IMPROVING RICE YIELD AND INCOME OF FARMERS BY MANGING THE SOIL ORGANIC CARBON IN SOUTH SUMATRA LANDSCAPE, INDONESIA

M. E. Armanto
Faculty of Agriculture, Sriwijaya University
Jln Raya Palembang-Prabumulih KM 32, Indralaya Campus, South Sumatra, Indonesia
***Corresponding author: mediarmanto@unsri.ac.id**

ABSTRACT

The research aimed to improve rice yield and income of farmers by managing the soil organic carbon to achieve food security in South Sumatra landscape. This research has been done in agricultural land of Ogan Komering Ilir (OKI) District, South Sumatra. This research is an experimental research by using completely randomized design in factorial. The first factor was rice variety (local and superior), and the second factor was six ricefields, namely ricefields of sandy rainfed; loamy rainfed; *lebak* (freshwater swamp); tidal swamp; and technical irrigation. Composite soil samples were taken from each ricefield and analyzed in the laboratory for organic C content. Rice production data were collected by quadratic methods measuring 5x5 m. The research resulted that the SOC can increase the soil productivity, if the soil productivity can be increased, then the rice yield also increases and the consequences income of household also increases linearly. The contribution of the SOC contents in the rooting areas is able to improve the soil productivity, especially for soils having the following characteristics: coarse and sandy textures, lower SOC contents, receiving lower chemical fertilizer, managed under rainfed conditions rather than irrigation, and poor soils rather than good quality of soils.

Keywords: Improving, rice yield, income, farmers, soil organic carbon

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تحسين حاصل الرز ودخل المزارعين بواسطة تحسين التربة بالكاربون العضوي في جنوب سومطرا في اندنوسيا

ارمانتو

المستخلص

إنتاج الأرز ودخل المزارعين عن طريق إدارة الكربون العضوي للتربة لتحقيق الأمن الغذائي في جنوب سومطرة. وقد تم هذا البحث في الأراضي الزراعية في منطقة أوغان كومرينغ إيلير (أوكي)، جنوب سومطرة. هذا البحث هو البحث التجريبي باستخدام تصميم عشوائي بالكامل في مضروبة. كان العامل الأول هو نوع الأرز)المحلي والمتفوق)، والعامل الثاني كان ستة حقول أرز، وهي حقول الأرز البعلية الرملية. طفيلي الأمطار مستنقع المياه العذبة مستنقع المد والجزر والري التقني. تم أخذ عينات التربة المركبة من كل حقل أرز وتحليلها في المختبر لمحتوى C العضوي. تم جمع بيانات إنتاج الأرز بواسطة طرق تربيعية قياس 5 x5م. وقد أظهرت الأبحاث أن شركة نفط الجنوب يمكن أن تزيد الإنتاجية، بحيث يزداد غلة الأرز كما تزداد نتائج الدخل من الأسر بشكل خطي. محتويات محتويات شركة نفط الجنوب في منطقة التجذير، والخصائص التالية: القوام الخشن والرملي ، ومحتويات SOC أقل ، والأسمدة الكيماوية المنخفضة ، التي تدار تحت ظروف المطر وليس الري، والفقراء. التربة بدلا من نوعية جيدة من التربة.

