Evaluation of growth and biomass production of sorghum on cadmium contaminated paddy field

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Abstract. The use of agrochemicals that exceed doses and over-exploitation of land for an agricultural commodity contributes to increasing cadmium concentration. Sorghum is a multifunctional crop that can be potential as a heavy metal remediation plant. The study aimed to obtain potential sorghum varieties for phytoremediation of cadmium by assessing the growth and capacity of sorghum biomass in Cd contaminated paddy fields. The study was arranged in a complete randomized factor group with four replications. Six sorghum varieties tested were: Super 1, Samurai, Suri 3, Numbu, Kawali, and Hitam. These varieties were planted with cadmium contaminated rice fields. In general, sorghum varieties can grow in cadmium contaminated rice fields. Three of the six varieties tested namely Super 1, Samurai, and Kawali have advantages in growth such as plant height, leaf area, leaf chlorophyll content, plant growth rate, and net assimilation rate. Big biomass performance is also approved by these three varieties. The results in this study will be described and used as a reference to complement the ability of this variety in the absorption and accumulation ability.

1. Introduction
Effort to realize the foodstuffs availability which are sufficient and safe for the community through intensification of plant cultivation to obtain high yields has had negative impacts. The application of technology, the management of soil and plants that are less precise and tend to be over exploited can reduce physical, chemical and biological soil fertility [1]. The application of fertilizers and pesticides that exceeds the dose to maintain and increase crop yields cause the concentration of several types of heavy metals in soil, water and plants to increase beyond the permissible threshold [2].

On the other hand, increased industrialization and urbanization have contaminated soil with Cadmium deposits (Cd). Disposal of industrial waste into waters that are used for agricultural irrigation worsen heavy metal contamination in paddy fields. Paddy field is defined as land used to cultivate rice continuously throughout the year or in rotation with secondary crops [3]. As the main source of nutrients for rice growth, paddy fields are also subject to Cd contamination and other heavy metals, thus threatening food production in the future.

Cadmium (Cd) is a non-essential element that is easily absorbed by plants, including one of the toxic heavy metals that causes pollution of paddy field, its accumulation in the soil poses a threat to agroecosystems [4] and human health [5]. The increased Cd toxicity in rice changes its morphology
and biochemical processes, thereby disrupting food availability and safety. [6] argued that the Cd absorbed during the growth and development of rice causes toxicity, so that changes the structure, morpho-physiology and biochemistry which causes leaf chlorosis, inhibits growth, reduces biomass until the plant dies.

The toxicity of Cd needs to be controlled by degrading, absorbing or making Cd contaminants in soil or water harmless to plants, animals and humans by using plants or what is known as phytoremediation technology. According to [7], phytoremediation is the use of plants to restore contaminated soil and water resources, the mechanism is reported [4] can be through a single or combined process of phytoaccumulation, phytostabilization, phytodegradation, phytovolatilization, hydraulic control.

Sorghum is a versatile C4 plant with widely expandable end products, including grains, forages, syrups, beverages, sugars and cellulose-bioethanol [8]. Sorghum has an adaptive capacity to grow in various environments, has high photosynthetic efficiency, resistant to disturbance of biotic and abiotic factors such as pests, drought, salinity, and alkaline soil [9]. Sorghum has the best carbon assimilation rate (50 g m⁻² day⁻¹) which allows its fast growth rate of net CO₂ utilization better than other plants. They are attracting a lot of attention as attractive candidates for soil phytoremediation [10]. The urgency of this research is to accelerate the decay of agricultural land (paddy fields) contaminated with Cd naturally by using sorghum as a phytoremediator and to improve plant growth and yields on Cd-contaminated land. Based on the description above, the aim of this study was to obtain potential sorghum varieties for Cadmium phytoremediation by assessing the growth and capacity of sorghum biomass in paddy fields contaminated with Cd.

### 2. Materials and methods

The research was conducted from March to June 2020 in Paddy field on Balecatur, Gamping, Sleman, Yogyakarta. Experiment was carried out using a single factor treatment arranged in a Completely Randomized Block Design (CRBD). The treatment given as variety: Super 1, Samurai 1, Suri 3, Numbu, Kawali and Hitam. The description of varieties as in the Table 1.

