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Evaluation of Source and Sink Capacity of New Cowpea Varieties

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Abstract

Cowpea *(Vigna unguiculata (L.) Walp)* is a perennial species originating from sub-Saharan Africa. Cowpea has long been cultivated in Indonesia and is classified as a species tolerant of drought and acidic soil. Cowpea shows its adaptation to acidic soil with a pH of 4.83 by being able to produce 50% to 60% of seed weight under optimum conditions. This enhances the potential of cowpea to be used and developed as one of the food options. Cowpea's adaptability research was carried out with the aim to optimise of cowpea productivity by studying the relationship between the source and sink of cowpea. This research was conducted from December 2020 to March 2021 at the Cikabayan experimental station, Bogor Agricultural University. The experiment was set up in a completely randomized block design. Four cowpea varieties were evaluated, “Albina” IPB, “Arghavan” IPB, and “Uno” IPB. The measured parameters consisted of photosynthesis rate, stomatal conductance, plant growth rate, the net assimilation rate of the number of pods, pod weight, number of seeds per pod, dry seed weight, the weight of 100-seeds, and productivity. The cowpea varieties did not show significant differences in the rate of photosynthesis, stomatal conductance, plant growth rate, and net assimilation rate. Photosynthesis rate in the three cowpea varieties ranged from 29.20 to 31.77 mol. $m^{-2}.s^{-1}$ at 50% flowering, and ranged from 17.01 to 19.79 mol.$m^{-2}.s^{-1}$ at the first harvest. The three cowpea varieties in this study showed no differences in their source-sink capacity and productivity.

Keywords: cowpea varieties, pods, productivity.

Introduction

Indonesia’s soybean production in 2015 was 963.18 thousand tons, decreased to 859.65 thousand tons in 2016, and drop further to 538.73 thousand tons in 2017. In 2018 soybean production had increased to 650.00 thousand tons, but drop to 424.19 thousand tons in 2019 (Ministry of Agriculture, 2021). Soybean consumption in Indonesia far exceeds the domestic soybean production capacity, so it must supply 2,670,086.4 tons of soybeans through imports (BPS, 2019). Soybean in Indonesia is predominantly consumed as tempeh, a cake made from fermented soybeans. There are other legumes that can be an alternative to making tempeh besides soybeans, such as cowpeas.

Cowpea (*Vigna unguiculata* (L.) Walp) is a perennial species originating from sub-Saharan Africa (Boukar et al., 2015). Cowpea has long been cultivated in Indonesia and is classified as a species tolerant of drought and acidic soil (Trustinah, 2015). Cowpea can adapt to various types of land ecology (Karsono, 1998; Trustinah et al., 2001), including to acidic soil with a pH of 4.83, by being able to produce 50% to 60% of the seed weight under optimum environment (Setyowati and Sutoro, 2010a).

Cowpea production in Indonesia is relatively low at only 1.5 – 2 $ton.ha^{-1}$ (Balitkabi, 2005). There is little information about the availability of high yielding cowpea varieties, source-sink activities and capacities, and how to increase cowpea production and productivity. It is known that there are two varieties of cowpea based on their growth patterns, i.e., creeping and shrubs. Ndiaga (2000) concluded that cowpea cultivars with different plant morphology require different optimum planting densities to fully express potential seed yield. The optimal planting density of cowpea depends on many factors such as rainfall, humidity and cultivar type, available nutrients, and management (El Naim and Jabereldar, 2010).

Information on the relationship between source and sink related to seed filling in cowpea varieties in Indonesia is still very limited. Crop production is determined by the amount of dry matter accumulation and the partition or distribution of the dry matter into parts to be harvested. The increase in crop yields can be done by increasing the accumulation of dry

A B C

Picture 1. Cowpea at 7 days (A), 21 days (B) and 55 days (C) after planting.

matter, or increasing the harvest index. Our study was conducted to increase the cowpea productivity by measuring the relationship between the source and sink of cowpea plants. Three varieties of cowpea used in this study were released by IPB University breeder, Prof. M. Syukur, in 2020; all have a bush-type growth pattern. The seeds have fat content 0.90-1.36%, protein content of 23.98-24.26%, and fiber content of 3.87-4.44% (Syukur et al., 2020).

Material and Methods

The study was conducted from December 2020 to March 2021 at the Cikabayan experimental station, Bogor Agricultural University, Bogor Regency, West Java, Indonesia, located at an altitude of about 250 meters above sea level.

