage at which a maximum mass of *Azolla* is observed. The area of the *Azolla* cover in the rice field at this stage is usually small and variable, ranging from a few square metres to about 200 square metres.

Although *Azolla* plants in the shade of the rice canopy remain green, those that get exposed to direct sunlight turn red occasionally. According to Lumpkin and Plucknett (1980), this reddening in *Azolla* is due to the formation of the pigment anthocyanin which is thought to protect the photosynthetic apparatus from damage caused by high light intensities. Besides light intensity, reddening in *Azolla* has been observed under other stress conditions such as limited availability of phosphorus and temperature (Kulasooriya *et al*, 1980; Watanabe *et al*, 1980; Gunapala and Amarasingi, 1983). However, in these natural habitats the reddening was observed only in plants directly exposed to sunlight and is probably an effect of high light intensity.

At the maximum bio-mass stage, *Azolla* plants are normally found laden with sporocarps indicating maturity. Only microsporocarps are visible to the naked eye. The megasporocarps could be observed through a hand lens. An infestation of *Azolla* plants by larvae of an insect pest (that has not yet been identified) is common at this time. The grey or dark brown larvae fasten the *Azolla* plants with a whitish silky thread to form cocoons within which they reside and feed fast on the leafy parts of plants

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leading to a rapid destruction of the cover. A very large number of pinkish and orange coloured sporocarps can be seen to settle on the mud with the decomposing plant debris.

Azolla plants are rarely observed at or near harvest of the rice crop when there is no standing water in the field. Those which remain get incorporated into the soil during land preparation for the next season. Soon after land preparation, no trace of *Azolla* could be seen in most of these habitats. The germination of spores in the soil probably leads to the reappearance of *Azolla* in the flood water of the next rice crop.

The fluctuation observed in the *Azolla* population in a rice field may be due to the influence of water availability, increased shading due to the growing rice canopy, pest attack and other environmental factors.

Most rice farmers who are familiar with *Azolla* growing in their rice fields have not associated it with any direct harmful or beneficial effect on rice. Some farmers however, have indicated its weed control ability in places where it forms a thick cover in the flood water. In an investigation to study the effect of an *Azolla* cover on the growth of weeds in a rice field, *Azolla* was found to suppress the normal weed growth by 34 to 53 percent under different planting patterns of rice (Kulasooriya *et al*, 1984). Janiya and Moody (1981) observed that the ability of *Azolla* to suppress weeds is dependent on the weed flora present. Their observations revealed that annual species with weak stems are easily suppressed by an *Azolla* cover in the rice field.

Azolla in fields having a rice-vegetable cropping system

Azolla is found in some fields in Hewaheta, Maturata, Nildandahinna and Welimada, where rice is cultivated in the wet season (maha) and vegetables are grown in the dry season (yala). The physical environment of these localities is quite similar to that described earlier for the rice-rice cropping system. Vegetables are cultivated in the dry season mainly owing to higher income than from rice; moreover, the availability of water for a rice crop is less than optimal in many fields.

The growth of *Azolla* during early maha in rice fields and its subsequent decline are almost identical to that described earlier. *Azolla* is not normally observed in these habitats when vegetables are cultivated during yala due to

the absence of standing water but sometimes may be found in small pockets of water close to the perennial springs. *Azolla* reappears as the fields are flooded for the maha rice crop. Farmers state that the amount of *Azolla* found in maha has declined steadily over the years, attributing this to the influence of the upland condition maintained in the soil for the yala vegetable crop which is a recent introduction.

The survival of *Azolla* between two maha seasons seems mainly to be through spores that may have the ability to retain their viability for long periods in the soil even in the absence of standing water. In fact, Lumpkin and Plucknett (1982) stated that spores of *Azolla* can withstand periods of a year or more out of water without losing viability. Gurunathan and Sreerangasami (1980) have observed a period of dormancy of 2—3 months in spores of *Azolla* before germination.