#### Table 1. Descriptions of several varieties of sorghum assessed.

| No | Origin | Description | Super 1 | Samurai 1 | Suri 3 | Numbu | Kawali | Hitam |
|----|--------|-------------|---------|-----------|--------|-------|-------|-------|
| 1. | Released | Sumba, NTT | BATAN | India | India | India | China |
| 2. | | 2013 | 2014 | 2014 | 2001 | 2001 | - |
| 3. | Flowering Age 50% (days) | 56 | 61 | 54 | 69 | 70 | 55 |
| 4. | Plant height (cm) | 204.8 | 187.7 | 230.4 | 187 | 135 | 150 |
| 5. | Harvest age (days) | 105–110 | 111 | 95 | 100–105 | 100–110 | 100–105 |
| 6. | Panicle length (cm) | 26.67 | 32.7 | 29.1 | 22–23 | 28–29 | 24–29 |
| 7. | Weight 1000 grains (grams) | 32.10 | 29.4 | 33.5 | 36–37 | 30 | 21 |
| 8. | Average yield (tonnes ha⁻¹) | 2.66 | 6.1 | 4.5 | 3.11 | 2.96 | - |
| 9. | Potential yield (tonnes ha⁻¹) | 5.75 | 7.5 | 6.0 | 4.0–5.0 | 4.0–5.0 | - |

Source: Balitsereal, BATAN dan CV. Agrindo.

The land used in the research was processed manually and loosened. The research plots were made with a size 6×4 m. Before using the land, soil samples were taken and analyzed. Analysis results (Table 2). The planting of sorghum was carried out by making hole with a space 20 cm in lines, while the distance between the lines was 60 cm so that there were 180 holes for each research plot. Each hole was planted with 2–3 sorghum seeds with a planting depth 5 cm, after the seeds germinate and grow normally, then thinning them out by separating one plant /hole. Fertilization used chemical fertilizers of Urea, SP36 and KCL at doses of 120 kg ha⁻¹, 36 kg/ha and 90 kg ha⁻¹. Fertilizer was applied twice, the first fertilization Urea: SP36: KCL as much as ⅓: 1: 1 part which was given at the age of 2 weeks after planting and ⅗ part of urea fertilizer was given when the plants were 6 weeks after planting by means of the array. Maintenance included irrigation, pest control and weed control.
The parameters measured include agronomic parameters: plant height, chlorophyll content, plant growth analysis (leaf area index, specific leaf weight, crop growth rate, net assimilation rate), plant fresh weight was measured from the production of sorghum sugarcane consisting of stems, leaves and panicles. Analysis of data obtained were analyzed using Analysis of Variance (ANOVA) with significance level of $\alpha = 5\%$. Further test was carried out using Duncan’s Multiple Range Test (DMRT) at a significance level of $\alpha = 5\%$ for data with significance differences between treatments.

3. Results and discussion

The land used in this study was technically irrigated agriculture land with rice crops throughout the season. Soil samples were taken from ex-rice paddy fields, then analyzed for several metal elements, the results are presented in Table 2. Critical limits classification of available metals in the soil according to [11], available of element Cr 2.5 ppm, Cu 60–125 ppm, Cd 0.50 ppm, Pb 100 ppm and Zn 70 ppm. These criteria data were used as a comparison to results of soil sample analysis in this study.

Table 2. Result of soil sample analysis.

| C-organic materials (%) | Organic materials (%) | Nitrogen (%) | $P_2O_5$ (%) | K2O (ppm) | Cr (ppm) | Cu (ppm) | Cd (ppm) | Pb (ppm) | Zn (ppm) |
|------------------------|-----------------------|--------------|--------------|-----------|---------|----------|---------|---------|---------|
| 1.016                  | 1.751                 | 0.207        | 0.084        | 253.5     | 2.758*  | 0.162    | 2.914*  | 0.167   | 0.233   |

*according to Ministry of state for Population dan Environment of Indonesia, and Dalhousieu University, Canada (1992).

