MASTERS' AND DOCTORAL SEMINAR REPORTS – 2014

Volume – I

Agronomy
Soil Science and Agrl. Chemistry

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Agronomy

Biomass briquetting

By

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(2014-11-118)

M. Sc. Agronomy

Seminar report

Submitted in partial fulfilment of requirement of the course

Agron. 591 Master's Seminar (0+1)

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CERTIFICATE

Certified that the seminar report entitled **'Biomass briquetting'** is a record of seminar presented by Rameeza E. M. (2014-11-118) on 27th November, 2015 and is submitted for partial requirement of the course Agron. 591.

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DECLARATION

I, Rameeza E. M. (2014-11-118), hereby declare that the seminar report entitled '**Biomass briquetting**', has been completed by me independently after going through the reference cited herein and I have not copied from any of the fellow students or previous seminar reports.

Vellanikkara

Date: 31. 12. 2015

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CERTIFICATE

Certified that the seminar report entitled '**Biomass briquetting**' for the course Agron.591 has been prepared by Rameeza E. M. (2014-11-118), after going through various references cited herein under my guidance, and she has not copied or borrowed from any of her fellow students.

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1. Introduction

Energy crisis is one of the setbacks affecting the economy of our country. The non renewable forms of energy such as coal and petroleum products are causing a huge concern regarding environment and depletion of natural resources. Hence, we have to go for alternate forms of energy which is environmental friendly and cost effective. The inclusion of biomass as a form of energy will serve the purpose to meet the energy demand to a certain extent. One of the viable and promising technologies by which the biomass can be converted to energy is through the process of briquetting. Even though it is an age old technology, there is much scope for briquetting in the present day to day life.

2. Biomass briquetting

Biomass briquetting is an age old densification technology invented during 18^{th} -19^{th} century. It is defined as the process of compaction of residues into a product of higher density than the original raw materials (Oladeji, 2015).

In 1923, the Pacific Coal and Wood Co. Los Angeles, California marketed wood waste briquettes first time in the world. In India, prime examples for briquettes are cow dung cakes, fuel balls from coal dust, etc. Insulation and architectural boards produced from forage materials are also the example of the techniques of densification.

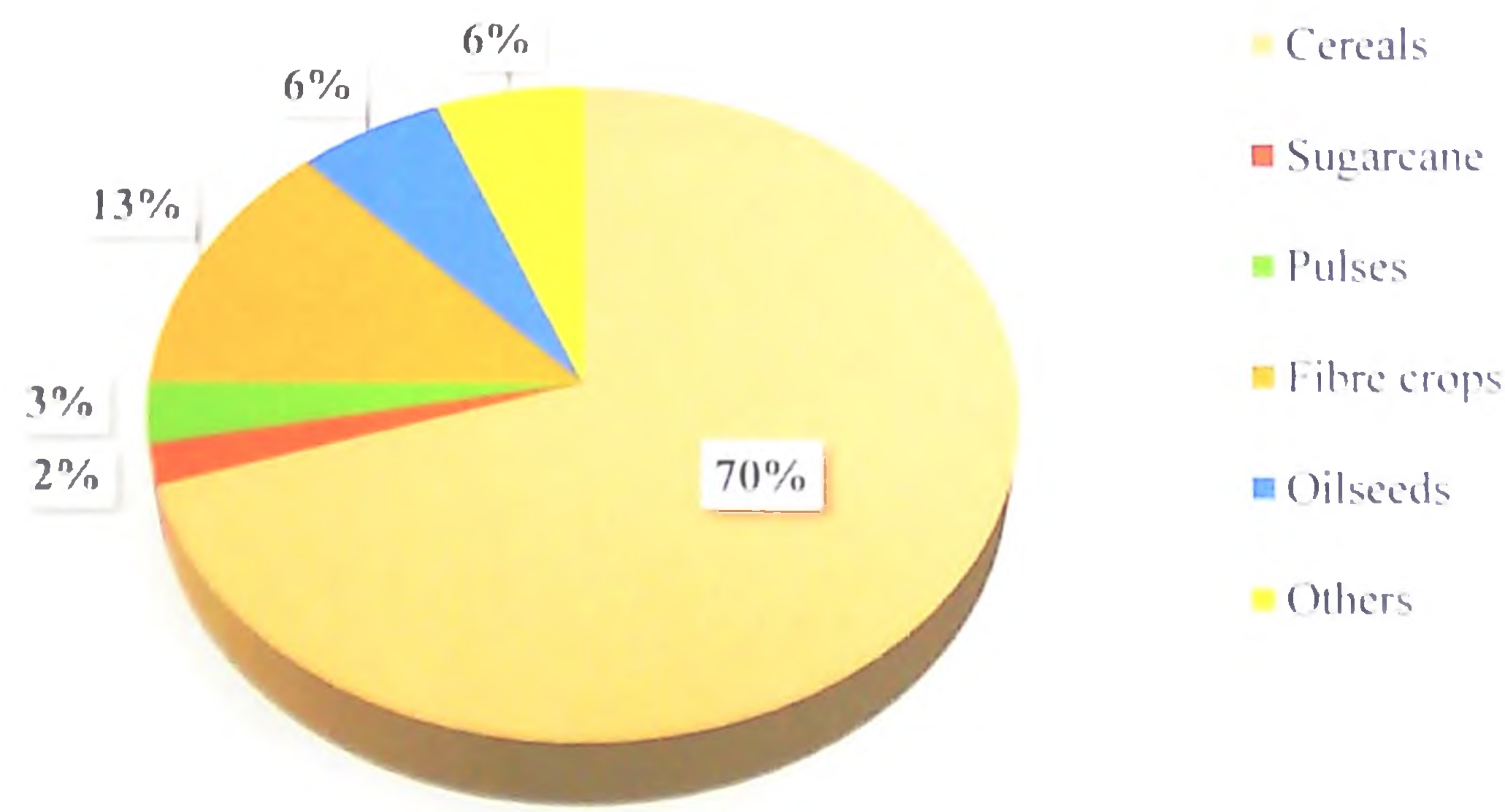
Plate 1. Cow dung cake

Plate 2. Insulation board

3. Agro-residue generation by different crops in India

According to Ministry of New and Renewable Energy (MNRE), 70 per cent of residue generation is from cereals followed by fiber crops (13%) and oil seeds (6%) and sugarcane alone is producing 2 per cent which is highest for all crops (Fig.1). With the increase in food production the crop residue generation is also increased. In India residue generation is about 600 million tons comprising of field residues and processing residues. After utilizing these crop residues for various purposes a surplus of 150- 200 million tons are left as waste. So, there is availability of raw materials for briquetting and thus indicating the scope for biomass briquette production.

Figure 1. Residue generation by different crops in India



(IARI, 2012)

4. Need for briquetting

4.1. Agro-residue management: The major problem faced by large scale farmer is the disposal of farm and processed residues, i.e., surplus agro residues, which is posing challenge to the farmers. Therefore, if these wastes could be used to generate energy, it would be a welcomed solution to the problem of waste disposal and pollution.

4.2. Easy handling and storage: The biomass materials are bulky in nature, so briquetting will facilitate easy handling and less space is needed for storage.

4.3. Consistent quality fuel production: High quality fuel with high burning efficiency can be produced through briquetting. The biomass fuel briquettes have the potential to replace conventional fuels.

4.4. Prevents pollution: Fuel briquettes are smokeless with no fly ash and will not emit sulphur. More over it is carbon neutral, so usage of biomass briquettes for heating purpose will not cause any pollution to atmosphere.

4.5. Additional income to farmers: The farmers will be benefited by two ways ie, residue management and additional income from selling residues or briquettes.

5. Biomass briquettes

Biomass briquettes can be produced from wide variety of materials and mainly residues from farm or processing unit can be utilized. The materials such as sugarcane bagasse, maize stover, cotton stalks, cereal straw, coir pith, sawdust etc. can be made into briquettes. It can also produced by using charcoal of coconut shell, rice husk etc. The quality characteristics such as colour, durability, heating value will vary according to the raw materials used.

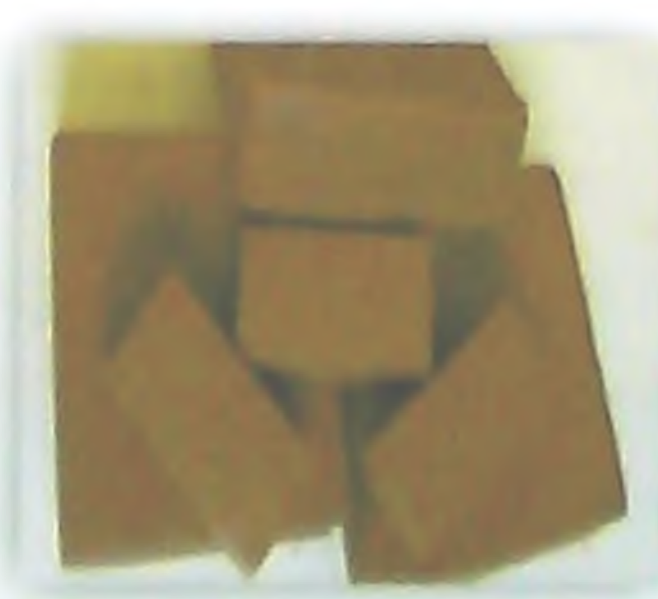
Plate 3. Biomass briquettes

Bagasse briquette

Wood briquette

Charcoal briquette

Sawdust briquette



Coir pith briquette

Straw briquette

6. Utilization of briquettes

Biomass briquettes are mainly utilized as a source of energy and have some application in agriculture as growing media and animal feed. It is utilized for domestic heating and as industrial fuel for agro processing unit and other industries. It is mainly exported as barbeque fuel. Electricity can be generated with the help of boilers and gasifiers.

