# VETIVER SYSTEM IN SOIL AND WATER CONSERVATION AND SOIL CARBON STOCK IN THAILAND

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## Abstract

Degradation of soil resources is very important problem in agricultural sector of Thailand, which soil loss and erosion is the main factor effect to decrease of soil fertility and productivity. Soil and water conservation measure play the important role to prevent such soil loss and erosion in slopping agricultural area. His Majesty the King of Thailand has initiated the use of vetiver grass for soil and water conservation, for environmental rehabilitation. Then application of vetiver grass for soil and water conservation is a measure to solve such problem. In the northern of Thailand, corn plantation along and across slope has different soil loss from 5.48 to 2.77 ton/ha, and plounging and planting corn across slope could decrease soil loss around 33.6%. The vetiver grass strip could decrease soil loss in average to 3.24 ton/ha. The single line of vetiver plantation was higher development of growth than the double line, especially in number of shooting and size of clumping. And in the second year, vetiver planted in double line will develop to dense strip, which is the crucial role on reduction of soil erosion. Then in the second year soil loss in such area was reduced 50 to 90%, and corn yield was increased around 15 to 30%. Vetiver grass planted with peanut as hedgerow in corn plantation area of eastern part of Thailand, amount of soil sediment loss in vetiver planted plot was less than in control plot as 4.78 and 24.45 ton/ha, respectively. Moreover, vetiver hedgerow significantly decreases soil loss 82%. In lowland of central region the conventional practice has the highest soil loss 2.25 ton/ha, vetiver grass hedgerow has 1.16 ton/ha and terrace has only 0.91 ton/ha. Within 1 year and 6 months of vetiver development, vetiver system has function as ditch because such soil sediment will accumulate in front of vetiver hedgerow. The rate of carbon sequestration in tropical region is approximately 10-150 kg C/ha/year. Crop residues are the direct source of the soil organic carbon pool. Assessment of vetiver grass biomass in the average of shoot and root is 96.90 g/plant, and carbon storage in aboveground is 54.10-108.20 kg C/ha and belowground is 46.84-93.70 kg C/ha. Decomposition of leaf residue will convert to soil organic matter estimated as 60% of vetiver biomass, which accumulate in soil.

## Introduction

Agriculture in Thailand is varied and differs in terms of activities in each region or locality, particularly in the way farm cultures and traditions have been handed down through the generations. Each region has clear social and economic differences. The agriculture of the Central region around the Chao Phraya river basin differs from the farm culture of the Northeast, and from that of the North and South of Thailand. Thai agriculture has had a long evolution in Southeast Asia. The development of farming has gone hand in hand with the growth of the Thai nation. Agriculture is important and affects the livelihood of most of the population. Not surprisingly, agricultural activities have been honored and closely observed all through Thai history. Agricultural activities in Thailand are strong and consolidated. The

agricultural sector has progressed in many areas, including management of water resources, land development, horticulture, animal husbandry, fisheries, agri-business, and agricultural industries and cooperatives. Thai people have made their living in agriculture for several generations.

However, degradation of soil resources is very important problem in agricultural sector of Thailand, which soil loss and erosion is the main factor effect to decrease of soil fertility and productivity. Soil and water conservation measure play the important role to prevent such soil loss and erosion in slopping agricultural area. Then application of vetiver grass for soil and water conservation is a measure to solve such problem. On patterns for application of vetiver grass, His Majesty King Bhumibol Adulyadej, accompanied by Princess Mahachakri Sirindhorn, on July 25, 1997 went to present the academic degrees to graduates at Kasetsart University, Bangkok, Thailand. A royal speech on that day is as follows;

"Things that are useful have to be used according to the principles and suitability to the circumstances. Then the usefulness will be shown. For example, planting of vetiver grass must be done in the way that the grass tillers are planted continually and in harmony with the existing terrains. On the highland the rows need to be put across the slope and the waterway. On the plain, the grass should be planted around the crop plots or as a grass strip among crop rows. For water resources, the grass should be planted in rows above the water surface, thus helping in keeping the soil intact, keep the soil moist, and prevent sediment and poisonous materials from polluting the water. Doing like this will be very useful for soil and water conservation, and improvement of soil and forests."

