Physio-Morphology of Pickerelweed \textit{(Monochoria vaginalis)} in Various Soil Moisture Levels

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Abstract. Rice is an important food crop for Indonesia, but its productivity is still low, which is 5.11 tons/ha. One of the factors causing the low productivity of rice is pickerelweed \textit{(Monochoria vaginalis)} which can reduce yields by 80%. This research was aimed to determine the physio-morphological character of pickerelweed at various soil moisture levels and obtain soil moisture levels which can suppress the growth of pickerelweed. The research was conducted with a single factor experimental method that was arranged in a Completely Randomized Design. The treatments were soil moisture levels that consisting of 4 levels, i.e. field capacity, muddy, waterlogged 2 cm, and waterlogged 5 cm, and additional treatment is rice cultivation according to Good Agricultural Practice as a control. The results of the research showed that the moisture level of the field capacity and the muddy can reduce height, the number of leaves, plant growth rate, root length, shoots dry weight, and roots of pickerelweed, while the moisture level of waterlogged 2 cm and 5 cm increase height, the number of leaves, leaf area, weed growth rate, root length, fresh weight and dry weight of pickerelweed.

Keywords: Monochoria vaginalis, Paddy, Physio-morphology, Pickerelweed, Soil moisture

1. Introduction

Paddy is an important crop because it produces rice as the main food of the Indonesian people. The need for rice continues to increase in line with the population growth which in 2019 reaches more than 265 million people. Indonesia's rice productivity is still low, which in 2019 was only 5.11 tons/ha [1].

One of the factors that cause low rice productivity is weeds, which can reduce yields by 20-80% [2-5]. One of the important lowland rice weeds is pickerelweed \textit{(Monochoria vaginalis} (Burm. f). C. Presl). Pickerelweed is an annual aquatic plant belonging to the Pontederiaceae family, is a fleshy herb, annual or perennial, with a shiny, smooth appearance, and a short rhizome, rosette-shaped and spread using short stolons, and has a wide distribution in tropical and subtropical Asia, Africa, and Australia. In Thailand, it is recognized as a monotypic species but shows great variation, not only in its vegetative state but also in its reproductive structure [6]. Although considered a weed in temperate regions, this weed is an aquatic plant that usually grows well in waterlogged rice fields, and is found in warm climates in Asia and Southeast Asia [7]. The growth of pickerelweed in organic rice production is a serious problem [8]. Pickerelweed is an annual weed in waterlogged rice fields, but can also grow in continuous flooding. This weed has roots in the mud, with the shoots growing above water, and includes dangerous semi-aquatic herbaceous weeds, which are found in rice fields throughout the rice-growing areas of the world [9]. Reproduction is mainly from seeds, but often new growth from tubers [10].
Although pickerelweed contains a lot of nitrogen (9.7 mg / 100 g), protein (10.8 g / 100 g) and carbohydrates (4.6 g / 100 g), phosphorus, potassium, magnesium copper, manganese, and calcium in leaves so that it allows these plants to provide adequate nutrition as a nutritious dietary supplement [11], but the potential losses they cause are also large. Pickerelweed is one of the dominant weeds in lowland rice fields [12, 13]. In organic and inorganic wetland rice fields, pickerelweeds were more numerous than other weeds [14]. Pickerelweed can compete more vigorously for nutrition with rice plants. The high density of pickerelweed causes yield loss in rice up to 82% [10].

Due to the losses caused by pickerelweeds in rice, it is necessary to control. In general, farmers control weeds mechanically or chemically. Mechanical weed control is widely used because it is easy and effective for narrow land, but not effective for perennial weeds and large areas. Chemical weed control using anorganic herbicides is effective because it does not require a lot of effort and the results are quickly visible, but potentially damages environment (Asih et al., 2018), water and plants, and non-target organisms. Proper weed control is necessary to obtain satisfactory results, therefore knowledge of weed biology and the factors that affect its growth is very important to know [16]. Therefore it is necessary to find alternative controls that are relatively safe for humans, plants, and the environment. One way that can be done is by modifying the environment so that the conditions formed are not suitable for the growth and development of pickerelweeds, for example by regulating soil moisture.

Pickerelweed generally lives in rice fields with lots of water and even waterlogged conditions. At moisture levels that are not under the needs of life, weeds will show different physio-morphological responses and can affect the growth and development of weeds. Therefore, it is necessary to research with to know the physio-morphological response of pickerelweeds at various soil moisture levels, as well as obtaining soil moisture levels that can suppress the growth of pickerelweeds. The results of this study can be used as one of the bases in determining effective and efficient weed control methods.

