APPLICATION OF AGRICULTURAL PRACTICES TO INCREASE SOIL CARBON SEQUESTRATION IN TAIWAN

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ABSTRACT

According to the global estimation, the annual increase in CO_2 concentration in the atmosphere can be halted by increasing 4‰ of the quantity of carbon contained in soils per year. The "Four per One Thousand Initiative" has been lunched by France on COP 21. Taiwan has signed the joint declaration as a response to the action. The action is also a major contributor to the greenhouse effect, climate change and food security. The objective of this study is to assess the possibility to achieve the goal of increasing 4‰ of soil organic carbon (SOC) every year in Taiwan. First, the SOC in Taiwan has been estimated by the sum of content of SOC in different soil groups. Second, the carbon sequestration potential of different agricultural practices has been estimated by long term experiment. The assessed practices include livestock manure and bio-char application on farmlands, organic farming, orchard grass cultivation, and afforestation in the plain area. The results reveal the content of SOC in Taiwan is about 237 million Mg in 0-100cm depth. The bio-char application has the highest potential carbon sequestration among the practices. However, the total of the potential carbon sequestration cannot achieve the goal of the initiative by all of the practices. Moreover, the total carbon sequestration of current practices is much lower than the target. In the future, some other practices, such as intercropping, restore the degraded land, land use change, and minimum tillage etc., might be improved to approach the goal of the initiative.

Keywords: 4 per 1000 initiative, soil carbon sequestration, agricultural practice

INTRODUCTION

The Paris Climate Agreement had been built upon the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21) on Nov. 30 to Dec. 11, 2015 in Paris, France. This is a global agreement on the reduction of climate change, limiting global warming to less than 2 Celsius degrees (℃). In order to keep temperature rise below 2 ℃, we need to limit our annual greenhouse gas emission with an estimate of 9.8 Gt (9.8×10^{15} g) C at a 64% probability (Meinshausen *et al.,* 2009).

The annual greenhouse gas emissions from fossil carbon are estimated as 8.9 Gt C (8.9×10^{15}g), and a global estimate of soil C stock to 2 m of soil depth of 2400 Gt (2400×10^{15}g) (Batjes, 1996). Taking the ratio of global anthropogenic C emissions and the total soil organic carbon (SOC) stock (8.9/2400), results in the value of 0.4% or 4‰ (4 per mille) (Ademe, 2015). Increasing SOC has been proposed to mitigate climate change with an additional benefit of improving soil structure and conditions (Lal, 2016).

The “4 per 1000 Initiative: soils for food security and climate” aspires to increase global soil organic matter stocks by 0.4 % per year as a compensation for the global emissions of greenhouse gases by anthropogenic sources. The initiative aims to show that food security and combating climate change are mutually complementary and to ensure that agriculture is a source of solutions. It was launched in COP21 as well and supported by almost 150 signatories (i.e., countries, regions, international agencies, private sectors and NGOs). Taiwan has signed the joint declaration as a response to the action. Stakeholders commit in a voluntary action plan to implement farming practices that maintain or enhance soil carbon stocks in agricultural soils and to preserve carbon-rich soils (Chambers *et al*., 2016; Lal, 2016).

In the world, if the land area is considered as 149 million km^2, SOC would be estimated about 161 tons/hectare on average. So 4 per mille of this equates to an average sequestration rate to offset emissions of C as 0.6 tons hectare^{-1} year^{-1}. This 4 per mille blanket value cannot be applied everywhere as soil varies widely in different environments, including desert, peat lands, mountains, etc., in turns of C storage. Soil types, aboveground vegetation, climate, and how quickly the soil biota uses the carbon which collectively impact the C storage. Nevertheless, studies from the world have estimated SOC sequestration rates and they suggest that annual carbon sequestration rate is about 0.2 to 0.5 tons/hectare, whilst adopting the most appropriate management practices, such as tillage reduction in combination with legume cover crops. In addition, some reports demonstrated that SOC increases due to the improvement on managements (Chen *et al*., 2015).