الكلمات المفتاحية: تحسين، محصول الأرز، الدخل، المزارعين، تربة الكربون العضوية

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INTRODUCTION

About 5-10% of Indonesian population was classified as unsafe in food security (23) (21). The food supply gap occurs because there is a difference between food production and demand, especially rice (5) (6) (15). The always arising question is "Can Indonesia provide sufficient rice as staple food by 2040". This is a major theme for the government to solve (4). Most farmers own less than 0.50 ha of land, use extractive farming practices and obtain low yields around less than 2.00 tons rice/ha/year (18) ((9). Most farming systems used by farmers are resulted in depletion of the soil organic carbon (SOC), making the soils to be highly susceptible to soil degradation processes, such as erosion, chemical pollution, structural damage, biodiversity depleting and overall soil degradation (14) (16). In addition, agricultural crops depend heavily on rainfall condition and have to cope with plant pests and pathogens, and other abiotic factors, such as drought (12), high temperature regimes and others (19) (2) (1). A seasonal failure (e.g. dry season) can lead to crop failure that has a profound impact on income of households (3) (8). The SOC materials are found in or on the surface of the soils derived from the rest of plants, animals, and humans, which have continued decomposition or are undergoing the process of decomposition and they show the differences in size, forming, composition, and character, physiochemistry of the original sources, which have been attached to other soil composers (10). Substantially the SOC consists of humus and non humus substances. Non-humic materials include materials that are being decomposed and partially decomposed (11). Non-humus materials are mostly utilized as energy sources for soil microorganisms as well as soil nutrient sources for plants (13). Through the process of the SOC mineralization, it will be available micro and macro nutrients, while humus material contains nutrients such as NH_4, NO_3, SO_4, S, and H_2PO_4. The SOC content varies from very low (generally mineral soil ranging 0.5-5.0%). Many parameters can be used to characterize the quality of organic materials, among others, organic carbon content, nitrogen, C/N, humus, lignin, cellulose and others. The SOC became one of the indicators of soil health because it has several key roles on the soils. Besides the SOC has interrelated functions, for example providing nutrients for microbial activity which can also increase the SOC decomposition, increase soil aggregate stability, and improve soil recoverability (7). The SOC content is mainly determined by the equilibrium between the rates of accumulation and decomposition. If the SOC accumulation rate exceeds its decomposition rate, especially in areas with saturated water and low temperatures, the SOC content will increase with a low decomposition rate (10). Factors influencing the SOC content are climate, vegetation, topography, time, parent material and cropping. The distribution of vegetation is closely related to certain patterns of temperature and rainfall. Areas with low rainfall and rare vegetation perform low SOC accumulation. In areas of cold temperatures, the activity of microorganism is also low, so that the decomposition process is slow. Some factors affecting the SOC levels are including climate, land use type, landform and human activities. Climate affects the SOC in terms of inhibit of the decomposition rate. Types of land use have an effect on the provision of the SOC resources, e.g. the SOC in ricefields will perform lower SOC content compared with those in forest areas. Landform factors affect the SOC collection or leaching process. Human activities will determine the soil organic content, for example by the provision of fertilizer or drainage affecting the SOC content in the soils (17) (20). This paper will explain and illustrate the positive SOC impacts on the rice yields and food sufficiency via improved soil productivity (22) (23). The research aimed to improve rice yield and income of farmers by managing the soil organic carbon to achieve food security in South Sumatra landscape. The research results will be useful to solve the problems of food insecurity and global warming through the SOC absorption. In addition, this research can be also utilized as an input for the government to do bargaining with poor farmers who are forced to deplete the soil resources in excess, so that it will be obtained a win-win approach that is timely and appropriate location.

MATERIALS AND METHODS

The research has been done in agricultural lands of Ogan Komering Ilir (OKI), District, South Sumatra Indonesia (Figure 1). This experimental research was designed by using factorial completely randomized design (CRD design in factorial). The first factor was two kinds of commonly used rice varieties (i.e. *Ciherang* and IR64), and the second factor was five ricefields, namely ricefields of sandy rainfed; loamy rainfed; *lebak* (back swamps or freshwater swamps); tidal swamp; and technical irrigation. Composite soil samples were taken from each ricefield and analyzed in the laboratory for organic C content (Walkey and Black method). Rice production data were collected by making some sampling plots (quadratic method) measuring 5x5 m. Collecting socio-economic data were done by combining the interview method with questionnaire and unstructured through the Focus Discussion Group (FDG) and direct observation in the field. An open questionnaire gives the respondents the freedom to answer questions; meanwhile, the closed questionnaire has given the answer option to be chosen by the respondent. Studying literature was done by analyzing reports and literatures relating to research theme. All data were collected and analyzed by SPSS program.