Azolla in irrigation reservoirs

Azolla is found on the banks of an irrigation reservoir at Sigiriya and also in the shallow waters of the irrigation reservoirs "Tissa wewa" and "Debokkawa wewa" at Tissamaharama and Debokkawa respectively. In these habitats *Azolla* grows among many other aquatic plants. Plants of genera *Lemna*, *Nymphaea*, *Pistia*, *Salvinia* and *Eichhornia* are commonly found in these habitats. *Azolla* is difficult to detect when growing among these plants.

The appearance of *Azolla* in these large water bodies commences following maha rains, *Azolla* multiplies vegetatively and is often found under the canopy of large water plants. An extensive coverage of *Azolla* was not found in any of these habitats at any time of the year. Presence of *Salvinia* and other hardy plants as well as the turbulence of water seem to limit the propagation and spread of *Azolla*. According to Ashton and Walmsley (1976), when *Azolla* plants are exposed to areas of open water where wind and wave action are high and a large degree of turbulence exists, plants get easily fragmented causing a marked reduction in growth and nitrogen fixing activity. The authors stated that on such bodies of water the successful development of *Azolla* covers would be very unlikely.

The likely lower nutrient content of the water at the centre of irrigation reservoirs than at the shallow regions may also be one of the reasons for *Azolla* to confine itself to the banks and not spread over the entire body of

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water. *Salvinia*, on the other hand, shows a much greater ability to rapidly cover a water surface in spite of it not being able to fix atmospheric nitrogen. According to Room and Kerr (1983), finely dissected leaves of *Salvinia molesta* (the species common in Sri Lanka) that are believed to function as roots, hang down from the rhizome to depths ranging from 4 cm in nutrient-rich water to 50 cm in nutrient-deficient water. In contrast, the length of the individual roots of *Azolla* plants when mature are reported to vary from 1 cm to 5 cm only (Lumpkin and Plucknett, 1982). This may explain the superior ability of *Salvinia* to spread over the surface of large water bodies.

Floods and drought wipe out *Azolla* from these water bodies, but it reappears when favourable conditions return. The presence of heavy sporulation in mature plants indicates the possibility of its continued existence in these habitats by way of spores.

Chemical characteristics of *Azolla* and its habitats

As shown in Table 2 the soil pH in all natural habitats found in rice fields ranged from 4.0 to 5.9. The pH of the growing medium is an important factor that can affect the growth of *Azolla* owing to its influence on the availability of essential nutrients. Effects of pH of the growing media on *Azolla* plants have been studied, but mostly using pot cultures which are not quite representative of actual field conditions. The optimum growth of *Azolla* in nutrient solution culture took place within the pH range of 4.5 to 7.9, but plants showed the ability to survive within the range of 3.5 to 10.0 (Lumpkin and Plucknett, 1982).

The most common nutrient element that limits the growth of *Azolla* in the field is phosphorus. Addition of phosphorus has been found to bring about a rapid growth and an increase in bio-mass of *Azolla* in the field (Watanabe *et al*, 1980; Gunapala and Amarasiri, 1983). The available P content in soils of natural habitats in rice fields ranged from values as low as 3.5 ppm to values over 100 ppm (Table 2). This wide variation is mainly due to the differing fertilizer application practices adopted at different locations. The soil P contents lower than 10 ppm were observed in rice fields where the practice of cultivating a rice crop twice a year had prevailed for many years. Here the application of chemical fertilizers and organic

manures to rice are somewhat limited. On the other hand the soil P values at Maturata and Welimada are quite high owing to addition of large quantities of fertilizer to the high-income-generating vegetables grown there.

Regardless of the amount of available P in the soil, the P content in flood water of rice fields ranged from 0.01 to 0.07 ppm (Table 2). *Azolla* obtains its entire P requirements from that dissolved in the water. The optimum concentration of P in the growing medium of *Azolla*, as found using nutrient culture solutions, was much higher than that of the flood water in this study (Subudhi and Watanabe, 1981). Although the P in the flood water is of low concentration in the natural system, it is replenished from the soil as *Azolla* absorbs phosphorus. Further, due to the topographical position of all natural habitats in these rice fields, the replenishment of P in the flood water could also be brought about by the movement of P-containing water from higher elevations. In fact, *Azolla* plants found in these natural habitats did not show P deficiency symptoms such as reduced frond size, red-brown discolouration in fronds and dark and elongated roots that become very fragile (Watanabe *et al*, 1977; Subudhi and Watanabe, 1981).

