

IMPROVING AGRICULTURAL RESILIENCE TO CLIMATE CHANGE THROUGH SOIL MANAGEMENT

Peningkatan Ketahanan Pertanian terhadap Perubahan Iklim melalui Pengelolaan Tanah

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ABSTRACT

Climate change affects soil properties and hence crop growth. Several soil management practices potentially reduce vulnerability to unfavorable climate conditions. This paper reviews how climate change affects soil properties and how should soil management be tailored to increase adaptation capacity to extreme climatic conditions. The main symptoms of climate change such as the increase in the global atmospheric temperature, unpredictable onset of the wet and dry seasons and excessive or substantial decrease in rainfall are unfavorable conditions that affect crop growth and production. Several approaches, singly or a combination of two or more measures, can be selected to adapt to the climate change. These include conservation tillage, vegetative and engineering soil conservation, mulching, water harvesting, nutrient management, soil amelioration and soil biological management. Management of soil organic matter is very central in adapting to climate change because of its important role in improving water holding capacity, increasing soil infiltration capacity and soil percolation, buffering soil temperature, improving soil fertility and enhancing soil microbial activities. Organic matter management and other soil management and conservation practices discussed in this paper are relatively simple and have long been known, but often ignored. This paper reemphasizes the importance of those practices for sustaining agriculture amid the ever more serious effects of climate change on agriculture.

Keywords: *Climate change, agriculture, adaptation, organic matter, soil conservation, soil management*

ABSTRAK

Perubahan iklim memengaruhi sifat-sifat tanah dan pertumbuhan tanaman. Beberapa praktik pengelolaan tanah berpotensi dapat mengurangi kerentanan terhadap kondisi iklim yang tidak menguntungkan. Tulisan ini mendiskusikan bagaimana perubahan iklim memengaruhi sifat-sifat tanah dan bagaimana seharusnya pengelolaan tanah disesuaikan untuk meningkatkan kapasitas adaptasi terhadap kondisi iklim yang ekstrem. Gejala utama perubahan iklim berupa peningkatan suhu atmosfer global, awal

musim hujan dan musim kemarau yang sulit diduga, dan penurunan atau kenaikan jumlah curah hujan merupakan kondisi yang tidak menguntungkan yang dapat memengaruhi pertumbuhan dan produksi tanaman. Beberapa pendekatan, baik secara tunggal atau kombinasi dari dua atau lebih tindakan, bisa dipilih untuk beradaptasi dengan perubahan iklim. Ini termasuk olah tanah konservasi, konservasi tanah vegetatif dan mekanis, penggunaan mulsa, pemanenan air, pengelolaan hara, ameliorasi tanah, dan manajemen biologi tanah. Pengelolaan bahan organik tanah sangat sentral dalam praktik pengelolaan tanah karena bahan organik tanah berperan penting dalam meningkatkan kapasitas tanah memegang air, meningkatkan kapasitas infiltrasi dan perkolasi tanah, menyangga suhu tanah, serta meningkatkan kesuburan tanah dan aktivitas mikroba tanah. Teknik pengelolaan bahan organik dan praktik pengelolaan dan konservasi tanah yang dibahas dalam makalah ini merupakan cara yang relatif sederhana dan telah lama dikenal, tetapi sering diabaikan. Makalah ini menekankan kembali pentingnya penerapan praktik-praktik pengelolaan tanah tersebut untuk mempertahankan peran pertanian di tengah efek perubahan iklim yang lebih serius.

Kata kunci: Perubahan iklim, pertanian, adaptasi, bahan organik, konservasi tanah, pengelolaan tanah

INTRODUCTION

The increase in greenhouse gases (GHG) emissions has caused the climate change which in turn has affected crop productivity for human livelihood. By the end of this century, mean air temperature may increase as high as 4.0 °C relative to the 1980–1999 level (IPCC 2013) if no significant mitigation action is implemented globally. With this increase, other climatic processes also change, including unpredictable weather, extremely high rainfall and long dry season. These changes affect the soil, living biota and agricultural production. Agriculture, especially the annual cropping systems, is the most vulnerable economic activity that can be severely affected by the climate change (Nelson *et al.* 2009).

Extreme climate events such as El-Niño and La-Niña which recently have become more intense and more

frequent can cause crop failure, damage agricultural land resources, increase intensity of floods and droughts, and increase intensity of pest and disease infestations. Changes in precipitation patterns increase the likelihood of annual crop growth failures that in turn threatens crop production. In some cases, there may be opportunity to expand planting areas to a higher altitude due to the increased atmospheric temperature, but the overall impacts of climate change on agriculture are negative (IPCC 2007; Nelson *et al.* 2009) threatening the household, national and global food securities. Soils also tend to be negatively affected by extreme climate in terms of accelerated erosion, aggregate breakdown, nutrient leaching, dryness, and the changes in microbial population and activity. On a global scale, food shortage will be experienced, especially in developing countries due to climate change. The food sufficiency can only be satisfied by improvement of agricultural methods including the use of fertilizer, pest control, breeding of new varieties, expansion of agricultural area, and a more sustainability-oriented consumer behavior (Sakschewski *et al.* 2014).