The materials used in this study were cowpea variety "Arghavan", "Uno", and "Albina". Manures 2 $ton.ha^{-1}$, urea 30 $kg.ha^{-1}$, SP6 100 $kg.ha^{-1}$, KCl 100 $kg.ha^{-1}$, and dolomite 500 $kg.ha^{-1}$ were supplied to the crops according to production guidelines by Fadillah (2019), Liana (2019) and Siregar, (2020). Pesticides were used to control pests and diseases when required. The equipment used included analytical balance, oven, Li-Cor 6400XT portable photosynthesis system, Image-J application, and a SPAD meter. For the chlorophyll measurement, scissors and a cooler box were used to carry fresh leaf samples prior to analysis.

The study tested a one-factor (cowpea variety) organized in a completely randomized block design with four replications, totalling 12 experimental units. After the beds are prepared, manure and dolomite are spread over the planting bed one week prior to planting. Cowpea seeds were planted 2 seeds per hole with a plant spacing of 60 cm x 50 cm. Crop maintenance included watering, thinning, weeding, and controlling pests and diseases. Cowpeas were harvested when the pod colour have turned brown and had dried up. Harvesting was carried out starting at 10 until 14 weeks after planting (WAP).

Measured parameters include morphological characters, physiological characters, and production components. Physiological characters were measured when 50% of the population flowered, and at the first harvest at 10 weeks after planting, consisting of rate, stomatal conductance, plant growth rate, net assimilation rate, and total carbohydrate content. Production components include the number of pods, pod weight, number of seeds per pod, dry seed weight, the weight of 100 seeds, and productivity. Crop growth rate (CGR) was carried out when 50% of population have flowered, and at the time of the first harvest.

The plant growth rate was calculated using the formula (Rajput et al., 2017):

$$LPT = \frac{\mathrm{w2} - \mathrm{w1}}{\mathrm{P\ t2} - \mathrm{t1}}$$

where

CGR	= crop growth rate (mg.m-2.day)
P	= Plant area (m^2)
w2	= Plant dry weight at t2 (g)
w1	= Plant dry weight at t1 (g)
t1	= time to 50% of flowering (day)
t2	= time to harvest (day)

Net assimilation rate (NAR) is the net assimilation result of assimilation per unit leaf area and time. Measurements were made when 50% of the plants flowered and at the time of the first harvest. NAR calculation using the formula (Shon et al., 1997):

$$LAB = \frac{1}{A} X \frac{\Delta W}{\Delta t} = \frac{\log A2 - Log\ A1}{A2 - A1}\ X\ \frac{\text{Log W2} - \text{Log W1}}{t2 - t1}$$

where

NAR	=	Net assimilation rate (g.cm-2 per day)
w1	=	the dry weight of the plant when 50% of the plant's flower (g)
w2	=	the dry weight of the plant at the time of the first harvest (g)
A1	=	total leaf area when 50% of the plants have flowered (cm²)
A2	=	total leaf area at first harvest (cm²)
t1	=	time to 50% of flowering (day)
t2	=	time to harvest (day)

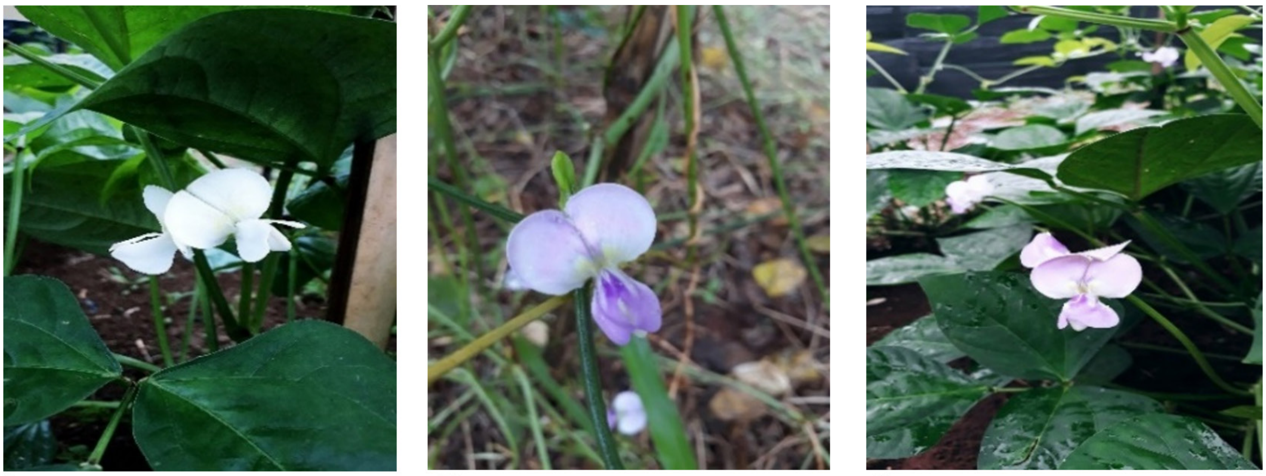
Data was analyzed using analysis of variance (ANOVA) a level of 5% with SAS design version 9.4. using the F test. If the treatments are significant, further tests are carried out using the Duncan Multiple Range Test (DMRT) at the level of significance = 5%. In addition, a correlation test was also carried out between all plant characteristics and pod production. Correlation analysis is carried out with a simple correlation according to Pearson as follows:

