Carbon sequestration of city agriculture: between farming and non-farming land

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Carbon sequestration of city agriculture: between farming and non-farming land

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Abstract. Urban agriculture is multifunctional. The environmental function is one of the agricultural functions. This research focuses on the level of carbon sequestration in food crops and vegetables. Furthermore, we estimate carbon sequestration differences in farming and non-farming land. This study calculates carbon sequestration using destructive methods. Furthermore, food crops carbon sequestration better than vegetable crops. In the same crop, there is more carbon sequestration in farming land when compared to non-farming land. Economically, this carbon sequestration can provide substantial economic value if it is better managed by considering urban spatial planning.

1. Introduction

The primary function of urban agriculture is to fulfill food needs [1], [2] as a substitute for urban and rural areas [3]. Therefore, it is necessary to increase food production sustainably with food security [4], [5], especially in developing countries [6]. Moreover, food is a fundamental problem for human civilization's continuity [7], whose population is increasing [8], [9]. Apart from these primary functions, urban agriculture has other multi-functions [3], [10], [11]. One of them is green open space [12], [13] that is productive and has economic value [14]. Also, make healthy [15], [16], reducing the carbon footprint [17]–[20]. This environmental function [21]–[23] can help overcome climate change [24]. Besides agricultural sustainability [25], especially for farmers small [26], even creating more sustainable cities [9], [16], [27]–[29].

Several studies have shown that trees [30] and tall cover crops [31] on agricultural land or green spaces [28], [32] helps the carbon sequestration of other sectors [20]. Also, organic agriculture [33], [34]. This contribution is limited quantities [35], [36]. Some studies show carbon loss due to high urbanization [37]–[39]. Besides, intensive land management [40], and changes in pastureland [41], [42] and forest [43] become agricultural land, but not the other way around [41], [44]. However, so far, there has not been a calculation of urban agriculture environmental services on farming land and non-farming land.

2. Methodology

a. *Study Area and Plot Area*

This study analyzes environmental services from carbon absorption limited to the soil surface in four potential sub-districts in Makassar City, namely, Tamalate, Manggala, Tamalanrea, and Biringkanaya sub-district with the purposive sampling method. The count was carried out destructively for understory

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[45] using a sample plot measuring 0.5m x 0.5m, both on farming land and non-farming land, carried out randomly.

b. Carbon Stocks Estimation

The first step in calculating the biomass estimate is using the equation:

$$DW\ total = \frac{subsample\ DW}{subsample\ WW} \times total\ weight \quad (1)$$

where DW is dry weight (g) and WW is wet weight (g) [45]. Furthermore, by multiplying the conversion factor by 46% [45], [46], the biomass carbon content can be obtained so that the estimated carbon content is:

$$C = DW \times 0{,}46 \quad (2)$$

where C is carbon stocks (t/ha) and DW is dry weight of biomass (t/ha).

c. Estimated CO_2 Sequestered and O_2 Released

The amount of absorbed carbon dioxide is calculated using the conversion of the C atom to the CO_2 molecule [47], [48] as follows:

$$CO_2 = C \times \frac{Mw\ CO_2}{Aw\ C} \quad (3)$$

where CO_2 is adsorbed carbon dioxide (t/ha), $Mw\ CO_2$ is relative molecular weight of CO_2 compound, and $Aw\ C$ is relative weight of atom C. Furthermore, the release of O_2 can be estimated from CO_2 sequestered using the development formula of the CO_2 sequestered formula through the conversion of the element CO_2 to O_2 [49] as follows:

$$O_2 = CO_2 \times \frac{Mw\ O_2}{Mw\ CO_2} \quad (4)$$

where O_2 is oxygen produced (t/ha) and $Mw\ O_2$ is relative molecular weight of the compound O_2.

d. The Value of Environmental Services from CO_2 Sequestration

The value of environmental services from or the calculated economic valuation is a direct benefit of CO_2 sequestration and is calculated by the equation:

$$V_{ES} = P_C \times CO_2 \quad (5)$$

Where V_{ES} is the value of environmental services (USD/ha) and P_C is the selling price of carbon (USD/t), valued at the 10 USD [50].

3. Result and Discussion

Biomass calculation is needed in estimating carbon absorbed because biomass is organic material stored from photosynthesis [51]. Previously, it was necessary to calculate the plant's wet and dry weight to be calculated its biomass. Figure 1 shows the average wet weight.

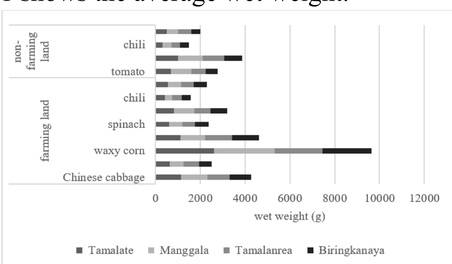

Figure 1. Crop wet weight

The whole plant's average wet weight was 3,379.73 g, where the highest average wet weight of waxy corn located in Manggala sub-district was 2,686.4 g, where 44.31% was in the stem section. Okra plants also had the highest average wet weight for the plant group on non-farming land of 1.097.7 g in Manggala sub-district with the most significant weight on the fruit part, namely 399.8 g. In contrast, the lowest wet weight was in chili plants, both on farming land and non-farming land, namely 1.570.40 g and 1.494.50 g, respectively.