6.1. Biomass briquettes as fuel

The pictures show the utilization of briquettes in smokeless stove (plate 4) tandoor chulha (plate 5) and for barbequeing (plate 6) i.e., grilling. Nowadays in star hotels barbeque chulhas are kept on dining table because of its advantage that it is being smokeless.

Plate 4

Plate 5

Plate 6

6.1.1. Advantages of biomass briquettes over coal

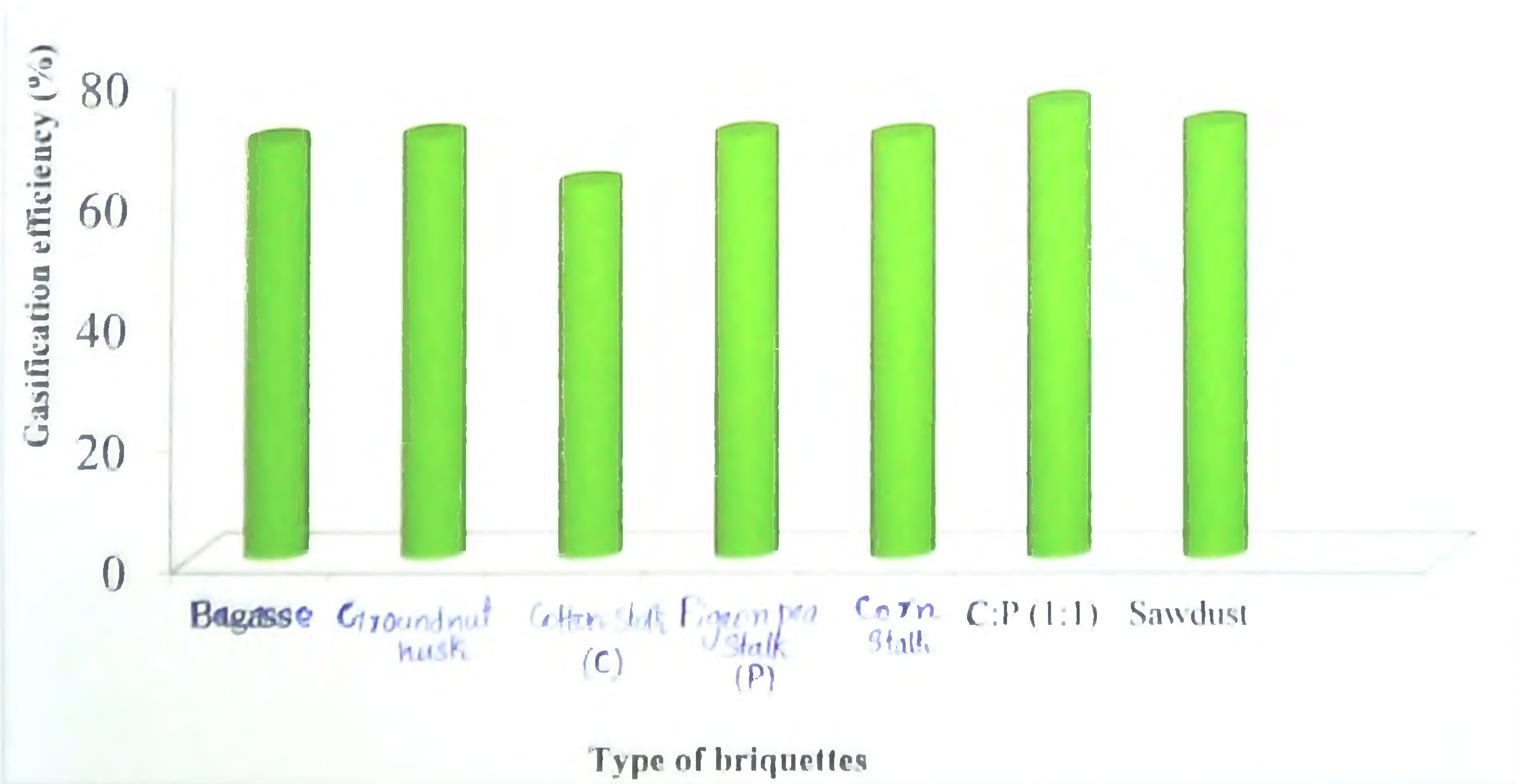
The calorific value of coal is in the range of 3800 to 5300 kcal/kg with high ash content. The biomass briquettes also having the high calorific value in the range of 3700 to 4700 kcal/kg with less ash content (Table 1). The comparison of coal over biomass briquettes produced from different raw materials shows that the coal can be replaced by biomass briquettes since biomass briquette is also having high calorific value and is causing less pollution (Singh, 1996).

Table 1. Comparison of coal over biomass briquettes

Fuel	Density (g/cm^3)	Calorific value (kcal/kg)	Ash content (%)
Coal	1.30	3800 - 5300	20 – 40
Sawdust briquette	1.10	4600	0.70
Groundnut shell briquette	1.05	4750	2.00
Rice husk briquette	1.30	3700	18.00
Sawdust + cotton briquette	1.12	4300	8.00

6.1.2. Gasification efficiency of biomass briquettes produced from agro-residues

Figure 2. Gasification efficiency of biomass briquettes



Pareek *et al.* (2012) studied the gasification efficiency of different biomass briquettes (Fig. 2). Gasification is the process of converting solid fuel into a gaseous combustible gas through partial oxidation at high temperature in a gasifier. This gas can be burned in a gas turbine to produce electricity. Here briquettes were produced from different biomass materials are having gasification efficiency in the range of 65 -75% which is the same as that of high grade coal. So it is evident that the biomass briquettes can replace coal for electricity production.

6.2. Biomass briquettes in agriculture

In agriculture, coir pith briquette is used as a growing medium. Nowadays coir pith is replacing the sand in potting media since availability of sand is limited and also of high cost of sand. It has the unique property of absorbing and retaining moisture to about 500-600% and thus improves the water infiltration rate and hydraulic conductivity of soil in addition to the supply of nutrients. In foreign countries coir pith is used as a soilless medium for growing plants and it is desirable in problem soils and also to prevent soil borne diseases. Hence there is great demand for coir pith briquette. A large quantity is exported from India to different countries. Rice straw briquette is used for tree nursery. Animal feed is also produced through briquetting by using cassava waste, de-oiled rice bran etc with appropriate binder.

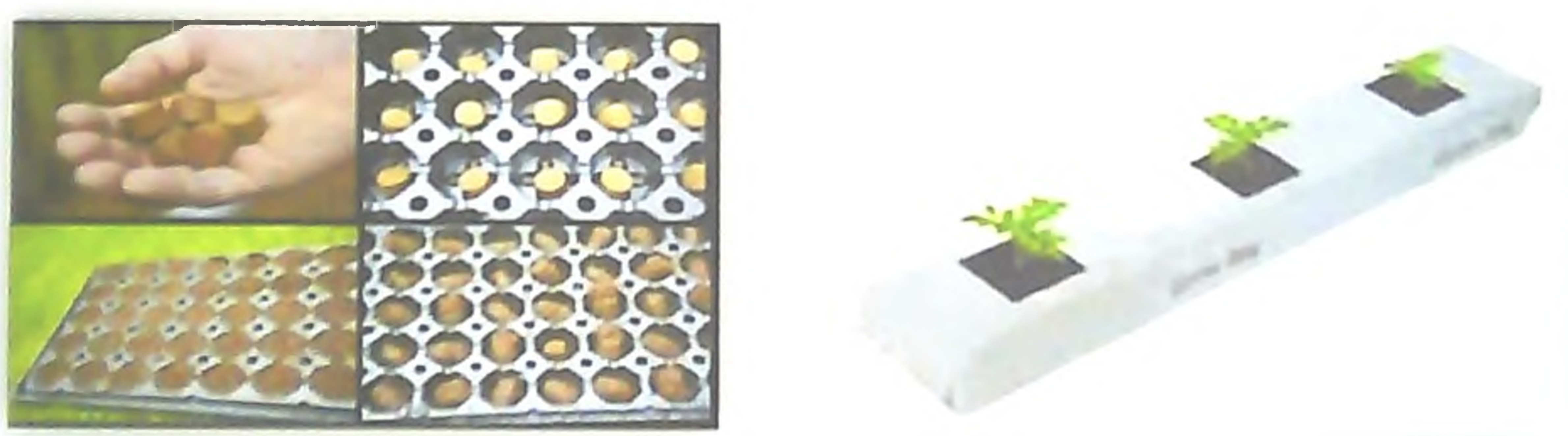


Plate 7. Coir pith briquette as growing medium

Plate 8. Rice straw briquette for tree nursery

Plate 9. Animal feed from de-oiled rice bran

7. Status of briquetting of biomass in India

According to All Gujarat Biomass Briquette Association (AGBBA), in India there are about 500 briquette manufacturers giving direct or indirect employment to more than one lakh people. The major producers are Gujarat, Punjab and Tamil Nadu. In Kerala, Coirfed and Sterling group is producing and selling coir pith briquettes. The potential users of biomass briquettes in India (Dhingra *et al.*, 1996) are listed below (Table 2).

Table 2. Potential users of briquettes

State	Type of industry	Briquettes used as replacement for
Kerala/Tamil Nadu/ Karnataka	Tea factories, rubber factories, pharmaceutical industries	Wood, coal
Punjab	Solvent extraction oil mills, brick kilns	Coal
Gujarat	Textile, dye and chemical industries	Coal
Madhya Pradesh/ Maharashtra	Textile industries, pharmaceutical industries, brick kilns	Coal

8. Steps involved in briquetting

The Steps involved in briquetting are collection and preparation of raw materials, briquetting with machine, cooling and storage. Raw materials can be collected both from the field and processing units. The preparation of raw materials includes drying, size reduction, mixing of raw materials in correct proportion, mixing of raw materials with binder. Compaction process takes place inside the briquetting machine. The process depends on the briquetting technology adopted. Briquettes extruding out of the machine are hot with temperatures exceeding 100^{o}C. They have to be cooled and stored in dry place.