The value of $r < 0$ indicates that each plant characteristic has a close relationship with the production of pods and seeds but is negative, while the value of $r > 0$ indicates that each plant characteristic has a close relationship with the production of pods and seeds and is positive. The closer the r value is to 0, the less each plant characteristic has a relationship with the production of pods and seeds. The value of $r = -1 \leq r \leq 1$.

Result and Discussion

Cowpea are rich in the phytonutrients and minerals (Kirigia et al., 2018), therefore it is a potential crop that still needs to be developed further. According to Horn and Shimelis (2020) cowpea has high adaptability and tolerance to drought, low soil fertility, and tolerance to acidic soils (Setyowati and Sutoro, 2010b). In addition, cowpeas can grow better in tropical areas with sandy and dry soils such as saffron areas when compared to soybeans (Sheahan, 2012).

Based on BMKG data from the Bogor climatology station in January to April 2021 (Table 1), the highest average rainfall occurred in February, which was 626.7 mm per month, and this occurred during mid-planting. Rainfall increased at harvest time in April. The length of irradiation during the planting period ranged from 19.5 to 116.9 hours per month, being the highest in April (116.9 hours per month) which occurred at harvest. The average temperature during the growing season ranged from 20.5-21.4ºC and the average air humidity during the growing season ranged from 85.1-92.5%. The relative humidity during the study was normal in the tropical study area and is suitable for cowpea growth. According to Karsono (1998a) the adaptation area of cowpea is in the tropics with optimum temperatures ranging from 25ºC –30ºC.



A B C

Figure 2. Flowers of cowpea flowers: “Albina” (A), “Arghavan” (B) and “Uno” (C).

Table 1. Agro-climatic data between January to April 2021

Month	January	February	March	April
Rainfall (mm)	384.0	626.7	186.8	357.8
Irradiation (hours per month)	19.5	34.5	115.2	116.9
Relative humidity (%)	88.1	92.5	85.1	85.9
Temperature (ºC)	20.5	20.5	21.6	21.4

Source: BMKG data January-April 2021 from Bogor Climatology Station

Table 2. Soil chemical properties before cowpea planting

Soil Parameter	Method	Value	Status
Water Content (%)	Gravimetry	5.58	Low*
pH	H_2O	5.05	Acidic**
Total N (%)	Kjedahl	0.20	Medium**
Available P (ppm)	Bray I	34.15	High*
CEC (cmol.kg^{-1})	NH_4OAc 1M, pH 7.00	14.42	Low*
K-dd (mol K.kg^{-1})	NH_4OAc 1M, pH 7.00	0.07	Very low*

Note: Soil chemical property criteria according to *Soil Research Institute (2005);** SEAMEO BIOTROP Soil Laboratory 2018.

Soil conditions in the study area were classified as acidic (medium N-total, high available P, very low K-dd and low CEC). This pH is suitable for cowpea that can grow well in soils with a pH of 5.0-6.5 (Karsono, 1998b). The soil physical and chemical properties are in Table 2. According to Hardjowigono (2015), the total N-level of >0.5% is considered high (Table 2).

Photosynthetic Rate and Stomatal Conductance

The rate of CO_2 exchange and stomata conductance were measured by a portable photosynthesis system LICOR LI-6400XT on the leaf located on the third node from the topmost leaf. Stomata conductance describes the activity of stomata in regulating CO_2 during the photosynthesis process and also controls the rate of transpiration in controlling the process of tissue water loss. The rate of photosynthesis is related to the chlorophyll content of the leaves which plays a role in absorbing energy from sunlight which is then transferred to chlorophyll (Porra et al., 1993). Chlorophyll is a pigment that plays an important role in photosynthesis and is mostly found in leaves. Table 2 showed no significant difference between varieties in the rate of photosynthesis and stomatal conductance. In general, the conductance capacity of stomata is related to the rate of photosynthesis. Photosynthesis rate in the three cowpea varieties ranged from 29.20 to 31.77 mol $m^{-2}s^{-1}$ at 50% flowering, and ranged from 17.01 to 19.79 mol $m^{-2}s^{-1}$ at the first harvest.