The 4 per mille initiative is feasible for the regions. The outcomes highlight regional specific efforts and scopes for soil carbon sequestration. Reported soil C sequestration rates globally show that under the most appropriate management practices, 4 per mille or even higher C sequestration rates can be accomplished. High C sequestration rates (up to 10 per mille) can be achieved for soils with low initial SOC stocks (topsoil less than 30 ton C ha^{-1}), and at the first 20 years after implementation of the most appropriate management practices. In addition, areas where they have reached the equilibrium of decomposition will not be able to further increase the C sequestration rate. (Budiman *et al*., 2017)

Taiwan is located in subtropical region with high temperature and high humidity. The decomposition of organic materials in soils is fast. The carbon sequestration is accumulated slowly by applying organic material. It is a challenge to achieve the goal of increasing 4‰ of SOC every year in Taiwan. The objective of this study is to evaluate the current and possible agricultural practices to reach the goal of the initiative and how to approach it in the future.

MATERIALS AND METHODS

Estimation of the SOC stocks in Taiwan

To estimate the Carbon sequestration rate, the current SOC stocks should be estimated first. The global SOC stocks have been estimated within different soil depths, from one to two meters, by different international research organizations (i.e., 4 per mille initiative, INRA, University of Sydney, etc.). According to the limitations of soil survey in the past, the SOC stocks in Taiwan had been estimated within one-meter-depth of soil. The SOC stocks in agricultural lands and forest with various depths in Taiwan had been estimated by the surveys as shown in Table 1 (Chen *et al.,* 2000; Chen and Hseu, 1997; Tsui *et al.,* 2016; Tsui *et al.,* 2016).

Table 1. Soil organic carbon (SOC) stocks with varied depths in Taiwan

Depth (cm)	SOC (Mg/ha)	Ratio (0-100)	Land use	Citations
0-20	32.4	29	Farmland	Chen *et al.,* 2000
0-30	36.4	54	Farmland & Forest	Chen and Hseu 1997
0-50	50.3	72	Farmland & Forest	Chen and Hseu 1997
0-100	73.1	100	Farmland & Forest	Chen and Hseu 1997
0-15	27.1	20-25	Farmland & Forest	Tsui et al., 2016
0-30	51.0	37-47	Farmland & Forest	Tsui *et al.,* 2016
0-50	88.5	65-81	Farmland & Forest	Tsui *et al.,* 2016
0-100	109-136	100	Farmland & Forest	Tsui *et al.,* 2016
0-30	48.2	50	Farmland	Jien *et al.,* 2010
0-50	67.3	70	Farmland	Jien *et al.,* 2010
0-100	96.4	100	Farmland	Jien *et al.,* 2010

Estimation of the decomposition of organic materials in soil

The accumulation of SOC by applying organic materials is a slow process. Since there is no regular monitoring network for cultivated soil carbon, SOC sequestration rates of various practices in cultivated soils were estimated based on limited long term experiments in this study. Those data from different sites in Taiwan have been collected, where different rates of crops residues or organic manure had been applied continuously as shown in Table 2.

(1) 48-year field trial of two crops paddy under applying different organic materials rice in Taipei.
(2) 14-year field trial of rice-rice-soybean under applying crop residue in Pingtung.
(3) 9-year field trial of 2-3 crops soybean under applying compost in Tainan.
(4) 10-year field trial of two crops paddy under applying swine manure in Taichung.

The decomposition and accumulation of organic matter in soil were simulated as the first order reaction (Chen and Lian, 2002) in the followings equation (1) :

$$\frac{d(SOC)}{dt} = A - k(SOC) \qquad (1)$$

A: Application rate of organic C.
K: Decomposition rate constant.

If we apply the same amount of organic materials on soil every year, SOC will reach a stable equilibrium status after several decades. At that time, the SOC decomposition rate will not increase any more. The equation was used to estimate SOC stocks at equilibrium of decomposition under applying the organic materials by curve fitting of long term data.