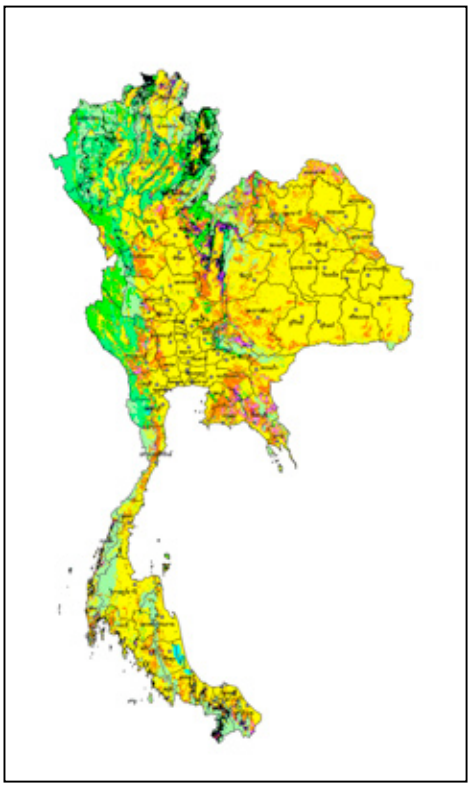
His Majesty has initiated the use of vetiver grass for soil and water conservation, for environmental rehabilitation. He has give speeches to several government agencies related to development. Land Development Department has fully accepted his ignition and has done research about the use of vetiver grass so that this technology can be transferred to farmers and others who are responsible for such works (Land Development Department, 1998).

**Assessment of soil erosion in Thailand**

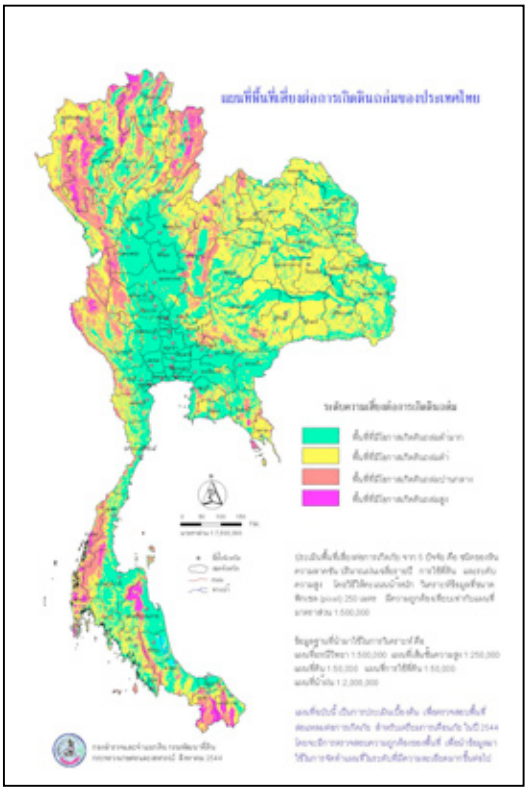
Soil and water conservation measures are extremely important for arable area in the country of which main occupation of the people is agriculture such as Thailand. This is due to losses of soil surface and nutrients mainly by erosion process on the bared and agricultural area with no soil conservation measure applied. Consequently, less soil nutrients left for plant growth as erosion process go on continuously for a long period of time, which will result in poor soil fertility and productivity. The implementation of soil conservation on upland and highland is being done by regional service centers throughout the country as demonstration plot for other government agencies and farmers. The soil conservation practices have been implemented both mechanical and vegetative measures where depend on topography and slope types of such area. The most common of soil conservation measures are terrace and hillside ditch which has been widely used in slopping area. Moreover, hillside ditches seem to be more potential to absorb and drain excesses water to waterway. At present, various types of mechanical combined with vegetative measures are implemented in many areas of northern highland.