2. Method
A research was conducted at the greenhouse and Research Laboratory of the Faculty of Agriculture, Universitas Muhammadiyah Yogyakarta in 2018. The main research materials used were pickerelweed and IR-64 rice seeds.

The research was conducted using a single factor experimental method that was arranged in a completely randomized design. The treatments were soil moisture levels consisting of four levels, i.e. field capacity, muddy, waterlogged 2 cm, and waterlogged 5 cm. Besides, treatment is rice cultivation according to Good Agricultural Practice (GAP) as a control. Each treatment consisted of 4 replications so that there were 20 experimental units, and each experimental unit consisted of 5 plants.

The research was conducted with material preparation, planting media preparation, planting, and maintenance. The watering treatment was started when the pickerelweed was 1 week after planting and was done every day in the afternoon. Watering is done by pouring water according to the treatment. In the field capacity treatment, was carried out by pouring water until it is saturated, because of the gravitational force and the polybag that is perforated causing the excess water to drip out and field capacity will occur. In the moisture content treatment of the muddy, it was carried out by pouring water to the surface of the soil in a polybag. To maintain moisture levels, water is added until the water is saturated right at the surface of the soil. In the waterlogged treatment is carried out by pouring water until it is saturated and stagnant as high as 2 or 5 cm above the soil surface in a polybag. Treatment according to GAP was carried out by giving water gradually as high as 2-5 cm since transplanting until the plants were 10 days after planting. After 10 days after planting, the land is allowed to dry for 5-6 days until the soil cracks, then it is flooded again as high as 5 cm and allowed to dry independently and so on. Water regulation after 50 HST, the soil condition is kept moist and the last one is during the flowering phase until the rice fields are ripe in wet conditions and sometimes flooded with water as high as 1-2 cm [17].

Observations were made during the research by observing height, number of leaves, fresh and dry weight, leaf area, root length, and growth analysis including leaf area index, net assimilation rate, and plant growth rate. Data were analyzed using analysis of variance or F test at α 5%. If there is a significant
difference between treatments, then a further test is carried out using Duncan’s Multiple Range Test at α 5%.

3. Results and Discussion
The water level is the most important determinant of the composition and distribution of submerged aquatic vegetation [18]. The results of the research showed that the height of pickerelweed from 1st week to 7th week at moisture levels of field capacity, muddy and waterlogged 2 cm was not significantly different from GAP, but from 8th-week weed height in field capacity is lower than the GAP. The height of weeds in waterlogged 5 cm since the second week is higher than the other moisture levels (Figure 1).

![Figure 1. Height of pickerelweed at various moisture levels](image)

Environmental and physiological factors affect pickerelweed germination [8]. Seed germination and growth of pickerelweeds were induced by immersion, varying according to humidity levels. Pickerelweed germination is driven by other plant residues in rice fields [19], and is influenced by the depth and duration of inundation. Under submerged conditions, the majority of sprouts appear in a short time, with peak germination 15-25 days after release [10]. Greater germination is obtained if the seeds are stored in saturated soil conditions and low inundation depth (i.e. less than 5 cm) for more than 4 days [9].

Height is an important agronomic trait, related to productivity and plant growth rate [20]. Plants tend to grow to a certain height during each growth [21]. Pickerelweed is 10–15 cm high and has no stems, with varying leaf sizes and shapes. The petiole is soft and hollow, usually less than 30 cm long, and grows from the shoot at the base [10]. Pickerelweed is an upright, uphill, or occasional vine herb that usually lives annually, but can grow as annuals under unfavorable conditions. Grows in muddy conditions or shallow water, with leaves that can float or grow up to 50 cm [22]. Pickerelweeds is a C₃ plant that grows relatively fast and is competitive [10].