Table 2. SOC decomposition rates under applying different organic materials in five sites, Taiwan

Location	Years	Crop System	Trt(z)	Crop residue/ Organic manure	Rate applied (Mg/ha/yr)		Decomposition rate	SOCeq(x)
					Matter(y)	C	constant(K,yr^{-1})	(%)
Taipei,	1924-1972	Rice-rice	NoF	rice stubble & root	1.4	0.6	0.0158	2.2
			IF	rice stubble & root	2.6	1.0	0.0229	2.4
			GM	rice stubble & root green manure (soybean)	2.6 31.6*	1.0 2.5	0.0805	2.5
			OF	rice stubble & root farm yard manure	2.7 18.2*	1.1 2.8	0.0795	2.8
Wanluan,	1974-1988	Rice-rice-	IF	rice stubble & root	5.8	2.3	0.06	2.0
Pingtung,		soybean	IF+res.	root rice straw soybean residue	4 6-8* 0-2*	1.6 2.2-2.9 0-0.7	0.115	2.1
Shanhua,Tainan,	1984-1992	Soybean -soybean -soybean	IF	root crop residue bagasse-filter cake compost	0.7-1.3 21.5-0 20-0*	0.3-0.5 8.6-0 1.5-0	0.5-0.059	0.4
			IF+OF	root crop residue bagasse-filter cake compost	0.7-1.3 21.5-0 150-20*	0.3-0.5 8.6-0 8.8-1.5	0.18	1.9
Wufeng, Taichung,	2004-2016	Rice-rice	NoF	rice stubble & root	7.6	3.0	0.1449	1.0
			IF	rice stubble & root organic fertilizer	15 0.8	6.1 0.3	0.185	1.6
			M	rice stubble & root swine manure	15 1.4	6.0 0.6	0.1683	1.8

(z)Trt: treatment, NoF: no fertilizer, IF: inorganic fertilizer, GM: green manure, OF: organic fertilizer, M: swine manure, OG: Orchard grass

(y)annotated '*' are based on fresh weight, while the rest are based on dry weight

(x)$SOC_{(eq)}$: estimated soil organic carbon content at equilibrium status.

Feasible agricultural practices on the improvement of SOC sequestration

There are some feasible practices which have been conducted to increase the SOC sequestration in Taiwan as the following. Some practices have been monitored and reviewed for the estimation of the SOC sequestration.

Application of livestock manure on farmland

The waste of livestock must be treated by a three-step process, and then discharged to the surface water in the past. After the evaluation of the experiments in 4-5 years, applications of livestock manure on farmlands for fertilization have been approved by the government of Taiwan since 2011 (Chen, 2013). There are more than 300 ha of farmlands applied with swine or cattle manure. The area of manure applications is continually increasing on a yearly basis. A 10-year-experiment of continuous swine manure applications has been conducted on farmlands by the Taiwan Agricultural Research Institute (TARI). The SOC sequestration has been estimated by this experiment. The annual SOC sequestrations were estimated according to Walkley-Black wet oxidation method (Nelson and Sommer, 1982).

Organic farming

Organic farming, by recycling the agricultural organic waste, is one of the effective practices to increase SOC sequestration. It is also one of the environmentally friendly agricultural practices. However, it is a the practices are challenging because they are costly and labor intensive under the special climate and complicated environment in Taiwan. The current area of organic farming is only about 7,600 ha (<1% of total cultivated land in Taiwan), including 2,700 ha in paddy fields and 4,900 ha in upland fields (Taiwan Organic Information Portal, 2018). Organic farming can be improved through the subsidy from the government. The goal of the area of organic farming by the government is to up to 40,000 ha (~5% of total cultivated land in Taiwan) in 2017. The SOC sequestration of organic farming is estimated from the data of a previously mentioned 10-year-experiment.

Orchard grass cultivation

Most of the orchard grows along a sloping hill in Taiwan. The grass cultivation is one of the strategies to inhibit weed growth, control the damages of insects and pests, and improve the conservation of soil, water and environment. The grass cultivation is improved on orchards, especially on the slope. Two of the short-term-experiments (Chen *et al.,* 2015; Juang and Jean, 1978) have been reviewed to estimate the SOC sequestration. However, both of them have not yet reached the steady status. In addition, the area of orchard grass cultivation had not been under monitoring by a national research institute.

Green manure cultivation

The green manure cultivation is one of the appropriate practices to maintain the soil fertility and to prevent the nutrients loss during fallow. For many years, it is being promoted by the government. The promotional area of the green manure cultivation is 0.4 M ha. In this study, the data of SOC accumulation from long term experiment by applying green manure in Taipei has been used to estimate the SOC sequestration for this practice.