Agriculture is one of the sectors that are particularly vulnerable to the effects of climate change so that adaptation is a must to avoid harvest failures. These adaptation actions require changes in land management and cropping patterns to increase its resilience in order to be able to adapt to the extreme climate conditions.

There are various soil management technologies that can readily be implemented to alleviate the negative climate change effects. These range from soil conservation practices, soil nutrient management, and soil biological activity enhancement. This paper discusses the effects of climate change on soil quality, the

opportunities to increase soil resilience, and range of soil management options that can be selected to alleviate the adverse climate change effects.

EFFECTS OF CLIMATE CHANGE ON SOIL QUALITY

Climate change affects the soils through the carbon, nitrogen and hydrologic cycles. On the other hand soils also affect the climate because of emissions of greenhouse gases (GHG) they exert. Climate change will impact soil organic matter dynamics, and various soil properties related to organic matter, soil water, and soil erosion (Brevik 2012). There are several elements of climate change that affect soil quality (Table 1).

Increased Temperature

In general, soil microorganism activities increase with the increase in soil temperature. Although relatively high activities of microorganisms are important for organic matter mineralization, very rapid activities may deplete soil organic matter content which in turn causes soil aggregate breakdown. This requires addition of organic matter into the soil.

Unpredictable Weather

Unpredictable weather, especially the onset of rainy season causes uncertainty of soil water availability and hence it's problematic among farmers on when to start

Table 1. Climate change variables, the effects on soil and adaptation approaches.

Climate change variables	Effects on soil	Adaptation approaches
Temperature rise	Increased microbial activities that potentially lead to increased carbon emissions and soil aggregate breakdown	Mulching with plant residues and regular recycling of organic matter to maintain high soil organic matter content
Unpredictable weather	Uncertainty in the amount and timing of soil water availability and hence uncertainty of planting date	Weather prediction, e.g. using cropping calendar
Extremely high rainfalls	Increased runoff, high erosion by water, high rate of soil nutrient leaching	Improvement of infiltration capacity, reduction of slope steepness and slope length, reduction of rain drop kinetic energy using cover crop and mulch, increasing soil organic matter content, improvement of drainage systems, and construction of water retardation systems
Low rainfall and long dry season	Soil dryness, cracks and surface sealing because of high evapo-transpiration	Water harvesting, mulching, organic matter application, irrigation, increasing water holding capacity
Sea level rise	Salty water intrusion and inundation causing salinization and dispersion of soil aggregate	Salt leaching, improving drainage, reducing evaporation (e.g. by mulching), applying chemical treatments, and a combination of these methods

their crop planting. Technology on rainfall prediction is a key to avoid water shortage or excessive water. This could be coupled with soil organic matter management technologies and selection of hardy high yielding varieties.

High Rainfall

Climate change is associated with higher intensity rainfall to a level far exceeding the soil infiltration capacity (Nelson *et al.* 2009). The high intensity rainfall increases the rate of splash erosion and hence the volume of runoff water (Runtuuwu and Syahbuddin 2011). As a result, the amount of soil loss also increases. Erosion can lead to the decline in productivity and carrying capacity of the land for agricultural production as well as damages on the environment in terms of river and stream siltation (Nearing *et al.* 2004). Accelerated soil erosion can also cause the deposition of clay, humus, and coarser soil particles and aggregates. Extremely high rainfalls with the intensity far exceeding soil infiltration capacity cause floods, which can be exacerbated by poor soil management (Yustika and Agus 2014). Water saturation during excessive rainfall or accumulation on concave areas causes soil aggregate dispersion that subsequently closes soil pores and reduces infiltration capacity. Following the inundation, surface sealing may occur and this can retard the emergence of seed (Estiningtyas *et al.* 2009).

Factors influencing the surface runoff include the amount, intensity and distribution of rainfall, soil types and the substratum properties (sandy soils have a lower runoff rate compared to clayey soils), as well as slope gradient and slope length (runoff increases with the increased slope gradient and slope length). However plant cover, canopy height and density as well as various soil conservation systems reduce surface runoff and soil loss (Agus and Widiyanto 2004; Arsyad 2010).

Excessive amount of water also affects soil biota activities. Microbial activities prefer moist rather than very dry or very wet soil moisture condition. A laboratory study using peat soil exhibited that microbial respiration increased sharply from wet with $\geq 80\%$ water filled pore space (WFPS) to moist soil (60 to 40% WFPS), and decreased when the soil is dried ($\leq 40\%$ WFPS) (Husen *et al.* 2014).