Depletion of fertility in cropland is brought by the combined action of many factors such as the removal of large amount of nutrients by annual cropping, losses of soluble components through leaching processes, and the rapid rate of organic matter decomposition as a result of microbial activity in cultivated soils. Moreover, the land used in agriculture is moderately or severely affected by soil degradation resulting in significant cost of inputs, lost

of productivity. In addition, the process of erosion is now recognized as one of the most serious forces in the rapid depletion of fertility and productivity of cultivated land. Moreover, the pattern of crop cultivation in upland and highland, such as the intertilled crops afford little protection to the soil so that erosion has proceeded. Rowcrops production especially on highly eroded land year after year without proper soil conservation, therefore cause serious erosion then the land will become unproductive.



Soil erosion map (LDD, 2004)



Land slide risk map (LDD, 2004)

Soil conservation projects have been implemented for nearly 40 years. At their inception in the early 1960, soil and water conservation stations and units were set up throughout the country, especially in the north and northeast where erosion was very serious. Initially, terracing was introduced as a free service to farmers, linked with ploughing their fields without charge. Farmers were willing to accept the new methodology due to the free ploughing service. Later they removed the terraces because of the reduced cultivation area. Today, however, some farmers have come to realize the long term benefits and accept some soil and water conservation measures and adopt them in their lands (especially in the north). The obstacles to accomplish such activities may be due to the lack of basic data and information needed for establishing appropriate soil conservation measures, local extension staffs do not allow for sufficient contact with farmers, approaches to farmers has been inappropriate measures, and the lack of adoption of soil and water conservation.

**Vetiver grass application for soil and water conservation**

Agricultural production on highland or sloping land is normally followed with soil erosion, which will affect soil resources and environment, usually in the aspects of the loss of

topsoil, decrease of soil fertility and sedimentation in water bodies. Erosion control measures cost money and farmers are not inclined to do it-with the main reason that the increased yields may not worth the investment. It is therefore preferable to the farmers to carry out simple soil and water conservation measures that can do by themselves and can assist maintaining or increasing yields. Those practices include planting crops/hedgerows as boundary or on the contour to function in stopping sediments from going downhill, the prominent plant to grow being vetiver grass, a Gramineae. It can be seen that planting crops/hedgerows in that way is basic for using vetiver grass in soil and water conservation and erosion control. The important point is how vetiver grass should be planted in various categories of land. For soil and water conservation purpose, plantation of vetiver grass is done in a single line. With the vetiver plants put close to each other to from a living wall for lowering the speed of runoff and collect sediments (Land Development Department, 2004).

The important point to consider is plantation of vetiver grass in agricultural area whether to use lowland or upland ecotypes of vetiver. The most important criteria is the kind of main crops are being plant in the area. In plots of field crops it is logical to use upland vetiver, and in those plots that need more care, such as vegetables, the lowland vetiver should be planted. It is known that the efficiency of both upland and lowland vetiver is still depending on soil properties and climate in the designated areas. However, several research activities in each part of Thailand are as follow;

1. Study case in northern part

The north is characterized by mountain ranges, where all of these ranges comprise the origins of various rivers which flowing down through valleys, forests, hills, plateaus, and foothill plains feed the main Mekong and Chao Phraya river. However the corn experimental plots of vetiver grass for soil and water conservation measure in 6% slope, where bared soil is control plot in northern part of Thailand. Corn is planted along across slope, compare with strip of tamarin and pigeon pea, strip of vetiver grass (with vertical interval of planting is 1.0, 2.0 and 3.0 meters) as showed in table 1.