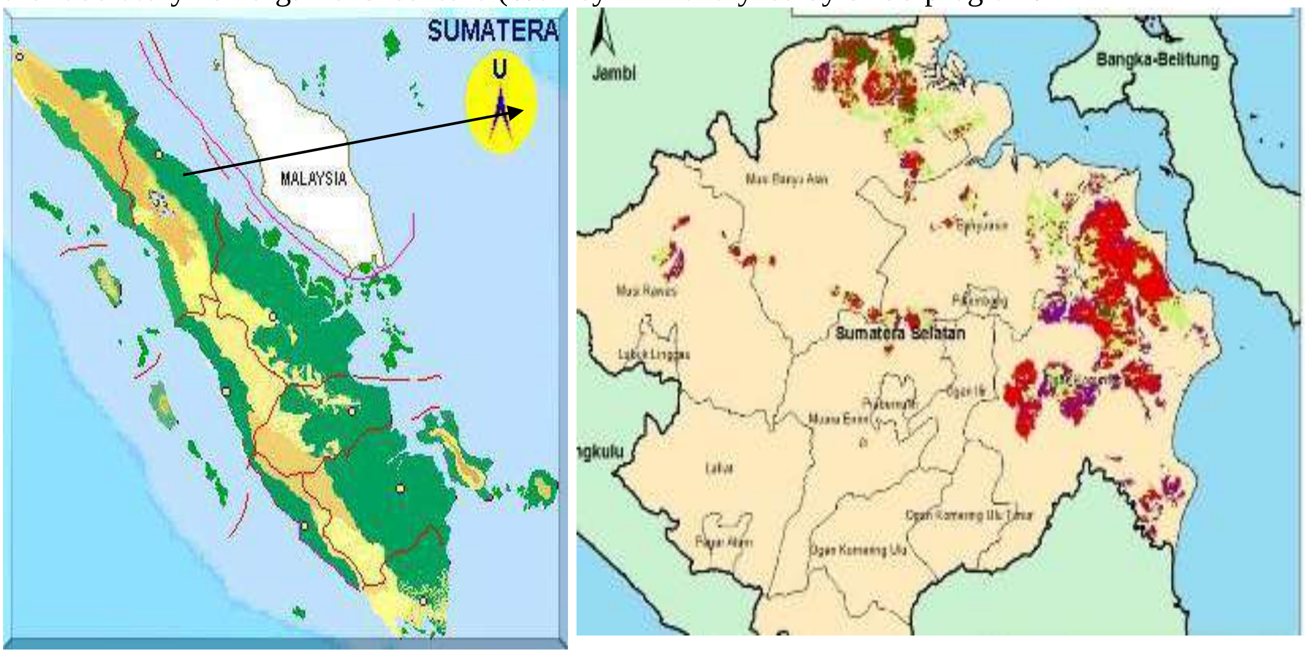

Figure 1. The location of research area

RESULTS AND DISCUSSION

The results and discussion of this research will emphasize on several important aspects, including the potential range of the SOC on agricultural soils; the role and function of the SOC in ecosystem services; responses of rice yield and income of household to the SOC contents.

1.1. Potential Range of the SOC on Agricultural Soils

Soil resources are able to provide an abundance of agroecosystem, namely providing main fiber and food supply, storage and fresh water, biodiversity and others. The ecosystem services provided by soil resources are heavily dependent on the number and quality of the SOC in the rooting areas. Many soils in agricultural ecosystems showed lower SOC levels than natural environments due to high mineralization, temperature to accelerate the SOC decomposition, land clearing by burning, tropical regimes of soil humidity, low input of the SOC to the soils, leaching and erosion processes. Average values of the SOC ricefields in South Sumatra can be summarized in Table 1. The highest range of the SOC values was found on technical irrigation (average 2.42%) and significantly different from the SOC in loamy rainfed and sandy rainfed (0.72% and 0.32% respectively). The lowest average SOC content was found in sandy rainfed ricefields with average value of 0.32% due to the inability of the soils to absorb and to retain SOC (due to erosion and leaching) and was significantly different compared to loamy rainfed ricefields (0.72%) and significantly different with *lebak* and tidal ricefields. The low SOC on rainfed ricefields was mainly caused by mismanaged soil cultivation and soil misuses. The main factors of the SOC capacity control can be done by managing water and soil resources, controlling soil erosion, improving soil structure and minimizing soil degradation. If the SOC can be properly managed, thus soil productivity and agricultural production can be optimally improved.

Table 1. The SOC contents of topsoils (0-20 cm) from ricefields in South Sumatra

Nr	Ricefields	Organic C (%)	Average value (%)
1	Sandy rainfed	0.25-0.60	0.32[a]
2	Loamy rainfed	0.50-1.25	0.72[b]
3	*Lebak*	1.00-4.70	2.34[c]
4	Tidal	1.20-6.50	2.41[c]
5	Technical irrigation	1.00-5.40	2.42[c]

Note: */ Individuals located in the similar column and indicated with the same superscripts show no significant difference according to Tukey 5% test