Salty Water Intrusion

Salt water intrusion and inundation may lead to salinization and dispersion of soil aggregates (Hillel 1998). Salty water also causes nutrient imbalance and thus retards the absorption of macro-essential elements such as potassium, calcium and magnesium due to sodium dominance.

Water Shortage

Water shortage due to the longer duration of dry season causes soil dryness, followed by shrinking and cracking, especially on montmorillonitic soils that in turn cause damages to roots. Dryness also reduces the availability and retards uptake of nutrients by plants (Hillel 1998). Water shortage also decreases crop vigor and yield. Early stage of crop growth is especially sensitive to drought. The magnitude and direction of those impacts depend on the amount of changes in atmospheric gases, temperature, and precipitation amounts and patterns (Brevik 2012).

ADAPTATION APPROACHES

Adaptation to the climate change is a must in all sectors, especially in agriculture as one of the most vulnerable sectors. The general adaptation approaches of each climate change impact on soil are provided in column 3 of Table 1. The use of organic matter is very central in improving soil physical, chemical and biological properties. The use of organic matter; in the form of mulch or incorporated plant residues, barnyard manure and living mulch improves soil structure (reduces soil bulk density, increases macro and water available porosities) and in turn increases infiltration capacity, water holding capacity and water percolation. These are the preferred properties needed to increase resilience to droughts and water logging. Soil chemical properties can also be improved by organic matter application, depending on the organic matter quality. Barnyard manure, for example, is superior to chemical fertilizers in terms of macro- and micro- nutrients contents. Organic matter also behaves as an electron donor in the soil that provides energy for soil microbial activities (Agus and Widiyanto 2004; Snapp 2011).

Regulating the spatial and temporal distributions of water through water harvesting, irrigation and drainage is also an important soil management approach. Except under aquatic system, the ideal soil water content for plant growth is the so called non-limiting water range, which is defined as the region bounded by the upper and lower soil water content over which water, oxygen, and mechanical resistance are not limiting to plant growth. Another term used for this is plant available water which varies from plant to plant (Hillel 1998; Tolk 2003). In general, the plant available water is the portion of soil water that is not subjected to fast gravity movement, nor it is held tightly by soil micro-pores.

Reducing slope length and steepness is also commonly practiced in an effort to allow enough time for water to infiltrate into the soil and reduce the velocity of runoff water. This, for example, is done by terracing, strip cropping, runoff/sediment pit construction, and contour hedgerow systems (Agus and Widiyanto 2004; Arsyad 2010).

As an archipelagic country, salt water intrusion and salinity problem are also common in Indonesia and their effects are considered serious in key agricultural areas such as the rice basket of the northern coast of Java island. In semi-arid regions of East Nusa Tenggara, salinity may occur because of excessive transpiration. Salinity affects not only soil chemical properties, but also soil biological activities and soil physical properties. Rectifying salinity problem ranges from leaching of excessive salt, amelioration, usually with gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), lime (CaCO_3) or dolomite ($\text{CaMg}(\text{CO}_3)_2$), and amendment with organic matter (Erfandi and Juarsah 2014).

BEST SOIL MANAGEMENT PRACTICES

In principle, the best management practice (BMP) is defined as the effective and practical site-specific techniques required for maintaining soil productivity and achieving satisfactory crop production. The BMPs alleviate the harmful effects of extreme climatic conditions and the causal sequenced of climate change such as soil salinity that is caused by sea level rise. In many instances, BMPs which in essence are adaptation approaches, are also in synergy with mitigation and these are the preferred management options in coping with the climate change (Duguma *et al.* 2014). The following section explains several soil management that may be chosen to adapt to the climate change.

Conservation Tillage

Tillage is done to facilitate seeding, control weeds, and incorporate fertilizers and soil amendment (Hillel 1998). Excessive tillage can have a negative impact on the breakdown of soil aggregates into smaller ones or dispersed into single soil particles, under which the soil is very prone to erosion.

Conservation tillage is defined as the method of soil cultivation that leaves the previous year's crop residue (such as corn stalks, rice straws or wheat stubble) on the fields before and after planting the next crop, to reduce soil erosion, evaporation and runoff. At least 30 to 70% of the soil surface must be covered with residue after planting the next crop in this system. Conservation tillage is especially suitable for erosion-prone crop land. In some agricultural regions, conservation tillage has become more common than the traditional tillage system. Conservation tillage methods include various kinds of reduced tillage including no-till, strip-till, ridge-till and mulch-till (Willekens *et al.* 2014).

In many circumstances, conservation tillage gives positive effects on soil properties, such as the increase in

soil organic matter content, reduction of soil erosion because of medium and macro-soil pores formation, increased activity of soil microbes, increased crop yields and increased farming efficiency. Increased crop yield under conservation tillage is especially occurring on light-textured soils (Bhatt and Khera 2006). Conservation tillage is a management system that is adaptive to water shortage as affected by a long dry season. It minimizes water evaporation and increases soil carbon and organic matter in the surface layer due to the presence of crop residues on the soil surface. Reduction of tillage intensity can increase soil organic carbon by reducing soil organic matter decomposition by soil microbes (Rachman *et al.* 2004; Zhang and Nearing 2005; Ugalde *et al.* 2007; Lal *et al.* 2011).