The number of pickerel weed leaves from 2nd week to 10th week at field capacity was not significantly different from GAP, while muddy, waterlogged 2 cm and 5 cm was higher than the GAP (Figure 2). Pickerelweed generally lives in rice fields with soil conditions that contain lots of water. Waterlogging causes pickerelweed to grow optimally. Water is needed by weeds for physiological processes including cell division and leaf formation. Water that is absorbed by pickerelweed contains nutrients needed for the photosynthesis process. The availability of sufficient nutrients causes photosynthesis to run rapidly for and elongation of stems and leaf formation so that the height and number of weed leaves are higher. Water is a common trigger for seed germination. Their absorption
from the soil facilitates inorganic mineral nutrition, and their flow through the vascular network circulates minerals and organic nutrients throughout the plant body. Water (and solute) retention determines turgor, promotes the expansion of plant cells, and contributes to plant form and function, including the movement of stomata. Loss of water through transpiration from leaf stomata, at the same time, is a by-product of gas exchange and CO2 absorption for photosynthesis and activation of water flux and its circulation throughout the plant [23]. Decreased soil moisture causes decreased plant height growth. The 65% humidity treatment on Corymbia citriodora resulted in an average height of 6.7% shorter than the treatment where humidity was maintained at 80% [24]. Soil moisture has a significant effect on height, stem diameter, number of leaves, and biomass of Lactuca serriola [25].

Figure 2. Leaves number of pickerel weed at various moisture levels

Pickerelweed that usually live in waterlogged rice fields, show height inhibition in field capacity. Weed growth is dependent on water availability, therefore weeds act in a different way to cope with drought stress. Stomata closure helps plants maintain the water status of the plant to reach water potential at very low values, which is positively correlated with stress intensity. Water deficit causes a significant reduction in leaf surface [26].

Moisture levels had a significant effect on the leaf area and leaf area index of pickerelweed in the 4th and 10th weeks. The leaf area of pickerelweed at the moisture level of waterlogged 5 cm in the 4th week and 10th week was higher than the GAP. The leaf area index 4th week at the field capacity, muddy and waterlogged 2 cm were not significantly different from GAP, while waterlogged 5 cm was higher than GAP. The leaf area index of the 10th week at the field capacity and muddy were not significantly different from the GAP, while waterlogged 2 cm and 5 cm was higher than GAP (Table 1).

Leaves represent the largest proportion of the total canopy surface as well as the main surface for active physiological exchange with the atmosphere. Processes such as photosynthetic light absorption, carbon sequestration and assimilation, water transpiration, and the emission of volatile organic compounds are almost exclusively carried out through the leaf surface, while processes such as element deposition, rain interception, evaporation, and susceptibility to wind damage are also partly area dependent canopy surface [27]. Leaf area is very sensitive to lack of water. The rate of leaf expansion reaches a maximum during the day when the leaf water deficit reaches its maximum. When cell hydration decreases and the plant experiences a water deficit, abscisic acid and solutes increase in the plant, especially in the root system (the increase in solute occurs relatively, due to water reduction). These factors will reduce stomatal conductance and consequently photosynthetic activity which in turn will result in a decrease in protein synthesis and cell walls, and a decrease in the rate of cell expansion [28]. This response to water deficits contributes to explaining the reduction in plant growth. Physiological responses are related to stress conditions by the root system, changes in turgor and water
potential, and consequently a decrease in stomatal conductance, internal CO₂ concentration, and photosynthetic activity [29].

| Moisture levels | Leaf area (cm²) week to | Leaf area index week to |
|-----------------|-------------------------|-------------------------|
|                 | 4                       | 10                      |
| Field capacity  | 35,00 c                 | 37,50 d                 | 1,02 b | 1,73 c |
| Muddy           | 73,00 bc                | 182,25 c                | 2,65 b | 9,78 bc|
| Waterlogged 2 cm| 213,50 ab               | 259,50 b                | 7,43 ab| 16,31 b|
| Waterlogged 5 cm| 335,00 a                | 610,00 a                | 11,38 a| 36,41 a|
| GAP             | 136,75 bc               | 45,25 d                 | 2,45 b | 1,31 c |

Note: Numbers followed by the same letter at the same column show a non-significant difference at DMRT a 5%.

Soil water content in heavy soils has a positive correlation with the leaf area index. Moisture levels greatly affect yield, therefore plants will not grow and develop with insufficient soil moisture [30]. Water stress results in a decrease in the total area of the developing leaf. Water stress results in less growth (formation of leaf area) during later growth stages [31]. Dryness and water deficit in leaves causes progressive suppression of photosynthesis. The decrease in the rate of photosynthesis is caused by stomata and non-stomata (biochemical) limitations. At the overall plant level, the effects of water deficiency are usually considered to be a reduction in photosynthesis and growth [32].