Table 1: amount of soil loss in each treatment (ton/ha) in corn plantation area

| **Treatment** | **soil loss (ton/hectare)** | | | |
|---|---|---|---|---|
| | **1st year** | **2nd year** | **3rd year** | **average** |
| 1. control | 20.38 a | 28.75 a | 29.06 a | 26.05 |
| 2. planting along slope | 12.88 ab | 2.63 b | 0.94 b | 5.48 |
| 3. planting along contour | 6.36 b | 1.06 b | 0.89 b | 2.77 |
| 4. strip cropping (VI=3.0 m) | 8.06 b | 0.69 b | 0.50 b | 3.08 |
| 5. vetiver strip (VI=1.0 m) | 8.56 b | 0.75 b | 0.69 b | 3.33 |
| 6. vetiver strip (VI=2.0 m) | 9.06 b | 1.19 b | 0.75 b | 3.67 |
| 7. vetiver strip (VI=3.0 m) | 8.06 b | 1.13 b | 0.75 b | 3.31 |

(Inthapan et al., 1994)

Inthapan et al. (1994) reported that the highest soil sediment loss is 26.05 ton/ha in control plot, and clearly significant different with both vegetative strip as conservation measure. In the case of corn plantation along and across slope is also different from 5.48 to 2.77 ton/ha, where it is indicated that plounging and planting corn across slope could decrease soil loss around 33.6%. In vetiver grass strip plot with the vertical interval of planting is 1.0,

2.0 and 3.0 meters, is not significantly different. However, the vetiver grass strip could decrease soil loss in average to 3.24 ton/ha. The result of this experiment indicated that strip of vetiver grass is very useful to prevent soil loss in corn plantation area, which it can reduce water runoff and soil erosion in agricultural land. Several experiments are indicated that the suitable vertical interval (VI) is 1.5 meters in the slopping area, where this distance of vertical interval is effective to collect soil sediment in front of the vetiver contour line.

2. Study case in northeastern part

The northeastern region is mostly a high plateau which sloped downward from the west and the south toward the east. These areas hold the main watersheds which flow east toward the Mekong river. The experimental plot was setup in northeastern part of Thailand on spacing and lining of vetiver plantation for soil conservation in upland. Including single and double line (30 cm. between hedge) of vetiver plantation and spacing between vetiver slip as 10, 15 and 20 cm. was carried out by Boonnap et al. (1995). The result showed that the single line of vetiver plantation was higher development of growth than the double line, especially in number of shooting and size of clumping. The average number of shooting in single line is 18.89 slip/clump and reduced to 15.82 slip/clump in double line of vetiver plantation. It is the same trend as average size of vetiver clump in single line is 15.90 to 13.50 slip/clump in double line.

Table 2: amount of soil loss in each treatment (ton/hectare)

| **Treatment** | **soil loss (ton/ha)** | |
|---|---|---|
| | **1st year** | **2nd year** |
| 1. control | 10.81 | 11.50 |
| 2. single line + slip space 10 cm. | 2.13 | 2.25 |
| 3. single line + slip space 15 cm. | 4.81 | 2.56 |
| 4. single line + slip space 20 cm. | 5.19 | 2.69 |
| 5. double line + slip space 10 cm. | 2.00 | 1.94 |
| 6. double line + slip space 15 cm. | 4.06 | 2.13 |
| 7. double line + slip space 20 cm. | 4.69 | 2.00 |

(Boonnap et al., 1995)

Moreover, the more distance of lining and spacing of vetiver plantation will be better growth as showed in table 2. In contrast, the highest of soil loss was found in control plot (as bared soil). Amount of soil sediment was detected in this experiment and the lowest of soil loss was found in 10 cm. spacing of slip on both of single and double line as 2.13 and 2.00 ton/ha, respectively. In case of 15 and 20 cm. spacing of vetiver slip had soil loss in single line

as 4.81 and 5.19 ton/ha, and the amount of soil loss was reduced to 4.06 and 4.69 ton/ha, respectively. And in the second year of this experiment, vetivers planted in double line and develop to dense strip, which play more importance role on reduction of soil erosion. Amount of soil loss in every treatment where planted with vetiver system is in range 1.94-2.69 ton/ha, and control plot is 11.50 ton/ha. It is clearly indicated the effective of vetiver system in soil sediment accumulation as soil and water conservation measure.