Vegetative Soil Conservation Techniques

There are various kinds of vegetative soil conservation measures, including agroforestry, vegetative grass strips, cover crop and cropping pattern (Agus and Widiyanto 2004).

Agroforestry

Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units for agricultural crops and/or animals in some form of spatial arrangement or temporal sequence (Lundgren and Raintree 1982). This definition implies that agroforestry normally involves two or more species of plants (or plants and animals), at least one of which is a woody perennial. Agroforestry system always has two or more outputs, the cycle of an agroforestry system is always more than one year and even the simplest agroforestry system is more complex, ecologically (structurally and functionally) and economically, than a monocropping system. There are both ecological and economical interactions between the different components in agroforestry systems (Lal 1991).

There are wide ranges of agroforestry models including alley cropping, contour hedgerow systems, live fences, traditional multi-strata farming, silvipasture and intercropping. The perennial crops are useful in dissipating the rainfall kinetic energy before reaching the soil surface. It's also the component of agroforestry that improves water percolation and thus minimizes water logging. With the deep rooting system, the perennial trees are also the components that can survive and continually provide feed for livestock and fruits for the farmers. It's also the source of organic matter for soil structure improvement from the regular pruning of the hedgerow shrub and the falls of leaves, twigs and branches (Agus

and Widiyanto 2004). In addition, tree component is also important sequestering carbon in the tree biomass above and below ground (Lal 2004). Multistory agroforestry has larger carbon stocks compared to simple agroforestry (Hairiah and Rahayu 2010).

On steep slopes, the contour hedgerow system effectively controls erosion compared to the conventional sloping agriculture (Lal 1991; Agus *et al.* 1997). Contour hedgerow system can gradually form natural bench terraces depending on soil condition and the distance between hedgerows. Agroforestry systems involving leguminous crops improve soil nitrogen status (Agus *et al.* 1999).

Besides the various advantages, there are several disadvantages associated with a contour hedgerow system. The hedgerow crops occupy 5–15% space, therefore there is a need to select the hedgerow crops with tangible advantages, such as significant economic value from the fruit and fodder and significant soil fertility improvement. The competition between the hedgerow and the alley crops for nutrients, water and light may be severe and therefore regular tree pruning will be necessary. There is also possible allelopathic effects among the crops. Finally, managing agroforestry system could be laborious. These all call for proper selection and management of the interacting species (Agus and Widiyanto 2004).

Cropping Pattern

Designing cropping pattern is a way to adjust water availability with the crop requirement and tolerance to excess and deficit water conditions. For example, mungbean or cowpea with high tolerance to limited amount of water may be planted at the end of rainy season or early dry season. Farmers' choice of cropping pattern is also a strategy for pests and diseases avoidance and seasonal market price fluctuation adaptation strategy of the products.

The cropping pattern is an adjustment strategy with rainfall amount and distribution under rainfed, annual crop, upland agriculture as follows (Agus and Widiyanto 2004):

- 1) In areas where there is no or only one dry month (rainfall ≥ 100 mm), planting can be done all the year round.
- 2) When the dry months are 2–3 months a year, planting can be done throughout the year but with more careful planning.
- 3) When the dry months are 4–6 months a year, planting can be done twice by relay (overlapping) cropping, i.e. the second crop, usually low water demanding crop, is planted a couple of weeks before the first crop is harvested.
- 4) When the dry months are 7–9 months a year, planting can be done only for one crop per year.
- 5) When the dry months are 10–12 months per year, the area is not suitable for food crops when no irrigation or water harvesting systems is implemented. Selected tree species may still be productive under this condition.

There are many types of cropping pattern, including multiple cropping, crop rotation, relay cropping and intercropping.

Multiple cropping is an agricultural system in which more than one crop is planted at a time. The advantage of this pattern is the maximum closure and efficient use of soil surface, thereby reducing runoff and erosion (O'Neal *et al.* 2005) and providing additional income to farmers. Multiple cropping can also reduce nutrient losses because nutrients leached into deeper soil layer bypassing short root plants can be taken up by plants with deeper roots.

Crop rotation is conducted not only on upland agriculture, but also on rainfed rice areas in which one or two consecutive rice crops are planted in the rainy season and one or two "secondary crops" are planted under the upland system in the drier season of the year (Sarvina dan Pramudia 2009). The rotation could be very intensive ones, especially in high population density areas, or the less intensive ones in which one season of food crop is followed by a long (three to tens of years) fallow period (Eaton and Lawrence 2009).

The purpose of crop rotation is to disrupt the life cycle of pest and disease organisms and to diversify farm products. The crops consuming high amount of water (such as maize) are planted in the beginning of rainy season, while the drought tolerant crops are planted at the end of rainy season or the on set of dry season. Crop rotation is also intended to maximize crop cover on soil surface such that it is protected from direct rain drops.