9. Criteria for selection of raw materials for briquetting

The selection of raw materials usually depends on what is easily available in the surrounding areas where the briquettes are made. The criteria for selection of raw materials for briquetting includes moisture content, ash content, flow characteristics and ability to bind together.

The moisture content should be in the range of 10-15%. High moisture content will pose problems in grinding and excessive energy is required for drying. The ash content should be low otherwise it will cause slagging in the machine. Biomass materials generally have low ash content except in rice husk. The material should be granular and uniform so that it can flow easily in machines. The materials having high natural binding ability can replace external binders.

10. Process of briquetting

Briquetting can be done by two ways namely direct compaction and compaction after pyrolysis or carbonization. Direct compaction can be achieved by use of binders and also without the use of binders. In binderless process the biomass will be semi- fluidized by applying high pressure so that the lignin present will be melted which will act as a binder. Compaction with binder requires addition of external binding materials like molasses, starch, sodium silicate, lignosulphonate, cotton seed oil, bentonite etc.

Pyrolysis is the process of destructive distillation with the absence or minimum presence of oxygen. During the pyrolysis process the fibre content of biomass is broken which later facilitates in briquetting of produced charcoal.

11. Binding mechanism

Densification of biomass under high pressure brings about mechanical interlocking and increased adhesion between the particles, forming intermolecular bonds in the contact area. In the case of biomass, the binding mechanisms under high pressure can be divided into adhesion and cohesion forces, attractive forces between solid particles, and interlocking bonds (Gebrekidan and Zeslase, 2015). Lignin of biomass/wood can also be assumed to help in binding in this way. Another important binding mechanism is van der Waals' forces. They are prominent at extremely short distances between the adhesion partners. This type of adhesion possibility is much higher for powders. Fibres or bulky particles can interlock or fold about each other as a result forming interlocking or form-closed bonds.

12. Types of briquetting

On the basis of compaction, the briquetting technologies can be divided into high pressure compaction, medium pressure compaction and low pressure compaction (Wilaipon, 2009).

In high pressure briquetting, pressure developed is more than 100 MPa. This type is suitable for the residues of high lignin content. At this high pressure the temperature rises to about 200 - 250^{0} C, which is sufficient to fuse the lignin content of the residue, which acts as a binder. At present, there are two high-pressure technologies i.e., Piston press and screw press.

In Medium pressure compaction, the pressure developed will be in the range of 5 MPa and 100MPa which results in lower heat generation. This type of machines requires additional heating to melt the lignin content of the agro residues which eliminates the use of an additional binder material.

Low pressure compaction works at a pressure less than 5 MPa and room temperature. This type of machines requires addition of binding materials and is applicable for the carbonized materials due to the lack of the lignin material.

13. Briquetting machines

The briquetting machines used for briquetting in India includes manual briquetter, piston press and hydraulic piston press, screw press and roll press. Manual briquetter is mainly used to produce animal feed and fuel for domestic purposes. Piston press and hydraulic piston press will produce solid briquettes. Screw press will produce high quality briquette with concentric hole, which will facilitate increased surface area for better combustion. Roll press machine is mainly used to produce barbeque briquettes of pillow shaped.

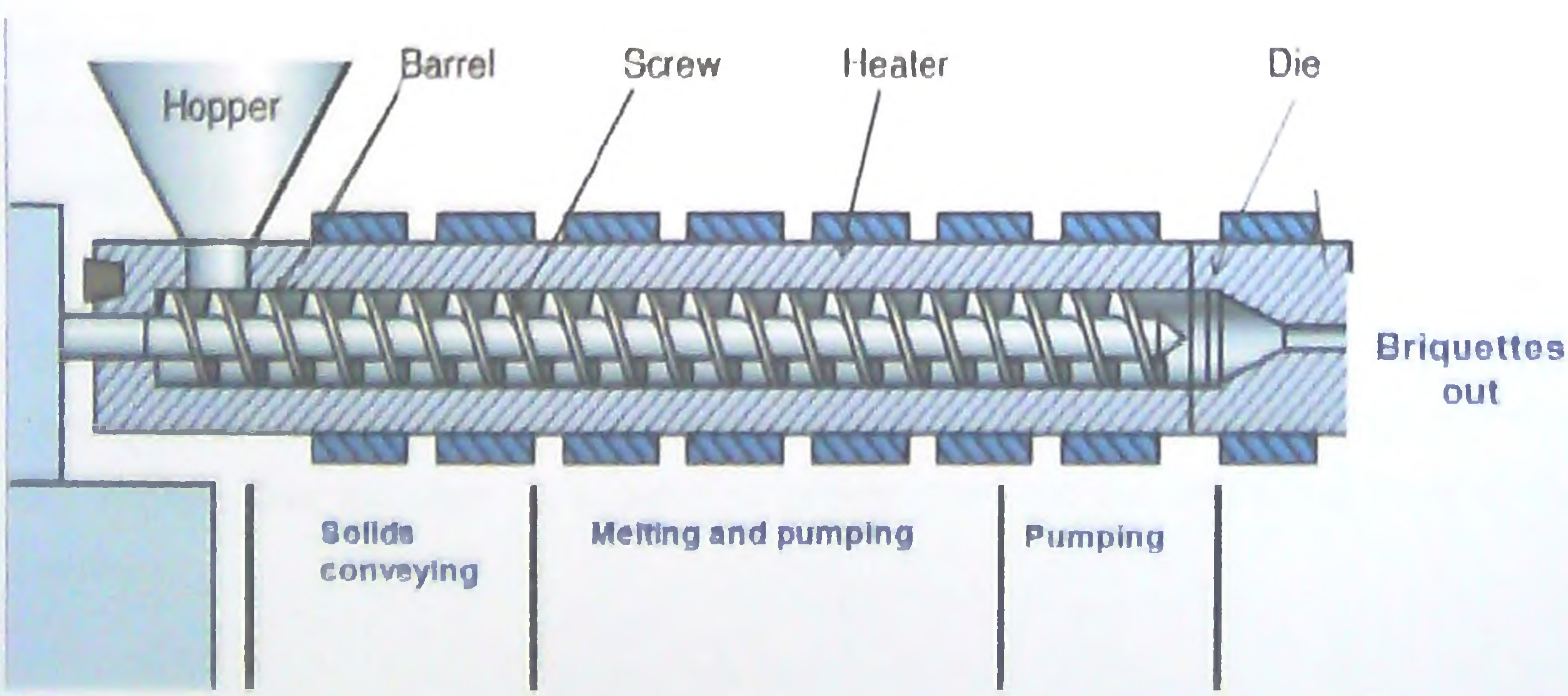
Plate 10. Briquetting machines

Piston press Screw extruder Roll press

13.1. Mechanism of working of a screw press

During briquetting, the raw materials will be fed through hopper and it will move towards the die with the help of a rotating screw, resulting in significant pressure gradient. The combined effects of wall friction, internal friction in the material, and high rotational speed (~600 rpm) of the screw, temperature will increase in the system (Tumuluru *et al.*, 2010). So when the material reaches to middle of the screw, lignin in the biomass will melt and act as a binder. This heated biomass is forced through the extrusion die or mould to form the briquettes where it gets compacted.

Plate 11. Working model of a screw press



13. 2. Specific energy consumption of different biomass material during briquetting

The table 3 shows the specific energy consumption by different densification units with different biomass materials. The specific energy consumption varies with the densification unit. The specific energy consumption for briquetting of sawdust and grass with piston press and similarly switch grass and alfalfa with pellet mill differs as cited by different authors. The screw press has high specific energy consumption which will produce high quality briquettes.

Table 3. Specific energy consumption of different biomass material

Materials	Type of densification unit	Specific energy consumption (kWh/t)	Reference
Grass	Piston press	77	Shepperson and Marchant (1978)
Sawdust	Piston press	37	Reed *et al.* (1980)
Straw	Screw press	150-220	Carre *et al.* (1987)
Alfalfa	Pellet mill	30	Tabil and Sokhansanj (1996)
Switch grass	Pellet mill	74	Jannasch *et al.* (2001)

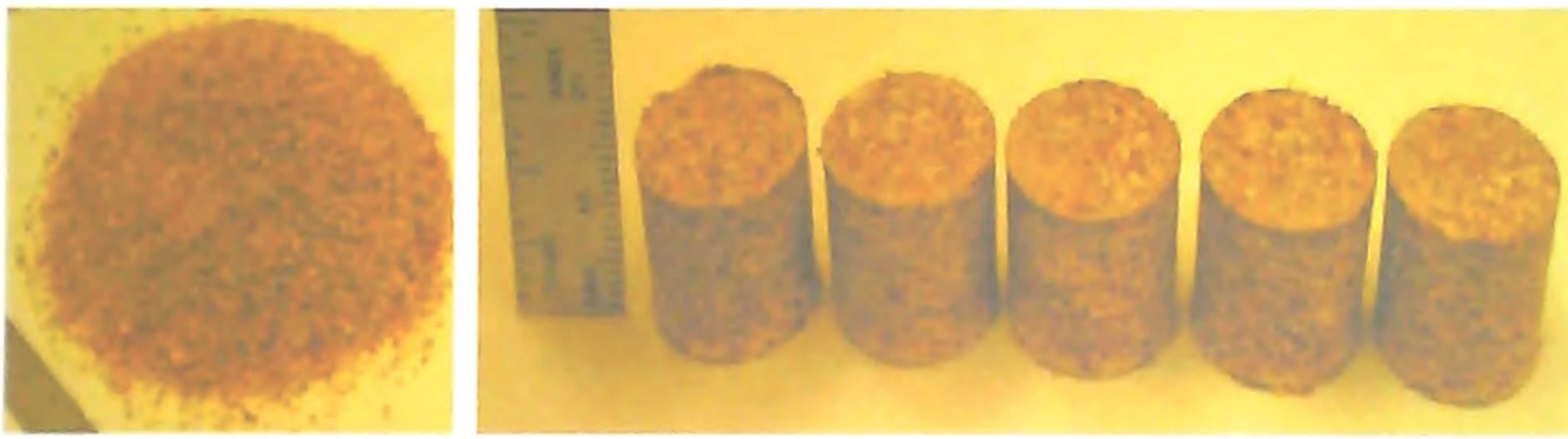
14. Factors affecting briquetting

14.1. Particle size: Particle size plays an important role in the densification process. Fine particles give larger surface for binding. The biomass material of 6 – 8 mm size with 13 – 15 % powdery component is best suited. If the particles are oversized, then the briquetting will not be smooth and it will result in clogging at the entrance of die.