The lowest weight on the Manggala sub-district farming land was 314.10 g and 323.7 g on the non-farming land of Tamalate sub-district with the most negligible weight in the leaf area from 25.95% - 26.57%. In comparison, Figure 2 shows the dry weight.

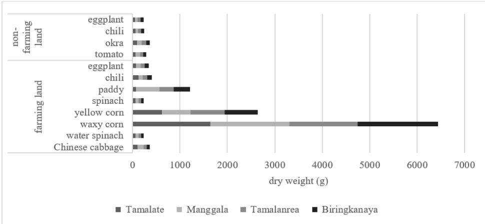

Figure 2. Crop' dry weight

Not different from the wet weight, the whole plant's average dry weight was 1,083.26 g, with the highest weight also in waxy corn. The highest weight is not in the Manggala sub-district but the Biringkanaya sub-district of 1,691.08 g with a composition of 47.7%, which is also in the stem section. Okra also has the highest dry weight for the plant group on a non-farming land of 100.13 g, located in the Manggala sub-district. However, in contrast to the wet weight, the stem's highest dry weight reaches 39%—the fruit's highest water content than to the stems and leaves.

Meanwhile, the lowest average dry weight was for water spinach on farming land and eggplant on non-farming land, 230.84 g and 229.14 g, respectively. Thus, the wet weight is not directly proportional to the dry weight, except for food crops.

Table 1. Crop' carbon stocks

Crop	Carbon stocks (t/ha)			
	Tamalate	Manggala	Tamalanrea	Biringkanaya
1. farming land				
Chinese cabbage	1.96	2.31	1.31	1.17
water spinach	1.06	1.23	1.10	0.85
waxy corn	30.27	30.53	26.51	31.12
yellow corn	11.51	10.97	13.26	12.83
spinach	1.14	1.19	1.08	0.86
paddy	7.37	9.05	5.50	6.42
chili	2.25	1.60	1.85	1.83
eggplant	1.40	1.62	1.61	1.67
2. non-farming land				
tomato	1.20	1.70	1.17	1.29
okra	1.69	1.84	1.70	1.42
chili	1.05	1.12	1.06	1.25
eggplant	0.92	0.98	1.27	1.04
sum	61.83	64.15	57.42	61.76
average	5.15	5.35	4.79	5.15

Overall, based on Table 2, it can be seen that the food crop groups that make a significant contribution to carbon stock, namely corn, and paddy. This contribution is due to the longer harvest life than vegetable crops. The highest carbon stock was obtained from waxy corn at 118.42 t/ha, followed by yellow corn and paddy. The three sequences are the same for the four sub-districts studied. Biringkanaya sub-district supplies the most significant carbon stocks for waxy corn, namely 31.12 t/ha or equivalent to 50.39% of the sub-district's total carbon stock, followed by Manggala and Tamalate sub-districts (Table 1).

Meanwhile, the most significant contribution to yellow corn comes from the Tamalanrea sub-district. Even though the Tamalate sub-district is not a minor contributor, the cost required is too large because it has to pump more water than other commodities. It gives a reluctance to plant yellow corn if not as a member of a farmer group. The paddy commodity, as the third-largest carbon store, on average, stores carbon of 7.09 t/ha, which is not much different from the findings of [25] in Thailand with the ability to store carbon by 7.08 t/ha and has the most significant carbon footprint in China [52].

The most significant contribution came from the Manggala sub-district, amounting to 9.05 t/ha. Paddy field area of 801 ha [53] with the most significant rice production support this contribution. Thus, we can estimate that paddy carbon stock's contribution in this sub-district will reach 7,249.05 tons for one planting season. Likewise, the sub-districts of Biringkanaya, Tamalanrea, and Tamalate have 639 ha, 632 ha, and 509 ha of paddy fields, whose carbon reserves can reach 3,476 t - 4,102.38 t per planting season.

Table 2. Estimates of biomass, carbon sequestration, and economic value

type of land	crops	wet weight (g)	dry weight (g)	Carbon stocks (t/ha)	CO_2 sequestration (t/ha)	O_2 released (t/ha)	Economic value (USD/ha)
farming land	Chinese cabbage	4,277.50	366.88	6.75	24.75	4.91	247.52
	water spinach	2,504.60	230.84	4.25	15.57	3.09	155.74
	waxy corn	9,635.40	6,435.86	118.42	434.21	86.12	4,342.06
	yellow corn	4,609.20	2,640.01	48.58	178.11	35.33	1,781.12
	spinach	2,366.90	232.27	4.27	15.67	3.11	156.70
	paddy	3,190.90	1,216.02	28.35	103.94	20.62	1,039.37
	chili	1,570.40	409.02	7.53	27.60	5.47	275.95
	eggplant	2,280.20	342.84	6.31	23.13	4.59	231.30
non-farming land	tomato	2,761.80	291.71	5.37	19.68	3.90	196.81
	okra	3,874.20	361.30	6.65	24.38	4.83	243.75
	chili	1,494.50	243.30	4.48	16.41	3.26	164.15
	eggplant	1,991.10	229.14	4.22	15.46	3.07	154.59
sum		40,556.70	12,999.17	245.16	898.91	178.30	8,989.07
average		3,379.73	1,083.26	20.43	74.91	14.86	749.09