Afforestation in plain areas

To reduce the impacts of WTO membership and to improve the environmental conservation in Taiwan, afforestation in the plain areas and the crop lands have been actively implemented since 2002. The government plans to afforest about 25,000 ha within five years. However, the strategies of afforestation has been terminated due to the national program of adjusting cropping system to make the arable land active since 2013 (Forestry Bureau, 2017). The total area of afforestation is about 18,399 ha in Taiwan. The monitoring of SOC accumulations (Lin *et al.,* 2011a) has been reviewed in this study.

Application of bio-char on farmlands

The benefits of applying bio-char on farmlands have been reviewed by many studies (Yu and Juang 2012；Lai *et al.,* 2013；Kelly *et al.,* 2015；Chen *et al.,* 2017(a)). One of the benefits is to increase the SOC stocks due to its low decomposition rate (Wang *et al.,* 2016). According to the reviewed papers, when applying bio-char on farmlands, more than 80% of carbon will be remained in the soil after several decades (Wang *et al.,* 2016). The area with strong acidic soil is about 0.3 million ha (~38% of total cultivated land) in Taiwan. It is expected to be improved by applying bio-char instead of liming (Chen *et al.,* 2017(b)). From the reviewed papers (Chen *et al.,* 2017(a); Chen *et al*., 2017(b)), applying 2% of bio-char in the soil will have the positive effect for crop growth. The rate of bio-char is used to estimate the potential carbon sequestration. However, the annual potential production of bio-char is only 10,000 Mg per year, in Taiwan, due to the current limitation of the amounts of kilns.

RESULTS AND DISCUSSION

Estimation of the SOC stocks in Taiwan

The areas of cultivated lands and forest lands are approximately 0.8 M ha and 2.2 M ha, respectively, and the total area is about 3.6 million ha in Taiwan (COA, 2018(b)). According to the results of soil surveys, the amounts of SOC stocks are between 73 - 136 Mg/ha within one meter depth among farmlands and forests as the table 1 (Chen and Hseu ,1997; Chen *et al.*, 2000; Tsui *et al.,* 2016; Tsui *et al.,* 2016). In this study, the SOC stocks for the top 1 m is estimated as 77 million Mg in cultivated soils (Jien *et al.,* 2010) and 160 million Mg in forest soils (Tsai *et al.,* 2010). Therefore, the total SOC stocks in Taiwan are about 237 million Mg.

In Taiwan, the average SOC stocks of cultivated soils tend to decrease from the north to the south because the climate is warmer in the south (Chen *et al.,* 2000; Tsui *et al.,* 2013). For forest soils, the variation of SOC stocks is significantly related to the air temperature and elevation gradients. In Taiwan, the current annual CO_2 emissions from fossil fuel are 253.92 Mt CO_2 (69.25 Mt C) (EPA, 2018). In general, 49.6% of cultivated lands are used for rice production, which is more efficient for C sequestration compared to the lands for other crops (Chen *et al.,* 2000).

Taiwan Agricultural Research Institute (TARI) has conducted a detailed soil survey based on a grid sampling design (250 m × 250 m) between 1992 and 2010. More than 130,000 pedons of soil with 0-1.5 m depth were collected from the cultivated soils. There was also a detailed survey for forest soils (~ 8,000 pedons) which was conducted by Taiwan Forestry Research Institute (TFRI) between 1993 and 2002. Those data are organized and analyzed to improve the SOC stocks estimation in Taiwan in the near future.

Estimation of the decomposition rate of organic materials in cultivated soils

According to the curve fitting of the long term experiment by the first order equation, the results reveal that it takes at least 20-30 years for SOC to reach the stable status of equilibrium in Taiwan. Chemical fertilizers had been applied for several decades in conventional farming. Therefore, we assume that the SOC sequestration is not increased under steady status. The long term experiments indicate that generally, soil organic matter can be maintained at higher level in paddy fields than in upland fields. The long-term applications of chemical fertilizers did not deplete the content of soil organic matter comparing to the applications without chemical fertilizers. However, we can discover slightly increasing of soil organic matter in the long-term applications of chemical fertilizers. In fact, a stabilized content of SOC (2.2%) was maintained in the soil without applications of fertilizers in this paddy soil; the content of SOC from the rice stubble and roots remained in the soil after the harvests were enough to maintain the organic matter without any tendency of depletion. On the other hand, the content of SOC in the long-term applications of green manure did not increase as significantly as that in the application of compost, although it did increase slightly higher than that of the application of chemical fertilizer as shown in Table 2 and Fig. 1. Apparently, increasing the content of SOC through the applications of organic materials is difficult in Taiwan due to its higher rate of decomposition. The average of SOC accumulation rate is only 0.02-0.03 % per year (Chen and Lian, 2002). However, it is advantageous for agricultural lands to dispose of the harmless organic wastes produced by animal husbandry. The environmental impacts will be minimized when applying organic materials with the reasonable rate which has been evaluated. In addition, government agencies also strongly recommend that rice-cropping systems that could be combined with applications of compost and crop residues.