Kaliyan and Morey (2010) were studied the effect of particle size on corn cob briquettes. The corn cob briquettes were produced at two particle sizes i.e., 2.88mm and 0.85 mm (Plate 12). They have reported that briquettes produced at a particle size of 0.85 mm had good compaction and strength than the other. It is better to powder corn cob for briquetting because of its hardiness.

Plate 12. Effect of particle size on corn cob briquettes

Particle size: 2.88mm



Particle size: 0.85mm

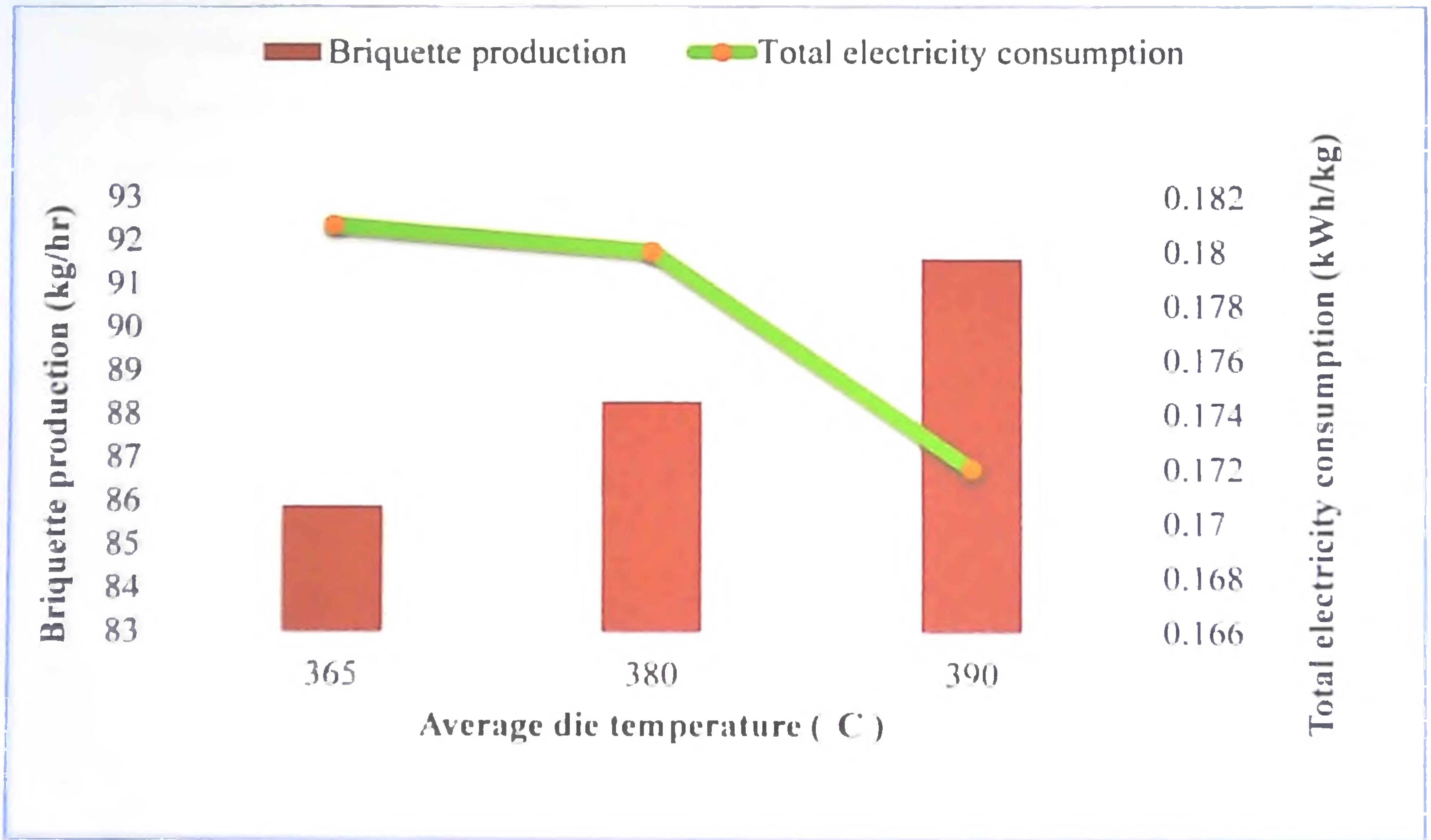
14. 2. Moisture content: In general, it has been found that when the feed moisture content is 10-12%, the briquettes will have 8-10% moisture. At this moisture content, the briquettes are strong and free of cracks and the briquetting process is smooth. Therefore, it is necessary to maintain optimum moisture content.

14. 3. Temperature of the biomass: The temperature of biomass during briquetting should not be increased beyond the decomposition temperature of biomass. A low temperature will reduce the quality of briquettes in terms of durability and strength.

14. 4. Temperature of the die: The temperature of the die should be kept at about 280-390^{0}C for better quality briquette production. The exposure of very high temperature to die will cause high wear and tear and thus increase the cost for repair and maintenance.

Bhattacharya *et al.* (2001) studied the effect of die temperature on briquette production and total electricity consumption. Rice husk briquettes were produced at three different temperatures ie, 365,380,390 degree Celsius. It is clear that the briquette production increased with increase in temperature whereas total electricity consumption decreased. Hence they have concluded that briquetting at high temperature will reduce the cost of production by lowering the electricity consumption.

Figure 3. Effect of die temperature on rice husk briquette production and total electricity consumption



15. Characteristics of briquettes

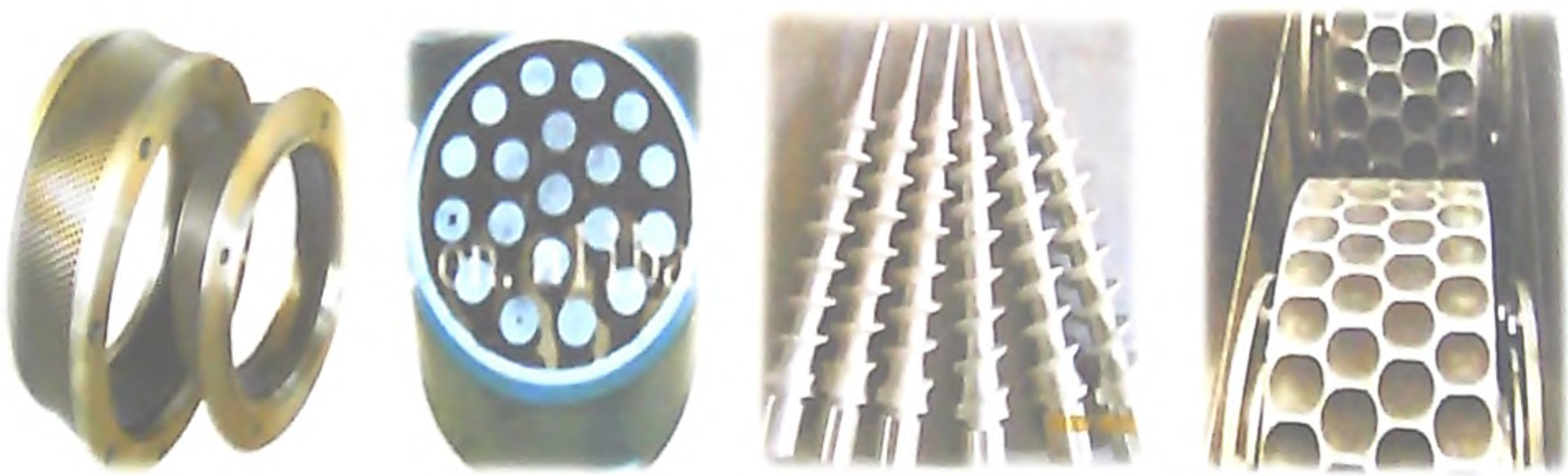
15. 1. Physical characteristics

- **Shape and size:** The shape and size of biomass briquette depends on the moulds or dies used during briquetting. The shape can be cylindrical, square or rectangle with varying diameter of 25-100 mm. The plate 13 shows the different types of die and the briquettes produced with it. From these images it is clear that the shape and size of the briquette will vary with the shape of the die.
- **Density:** The bulk density of briquettes depends upon the initial density of biomass, binders used and the briquetting technology adopted. The bulk density of briquettes produced will be higher than the bulk density of raw materials. The table 4 shows the

change in bulk density before and after briquetting (Umesh- Kanna *et al*., 2011). The bulk density was drastically increased from loose biomass materials to powder form and then to briquette. So the increased bulk density of briquette is desirable in easy handling and storage of residues.

- **Free volume expansion**: The term free volume expansion is expressed as the per cent increase in volume during compression. As the pressure increases during briquetting the free volume expansion will decrease.
- **Degree of densification**: The term degree of densification is expressed as the per cent increase in the bulk density of the biomass. As the pressure increases during briquetting the degree of densification will increase.