3.1. Plant height

Plant height is one of the research parameters to determine how plant growth is. The average plant height during the study is presented in Figure 1. Plants increase in height with time. At the beginning of the vegetative growth phase (2 weeks after planting) the varieties Super 1, Suri 3 and Numbu had the highest plant height. However, at 6 weeks after planting until the end of the vegetative phase, varieties Super 1, Samurai 1 and Kawali showed the highest plant height compared to Suri 3, Numbu and Hitam. Suri 3 and Numbu varieties at the beginning of vegetative development had not experienced growth disturbances even though the planting medium was contaminated with cadmium of 2.91 ppm. This was presumably because each different variety had different genetic abilities. Each variety of sorghum responds differently to the environment. The growing potential of sorghum is influenced by the genetic characteristics of the variety, climatic conditions and the environment in which it grows and its cultivation practices [7].

Table 3. Average plant height of several sorghum varieties in cadmium contaminated paddy fields.

| Variety | Plant height 2 wap | Plant height 6 wap | Plant height 10 wap |
|---------|--------------------|--------------------|---------------------|
| Super 1 | 33.32$^a$          | 131.31$^a$         | 220.93$^a$          |
| Samurai 1 | 20.11$^b$          | 144.64$^a$         | 205.41$^a$          |
| Suri 3  | 30.85$^a$          | 89.73$^b$          | 173.09$^b$          |
| Numbu  | 35.56$^a$          | 107.31$^{ab}$      | 170.20$^b$          |
| Kawali | 27.38$^{ab}$       | 132.51$^a$         | 218.38$^a$          |
| Hitam  | 20.37$^b$          | 80.48$^b$          | 135.65$^c$          |

Note: wap = weeks after planting, the average number with the same letter at the same column is not significant at ($\alpha = 5\%$).

The results showed that Super 1, Samurai 1 and Kawali varieties had a plant height of more than 2 m, which was significantly different from Hitam varieties (Table 3). Meanwhile, Suri 3 and Numbu varieties are classified as having medium plant height. The average plant height of Suri 3, Numbu and Hitam varieties was lower than varieties description (Table 1). The three varieties showed suppressed growth with Cd contaminants in the paddy field 2.91 ppm. Meanwhile, Super 1, Samurai 1 and Kawali varieties showed higher plant height. The response of plants to heavy metals depends on many factors such as metal concentration, metal species, plant growth period, soil type, soil texture, soil properties
and local climate [12]. In this case, it means that the contamination of the paddy field with a Cd 2.91 ppm is still not disturbed by its growth metabolism, it is not known how much Cd accumulation in the organs of root and shoot plants.

Figure 1. Plant height dynamics of several sorghum varieties.

Table 4. Average typical leaf weight, leaf area index, net assimilation rate, plant growth rate, plant fresh weight and chlorophyll content of several sorghum varieties in paddy fields contaminated with cadmium.

| Variety   | SLW  | LAI  | NAR  | CGR   | PFW   | CC    |
|-----------|------|------|------|-------|-------|-------|
| Super 1   | 0.136b | 1.03b | 0.010b | 0.0778b | 340.23b | 235.70a |
| Samurai 1 | 0.174a  | 1.85a  | 0.014b  | 0.1538a  | 574.17a  | 243.00a |
| Suri 3    | 0.054c  | 0.90c  | 0.008b  | 0.0577b  | 203.24c  | 168.54bc |
| Numbu     | 0.064c  | 0.99c  | 0.008b  | 0.0562b  | 323.83b  | 214.90ab |
| Kawali    | 0.105b  | 1.47ab | 0.011b  | 0.1068ab | 361.92b  | 238.78a |
| Hitam     | 0.063c  | 0.52d  | 0.007b  | 0.0344b  | 112.51d  | 160.17c |

Note: the average number with the same letter at the same column is not significant at (α = 5%).

3.2. Chlorophyll content
Chlorophyll is a determining element of plant photosynthetic ability, which is mostly found in plant leaves. Leaf chlorophyll levels are closely related to the greenish color of the leaves. Chlorophyll content in Super 1, Samurai 1 and Kawali varieties showed the highest levels and was significantly different from Hitam varieties (Table 4). The rate of leaf photosynthesis is influenced by internal factors in the leaves, namely chlorophyll content, leaves that have high chlorophyll content are expected to be more efficient in capturing sunlight energy for photosynthesis [13].