Even though *Azolla* has been growing naturally in these habitats for a very long time, the organic matter content of the soils is not very significant (Table 2). This would indicate that a considerable amount of *Azolla* bio-mass has not got incorporated into the soils in these habitats. This may be due to production of low bio-mass, loss of *Azolla* from the field in the moving flood water and rapid mineralization of the material left behind.

The dry weight nitrogen content of naturally existing *Azolla* was found to range from 2.81 to 5.40% (Table 2), indicating that under natural conditions *Azolla* plants have accumulated a considerable amount of nitrogen. Such large accumulation of nitrogen by *Azolla* while growing in a low nitrogen environment as flood water, is perhaps indicative of its considerable ability to fix atmospheric nitrogen.

The dry weight organic carbon content of *Azolla* plants ranged from 24.94 to 44.08% (Table 2). An effective incorporation of a dense cover of *Azolla* may lead to a build up of organic matter in the soil over time.

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Environment and natural existence of *Azolla*

Observations made in this study indicate that the natural existence of *Azolla* is influenced by the environment in many ways. Lumpkin and Plucknett (1982) have stated that knowledge about all environmental factors and their interactions which establish the parameters of natural habitats of *Azolla* is limited. According to them, a suitable combination of these factors in nature is so rare that naturally growing *Azolla* occupies a very small niche. This may be the reason why the natural habitats of *Azolla* encountered in this study were found confined to small areas, mostly less than 200 m². Furthermore, naturally occurring *Azolla* was not encountered in many rice fields where water was freely present throughout the year. Although naturally growing *Azolla* was encountered in shallow waters near the banks of the water bodies mentioned in this study, it is not found in many other similar water bodies in the country. These observations indicate that environments favourable for *Azolla* are not very common. Beside water, availability of nutrients, temperature, light, pH and water turbulence are some important environmental factors affecting growth of *Azolla* (Lumpkin and Plucknett, 1982).

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Table 1. Natural habitats of *Azolla* in Sri Lanka

	Location	Rainfall* (mm)	Elevation† (m)	Remarks
01	Deegalla, Bopana	889	915.0	rice — rice‡
02	Bulugahapitiya, Hewaheta	1905	1128.5	rice — vegetable‡
03	Rambukpotha, Hunnasgiriya	2159	915.0	rice — rice
04	Mawela, Kotmale	3175	823.5	rice — rice
05	Oruthotawella, Kotmale	3175	671.0	rice — rice
06	Othalawa, Kormale	3175	701.5	rice — rice
07	Rawanagoda, Kormale	3175	945.5	rice — rice
08	Wetakepotha, Maturata	1397	1067.5	rice — vegetable
09	Kuhukwela, Nildandahinna	1397	1067.5	rice — vegetable
10	Panwattaulpotha, Pussellawa	1905	915.0	rice — rice
11	Boralanda, Welimada	1143	1281.0	rice — vegetable
12	Keppetipola, Welimada	1143	1220.0	rice — vegetable
13	Widurupola, Welimada	1143	1128.5	rice — vegetable
14	Debokkawa	762	61.0	irrigation reservoir
15	Sigiriya	762	91.5	irrigation reservoir
16	Tissamaharama	508	18.3	irrigation reservoir

* 75% expectancy value of rainfall ‡ — indicates cropping system.

* Source: Agro — ecological regions of Sri Lanka — Map (1979).
Land and Water Use Division, Department of Agriculture, Peradeniya,
Sri Lanka.

† Source: Topographical Sheets (1 inch = 1 mile)
Survey Department, Sri Lanka.

Table 2. Analysis of soil, flood water and *Azolla*.