Plate 13. Forms of die and briquette



Round die Honey comb die Screw die Roll die

Briquettes produced with respective die

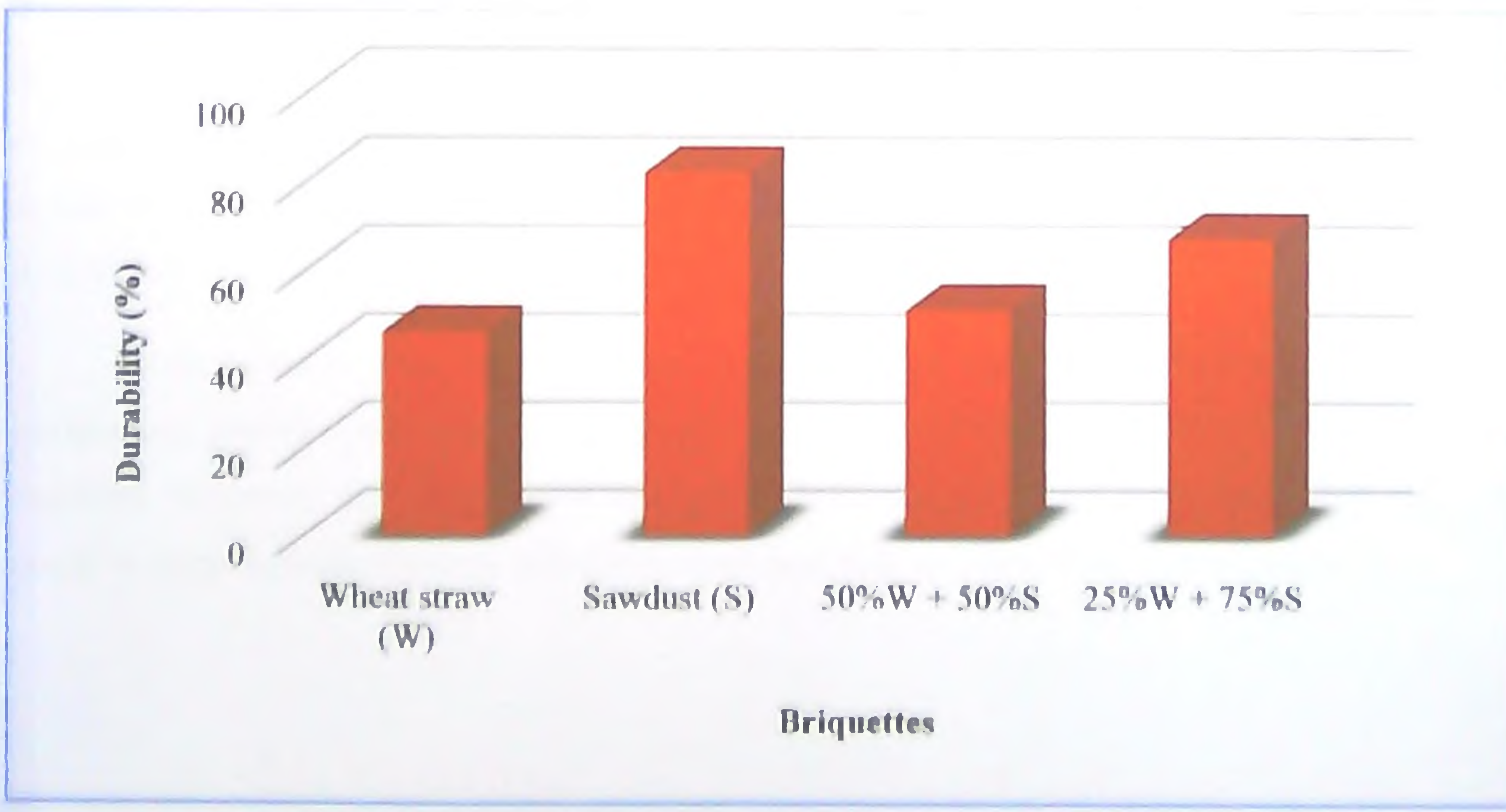
Table 4. Change in bulk density during briquetting

Raw materials	Bulk density (kg/m^3)		
	Loose	Powder	Briquette
Saw dust	-	240.00	615.00
Leaf residues	37.20	316.53	442.00
Oil seed residues	148.50	148.50	684.70

15. 2. Mechanical characteristics

- **Durability:** The durability of the briquettes depends upon the raw materials, binders used and densification technology adopted. Raw materials having high carbon content such as saw dust and charcoal having 100 % durability without the addition of binder.

Figure 4. Effect of blending of raw materials on briquette durability



Wamukonya and Jenkins (1996) were studied the effect of blending of different raw materials on durability of briquettes produced from wheat straw and sawdust (Fig. 4). The sawdust briquette is having high durability percentage and thus high quality whereas wheat straw briquette is less durable. The sawdust is having high lignin and cellulose which will improve the binding and thus durability. So mixing sawdust with wheat straw will improve the strength and durability results in lower cost of densification.

- **Penetration resistance:** It determines the hardness of the briquette and is measured by using penetrometer. It indicates stability which ensures the quality of the briquette.

- **Compressive strength:** It is the maximum crushing load a briquette can withstand before cracking or breaking.

Mitchual *et al.* (2013) studied the compressive strength of briquettes produced from maize cobs and *Ceiba pentandra* (Kapok tree) at different mixing ratio and at varying compacting pressure levels (Table 5). The results indicate that, at all compacting pressure levels, the compressive strength of briquettes produced from maize cob particles alone was very low, compared to briquettes produced from *Cieba pentandra* alone. It is due to the less carbon content of maize cobs. Furthermore, the compressive strength of briquettes produced from combination of maize cob particles and *C. pentandra* have high compressive strength compared to maize cob briquettes.

It is revealed that the briquettes produced from maize cobs particle alone at low compacting pressure and room temperature will not have adequate compressive strength for handling. However, the compressive strength of briquettes produced from maize cob particles could be improved significantly when it is combined with sawdust from *C. pentandra*.

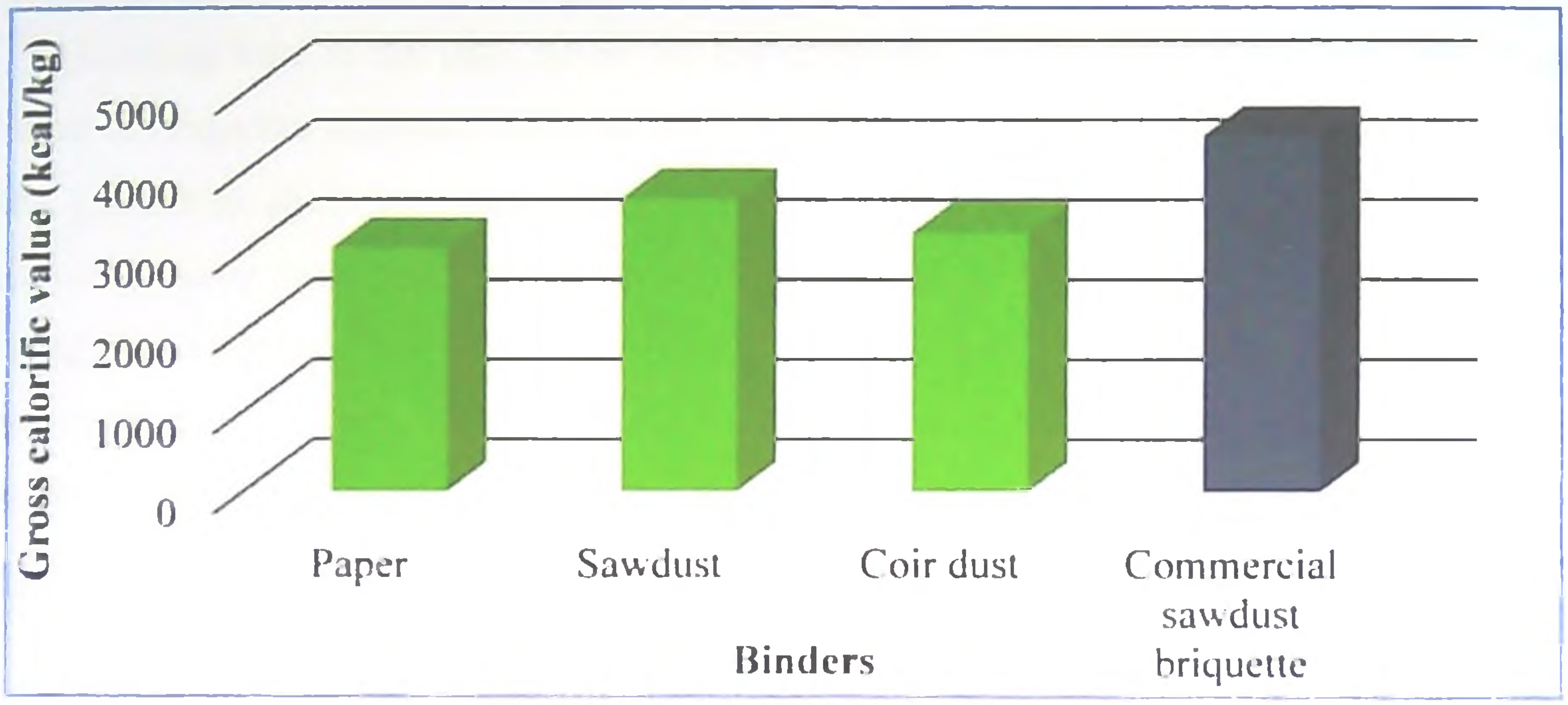
Table 5. Compressive strength of briquettes at different compacting pressure levels

Biomass material	Mixing percentages (Weight basis)	Compressive strength (N/mm)			
		20 MPa	30 MPa	40 MPa	50 MPa
Maize cobs	100	0.12	0.12	0.41	0.54
Ceiba pentandra	100	29.23	39.26	40.40	44.58
C. pentandra + Maize cobs	90: 10	27.29	37.33	44.98	59.22
C. pentandra + Maize cobs	70:30	16.66	22.82	30.00	33.47
C. pentandra + Maize cobs	50:50	7.72	13.02	19.46	24.04

15. 3. Calorific value

Calorific value is a most important characteristic of a fuel. This is the measurement of energy released by a fuel during the complete combustion .Calorific value depends upon the type of biomass and the binders used. Biomass briquettes have a calorific value in the range of 3000 to 5000 kcal/kg.