Hitam varieties were thought to have experienced growth problems due to soil contamination with cadmium. It was shown by decreasing plant height and marked by reduced plant chlorophyll. Root growth and leaf color generally become a benchmark for plant physiological responses due to heavy metal stress because they are closely related to disruption of activity in cells and plant metabolism so that plants experience chlorosis or necrosis [12,14] Cd metal inhibits growth by blocking nutrients, interfering with cell expansion and division as well as photosynthetic disorders [15].
3.3. Specific leaf weight
Specific leaf weight contains information about leaf thickness. The higher the specific leaf weight, the higher the leaf thickness. Leaf thickness indicates the number of photosynthetic organelles in the leaf [13]. Based on Table 4, Samurai 1 variety showed the largest leaf specific weight and was significantly different from Super 1, Suri 3, Numbu, Kawali and Hitam varieties. The high leaf thickness in Samurai 1 variety supported the high growth rate of Samurai 1 variety.

3.4. Leaf area index
Leaves are the main component of plants which have the main function as a place to carry out the photosynthesis process. Leaf area index shows the capacity of a plant in the process of photosynthetic carbon assimilation as an estimate of plant growth potential [16] and determines plant biomass production [17]. Samurai 1 variety showed the highest leaf area index and was significantly different from Super 1, Suri 3, Numbu and Hitam. However, the Samurai 1 variety is not significantly different from Kawali (Table 4).

Samurai 1 variety with high leaf area index and specific leaf weight produced high plant fresh weight. Contamination of paddy fields with a Cd 2.91 ppm had not resulted yet in disruption of growth in Samurai 1. Plant varieties have very large variations of tolerance to Cd, in various plant species this difference is controlled by genetic factors [14].

3.5. Plant growth rate
Plant growth rate describes the rate of increase in plant dry weight based on initial dry weight per unit time. Increasing the plant growth rate will increase the dry weight of the plant supported by the presence of high leaf area which will increase sunlight reception [10]. Samurai 1 variety showed the highest plant growth rate, although it was not significantly different from Kawali variety (Table 4). This was in line with the high leaf area index value of the Samurai 1 variety and not significantly different from the Kawali variety.

3.6. Net assimilation rate
Net assimilation rate is the ability to produce dry matter per leaf area per unit time. The net assimilation rate is used as a measure of the plant photosynthetic rate after subtracting respiration. The net assimilation rate describes the plant's ability to produce biomass per unit leaf area per unit time. Although the leaf area index and specific leaf weight were high in the Samurai 1 variety, the net assimilation rate for the Samurai 1 variety was the same and not significantly different from the Super 1, Suri 3, Numbu, Kawali and Hitam varieties (Table 4). The net assimilation rate will decrease/ontogenic with plant age [15]

3.7. Plant fresh weight
The indicator of plant biomass production is known from the wet stover weight. The weight of wet stover is a reflection of the rate of water and nutrient uptake for plant metabolic processes [3] and is a combination of the development and increase of plant tissue such as leaf area and plant height [5]. Sorghum varieties had a significant effect on plant wet weight (pr <0.005). The differences in plant wet weight are presented in Table 4.

Based on Table 4, the Samurai 1 variety showed the highest plant wet weight compared to the other five varieties tested. Heavy metal accumulator plants with greater biomass are more potential and effective when used for phytoextraction on heavy metal contaminated soils [18]. The success of phytoremediation requires plants that have large biomass in addition to the ability to accumulate contaminants in the biomass [11]

4. Conclusion
In general, the planted sorghum varieties were able to grow in paddy fields contaminated with cadmium. Cadmium contamination 2.91 ppm affected the growth of Suri 3 and Hitam varieties. The
tolerant varieties were shown by the Samurai 1 variety that was showed higher values and expressed better growth than the Super 1, Numbu and Kawali varieties. Varieties that were able to produce large plant biomass were shown by the Super 1, Samurai 1, Numbu and Kawali varieties. The growth and production of biomass (plant height and fresh biomass production) of varieties Samurai 1, Kawali and Super 1 were higher. These three varieties can be used as a reference to test the sorghum's ability to absorb and accumulate cadmium in plant organs.

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