Relay cropping is a cropping pattern system where two or more crops per year are planted in rotation, in which the second and third crops are planted before the first and second crops are harvested, respectively. This means that the soil surface is well covered by crop canopy in most time of the year.

Cropping calendar is an important tool to support the selection of cropping pattern systems. It is a dynamic system that advises farmers about the planting time, warns about the areas likely to experience floods and droughts, recommends rice crop varieties, and provides time series information on fertilizer needs in certain districts such that the local authorities can adjust fertilizer distribution and advise on farming tools needed for the season (Runtuwuu and Syahbuddin 2011).

Engineering Soil Conservation Techniques

Engineering techniques in soil conservation provide a rapid effects, but rather costly and labor intensive. Bench

terrace is one of the most popular engineering soil conservation techniques in Indonesia and elsewhere in Southeast Asia (Agus 2001). The main idea is to cut slope length and reduce slope gradient to allow more time for rain water to infiltrate into the soil and reduce the runoff water volume and velocity which in turn reduce soil erosion and sedimentation.

Constructing bench terraces is laborious and hence smallholders wisely construct them step-wisely. Bench terraces cause exposures of infertile subsoil layer into the surface and thus temporarily reduce crop production near the base of the terraces. Contour hedgerow is a strategy for minimizing labor requirement to gradually construct bench terraces. Tillage operation between hedgerows on sloping land moves soil clods and aggregates from the upper to the lower part of the land between hedgerows and accelerates the formation of terraces (Agus *et al.* 1997).

Variants of engineering soil conservation techniques are recommendable for improving soil water content, including sediment pits, ridge tillage, biopores and vertical mulch. Padzarudin (2010) tested combination of these techniques in palm oil plantation. Figure 1 shows that sediment pits gave the highest monthly average soil water content, followed by ridge tillage. The higher soil water content for sediment pit and ridge tillage systems kept the soil moist.

Under coffee plantation, bench terraces are superior in reducing surface runoff and soil loss right from the first few years of their construction. In general, grass strips or hedgerows improve the effectiveness of bench terraces (Sang-Arun *et al.* 2006). Starting from the third and the

following years since the perennial crop planting, the soil structure stabilized and there was no difference in soil losses between plots with and without bench terraces indicating that the perennial trees were effective in controlling erosion after the canopy and root system developed (Pujiyanto *et al.* 2001). Similar results were also found in an experiment comparing between bench terraces and contour ridging (Haryati *et al.* 1995). Nevertheless farmers prefer bench terraces because of ease of field works on the flat area (Agus and Widiyanto 2004). Simulation of conservation techniques in the upper Ciliwung sub-watershed using the Soil and Water Assessment Tool (SWAT) showed that bench terraces in combination with agroforestry system is quite effective in reducing surface runoff (Yustika *et al.* 2012).

The traditional mulching technique by using plant residues is aimed at reducing the impact of direct rain drops, reducing erosion, regulating soil temperature, increasing soil organic matter content, and suppressing weed growth (Agus and Widiyanto 2004). Full coverage of soil surface with mulch reduced the maximum soil temperature of 1.4 to 2.4°C compared to open field (Bhatt and Khera 2006). Minimum tillage with mulch application maintained higher soil moisture content compared to conventional tillage (Edwards *et al.* 2000), but very thin mulch did not benefit soil moisture (Doring *et al.* 2005). Mulch usually reduces runoff by 33% to 49%. Such conditions may occur because the mulch improves soil aggregation and hence increases infiltration (Bhatt and Khera 2006). Mulching is a way to improve soil quality and increase crop productivity because it can provide