Figure 5. Calorific value of coconut leaf briquette with different binders



The suitability of coconut leaf along with different binders for briquetting was studied by Deepak and Jnanesh in 2014 (Fig. 5).The calorific value of coconut leaf briquette with news paper, sawdust and coir dust as binder was analyzed and compared with commercially available sawdust briquette. The briquettes were prepared by mixing chopped coconut leaf with binder in the ratio 2:1 and densified by a piston press. Result shows that the briquettes produced by using coconut leaves and sawdust as a binder had a high calorific value than other briquettes, but less than the commercially available sawdust briquette. The coconut leaves with sawdust as binder will produce the best biomass briquette, which can be used as a replacement for the commercially available sawdust briquette.

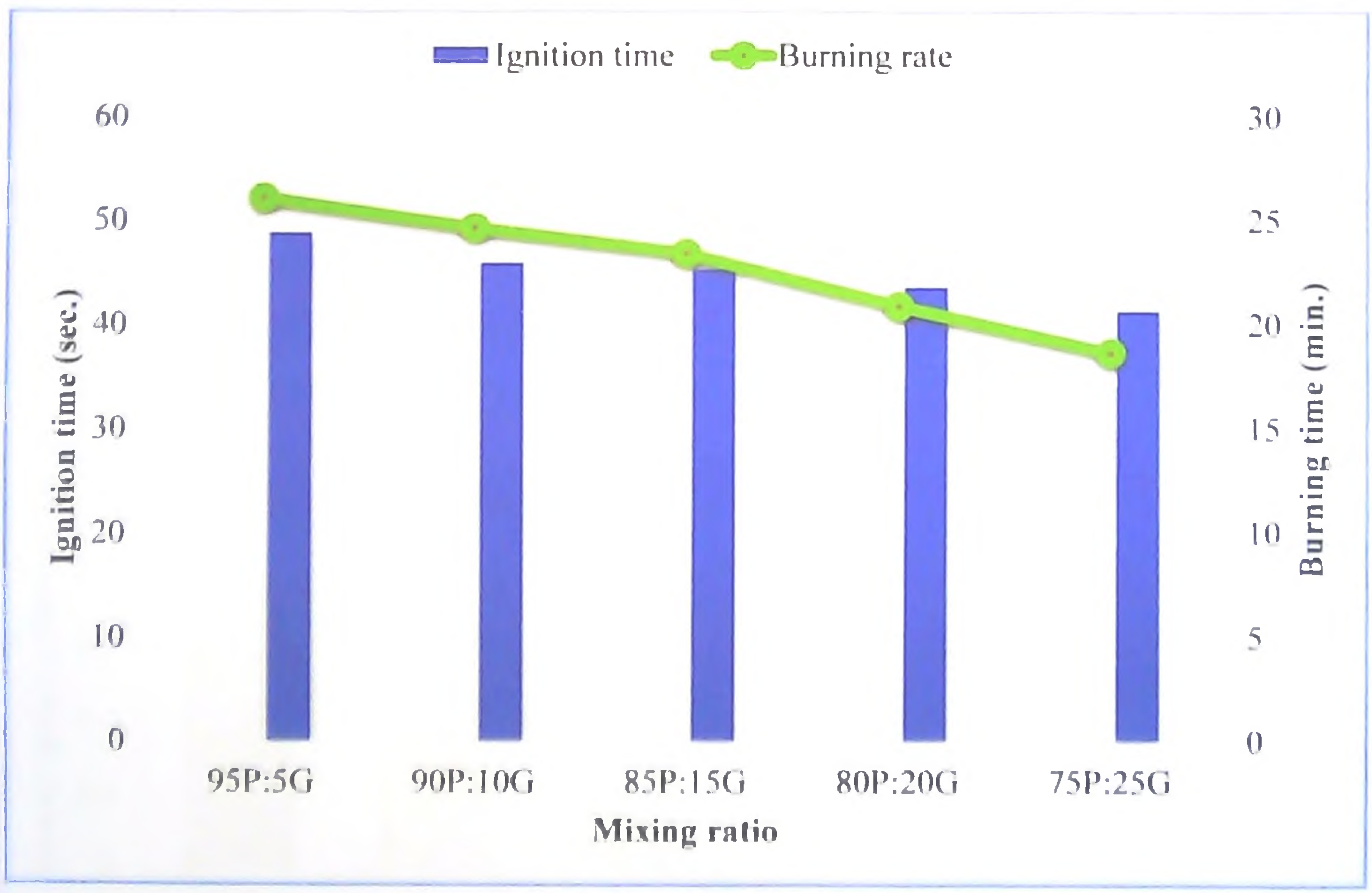
15. 4. Combustion characteristics

- **Ignition time:** It is defined as the minimum time at which the substance ignites and burns without further addition of heat from outside. The ignition time should be less for a good briquette so that fuel briquette will easily ignite and attain steady glow.

Oyelaran *et al.* (2015) studied the combustion characteristics of briquettes produced from combination of waste paper and groundnut shell (Fig. 6). Here ignition time was taken as the average time taken to achieve steady glowing flame. The ignition time decreased with increase in the content of groundnut shell. A combustible material should be easily ignitable, particularly for household. The ignition time of 41.34 – 48.84 seconds obtained in this experiment is lower than 286 seconds obtained for coal.

Burning time is the time taken for the briquette combustion to complete. The burning duration of briquettes decreased with amount of groundnut shell. The rapid combustion observed as the groundnut shell increases could be due to the increase in porosity which enables the volatiles to leave more readily and be consumed rapidly and also can be attributed to poor bonding. So, it can be concluded that binderless briquette can be produced from waste paper and ground nut shell. However the content of groundnut shell should not exceed 25% for good binderless briquette. However the 15% groundnut shells compositions possess better quality.

Figure 6. Combustion characteristics of waste paper- groundnut shell briquette



P: Waste paper

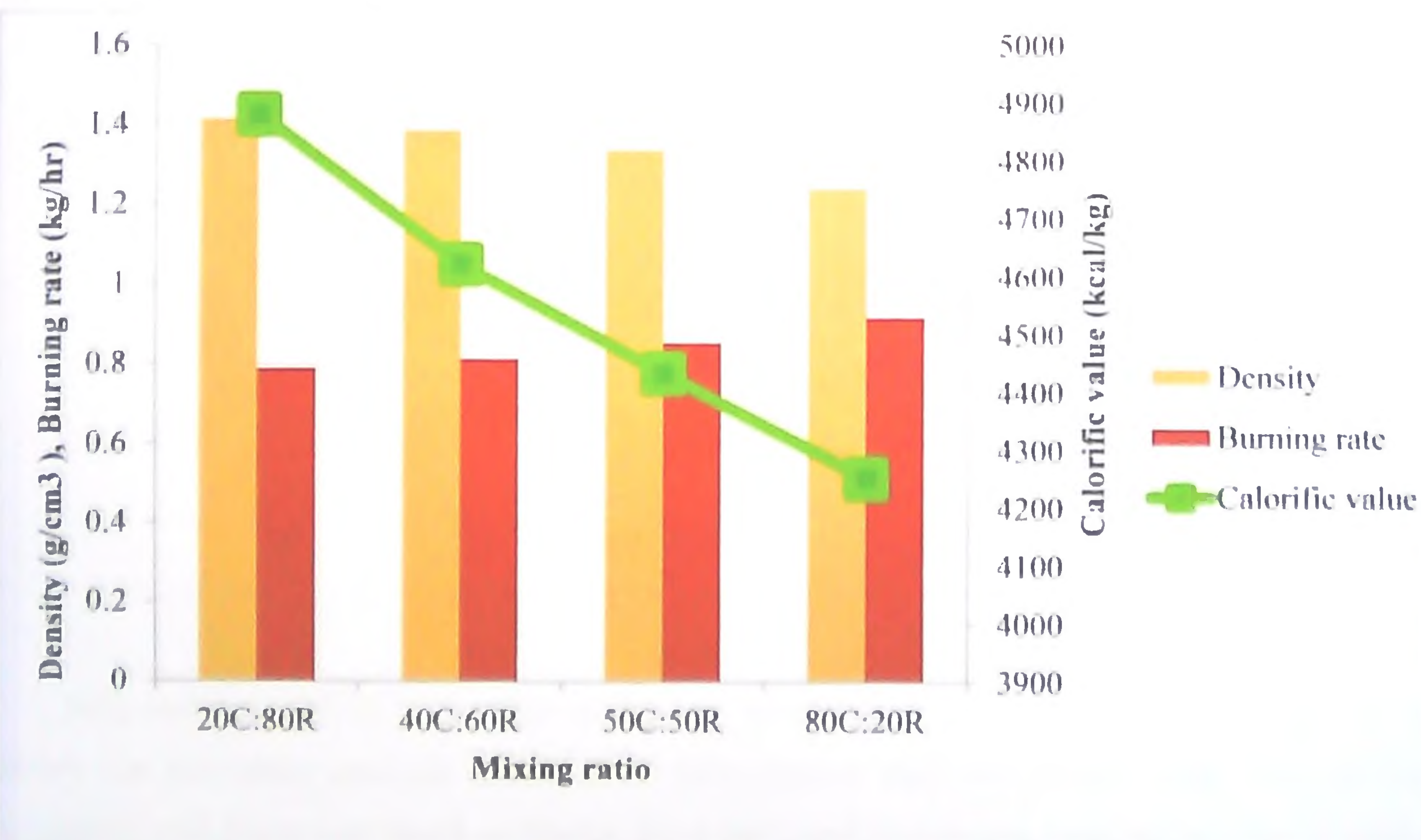
G: Groundnut shell

- **Burning rate:** It determines the rate at which a certain mass of fuel is combusted in air. The burning rate should be less for a good briquette so that fuel consumption will be less.