Application of vetiver grass for soil conservation measures with several legume crops in upland corn plantation of northeastern part of Thailand, where soil texture is silty loam and 6-8% slope. No measure of soil conservation (as control plot) was compared with 1 and 2 lines of vetiver grass, and 1 line of legume crop across the slope in corn plantation area. Anusontpornperm et al. (1996) indicated that amount of soil loss in control plot was 7.25 ton/ha in the first year, and increased to 16.75 ton/ha in the second year. Moreover, vegetative measure for conservation such as vetiver (2 lines) and legume (1 line) should be more effective on prevention of soil loss in the second year, as showed in table 3. This result was confirmed by Phien and Tam (2000), which indicated that vetiver and legume hedge in the second year, should be more effective than the first year because of the growth and development of shoot and root system of vetiver and legume crop. Then in the second year of vetiver system development, soil loss in such area was reduced 50 to 90%, and corn yield was increased around 15 to 30% (compared to control plot).

Table 3: amount of soil loss in each treatment (ton/hectare) in corn plantation area

| **Treatment** | **soil loss (ton/hectare)** | |
|---|---|---|
| | **1st year** | **2nd year** |
| Control (no measure) | 7.25 | 16.75 |
| Vetiver hedge 1 line | 4.50 | 5.19 |
| Vetiver hedge 2 lines | 4.81 | 6.63 |
| Bean strip 1 line | 6.88 | 5.81 |

(Anusontpornperm et al., 1996)

3. Study case in eastern part

The eastern region is characterized by low mountains and rolling plains. The plains are interspersed with low hills which are the watershed of short rivers flowing from north to south toward the Gulf of Thailand. Vetiver grass planted with peanut as hedgerow in corn plantation area of eastern part of Thailand, where it is loamy sand soil and 5% slope. Vetiver was planted in single and double line (30 cm. between line) and space between slip was 10, 15 and 20 cm., compare with non vegetative measure (vetiver with peanut). Peanut was planted in space between vetiver lines. And interval between hedgerows of vetiver grass is 15 meters along slope. Chaovanakit et al. (1995) reported that amount of soil sediment loss in vetiver planted plot was less than in control plot as 4.78 and 24.45 ton/ha, respectively. Moreover, vetiver hedgerow significantly decreases soil loss 82%. Double line of vetiver was higher efficient in soil loss control than single line. Moreover, spacing of vetiver grass plantation at 10 cm. is better than 15 and 20 cm (as showed in table 4).

Table 4: amount of soil loss in each treatment (ton/hectare)

| Treatment | 1st year | 2nd year | 3rd year | total | average |
|---|---|---|---|---|---|
| 1. control | 34.04 | 36.72 | 4.09 | 74.85 | 24.95 |
| 2. single line + space 10 cm. | 7.91 | 2.31 | 050 | 10.73 | 3.58 |
| 3. single line + space 15 cm. | 11.59 | 4.30 | 0.99 | 16.88 | 5.63 |
| 4. single line + space 20 cm. | 14.19 | 2.89 | 0.91 | 17.98 | 5.99 |
| 5. double line + space 10 cm. | 5.73 | 2.09 | 0.36 | 8.18 | 2.73 |
| 6. double line + space 15 cm. | 11.43 | 2.39 | 0.53 | 14.34 | 4.78 |
| 7. double line + space 20 cm. | 8.18 | 2.65 | 0.30 | 11.13 | 3.71 |

(Chaovanakit et al., 1995)