Moisture levels had no significant effect on the net assimilation rate but had a significant effect on the growth rate of pickerelweeds. The growth rate of pickerelweeds at field capacity, muddy and waterlogged 2 cm were not significantly different from the GAP, while the waterlogged 5 cm was higher than the GAP (Table 2). The net assimilation rate is the rate of accumulation of dry weight per unit leaf area per unit time [33]. Leaf area index is closely related to the net assimilation rate. In plants with a wider leaf area index, the net assimilation rate will decrease because the lower leaves are unable to perform maximum photosynthesis.

| Moisture levels | Nett assimilation rate (g/cm²/week) | Relative growth rate (g/m²/week) |
|-----------------|--------------------------------------|----------------------------------|
| Field capacity  | 0,00009 a                            | 0,01021 b                        |
| Muddy           | 0,00087 a                            | 0,02550 b                        |
| Waterlogged 2 cm| 0,00045 a                            | 0,06210 b                        |
| Waterlogged 5 cm| 0,00147 a                            | 0,17521 a                        |
| GAP             | 0,00313 a                            | 0,03210 b                        |

Note: Numbers followed by the same letter at the same column show a non-significant difference at DMRT a 5%.

Leaf area growth determines a plant’s light-interception capacity and is often used as a substitute for plant growth. The relationship between the growth of leaf area and growth in terms of mass will depend on how carbon is divided between new leaf area, leaf mass, root mass, reproduction, and respiration [34]. Weeds that have high height, leaf number, and high leaf area can absorb nutrients from the soil and sunlight so that the assimilation rate will be large. The plant growth rate indicates the increase in dry matter in the unitary plant community of land area in time units, which is widely used in the analysis of the growth of cultivated plants in the field [33]. Leaf functional, dry matter production, and leaf area index is the main growth factors that can directly reflect yield. The relative growth rate (RGR) shows the increase in dry matter with a certain amount of assimilated material at a certain point in time and the net assimilation rate (NAR) is the net gain of total dry matter per unit leaf area per unit time [35].
The weed growth rate at waterlogged 5 cm higher than that of the GAP. The higher the value of the plant growth rate followed by the optimal plant age, the higher the total dry weight. The higher the total dry weight produced and followed by the ability of the plants to distribute high assimilates, the higher the dry weight.

Moisture levels did not significantly affect the root length of the pickerelweed at the 4th week but showed a significant effect at the 10th week. The root length of pickerelweed in the 10th week at the field capacity and the muddy were not significantly different from GAP, while waterlogged 2 cm and 5 cm were higher than the GAP (Figure 3).

In general, when there is a lack of water, the roots play an important role in plant adaptation because the roots can absorb water by maximizing the root system. Some of the root morphological characters that indicate plant resistance to water deficiency are root elongation to a deeper soil layer, increase in the area and depth of the root system, expansion of the horizontal and vertical distribution of roots, greater root dry weight in plant genotypes that are drier resistant, increase root volume, increased root density and longitudinal resistance to roots, high penetrating power, higher root and canopy ratio, and root length to plant height ratio [36].

Root length is a form of extension of the cells behind the end meristem [37]. Pickerelweed, like other broadleaf weeds, is mostly found in waterlogged or flooded water levels [38]; [39]. The length of the roots at waterlogged 2 cm and 5 cm at the 10th week was higher than GAP due to the optimal absorption of water in the soil by the roots. Growth will be influenced by internal and external factors. One of the external factors that influence root growth is water. In sufficient water, the nutrients needed by plants can be fulfilled properly. Increasing root length is a form of root response to the availability of water and plant nutrients.

Moisture levels had a significant effect on fresh weight and dry weight of the weed shoots in the 4th week and 10th week. Fresh weight and dry weight of the weed shoots at 4th week at the field capacity and muddy were not significantly different from GAP, while waterlogged 2 cm and 5 cm higher than GAP. Fresh weight and dry weight of weed shoot 10th week at muddy and waterlogged 2 cm were not significantly different from GAP, while at field capacity, waterlogged 5 cm higher than GAP (Table 3).

The fresh weight of weeds 4th week and 10th week at waterlogged 5 cm higher than the GAP due to the height of weeds and the high number of leaves. Leaf area can form and store more nutrients, this results in an increase in plant canopy fresh weight. Pickerelweed usually lives in soft mud on the edges of swamps, lagoons, or other quiet areas including waterways, ditches, and roadside drains. If the environment is always wet. Pickerelweed can live chronically [40].