Meanwhile, the vegetable crop group can store carbon ranging from 4.22 t/ha - 7.53 t/ha. On the farming land of commodity, chilies, Chinese cabbage, and eggplants can store more carbon than spinach and water spinach. The highest carbon storage in chili commodity comes from Tamalate sub-district, while Manggala sub-district for Chinese cabbage and eggplant commodities in Biringkanaya sub-district. Furthermore, in the crop group on non-farming land, the highest carbon stock came from okra, namely 6.65 t/ha and tomatoes, which ranged from 1.17 t/ha - 1.7 t/ha. Compared to the same two commodities, namely chili and eggplant, the carbon stock is more significant in farming land due to the absorption of nutrients from the soil and above the soil surface and the more excellent absorption of sunlight on the farming land.

The most significant average value of carbon stock was in the Manggala sub-district, namely 5.35 t/ha, and the smallest was in the Tamalanrea sub-district. However, the Tamalanrea sub-district contributed carbon reserves of 24,304.92 g [51] or the equivalent of 121.52 t/ha as one of the urban forests. It is not like [32] findings that the carbon in urban park soils in winter is greater than that of forest soils. This contribution is smaller than the contribution of urban agriculture of 245.16 t/ha. The findings of [54] stated that urban agriculture absorbs more carbon than urban green open space, such as parks and forests.

Likewise, [28] calculates urban agricultural carbon stock, identical to seasonal crops of 123.22 t/ha. The four sub-districts have the largest carbon reserves originating from waxy corn, but not the minor contribution, except for Tamalate and Manggala sub-districts with the same commodity eggplant on non-farming land. Meanwhile, in the Tamalanrea sub-district is chili and water spinach on non-farming land in the Biringkanaya sub-district.

The uptake of CO_2, O_2 released, and environmental services can be obtained estimates by the obtained carbon stocks. The ability to absorb CO_2 in the atmosphere is estimated to reach 898.91 t/ha with the order of contributions such as carbon stocks, namely Manggala, Tamalate, Biringkanaya, and Tamalanrea sub-district. This sequence also applies to O_2 and the environmental services it produces. Food crops contribute 79.68% to CO_2 absorption, while plants on non-agricultural land only support 8.45%. This carbon absorption is still smaller than Seoul's agricultural city, which can reduce CO_2 emissions by 11,670 tons each year [18].

Table 3. Estimated population oxygen sufficiency

sub-district	Population* (people)	O_2 needs (kg/day)	availability of O_2** (kg/day)
Tamalate	180,824	151,892.16	706.33
Manggala	146,724	123,248.16	741.27
Tamalanrea	103,177	86,668.68	640.34
Biringkanaya	209,048	175,600.32	675.30
sum	639,773	537,409.32	2,763.25
average	159,943	134,352.33	690.81

**based on the results of the 2020 population census,*
*** based on planted area per hectare of the twelve commodities studied*

If the oxygen demand is 0.84 kg/day/person [55], then the amount of oxygen sufficiency in the four sub-districts can be estimated (Table 3). Manggala sub-district, as the agricultural center of Makassar City, has the most significant O_2 availability, but only 0.60% of the O_2 needs of its population due to its large population. Another case that happened in the Tamalanrea sub-district was the lowest available O_2 but was able to meet 0.74% of the O_2 needs of the population. Overall, the available O_2 can meet the O_2 needs of the four sub-districts residents by 0.51% or equivalent to 3,290 residents.

The availability of O_2 is inseparable from the carbon stocks of food crops, Chinese cabbage, chilies, and eggplant in farming land and okra and tomatoes on non-stretched soils (Table 1 and Table 2). The economic value obtained reaches 8,989.07 USD with a range of 156 - 4,342 USD/ha for commodities on farming land. Non-farming land also contributes 155 - 244 USD/ha. This indirect economic value is often neglected because of the tendency to leave agriculture which is not financially economical. This will affect carbon absorption [56].

However, better agricultural management will have various environmental and economic benefits in addition to climate mitigation potential [57]. Therefore, by estimating the economic value, it is hoped that urban agriculture will become policy makers' attention in the further development of urban spatial planning.

4. Conclusion

Makassar City agriculture has higher carbon sequestration in the food crop group than in the vegetables crop group. In the same types of plants, namely chilies and eggplants, the value of carbon uptake was higher in farming land than in non-farming land. This carbon sequestration provides the highest oxygen adequacy in the Tamalanrea sub-district. This carbon sequestration also has potential economic value. Therefore, in making policies, especially in urban spatial planning, it is necessary to pay attention to these economic values.

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