Phopan and Vatthanathum (1994) compare efficiency of vetiver grass system and terrace on water runoff and soil erosion in loamy sand soil of eastern part of Thailand with gentle slope of 5-7%. Two types of ploughing as along the slope and along the contour combined with 2 lines of terrace and 2 and 3 lines of vetiver hedge were compared in this experiment. The result was indicated that application of 2 lines of vetiver grass on ploughing along the contour reduced water runoff 6-17% compared with non vetiver plantation. However, 3 lines of vetiver was higher efficiency in runoff and erosion control than 2 lines of vetiver, especially in the first year of application. However, the 2 lines of vetiver can prevent soil loss lower than 3 lines of vetiver around 10% as showed in table 5. On this matter, the high efficiency of 2 lines of terrace nearly the same as vetiver plantation in both 2 and 3 lines of such hedge. When vetiver grass grows in the third year, the soil erosion control efficiency of 2 and 3 lines of vetiver were nearly the same. This indicated that the line of matured vetiver grass would have full function to control runoff and erosion in such slope area.

Table 5: amount of water runoff (cubic meter/hectare) in each treatment in cassava plantation

| Treatment | 1st year | | 2nd year | | 3rd year | |
|---|---|---|---|---|---|---|
| | runoff | R.E. | runoff | R.E. | runoff | R.E. |
| 1. plough along slope | 2605.69 b | - | 1408.56 c | - | 2419.05 c | - |
| 2. plough along contour | 2175.00 b | 16.53 | 1240.00 bc | 11.97 | 2150.38 a | 11.82 |
| 3. plough along contour + terrace 2 lines | 1620.00 a | 37.83 | 937.13 a | 33.47 | 1527.88 a | 37.35 |
| 4. plough along contour + vetiver hedge 2 lines | 2010.00 ab | 22.86 | 1111.44 ab | 21.09 | 1739.31 ab | 28.67 |
| 5. plough along contour + vetiver hedge 3 lines | 1941.44 ab | 25.49 | 1031.44 ab | 26.77 | 1787.88 ab | 26.68 |

(Phopan and Vatthanathum, 1994)

4. Study case in central plain

The central region is largely composed of a vast and fertile floodplain. The Chao Phraya river is the major waterway. In the west, the mountains are a continuation of mountain ranges from the north to south. In corn cultivation area of central plain of Thailand, where is

10% slope and shallow soil with problem of soil erosion. Chareonrungrueng et al (1994) reported that conventional practice has the highest soil loss 2.25 ton/ha, vetiver grass hedgerow has 1.16 ton/ha and terrace has only 0.91 ton/ha. The highest of corn yield is in terrace plot as 3.56 kg/ha, and slightly decrease to 3.29 kg/ha in vetiver plantation, where it is significantly decrease to 2.74 kg/ha in conventional practice as showed in table 6. Within 1 year and 6 months of vetiver development, vetiver system has function as ditch.

Table 6: amount of soil loss in each treatment (ton/hectare)

| Treatment | soil loss | soil sediment | collection efficiency |
|---|---|---|---|
| control | 2.25 | 0.00 | 0.00 |
| terrace | 0.91 | 1.34 | 6.25 |
| vetiver | 1.16 | 1.09 | 5.06 |

(Chareonrungrueng et al., 1994)

However, several scientific reports contributed cultivation of vetiver grass across slope is efficient nearly the same as terrace and clearly different from non conservation measure as most of farmer done in corn cultivation area. Application of vetiver system for soil and water conservation as hedgerow on slope area will develop to ditch, because such soil sediment will accumulate in front of vetiver hedgerow. Moreover, root system of vetiver penetrate depthly in soil has effect in water absorption and moisture accumulation in such layer of soil. As the research result of Babolola et al. (2005) clearly indicated that strip of vetiver grass can prevent water runoff and soil erosion in Oxic Paleustaff, Altisol. Amount of soil loss in control plot (without vetiver) is 70.00 ton/ha, where vetiver planted plot is only 1.75 ton/ha. In upland agricultural area, Nakalevu et al. (2000) reported that vetiver strip reduced soil loss in upland agriculture area, where soil sediment loss in control plot 3.31-312.63 ton/ha in ginger cultivation, soil loss in pineapple strip plot was reduced to 0.25-120.13 ton/ha. In case of vetiver strip plot, soil loss was clearly reduced to 0.19-5.00 ton/ha as showed in table 7.