The rate of photosynthesis shows the capacity of plant sources, i.e., the ability of plants to produce assimilates. The rate of photosynthesis of plants is influenced by sunlight received by plants through the leaves (Pantilu et al., 2012). The average stomatal conductance is 0.28 μmol.m^{-2}.s^{-1}- 0.74 μmol.m^{-2}.s^{-1}. According to Hassan et al. (2009) as chlorophylls play a very important role in photosynthesis, they will impact the biomass production. Taiz and Zeiger (2002) reported that the more and wider the stomata opening, the higher the CO_2 gas exchange, as well as stomatal conductance.

Crop Growth Rate and Net Assimilation Rate

Photosynthetic activity is related to source capacity which is characterized by the growth rate of leaf area index, chlorophyll content, and stomata density. Leaf area index, leaf-specific weight, and chlorophyll content play a role in determining the ability of plants to absorb solar radiation and the process of photolysis of water. Stomata aperture are important for the smooth entry and exit of CO_2 and water for photosynthesis (Purnamawati and Manshuri, 2015).

Crop growth rate shows the production of biomass per unit area in a certain duration (Atmaja, 2020). The cowpea growth rate was measured from the difference in plant dry weight at 50% of plants that had flowered and at the time of the first harvest. The growth rates of the three cowpea varieties were not significantly different. The average plant growth rate in the three varieties ranged from 19.50 – 24.77g.m^{-2} per day (Table 3). The increase in the growth rate of cowpea is possible to increase the source capacity (leaf growth) to meet the needs of sinks (pod formation) (Liana, 2019). The crop growth rate is an important factor in analyzing plant growth because it shows the amount of accumulated dry matter produced per unit area in a certain period. The higher the dry matter produced, the higher the plant growth rate will be.

Net assimilation rate is the ability of plants to produce dry matter assimilated per unit leaf area per unit time. The net assimilation rate shows the increase in plant dry weight resulting from the increase in leaf area at a certain time interval. The net assimilation rate was not affected by the three cowpea varieties used and the three varieties were not significantly different. The average net assimilation rate in the three varieties ranged from 3.28 to 3.87 $g.cm^{-2}$ per day. The cowpea net assimilation rate in this study was related to plant dry weight and plant leaf area (Table 3).

Cowpea Yield and Yield Component

The yield components of cowpea measured in this experiment included pod dry weight, pod length, number of seeds per pod, seed dry weight, and 100-seed weight. The yield of pods and seeds per plant in the three varieties did not show significant differences. The highest pod length, pod weight and number of seeds per pod was produced by “Arghavan”. The highest dry seed production was produced by “Albina”. Cowpea seeds in all three varieties produced pithy seeds. The pithy seeds are thought to be caused by the element potassium which plays an important role in translocating the assimilates. Seed filling in cowpea pods is also influenced by environmental factors (Afitu et al., 2016).

The yield of the three cowpea varieties were not significantly different (Table 5). The pod weights of the three varieties were not significantly different. The average weight of the pods per plant is 32.80 – 36.47 g. The average length of the pods was 20.09 – 21.21 cm. The average number of seeds per pod in the three varieties ranged from 10.42 to 10.67. The highest production variables including dry seed weight and 100-seed weight were produced by the “Albina”. The average dry seed weight was 20.28 – 23.98 g. Weight of 100-seeds in the three varieties were significantly different; “Albina” produced the highest 100-seed weight compared to the other two cowpea varieties. The average weight of 100-seeds in the three varieties ranged from 13.08 – 14.16 g (Table 5). This is in line with the research of Rabbani (2021) that the weight of 100 seeds of “Albina” is higher than the “Uno”. The average 100-seed weight ranged from 13.33 to 14.37 g. The average weight of 100 soybean seeds of the “Anjasmoro” and “Grobogan” varieties ranges from 14.40 – 18.23 g (Atmaja, 2020), so cowpeas can be used as an alternative to soybeans.