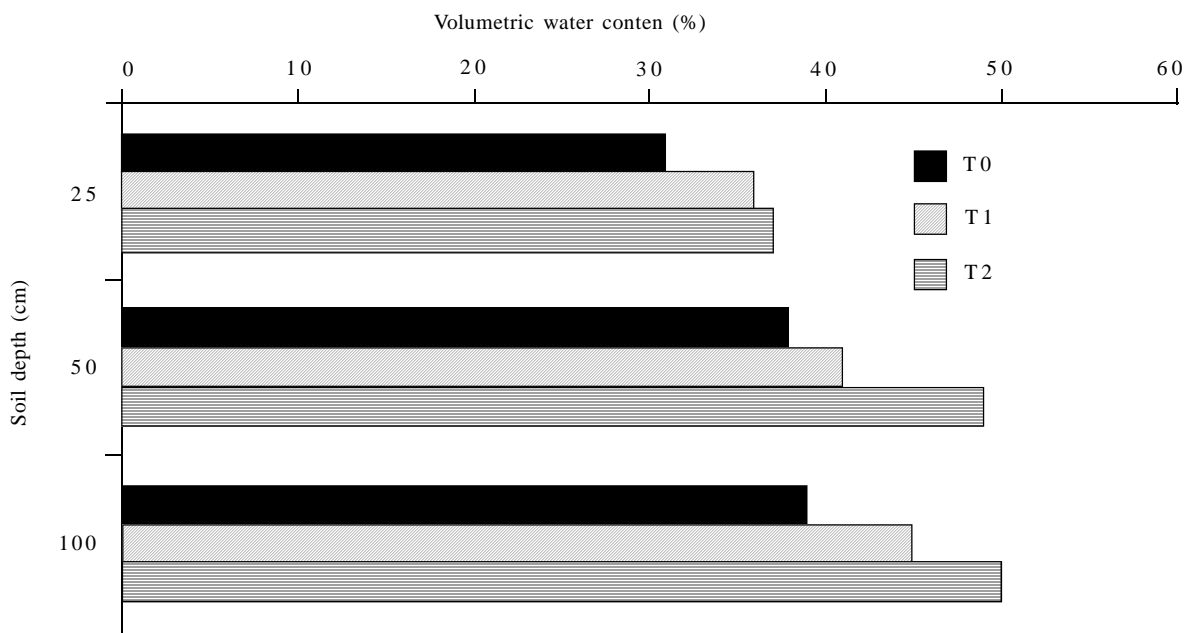


Figure 1. Mean soil water content from January to August 2009 at various soil depths (adapted from Padzarudin 2010). T0 = control, T1 = ridge tillage with biopore and vertical mulch, T2 = sediment pit with biopore and vertical mulch.

some amount of various kinds of plant nutrients (Agus and Widiyanto 2004) and increase water use efficiency (Table 2).

Life mulch or cover crops, for example of centrosema (*Centrosema pubescens*), pueraria (*Pueraria javanica*), mucuna (*Mucuna* sp.) and arachis (*Arachis pintoii*) are commonly used to protect soil surface under young perennial trees such as oil palm (*Elaeis guineensis*), rubber (*Hevea brasiliensis*) and pepper (*Piper nigrum*). Figure 2 shows *Arachis pintoii* under pepper plantation in Lampung, Indonesia. The life mulch evenly covers the soil surface under pepper plantation except for 2 m diameter weeded circle around the *Gliricidia sepium* supporting trees. This system reduces erosion because of effective filtration of soil aggregates and particles and

minimizes the volume of runoff water (Agus and Widiyanto 2004).

Application of Organic Fertilizers

Organic fertilizer is defined as fertilizer containing a large part or all of the materials from partially decomposed plant and/or of animal origin. In general this includes various kinds of organic matters such as compost, green manure, animal manure, plant residues, processed agriculture-based industrial waste, and organic municipal wastes (Agus and Widiyanto 2004). There are many kinds of organic matter that could be collected locally. The most easily accessible ones include barnyard manure, crop residue, and compost. Organic matter has many beneficial functions for soils such as increasing soil water holding capacity, improving soil structure, releasing micro and micro-nutrients from the labile pool, improving soil biological activities, and increasing soil carbon stock. The main precaution in applying organic material is its maturity (i.e. C : N ratio), nutrient content and handling. The C : N ratio in soils and residues has a significant impact on decomposition and nutrient release. Applying organic matter to the soil changes soil C : N ratio. Soil organic matter decomposition slows down when C : N ratio is high (> 30:1) and rapid when C : N ratio is low (< 20 : 1) (Brady and Weil 2007; Kowalenko et al. 2007). Generally N is

Table 2. Grain yield of wheat and water use efficiency as influenced by mulch levels.

Mulch level (t/ha)	Grain yield (kg/ha)	Water use efficiency (kg/ha/mm)
0	2,343	9.72
2	2,972	12.26
4	3,372	12.99
6	3,495	13.15
LSD (P = 0.05)	151	0.62

Source: Sharma et al. (1998).



Figure 2. Vegetative conservation measure using *Arachis pintoii* as life mulch for pepper (*Piper nigrum*) production (Agus and Widiyanto 2004).

released when C : N is less than 20 : 1 and immobilized when C : N is greater than 30 : 1. Composting is a way to decrease C : N ratio and the use of compost is safer in terms of nitrogen release compared to applying fresh organic matter.

Water Harvesting

Water harvesting is an important intervention in the low annual rainfall areas and in areas with distinct rainy and dry season rainfalls. The principle of water harvesting is to collect excess water in the rainy season in such a way that it contributes to reducing the risk of floods and redistribute it in the dry season to minimize drought stress. Water retardation pond (WRP) is an example of water harvesting. Appropriate design of WRP determines its optimal use. Its structure and design must consider the soil permeability, hydrology and topography. Its volume and construction should also be adjusted with the area of its water catchment and the area it supposed to irrigate. The costs and labor needs for its regular maintenance are also need to be budgeted to keep it functional. Routine inspection is needed to identify minor damage, and immediate mending should be taken to avoid higher costs of maintenance (Saadi 2013).