Table 7: amount of soil loss (ton/ha) with vetiver grass and pineapple hedge in ginger plantation

| Treatment | amount of soil loss (ton/hectare) | | | | | |
|---|---|---|---|---|---|---|
| | 1st year | 2nd year | 3rd year | 4th year | 5th year | 6th year |
| control | 3.31 | 141.25 | 312.63 | 161.38 | 10.81 | 26.81 |
| pineapple hedge | 0.69 | 4.00 | 2.06 | 120.13 | 5.56 | 0.25 |
| vetiver hedge | 1.69 | 2.63 | 1.31 | 5.00 | 0.25 | 0.19 |

(Nakalevu et al, 2000)

**Soil carbon stock and carbon sequestration**

Soil resource is the big carbon pool of the global, where soil carbon pool is about 3 times higher than atmospheric carbon pool and about 4 times higher than biotic carbon pool (as show in fig 1). Moreover, soil is the important source of carbon stock in agricultural area, where implementation of appropriated soil management is the best solution to reach the

highest carbon sequestration. The soil management for reduction of $CO_2$ emission from soil surface will sequestrate carbon more than 50-100 mt C/year by covering soil surface, measures of soil and water conservation and no or minimum tillage. The rate of carbon sequestration extremely depend on climate of such region, where in tropical region is approximately 10-150 kg C/ha/year, but rate is increase 10 times in temperate region to 100-1,000 kg C/ha/year. Moreover, land use pattern is also important factor effecting amount of soil carbon stock, whereas natural forest is approximately 118 t C/ha, forest plantation (16 years) is 66 t C/ha and agricultural area (16 years of corn plantation) is only 57 t C/ha. Thus the appropriated soil management is very important matter on absorption and sequestration carbon from atmosphere into soil.

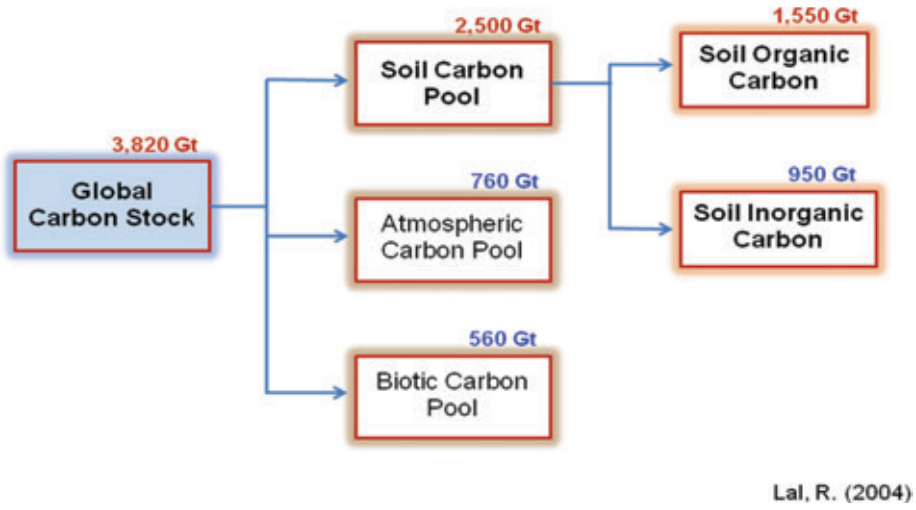



Figure 1: Amount of carbon pool in soil, atmosphere and biotic carbon

The important point on adaptation of climate changes in agricultural approach is to addition of organic matter to soil, protection of soil surface, implementation of soil and water conservation measure, improvement of soil structure, enhancement of soil microbial activities and diversities, and promotion of plant nutrient cycling in soil. Crop residue is a valuable resource for providing abundant ecosystem and economic benefits, including soil and water conservation and improvement in crop production and environment quality in agricultural area. It improves soil fertility; protects the soil surface from impacting raindrops; reduces surface sealing and crusting; increases soil aggregation; reduces soil compaction; improves water infiltration; reduces evaporation; increase water storage; reduces runoff; and increases microbial activity. Crop residues are particularly important to maintain soil organic matter content and consequently sustaining crop production. Crop residues are also the important source of energy for soil microorganisms, which stabilize soil aggregates, enhance microbial activities especially in nutrient cycling and plant growth regulators in soil.