Location*	Soil			Water	Azolla plants			
	pH (1:1)	Phosphorus Olsen's P (ppm)	Organic matter (%)	P (ppm)	N (%)	P (%)	K (%)	C (%)
1	5.3	19.0	2.53	0.02	4.04	0.17	2.50	44.08
2	5.0	18.5	5.80	0.07	3.13	0.10	0.92	30.16
3	5.0	8.2	3.80	0.05	3.35	0.13	1.70	37.12
4	4.9	3.5	3.13	0.01	4.06	0.27	2.24	33.64
5	4.9	13.7	1.04	0.04	2.81	0.12	1.32	24.94
6	4.9	6.5	6.26	0.03	3.71	0.19	1.40	31.90
7	4.0	7.5	3.30	0.02	4.87	0.39	2.38	29.58
8	4.6	>100.0	7.31	0.02	5.40	0.19	1.65	42.92
9	4.4	6.5	3.00	0.01	3.52	0.11	2.30	42.34
10	5.8	8.5	5.90	0.01	3.94	0.14	1.80	35.96
11	5.4	>100.0	3.30	0.02	5.23	0.42	3.25	35.96
12	5.2	71.0	2.20	0.01	4.60	0.29	3.45	34.22
13	5.9	29.0	3.80	0.02	4.71	0.32	2.85	35.38

* See Table 1.