According to the results of the experiments and simulation analysis, the continuous applications of 17Mg/ha/year (fresh weight basis) of farm yard manure for 70 years is required to raise SOC from the level of 2.2 % to 2.8 % at nearly steady state in the paddy field, Taipei. On the other hand, the continuous application of 110 Mg/ha/year (fresh weight basis) of bagasse filter cake compost for 30 years is required to raise SOC from the level of 0.4 % to 1.9 % at nearly steady state in the upland field, Tainan. However, the rate of N release at steady state needs to be 740 kg N/ha/year to maintain 1.9 % of SOC. The long-term continuous application of 110 Mg/ha/year (fresh weight basis) of bagasse filter cake compost apparently will result in the environmental pollution (Chen and Lian, 2002). Such high applying rate is not recommended.

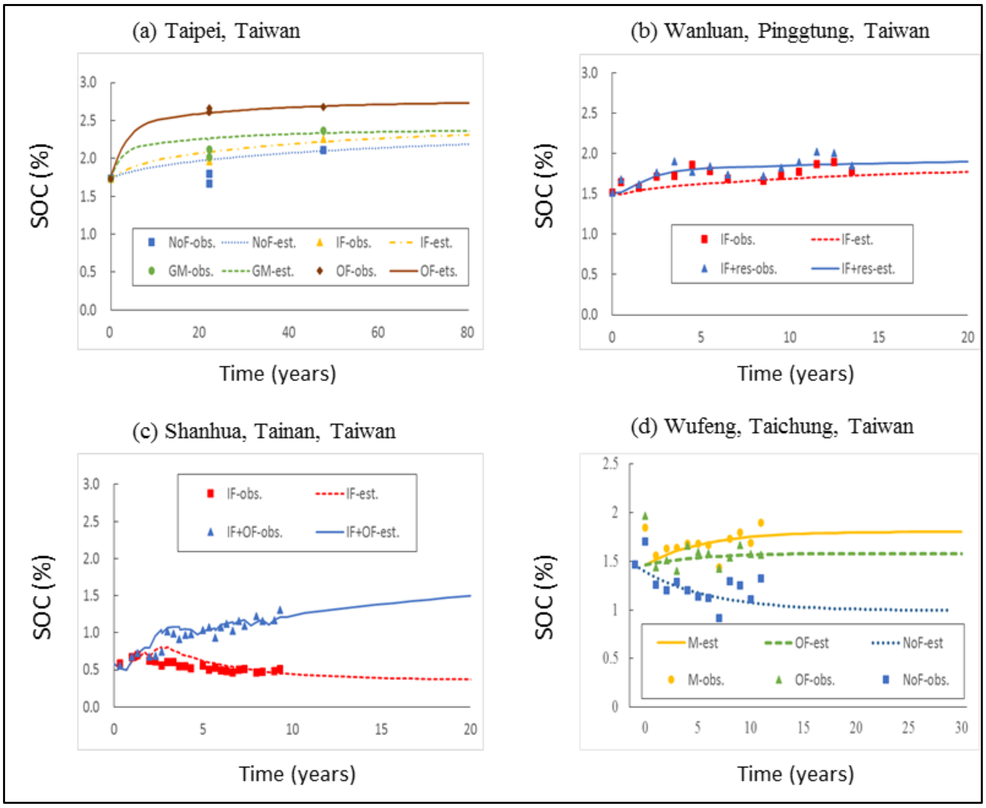

Fig. 1. SOC accumulation by applying different organic materials in the long term experiments in (a) Taipei, (b) Pingtung, (c) Tainan, (d) Taichung. (NoF: no fertilizer; IF: inorganic fertilizer; GM: green manure; OF: organic fertilizer; M: swine manure; obs: observed data; est: estimated data by model).