1.2. The Role and Function of the SOC in Ecosystem Services

Generally the SOC can be derived from various main components, namely primary sources include the organic tissues of plants (flora) that can be leaves, branches, stem, fruit, roots and others. Secondary sources come from organic fauna, which can be in the form of macro and micro fauna. Other sources come from some organic fertilizers in the form of manure, green manure, compost, biological fertilizers and others. Based on the level of decomposition, the SOC can be divided into two groups, namely ingredients that have been humifized, called humic substances (humic substances) and materials that are not humifized, called non-humic substances. Humic substances are commonly known as "humus" which is the end result of the SOC decomposition process, which is stable and resistant to bio-degradation process and consist of fraction of humic acid, acid and humin. Humus composes around 90% of the SOC. Non-humic substances include organic compounds, such as carbohydrates, amino acids, peptides, fats, waxes, lignin, nucleic acids, proteins and others. The soil criticality level is within the optimum range of the SOC contents (about 1-3% in the rooting areas). The increased SOC directly improved rice yield because the SOC can improve soil properties. The SOC became one of the indicators of soil health because it has several key roles on the soils. The SOC functions are related to each other. For example, the SOC provides nutrients for microbial activity that can also increase the SOC decomposition, increase soil aggregate stability, and improve soil recoverability. The SOC key roles can be grouped into three groups (Table 2).

a. The SOC Role on Biological Fertility of Soils

The SOC can be mainly utilized by soil macro and micro fauna as main energy sources. The SOC addition in the soils will cause the activity and the microbiological population in the soil to increase, especially in relation to the SOC decomposition and mineralization activities. Some of the microorganisms in the SOC decomposition are fungi, bacteria and actinomycetes. Soil microorganisms are also supporting in decomposing the SOC, among others belonging to protozoa, nematodes, collembola, and earthworms. They help to accelerate some humification process and mineralization or nutrient release, and even partly responsible for the maintenance of soil structure. These soil micro flora and fauna interact with their needs for the SOC, as the SOC provides the energy to grow and the SOC provides carbon as an energy source. Another positive influence of the SOC addition is its effect on plant growth. There are compounds that have an influence on the biological activity found in the soil, which stimulate compound (auxin), and vitamins. These compounds in the soils are derived from plant exudates, manure, compost, plant residues and also derived from microbial activity in the soils. In addition, it is indicated that organic acids with low molecular weight, especially bicarbonate (such as succinate, ciannamate, and fumarate) of the SOC decomposition, in low contents can have properties such as growth stimulants, which positively affect plant growth.

Table 2. The role and function of the soil organic matter (SOC)

Nr	Function	Description
1	Biological	Provide food and habitat for organisms (including microbial) in soils; providing energy for soil biological processes; contributing to the recovering capability of soils
2	Chemical	It is a measure of soil nutrient retention capacity; essential for soil recovery due to soil pH change; storing reserves or soil nutrients, especially N and K.
3	Physical	Improving soil aggregates; binding the soil particles into more crumbs to improve the stability of the soil structure; increasing available water capacity; minimizing the risk of soil erosion; improving soil capacity in storing water; moderating change to soil temperature

Source: Results of field survey and observation (2019).

b. The SOC Role on Chemical Fertility of Soils

The SOC is especially influential on soil nutrient supply both macro nutrient and micro nutrients. In addition, the SOC is able to produce soil humus acting colloidal from residual compounds of mineralization. The compounds are difficult to decompose in the humification process and improve the soil cation exchange capacity around 25-50 times larger than inorganic colloids. The role of other SOC is to reduce the positive charge of the soil through the process of chelation to oxidized minerals and reactive Al and Fe cations, thereby decreasing the soil P fixation and increasing the availability and efficiency of fertilization.

c. The SOC Role on Physical Fertility of Soils

Soil physical condition can guarantee the good growth of plant roots and as a good place of aeration and soil moisture. All is related to the SOC role. The greatest SOC role on soil physical properties includes the improvement of structure, consistency, porosity, water binding capacity and etc, the increase of resistance to erosion is found. The SOC is one of soil aggregate forming, which has the role of adhesive material between soil particles to unite into soil aggregates, so the SOC is important in the formation of soil structures. The SOC effect on soil structure is closely related to the texture of the treated soil. In heavy clay, there is a rough and strong clump structure changes to a finer, non-abrasive structure, with moderate to strong degree of structure, making it easier to process. Organic components such as humic acid and fulvic acid acted as clay cement by forming a clay-metal-humus complex. The formation mechanism of soil aggregates by the SOC can be divided into four forms, namely the SOC addition can increase the population of soil microorganisms (fungi and actinomycetes). By physically binding the primary grains is done by mycelia myceloma and actinomycetes, it will form aggregate even in the absence of clay fraction. Chemical bonding of clays is done by bonding between positive parts in clays with the negative (carboxyl) group of long-chain organic compounds (polymers). Chemical bonding of clay grains is showed by bonding between negative parts in clay with a negative chain (carboxyl) group of long-chain organic compounds by means of the bases of Ca, Mg, Fe and hydrogen bonds. Chemical bonding of clays is determined by bonding between negative parts in clays with positive groups (amine, amide, and amino groups) long-chain organic compounds (polymers).