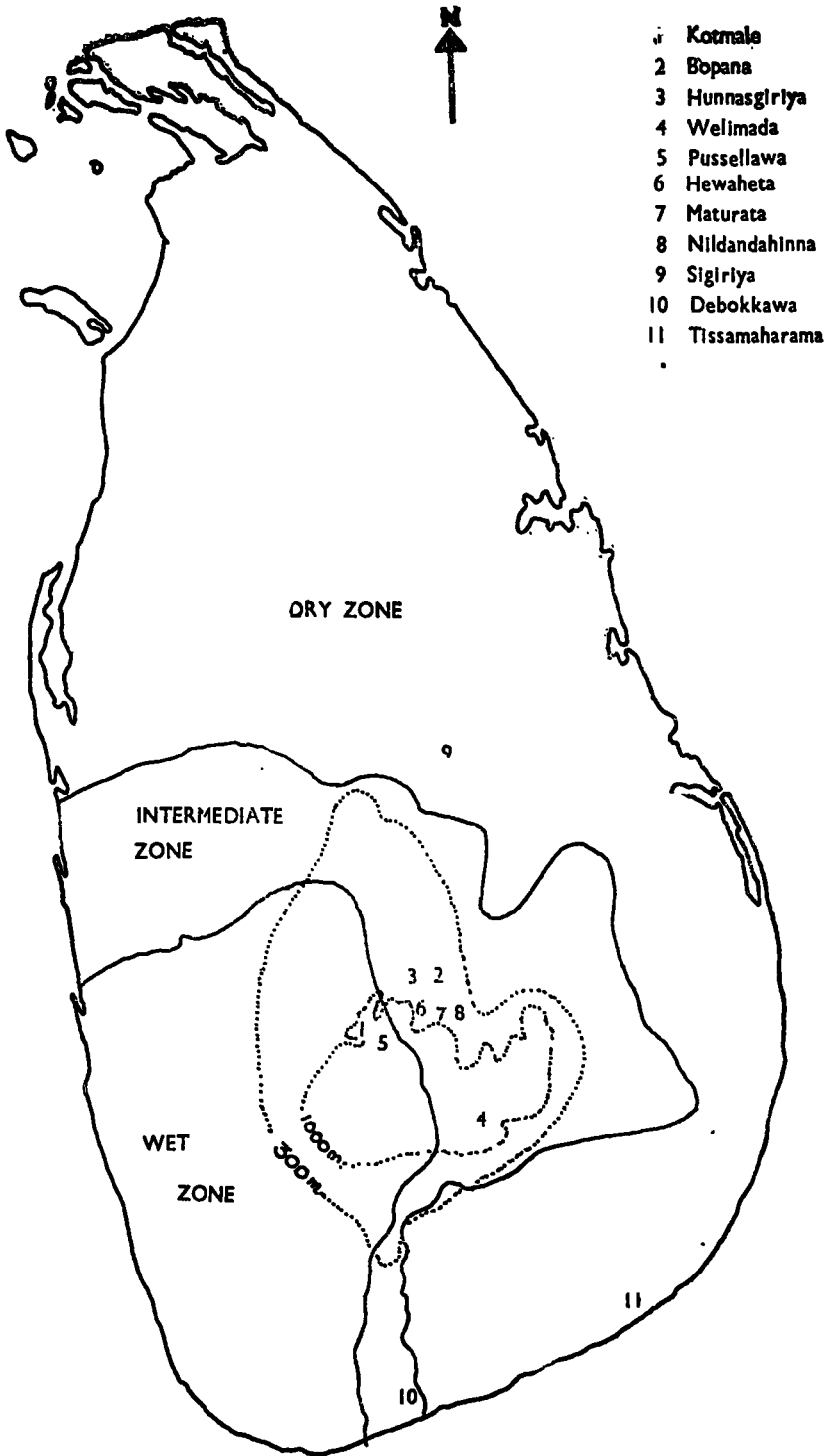


Fig. 1. Natural habitats of *Azolla* in Sri Lanka

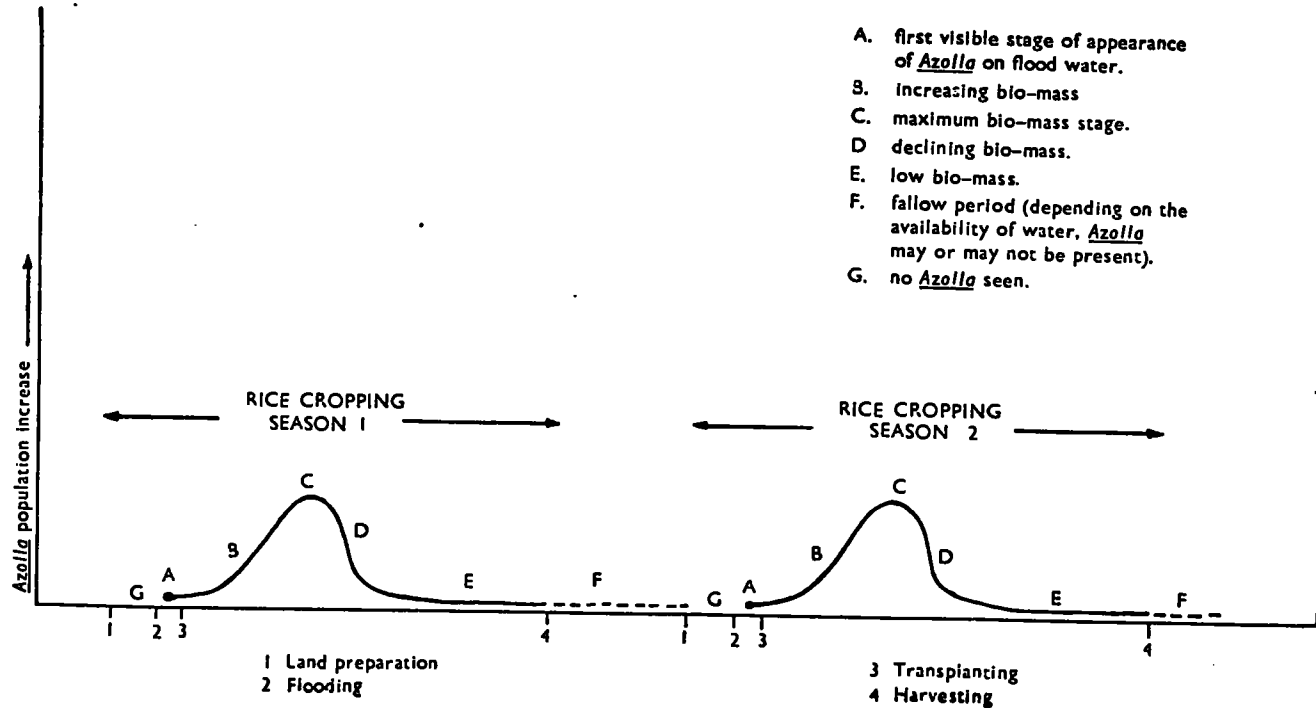


Fig. 2. Diagrammatic representation of the natural fluctuation of the *Azolla* population in a rice field habitat (rice-rice cropping system.)