The dry weight of the shoot of pickerelweed at waterlogged 5 cm 4th week and 10th week is higher than GAP because the water needed by pickerelweed is sufficient so that it can dissolve nutrients.
properly so that the photosynthesis process increases. The increasing rate of photosynthesis increases the resulting photosynthate at the dry weight of the pickerelweed shoot. Larger photosynthate will allow to form larger organs and then result in greater production of dry matter [41]. Moisture level had a significant effect on fresh weight and dry weight of pickerelweed roots in the 4th week and 10th week. Fresh weight of pickerelweed roots 4th week at the field capacity and the muddy were not significantly different from GAP, while at waterlogged 2 cm and 5 cm was higher than GAP. The fresh weight of weed roots at 10th week at the field capacity, the muddy and waterlogged 2 cm were not significantly different from GAP, while waterlogged 5 cm higher than GAP (Figure 4). The dry weight of the weed roots at 4th week and 10th week at the field capacity, muddy and waterlogged 2 cm were not significantly different from GAP, while waterlogged 5 cm higher than GAP (Figure 5).

| Moisture levels  | Fresh weights week to | Dry weights week to |
|------------------|-----------------------|---------------------|
|                  | 4                     | 10                  | 4                  | 10                  |
| Field capacity   | 2.09 b                | 49.52 b             | 0.29 b             | 1.92 c              |
| Muddy            | 7.70 b                | 47.51 b             | 0.73 b             | 3.14 c              |
| Waterlogged 2 cm | 23.80 a               | 104.02 ab           | 3.62 a             | 8.72 b              |
| Waterlogged 5 cm | 34.77 a               | 159.06 a            | 4.76 a             | 17.74 a             |
| GAP              | 6.03 b                | 49.94 b             | 1.01 b             | 3.80 cb             |

Note: Numbers followed by the same letter at the same column show a non-significant difference at DMRT α 5%.

Fresh weight shows the accumulation of dry matter resulting from photosynthesis and water content absorbed by weeds. At waterlogged 2 cm and 5 cm, weeds have a high fresh weight due to the availability of sufficient water. Besides with long roots, the ability to absorb water and nutrients is also higher so that it affects the plant fresh weight [42]. Flooded plants have a higher dry weight because plant biomass reflects the net photosynthesis results associated with the availability of nutrients that can be absorbed by plants [43].

Overall, the lower the moisture levels of the soil, the lower the weed growth, as indicated by height, number of leaves, leaf area, leaf area index, growth rate, root length, fresh weight, and dry weight of shoots and roots. Water stress resulted in a decrease in growth parameters by reducing the relative length and diameter of shoots and the fresh and dry weight of the plant. Water stress significantly affects most of the morphological, physiological, and biochemical characteristics. Increasing water stress reduces the relative moisture content of leaves, chlorophyll index, diameter, and fresh and dry weight of plants [44]. Drought stress affects the morphological, biochemical, and physiological attributes, and, in severe cases leads to cell death [45]. Conversely, waterlogged 2 cm and 5 cm increased the growth of pickerelweeds. Adaptive traits of plants enabling survival under soil waterlogging and partial submergence are those directed to oxygenation of submerged tissues (i.e., parts of shoots and entire root system), and the location of leaves above water to continue with carbon fixation. Aerenchyma formation and development of adventitious roots, with barriers to radial oxygen loss, appear as the most important features facilitating longitudinal oxygen transport to sustain root aeration and thus continue with water absorption in anaerobic soils [46].

Plants show diverse reactions in response to stress at various stages of the growth period. The ability of pickerelweeds, demonstrated by its physio-morphology in various moisture levels, led to the introduction of strategies that minimize weed survival and maximize irrigation efficiency for crops. Its ability to sustain growth through adaptation to morphology, physiological, and biochemical regulation, even during times of water stress, ensures that pickerelweeds have a strong mechanism to continue to spread to new areas. A clear understanding of the ecological and biological characteristics of weeds will help land managers take appropriate control measures to reduce the impact of this species on economic crop productivity [25]. Management strategies for pickerelweeds should include early control of this weed in the cultivated field, as the combined pressure of increased weed competition and water stress conditions can severely disrupt crop yields.
4. Conclusion
Soil moisture levels affect the physio-morphology of pickerelweeds. Moisture levels of field capacity and muddy can suppress height, number of leaves, weed growth rate, root length, and canopy and root dry weight of pickerelweed. Moisture levels of waterlogged 2 cm and 5 cm increased height, number of leaves, leaf area, weed growth rate, root length, fresh weight and dry weight of the shoot and root of pickerelweeds. As recommendation, to get the high effectivity and efficiency, pickerelweed control can be done by adjusting soil moisture level in muddy or field capacity.

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