- **Smoke emission**: Biomass briquettes are comparatively smokeless compared to other energy sources. During briquetting the majority of volatile compounds will go off due to the high temperature developed inside the briquetting machine.

Islam *et al.* (2014) studied the effect of blending of coir dust (C) and rice husk(R) on quality characteristics of briquettes (Fig.7). The result indicates that briquette from 20% coir dust with 80% rice husk had higher value of density followed by other briquettes. It is due to the low bulk density of coir dust than rice husk and also the high lignin content. So briquettes produced from coir dust and rice husk blend became more compact and resulted in high density products. The calorific value decreased significantly with the increase in per cent of coir dust whereas burning rate increased. This indicates that the calorific value of the briquette depends on the calorific value of raw material and the density of the briquette. A slow burning rate is desirable because less fuel is required. Hence it can be concluded that the briquette produced from 20% coir dust and 80% rice husk possess better quality than all other briquettes.

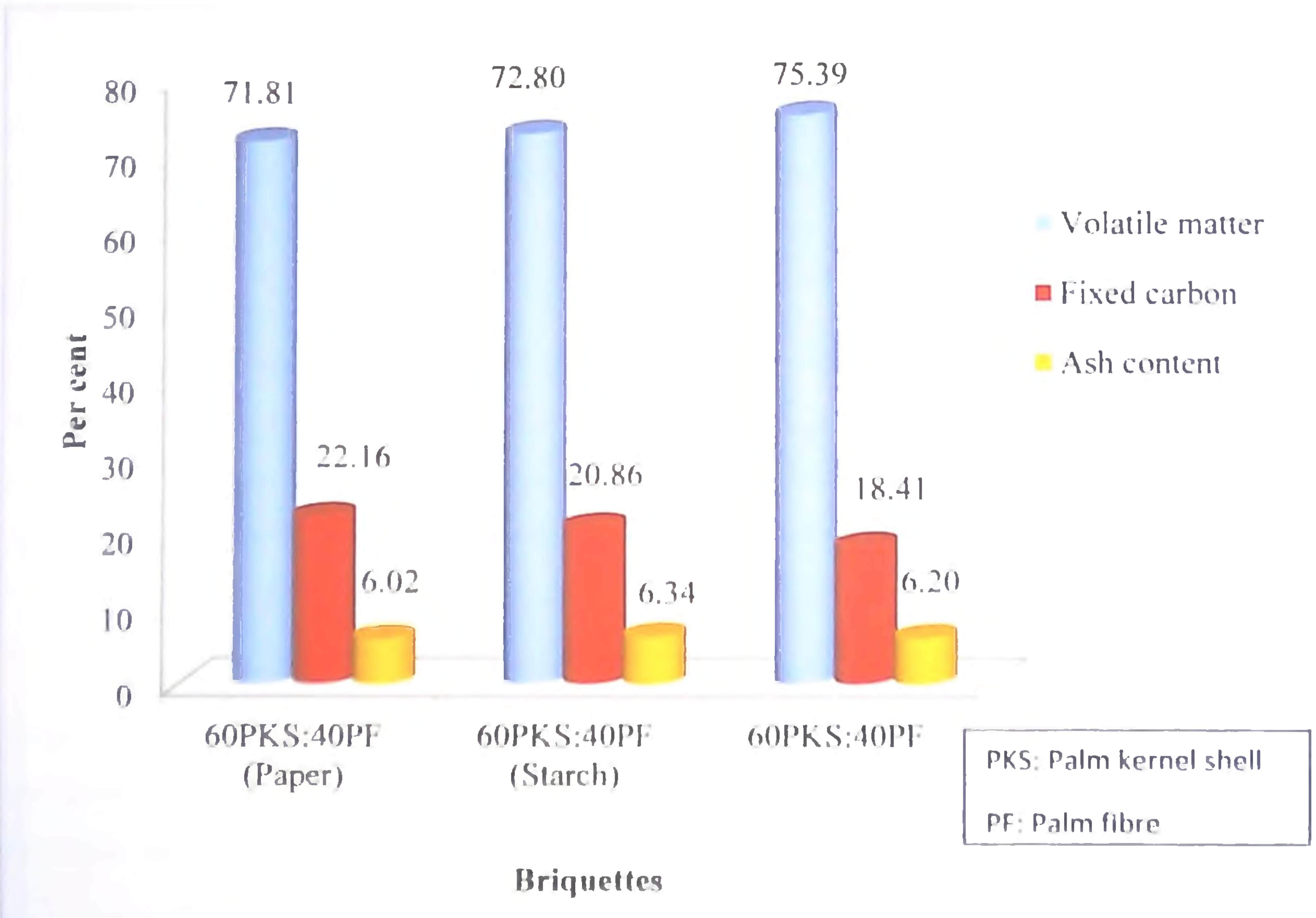
Figure 7. Effect of mixing ratio of coir dust and rice husk on briquette quality



15. 5. Proximate analysis

Proximate analysis of briquettes gives an idea about their fixed carbon, volatile matter and ash content. High value of fixed carbon can be related with high heating efficiency. Volatile matter in the briquettes should be in the range of 65-70 % for better combustion. A biomass briquette usually produces less amount of white ash while burning.

Figure 8. Proximate analysis of briquettes from oil palm kernel shell and fibre



Sing and Aris (2013) studied the briquetting suitability of oil palm mill wastes. The Fig. 8 shows the proximate analysis result of oil palm kernel shell (60%) and palm fibre (40%) briquettes with paper and starch as binder. Here this combination was selected because of palm kernel shell is having less ash content while palm fibre is having high burning duration.

The volatile matter content is high in all the briquettes indicating better combustion characteristics. There is no significant difference in the percentage of ash content. The fixed carbon content is high for briquette produced from 60% palm kernel shell and 40% palm fibre with paper as binder. So the briquette having high fixed carbon possesses high calorific value.

16. Limitations

The major limitation of this technology is of its high initial investment cost and maintenance cost of machinery. The high electricity consumption during the process is an important barrier affecting the briquetting industry. Undesirable combustion characteristics often observed in low quality briquettes such as poor ignitability, smoke emission etc. Another drawback is the tendency of briquettes to loosen when exposed to water. So, there is a need for covered storage which again increases the cost of production.

17. Summary

Biomass briquetting is an age old densification technology. Densification of biomass under high pressure brings about mechanical interlocking and increased adhesion between the particles. Biomass briquettes are mainly utilized as a source of energy and have some application in agriculture as growing media and animal feed. It is utilized for domestic heating and as an industrial fuel for agro processing units and other industries.

Electricity can be generated with the help of boilers and gasifiers. Factors affecting briquetting includes particle size, moisture content, temperature of the biomass and the die. The characteristics of biomass briquettes are physical, mechanical, calorific value, combustion and proximate analysis.

8. Conclusion

The art of briquetting technology can be attempted by using various biomass residues, and it has proved quite attractive in terms of technological value coupled with the associated economical and environmental values. Biomass briquetting can be adopted for the effective management and utilization of surplus agro residues, so that they can replace the conventional nonrenewable source of energy such as coal, petroleum products etc. The fuel produced through biomass briquetting is environment friendly and cheap.

It is gaining momentum in the field of agriculture as a tool for residue management and for easy handling of bulky materials. With the increase in cost of fossil fuels and depleting reserves of natural forests, the net zero carbon emitting biomass briquettes may find large scale application in industrial heating besides satisfying the energy demands of domestic needs.

Even though the briquetting is advantageous, the high repair cost of machineries is limiting the profit from this sector. However, this technology has to be popularized to meet the ever increasing energy demand and to avoid dependence on coal. Further research is needed to improve the efficiency of existing briquetting technology.

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20. Discussion

1. What is the difference between piston press and screw press?

   Piston press and screw press are high pressure briquetting machines. In piston press the densification carried out with the help of piston and will produce cylindrical solid briquettes where as in the case of screw press briquetting is achieved with rotating screw and the briquettes will have a concentric hole. So good quality briquettes can be produced by using screw press.

2. What is carbon neutral fuel?

   When a fuel burns it will emit carbon dioxide naturally. So while using biomass briquettes for heating purpose it will emit carbon dioxide which is already the part of carbon cycle. Plants have the ability to sequestrate carbon and will act as renewable source. The carbon emission and sequestration can be balanced here, where as it is not possible in the case of non renewable sources such as coal. Hence it is called as carbon neutral fuel.

3. Are there any standards for biomass briquettes in international markets?

   Yes, at present several developed countries, such as Sweden, Europian Union, USA and Australia have established standards for determining the quality of fuel briquettes. The major standars include ASBAE (American Standards for Biological and Agricultural Engineering) and EU standards. They are prescribing the procedures for conducting quality tests.

4. How briquetting is different from baling?

   Baling is the process of compressing the straw by using a machine called baler. During baling physiological change does not occur and hence the form of material will not change. No binder is advocated during baling where as internal or external binder is used in briquetting and prominent physiological changes are visible.

5. Is there any significance for shape of briquettes produced by using different types of dies?

   Yes, the shape of the briquettes will differ with the type of die used and the heating value is influenced by the shape of briquette. For example, the briquettes produced by using screw die and honey comb die will have holes in it. So this will increase the surface area for burning and thus improve the heating value.