WRP in East Nusa Tenggara, Indonesia had the capacity between 20,000 m³ (about 100 m x 100 m, 2 m deep) and 60,000 m³. With this capacity, the pond can provide supplementary (beyond that obtained from well, harvested rainwater etc.) water needs for 9 months of a small village with 100 families. We also observed much smaller ponds, for example, 1,200 m³ (30 m x 20 m x 2 m) capacity or even smaller which supplement water needs for much smaller areas.

For horticultural farming, the use of small WRP increases cropping intensity from one to two or three crops per year in a pot (plastic bag) system. Commodities planted included chili, cucumber, chickpeas and beans. For pots of 6 kg media with soil : manure mixture of 1:1, watering was done daily with 2 to 4 glasses of water (about 500 to 1000 ml) per pot (Saadi 2013).

Soil Nutrient Management

The three main climate factors affected crop response are temperature, soil moisture and increased carbon dioxide. Increasing temperature and soil moisture may positively affect the chemical and biological reactions in the soil. Carbon dioxide is considered plant nutrient and CO₂ elevation may increase plant metabolism. Many studies reported that chemical and biological reactions in the soil were mostly affected by temperature and water regime rather than elevated CO₂, C, N and other element content in soil. Increasing temperature will accelerate adsorption/desorption reactions and changes in soil moisture would

change the reactions by altering the ionic strength of the soil solution favoring nutrient availability in the root zone (Broader and Volenec 2008). A long series of crop modeling study proved that climate change impacts on nutrient will be primarily affected through direct impacts on root surface area (Claassen and Barber 1976; Barber and Cushman 1981; Itoh and Barber 1983). Like soil temperature, soil moisture and CO₂ elevation affected nutrient acquisition. It is reasonable to assume that the outcomes of the processes are reflective of the changed climate (Broader and Volenec 2008). However, large uncertainties on the magnitude of the effect of each factors make it very challenging to predict how climate change will impact on nutrient availability, dynamics and acquisition by plant.

Soil nutrients affect at least 20% of crop production (Irianto 2012). About 48% of the global people are currently fed as a result of nitrogen fertilizer use (Erisman *et al.* 2007). Fertilizers are essential to increase production of existing agricultural land and have been proven to play an important role in achieving food security. However, excessive use of chemicals may harm the crop, the soil and the environment. The negative impact can be reduced if chemical fertilizers are used in a balanced manner to meet the crop needs and in combination with organic matter.

The main target of nutrient management is to optimize the yield and quality of crop production and, at the same time, minimize costs and negative environmental impacts. Since crop growth and the cycling of nutrients depend on temperature and moisture conditions, nutrient management should adapt to the changing climate. Proper and balance use of fertilizers will increase crop resilience to extreme climatic conditions and increase crop yield.

The Liebig's law of the minimum is a key concept in plant nutrition and nutrient management. The shortest supply of a nutrient could be a limiting factor for plant growth, and a deficiency of a nutrient in most cases cannot be corrected by applying different nutrients (van der Ploeg *et al.* 1999; Brady and Weil 2007). Therefore, improving fertilizer use efficiency and applying nutrients by taking into account soil available nutrients and plant needs are the answers. There are many ways to achieve better fertilizer use efficiency. It include better nutrient management in terms of timing, amount, quality and balance between one element and the other (Krauss 2004).

Balanced fertilizer application refers to the application of plant nutrients in optimum quantities in the right proportion through appropriate methods at the time suited for a specific crop and agro-climatic condition. Balanced fertilization does not mean only an application to soil a certain proportion of N, P, K and other nutrients in the form of fertilizers, but also the use of organic matters to supplement the nutrients and ensure minimum adverse effects on environment. In contrast, unbalanced use of

fertilizer results in poor crop yields and deterioration of the physical and chemical conditions of the soil. Moreover, imbalance use of chemical fertilization may lead to the deficiency of secondary and micronutrients in the soil (Mahajan and Gupta 2009) in addition to the financial loss of landholders.

The right fertilizer application should meet the 4R principle: the right source, the right amount, the right place and the right time to match plant growth stages and demand (IPNI 2014). In addition, controlled release fertilizers and the use of urease and nitrification inhibitors are designed to manipulate the timing of nutrient availability. The right application will vary depending on the location, crop and weather, and farming system. The accurate, yet somewhat costly and time consuming technique for determining fertilizer requirement is laboratory testing of soil and/or plant samples. However many simpler approaches are also available for supporting decision making, ranging from paper-based guidelines, computer based decision support system and soil and fertilizer test kits (<http://balittanah.litbang.pertanian.go.id>). In extreme weather condition such as high rainfall or even drought, improved management of fertilization and organic matter are very important. For example, one should avoid broadcast fertilizer in the rainy season to reduce nutrient loss. Instead, fertilizer incorporation in the surface layer is more recommendable.