1.3. Responses of Rice yield and Income of Household to the SOC contents

The rice response to the SOC contents in the rooting areas was influenced by many components, such as soil fractions, mineralizable minerals, and managerial input, particularly water and soil nutrients. Some trials have been carried out especially to establish a relationship between the SOC content and rice yields. Much of the available data regarding the yields of the SOC contents figured some different results to discover the SOC roles on rice yields (Table 3 and Table 4)

Table 3. Average rice yields and income of household from ricefields

Nr	Ricefields	Rice yields (tons DMG/ha/planting season)**	household Income (US$/ha/planting season)
1	Sandy rainfed	0.80±0.06[a]	65.71±0.07[a]
2	Loamy rainfed	2.45±0.18[b]	232.86±0.26[b]
3	*Lebak*	4.70±0.36[c]	275.01±0.27[b]
4	Tidal	5.50±0.39[c]	285.71±0.88[b]
5	Technical irrigation	7.40±1.05[d]	450.02±1.09[c]

Note: * Individuals located in the similar column and indicated with the same superscripts show no significant difference according to Tukey 5% test
**** DMG (Dry Milled Grains)**

a. Responses of Rice Yield to the SOC Contents

The highest rice yields was found in technical irrigation (average 7.40 ton DMG/ha/year) and was significantly different when compared to ricefields of rainfed, *lebak* and tidal (0.80; 2.45; 4.70; and 5.50 tons DMG/ha/ planting season respectively). The lowest average rice yield was found in sandy rainfed ricefields with a value of 0.80 ton DMG/ha/year due to the inability of the soils to produce and significantly different and very significantly different compared to other ricefields. All of the differences are due to differences in the SOC content that is also distinctly different for each ricefields. The results of the literature study showed different determinant coefficient (R^2) for some crops and was summarized in Table 4. It is generally found that about 51-99% of the yields of food crops was dominantly determined by the SOC presence in the rooting areas of the plant. This value is highly dominant in determining the success of yields due to the SOC presence in rooting areas, particularly for rice, cereals, wheat, barley, mustard, cowpea and maize crops (Table 4)

Table 4. Regression and correlation between soil organic C and yields

Crops/soils/literature	Regression	R^2
Rice, Inceptisols, China, Tang *et al* (2010)	Y=1.853X+4.23	0.95
Rice, Inceptisols, China, Tang *et al* (2010)	Y=2.66X+1.53	0.99
Rice, Inceptisols, China, Majumdar *et al* (2007)	Y=1.01X+3.02	0.96
Rice, Vertisols, India, More (1994)	Y=9.33X-2.42	0.52
Rice, Inceptisols, China, Tang *et al* (2010)	Y=2.3X+5.56	0.95
Cereals, Ultisols, China, Pan *et al* (2009)	Y=2.038X+1.323	0.93
Cereals, Ultisols, China, Pan *et al* (2009)	Y=1.51X+0.752	0.80
Wheat, Inceptisols, China, Tang *et al* (2010)	Y=4.54X+7.48	0.99
Wheat, Vertisols, India, More (1994)	Y=9.44X−1.91	0.51
Wheat, Entisols, Russia, Kanchikerimath & Singh (2001)	Y=12.70X+1.88	0.71
Wheat, Inceptisol, Benbi and Chand (2007)	$Y=-2.60X^2+5.65X$	0.96
Wheat, Alfisols, Russia, Tripol'skaya *et al* (2008)	Y=0.34X+3.28	0.78
Barley, Alfisols, Russia, Tripol'skaya *et al* (2008)	Y=0.28X+3.00	0.58
Barley, Inceptisols, Lithuania, Jankauskas *et al* (2007)	Y=1.80X−1.01	0.78
Barley, Entisols, Russia, Ganzhara (1998)	Y=0.142X+3.05	0.50
Maize, Inceptisols, China, Tang *et al* (2010)	Y=1.764X+4.70	0.91
Maize, Entisols, India, Kanchikerimath & Singh (2001)	Y=7.94X+0.33	0.83
Maize, Alfisols, Nigeria, Lal (2010)	Y=2.875X+0.28	0.75
Maize, Entisols, Russia, Ganzhara (1998)	Y=8.13X+36.40	0.59
Maize, Alfisol, Petchawee and Chaitep (1995)	Y=4.82X+0.29	0.78
Cowpea, Inceptisols, India, Kanchikerimath & Singh (2001)	Y=1.64X−0.22	0.75
Cowpea, Alfisols, Nigeria, Lal (2010)	Y=0.225X+0.04	0.55
Mustard, Entisols, Russia, Ganzhara (1998)	Y=1.84X+10.95	0.89

Sources: Compilation from some literatures (2019).