Crop residues are the direct source of the soil organic carbon pool, and thus their management greatly impacts the soil organic carbon dynamics. In general, crop residues contain about 45%C on dry-weight basis. Thus aboveground crop residues have a large potential to store soil organic carbon in the passive form on a global basis, assuming that crop residues contain an average of 45%C and that about 15% of residue-derived C is stored as passive C in the soil. Moreover, the total amount of soil organic carbon storage depends on the crops, soil texture, soil profile, climate and other factors of environment. The residue-derived

soil organic carbon is critical to compensating organic carbon losses, which also affects the root-derived soil organic carbon amount by reducing belowground biomass production. Both aboveground and belowground crop residues are important to increase the soil organic carbon pool. Reduction in surface residue input will decrease the soil organic carbon concentration because there is less carbon to be humified and thus less residue-derived soil organic carbon. Decomposition of crop residues depends on the C/N ratio and other properties, such as crop residues with lower C/N ratio decompose faster than those with higher C/N ratio.

Soil and water conservation is directly enhancing carbon sequestration and storage organic carbon into soil. In case of vetiver grass plantation for soil and water conservation, where it is not only reduces rate of soil erosion and water runoff, but also enhance sequestrate carbon to soil. Vetiver grass can absorb $CO_2$ from atmosphere by photosynthesis process, which converts $CO_2$ to organic carbon as composition in stem and root of vetiver grass and store as biomass of such plant. Assessment of vetiver grass biomass in the average of aboveground (stem and leaf) is 48.51 g/plant and belowground (root) is 48.39 g/plant (total average biomass 96.90 g/plant). Whereas organic carbon content in aboveground is 44.61% and belowground is 38.72% (as show in table 8). Moreover, on the basis of such data it can calculate to aboveground carbon storage is 21.64 g C/plant and belowground is 18.74 g C/plant. However, plantation of vetiver grass in soil and water conservation measure across the slop should plant 1-2 lines (in area 1 hectare necessary to plant 2500-5000 slips). Vetiver grass will grow and develop biomass in both shoot and root, such hedge row will dense and reach full function of vegetation measure on soil and water conservation. In general, around 1 year after plantation of vetiver grass, then it continuously absorbs $CO_2$ to carbon storage in aboveground to 54.10-108.20 kg C/ha and belowground to 46.84-93.70 kg C/ha. However, the best management of vetiver grass is cutting leaf and let leaf residue covered the soil surface. Decomposition of leaf residue will directly effect to increase organic matter in such soil and estimated as 60% of vetiver biomass will accumulate in soil. However, content of carbon sequestrated is not so high but the appropriate management of vetiver residue will absorb $CO_2$ from the atmosphere and convert to organic carbon in composition of vetiver grass and such absorbed carbon will accumulate into soil, which also increase soil fertility and productivity.

Table 8: Biomass and organic carbon storage of aboveground and belowground of vetiver grass

| Vetiver grass | Biomass (g/plant) | Biomass (kg/ha) | Organic carbon content (%) | Carbon storage (g C/plant) | Carbon storage (kg C/ha) |
|---|---|---|---|---|---|
| aboveground (stem and leaf) | 48.51 | 121.28-242.55 | 44.61 | 21.64 | 54.10-108.20 |
| belowground (root) | 48.39 | 120.98-241.95 | 38.72 | 18.74 | 46.85-93.68 |
| Total | 96.90 | -- | -- | 40.38 | -- |

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