Estimation of the potential SOC sequestration of agricultural practices

Estimation of the SOC sequestration of different practices

Since there is no regular monitoring network for cultivated soil carbon, SOC sequestration of various practices in cultivated soils were estimated based on limited long-term studies. The SOC sequestration rates of organic farming, green manure cultivation and application of poultry manure are estimated based on the former results of the long term experiments in Taipei. The SOC accumulation rate by applying the swine manure with the data of 10-year-experiment at Wufeng was estimated and showed in Fig. 1. The SOC accumulation is estimated to be 1.8 % under the steady status. It is 0.2 % higher than that of applying chemical fertilizer.

Bahia grass (*Paspalum notatum* Fliigge) is one species of grasses with higher biomass. It is used to cultivate in slopes to prevent the soil erosion and enhance soil fertility. After five-year cultivation, the SOC stock of orchard with Bahia grass cultivation is 1% which is higher than that of orchard without Bahia grass cultivation (0.5%) (Juang and Jean, 1978). The SOC stock will increase 0.8 % and 0.5 % after nine months by cultivating Chinese wedelia (*Wedelia chinensis* Merr) and Alligator weed (*Alternanthera philoxeroidex* Mart) in wax apple orchards (Chen *et al.,* 2015). However, the SOC stocks of both experiments have not yet reached the steady status. In this study, we estimate 0.5% of SOC stocks will be increased by orchard grass cultivation based on the previous experiments.

The long-term monitoring of the SOC stocks in abandoned orchards and afforested sites revealed that afforestation could result in lower pH, lower bulk density, higher soil organic C, and higher nitrogen content, and higher storages compared to the adjacent cultivated stands. However, this general trend can be deflected by the specific management in the individual cultivated stands. The average SOC storage at 0-20 cm depth is 7.8 ton C ha^{-1} in the afforested stands which is higher than that of the cultivated stands. While most of the sequestrated C storages belonged to the labile C pools and only a few amount of sequestrated C storages can be stored in the recalcitrant C pools. Annual SOC accumulation was 0.34 ton C ha^{-1} y^{-1} which was close to the mean value of annual SOC accumulation from global afforestation (0.3 ton C ha^{-1} y^{-1}) (Lin *et al.,* 2011a). In this study, we estimate the SOC sequestration rate as 0.0175 % /yr based on the reviewed study.

From the reviewed papers (Chen *et al.,* 2017(a); Chen *et al.*, 2017(b)), applying 2% of bio-char will have active effects for crop growth. The rate is used to estimate the potential SOC sequestration. And, we assume that the carbon content of bio-char is 50% and 20 % of bio-char will be decomposed in soil (Johannes *et al.,* 2006; Wang *et al.,* 2016). Then, 0.8 % of SOC content from bio-char will be remained in soil.

Estimation of applied maximum area of different practices

For estimating the potential SOC sequestration, the maximum area which can be applied for various practices must be estimated first. The estimation of total area is about 235, 000 ha that can be applied with livestock manure with 400 kg N/ha demanded. It is estimated using the total produced nitrogen in manure of 5.4 million heads of swine, 0.1 billion heads of poultry and 147,000 of cattle in 2017 (COA, 2018(a)). The expected maximum area is 400,000 ha for green manure cultivation which is the area of paddy field in Taiwan. The area of 40,000 ha will be improved by government in the near 10 years (COA, 2018(c)). The maximum area can be applied for orchard grass cultivation is 180,000 ha, which is the total area of orchard in Taiwan. The afforestation in plain areas has been applied for 18,000 ha. Due to the strategy on the promotion of this practice has been terminated by 2013, the area will not be expanded in the near future. The maximum area for applying bio-char is 300,000 ha which is the area of strong acidy soil in Taiwan.

To summarize all of the areas from these practices, the total potential SOC sequestration is about 9.2 million Mg per year as Table 3. It is higher than the goal of the initiative based on the agricultural SOC only. However, it will be lower than the goal if based on the total SOC (with both agricultural SOC and forest SOC).