The highest determinant coefficients (R^2) were performed by Inceptisols with a value range of 75-99%. Thus a 1% increase of the SOC content in the rooting areas was able to increase rice yields by about 1.85 ton/ha. The highest yield increase was shown by wheat ranging of about 4.54 tons/ha, about 1.80 tons/ha for barley and about 1.76 tons/ha for maize and cowpea by about 1.64 tons/ha. This is because Inceptiosls are classified as slightly developing soils, thus the SOC increase in the rooting areas influenced an impact on increasing the soil capability to hold much soil nutrients. The weathering process of the parent material will release the micro nutrients and will increase the rice yield. Vertisols showed the lowest R^2 values ranging of 51-52% for some food crops. Although Vertisols did not show high R^2 values that were determined as low, but the increase of the SOC content by 1% in the rooting areas can increase rice yield around 9.33 ton/ha and about 9.44 ton/ha for wheat. This increase is relatively high compared to other agricultural commodities. This is because Vertisols have naturally high clay content (more than 50%) and the high clay will be able to hold and to absorb also high soil nutrients, thus to some extent there is a tendency that the higher the SOC in the rooting areas, the higher rice yield will be obtained. Ultisols can be classified as highly weathered soils and have a very low soil fertility level with high clay content. Naturally the soils content a low SOC because of the high leaching process and soil degradation, such as soil erosion. The giving of the SOC on the soils showed very positive respond, therefore the soils indicated the highest variation of R^2 values, which are around 80-93%. Increasing the SOC content about 1% in the rooting areas can increase the rice yields in the range of 1.51-2.04 ton/ha. Therefore the SOC on Ultisols is the key how to manage the soils for the production of agricultural commodities in general. Alfisols morphology and genesis have similarities in the naturally genetic processes with Ultisols, but the weathering process on the soils is not as intensive as Ultisols. In addition, the soils have an initial SOC content of 2-4 times higher than Ultisols. Therefore, the soils have R^2 values ranging from 55-78% for rice crops. With a 1% increase of the SOC was able to improve production of wheat biomass by 0.34 ton/ha, about 0.29 ton/ha for barley, for maize around 4.82 ton/ha and around 0.23 ton/ha found in cowpea. Entisols are classified as undeveloped soil types and do not have horizontal differentiation. The SOC content in the soils is mentioned as low to high depending on their parent materials and the locations where the soils are developed. The soils showed R^2 values varying between 50-89% for different food crops. With an increase of 1% of the SOC in the rooting areas, it can increase the production of wheat biomass by 12.70 ton/ha, around 0.14 ton/ha for barley, and about 7.94 ton/ha for maize. In general, the contribution of the SOC contents in the rooting areas is able to improve the soil productivity, especially for soils having the following characteristics: coarse and sandy textures, lower SOC contents, receiving lower chemical fertilizer, managed under rainfed conditions rather than irrigation, and poor soils rather than good quality of soils.

b. Income Responses of Household to the SOC Contents

The impact of the SOC increase in the rooting areas on each ricefield directly gave a significant difference to the income of household. The highest income of household range was found in technical irrigation (average US$ 450.02/ha/planting season) and significantly different compared to ricefields of rainfed, *lebak*, and tidal (US$ 65.71; 232.86; 275.01; and 285.71/ha/planting season). The lowest average income of households was found in sandy rainfed ricefields with a value of around US$ 65.71/ha/planting season due to the inability of the soils to produce rice yields and significantly different from other ricefields. All of the differences were mainly due to differences in the SOC contents which were also distinctly different for each ricefields.

The contribution of the SOC contents in the rooting areas is able to improve the soil productivity, especially for soils having the following characteristics, namely coarse and sandy textures, lower SOC contents, receiving lower chemical fertilizer, managed under rainfed conditions rather than irrigation, and poor soils rather than good quality of soils.

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