Soil Amelioration

Soil ameliorants can be used to rectify problematic soil physical, chemical and biological conditions. Among the chemical soil problems that can be rectified with ameliorants are acidity, salinity and heavy metal contamination. Some soil ameliorants such as organic matter can also improve soil structure and protect soils from structural degradation. Soil ameliorants improve crops' vigor and hence their resilience to various stresses, including those related to climate change. Good soil structure is important in increasing water holding capacity which can improve biological activity and biodiversity and crop yield (Hillel 1998).

Ground limestone, gypsum, dolomite and organic matter are the most common ameliorants for improving soil structural stability due to their effects on electrolyte concentration and cation exchange effects (replacement of sodium ions attached to the clay surfaces with calcium and or magnesium ions) (Loveday 1976). Lime and dolomite have similar functions as gypsum. Gypsum provides immediate source of calcium and electrolyte, while the less soluble lime provides a longer term supply. Dolomite provide both Ca and Mg and both lime and dolomite are important ameliorants in acid soils as they increase soil pH.

Depending on availability, fly ash, blue vitriol (copper(II) sulfate pentahydrate, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) and silica

may be used as soil ameliorants. Applying silica fertilizer stimulates rice plant growth, especially root biomass and rhizosphere oxygen concentration; the latter is related to reduction of methane emission. Therefore silicate fertilizer is a good soil amendment for reducing methane emission as well as increasing lowland rice production.

Biochar, material produced through pyrolysis of organic matters has been receiving increasing research attention in the last two decades. It improves soil chemical characteristics by increasing nutrient retention and nutrient availability, but in some cases it may reduce N availability temporarily. It also improves soil physical characteristics, including reduction of soil bulk density, and increase saturated hydraulic conductivity, water holding capacity and permeability. It can also increase microbial activities. These effects, however, are material and soil and environment specific (Glaser *et al.* 2002; Lehmann and Rondon 2006; Asai *et al.* 2009; Nurida *et al.* 2013).

Soil Biological Management

The management of soil biology is conducted by improving soil conditions (soil organic matter content and quality, soil aeration, soil moisture and soil chemical conditions especially soil pH and redox potential) and by enriching soil through inoculation of organisms of specified functions. There are two main biological approaches of manipulating soil biological activities, i.e. using organic fertilizers and using biofertilizers. Biofertilizer is defined as inoculant containing living microorganisms which function to fix a particular nutrients and facilitate the availability of soil nutrients to plants (Permentan No. 70/2011). Increasing access of plants to soil nutrients by arbuscular mycorrhizal fungi, phosphate solubilization by phosphate-solubilizing microorganisms, as well accelerated organic matter decomposition by fungi, actinomycetes or soil worms are among the roles of inoculants. The main forms of biofertilizers include biodecomposers, nitrogen fixing bacteria, phosphate solubilizing microorganisms, mycorrhizal fungi and growth stimulating enzymes produced by rhizobia (Simanungkalit *et al.* 2006).

Biodecomposers are used to increase the decomposition process of organic matter to lower its C:N ratio and hence minimize nitrogen immobilization. It is usually used for speeding up the decomposition process of slow decomposing organic matters such as rice straw, corn stalk, empty fruit bunch of oil palm and municipal organic wastes from a few months to a couple of weeks. Inoculants of nitrogen fixing bacteria is used to activate N_2 fixation in root nodules of leguminous plants. It contains *Rhizobium* sp., *Azospirillum* and *Bacillus* sp. In many cases nitrogen fixing bacteria are packed in the same inoculant as phosphate solubilizing bacteria to produce multifunctional biofertilizers. Simanungkalit *et al.* (2006),

and <http://balittanah.litbang.pertanian.go.id/ind/index.php/> explain the detail of these inoculants.

CONCLUSION

Climate change affects agriculture because of more frequent and more intensified floods and droughts, higher temperature, sea water level rise and saline water intrusion. In general, annual crops are more vulnerable to the unfavorable soil conditions due to shallow roots which make them susceptible to drought and short shoots subjecting them to inundation. Various options of soil management techniques are available to reduce the negative effects caused by the climate change, ranging from conservation tillage technique, various kinds of vegetative and engineering approaches of erosion control, protection of soil surface by mulching, water harvesting and redistribution, soil nutrient management, soil amelioration, and soil biological manipulation. In principle, those management techniques are aimed at improving soil physical, chemical and biological properties, water availability and crop vigor such that the crop can withstand certain degree of droughts, inundation, salinity and other unfavorable conditions.

Landholders, especially resource-poor smallholders are vulnerable to the climate change because of limited capacity to access the needed materials and implement the climate change adaptation technologies. Therefore it's the responsibility of the government and civil society to disseminate and adapt the technologies to fit the local socio-economic and biophysical circumstances. Future research on the advancement on the subjects related to vulnerability and adaptation as well as mitigation should be on the priority agenda.

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