Table 3. Potential increased SOC sequestration of agricultural practices in Taiwan

Practices		Increasing SOC in 25-yr (%)	Area(10^3 ha)	SOC (10^3 Mg)
Applying Manure	Swine	0.2	120	480
	Poultry	0.4	100	800
	Cattle	0.2	15	60
Green manure		0.1	400	800
Organic Farming		0.4	40	320
Grass Cultivation		0.5	180	1,800
Afforestation		0.4	18	144
Applying Bio-char		0.8	300	4,800
Total				9,204 (368/yr)

Estimation of the current annual SOC sequestration of agricultural practices

The estimated potential SOC sequestration is lower than the goal of the initiative. However, it might be much lower than the goal in current status due to the limitations of promotional strategies by the government (Table 4). The limitations of practices are described as follows:

Application of livestock manure on farmlands

Since the nutrient content of swine and cattle waste water is quite low and is not constant, the cost of transportation is expensive and this practice is promoted very slowly. The estimated average increased area for applying swine and cattle wastes is about 2000 ha/yr. In addition, the over addition of copper and zinc in feeding might cause the metal accumulation in soils. So the standards of metal contents in feeding must be adjusted and the management of livestock feeding must be monitored.

Organic farming

The limitations for the promotions of practices must be solved. For example, low profits during the transition period, the standards of certification are restricted on heavy metal contents and organic materials, organic fields might be polluted by the residual pesticides from neighbor conventional field, pest insects and weeds are not easily controlled due to the high temperature and humidity in Taiwan, the higher input for production and extra cost for certification monitoring than conventional farming etc.

Afforestation in plain areas

Although this practice have some advantages, such as increase in SOC sequestration, green landscaping and minimizing the effect of global warming, etc., there are also some disadvantages, such as replacing the potential crop yields in farmlands, reducing the development area, limited to a few of tree species, loss of the original biodiversity, etc. Therefore, the government terminated the strategy due to the program of adjusting cropping system in which arable land hasn’t been active since 2013 (Forestry Bureau, 2013). However, we estimate the SOC accumulation within 20 years since it has not yet reached the steady status.

Application of bio-char on farmlands

The total SOC sequestration is estimated up to 12 million Mg by applying 2% of bio-char in strong acidic soil. However, the annual potential production of bio-char is only 10,000 Mg per year due to the current limitation in the amounts of kilns. This practice is expected to accelerate by increasing the facilities of bio-char production. The classification standards of bio-char production should be established urgently to assure the quality of bio-char for agricultural production and environmental protection.

More applications of agricultural practices in the future

Some practices have been applied effectively in other countries. For example, intercropping, restoring the degraded land, land use change, and minimum tillage, etc. Since the total SOC sequestration rates of the current practices cannot reach the goal of the initiative in Taiwan, more practices will be promoted and improved so the goal will be approached in the future.

However, the strategies of promotions and improvement on SOC sequestrations might be getting more difficult in practice. In Taiwan, it is costly to restore the degraded soil, such as saline soil, acid soil, alkali soil, etc. The weed and disease control are not easy for minimum tillage. The change of land use might be involved the food security problem.

Table 4. Current annual SOC sequestration of agricultural practices in Taiwan

Practices		Increasing SOC (%/yr)	Area(10^3 ha)	SOC (10^3 Mg)
Applying Manure	Swine	0.008	1	0.16
	Poultry	0.016	100	32
	Cattle	0.008	1	0.16
Green manure		0.004	200	160
Organic Farming		0.016	10	3.2
Grass Cultivation		0.02	10	4
Afforestation		0.0175	18	6.3
Applying Bio-char		0.032	0.5	0.32
Total				62.14

CONCLUSION

Because of the high decomposition rates of SOC and the limitations of the government strategies, it is a challenge to reach the goal of the initiative in Taiwan. From the results of the estimations, the goal of the initiative may not be reached by the current agricultural practices, including livestock manure and bio-char application on farmlands, organic farming, orchard grass cultivation, and afforestation in the plain areas. However, the SOC sequestration can be estimated accurately by monitoring of these practices. In the future, more practices, such as restoring the degraded land, land use change, and minimum tillage intercropping, etc., will be implemented to approach the goal of the initiative year by year.

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