Table 6 shows that variety has no significant effect on cowpea productivity. The productivity of “Arghavan” is 0.87-$ton.ha^{-1}$, “Albina” 0.88-$ton.ha^{-1}$, and “Uno” 0.79 $ton.ha^{-1}$. The low productivity is thought to be due to the low plant population, which in this study was 33,333 per hectare from the spacing of 60 cm x 50 cm. The results of Rabani’s research (2021) also showed that the productivity of cowpea “Albina” was 0.84 $ton.ha^{-1}$ and “Uno” was 0.80 $ton.ha^{-1}$ with a plant population of 40,000 per hectare.

The low productivity of cowpeas in this study could

Table 3. Photosynthesis rate and stomatal conductance of the three cowpea varieties

Treatment	Photosynthetic rate ($\mu mol.m^{-2}.s^{-1}$)		Stomatal conductance ($\mu mol.m^{-2}.s^{-1}$)	
	7 WAP	10 WAP	7 WAP	10 WAP
“Arghavan”	31.77	17.01	0.70	0.28
“Albina”	29.20	19.79	0.61	0.30
“Uno”	30.09	19.27	0.74	0.30
HSD 5%	ns	ns	ns	ns

Note: ns = not significant according to orthogonal polynomial contrast at 5%. WAP = weeks after planting.

Table 4. Growth rate and net assimilation rate of the three cowpea varieties

Cowpea variety	Crop growth rate ($g.cm^{-2}$ per day)	Net assimilation rate ($g.cm^{-2}$ per day)
“Arghavan”	19.50	3.28
“Albina”	21.84	3.50
“Uno”	24.77	3.87
HSD 5%	ns	ns

Table 5. Yield components of the three cowpea varieties

Treatment	Pod weight per plant (g)	Pod length (cm)	Number of seeds per pod	Seed weight per plant (g)	100-seeds weight (g)
“Arghavan”	35.83	21.21	10.67	22.49	13.18b
“Albina”	36.47	20.19	10.50	23.98	14.16a
“Uno”	32.80	20.09	10.42	20.28	13.08b
HSD 5 %	ns	ns	ns	ns	*

Note: ns = not significant according to orthogonal polynomial contrast at 5%. * = significantly different at the 5% level.

Table 6 Cowpea productivity

Treatment	Productivity (ton.ha^{-1})
“Arghavan”	0.87
“Albina”	0.88
“Uno”	0.79
HSD 5%	ns

Note: ns = not significant according to orthogonal polynomial contrast at 5%.

Table 7. Correlation analysis between plant characters

	Pr-1	Pr-2	CGR	Pod dry weight	Seed dry weight	100-seed weight
Pr-1						
Pr-2						
CGR	-0.259	0.341				
Pod dry weight	0.080	-0.226	-0.286			
Seed dry weight	-0.027	-0.008	-0.473	-0.011		
100-seed-weight	-0.039	0.242	-0.122	-0.277	0.384	
Productivity	-0.025	-0.012	-0.459	-0.023	0.999	0.401

Notes: Pr-1 = photosynthetic rate at 7 weeks after planting, Pr-2 = photosynthetic rate at 10 weeks after planting, CGR = crop growth rate, NAR = net assimilation rate.

be caused by the low intensity of sunlight and too high humidity due to the high and prolonged rainfall intensity during the study period. Liana (2019) also reported that the low cowpea production (0.32 ton. ha^{-1}) was caused by the high rainfall during the trial period. According to Gardner et al. (1991), the yield component is strongly influenced by the growing management, technology, genotypes, and environment, and environmental factors strongly affect the ability of plants to achieve their genetic potential.

Correlation Between Characters

Based on the measured characteristics including the rate of photosynthesis, plant growth rate, net assimilation rate, and yield components, the correlation test results are obtained as shown in Table 7. The correlation coefficient values are classified into several categories, i.e. very low (0.00 – 0.19), low (0.20 – 0.39), moderate (0.40 – 0.59), strong (0.60 – 0.79), very strong (0.80 – 1.00). Based on correlation analysis, the characters measured in this study did not correlate much with each other, neither the rate of photosynthesis, the rate of plant growth, the rate of net assimilation, nor yield components. Only dry seed weight was closely correlated with productivity (0.999). This shows that the amount of dry weight of the seeds produced affects the productivity. The measured characters were negatively correlated with productivity, presumably due to the large population of plants, so high shade levels resulted in inhibited pod filling, which shows a high source capacity while the resulting sink is low.

Conclusion

The three cowpea varieties in this study, “Arghavan”, “Albina” and “Uno”, showed no differences in the source-sink capacity and production per plant. The difference was only in the weight of 100-seeds where the “Albina” had the highest 100-seed weight of 20.33 g.

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