6. What is *Ceiba pentandra* and which part is used for briquetting?

   Ceiba pentandra is kapok tree and the soft wood saw dust is used for producing briquettes.

21. Abstract

Biomass briquetting

Energy crisis is one of the setbacks affecting the economy of our country. Nowadays, the uses of non renewable forms of energy such as coal and petroleum products are causing a huge concern regarding environment and depletion of natural resources. In order to reduce such effects alternate forms of energy, which are environment friendly and cost effective, have to be considered. The inclusion of biomass as a form of energy will serve the purpose to meet the energy demand to a certain extent.

Biomass briquetting is the process of compaction of residues into a product of higher density than the original raw materials (Oladeji, 2015). It is an age old densification technology invented during 18th century. Every year, million tons of agricultural wastes are generated in India which are either destroyed or burnt inefficiently in loose form causing air pollution. These wastes can be recycled for producing high density carbon-neutral fuel briquettes. Briquetting of biomass improves its handling characteristics, increases the volumetric calorific value, reduces transportation costs, and makes it available for a variety of application. The process also helps to reduce deforestation by providing a substitute for fuel wood (Maninder *et al.*, 2012).

The briquettes can be used for domestic and industrial purposes in both rural and urban areas. The end use of briquettes is mainly for replacing coal in industrial applications and power generation through gasification of the biomass. Briquetting can be done either by direct compaction or compaction after pyrolysis or carbonization. Direct compaction can be achieved with or without the use of binders. Compaction with binder requires addition of external binding materials like molasses, starch, sodium silicate, cotton seed oil, etc.

Densification of biomass under high pressure brings about mechanical interlocking and increased adhesion between the particles forming intermolecular bonds in the contact area (Moral and Khan, 2004). On the basis of compaction, the briquetting technologies can be divided into high pressure compaction, medium pressure compaction with a heating device, and low pressure compaction with a binder (Wilaipon, 2009).

The major factors affecting briquetting include particle size, moisture content, temperature of biomass, and die. A higher density makes the briquettes burn more slowly as compared to the raw materials from which they are made and provides high heating value (Kaliyan and Morey, 2009). Briquettes have better physical properties and combustion rate than the initial waste.

The main limitation of this technology is high initial investment cost and high electricity consumption during the process. However, this technology has to be popularised to meet the ever increasing energy demand and to avoid dependence on coal.

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SEMINAR REPORT

LOW CARBON TECHNOLOGIES FOR CROP PRODUCTION

By

ANCY U. A.
(2014-11-125)

Submitted in partial fulfilment of requirement of the course
AGRON 591- Master's Seminar (0+1)

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DECLARATION

I, Ancy U.A. (2014-11-125) hereby declare that the seminar entitled '**Low carbon technologies for crop production**' has been prepared by me after going through various references cited at the end and I haven't copied from any of my fellow students.

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CERTIFICATE

This is to certify that the seminar report entitled '**Low carbon technologies for crop production**' for the course Agron.591 has been solely prepared by Ancy U.A. (2014-11-125) after going through various references cited herein under my guidance and has not copied from seminar reports of any seniors, juniors or fellow students.

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8.5/10

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Introduction

Green house effect, global warming and climate change are continued to be alarming issues of the 21st ıtury. Global attempt to tackle climate change had finished its two decades. Starting from Rio earth nmit in the year 1992 till COP21 held at Paris in 2015 were raising same voice to reduce green house s (GHG) emission.So far, none of the actions taken to tackle climate change slowed GHGs inexorable e. Keeling curve, which plots ongoing changes in the atmosphere since 1958 exceeded 400ppm during 15. Even though major share of the anthropogenic emissions are coming from the combustion of fossil els and from industrial processes, there is a considerable contribution from agriculture. Agriculture eases to the atmosphere significant amounts of CO_2, CH_4 and N_2O (IPCC, 2001). Crop production ntributes to the major share of agricultural GHG emission. Calls for mitigation of GHGs from the crop oduction sector is becoming louder in recent days as this sector being a culprit and major victim of global ırming.

Agricultural green house gas emission scenario

CO_2, CH_4 and N_2O are the major anthropogenic GHGs by volume basis. Globally, agriculture sector presents 4th position with 13 per cent contribution to the total GHG emission. Emission from power ıtions, industrial processes and transportation fuels stands first, second and third positions respectively g.1). Net CO_2 emission from agriculture sector is negligible as there is significant amount of C questration. More than 40 per cent of the CH_4 and 63 per cent of N_2O emission is from agriculture DGAR, 2011). This sector accounts for estimated emissions of 5.1–6.1 Gt CO_2-eq. /yr, including 3.3 Gt O_2-eq. /yr as CH_4 and 2.8 Gt CO_2-eq./yr as N_2O (Smith *et al.* 2007).

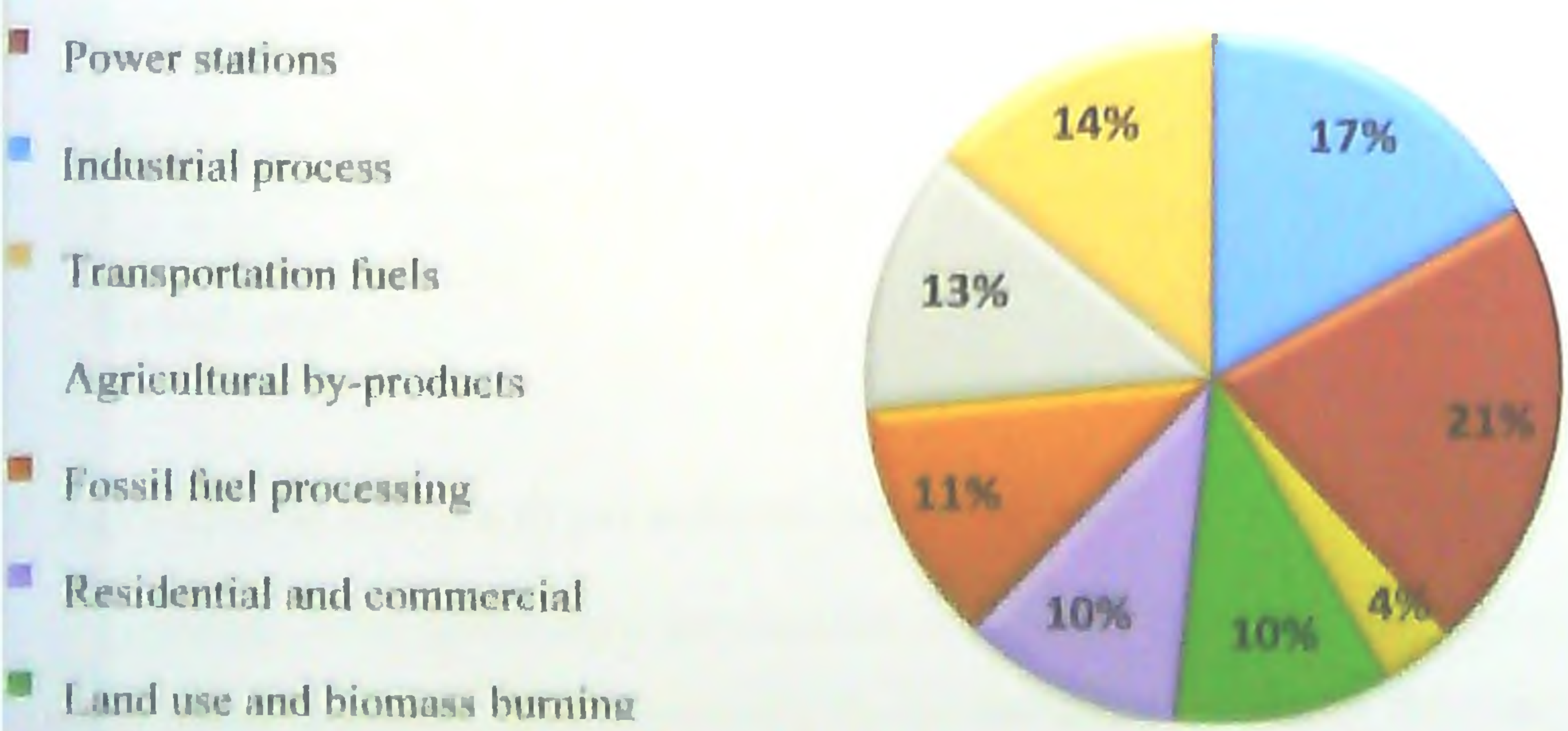


Fig.1. Global annual green house gas emission

Globally, emission sources accounted for are enteric fermentation in livestock, manure management, rice cultivation, agricultural soils and burning of crop residues. Agricultural related total emission is about 6630 Mt CO_2 eq. which include 5621 Mt CO_2 eq. of direct emission and 1009 MtCO2 eq. of indirect emission (GREENPEACE, 2008)

An inventory of GHG emissions from Indian agriculture has been prepared by Indian Network for Climate Change Assessment (INCCA, 2010). According to them, the agricultural sector emitted 334.4 Mt of CO_2 eq. as direct emission and indirect emission is about 184.86 Mt CO_2 eq. Livestock management constituted lion share of the direct CO_2 eq. emissions. Energy use for the fertilizer production contributes to the major portion of the indirect emission. More details regarding agricultural GHG emission is given in table. 1

Table 1. Green house gas emission from agricultural production

Agriculture related direct emission (Mt CO_2 eq.)		
	World	India
Livestock	1792	212.10
Rice cultivation	616	69.87
Soil management	2128	43.40
Burning of crop residue	672	6.61
Manure management	413	2.41
Sub-total	5621	334.41
Agriculture related indirect emission (Mt CO_2 eq.)		
Use of electricity	369	130.63
Use of other energy	230	33.66
Energy use in fertilizer Production	410	20.57
Sub-total	1009	184.86
Grand total	**6630**	**519.27**

(GREENPEACE, 2008; INCCA, 2010)

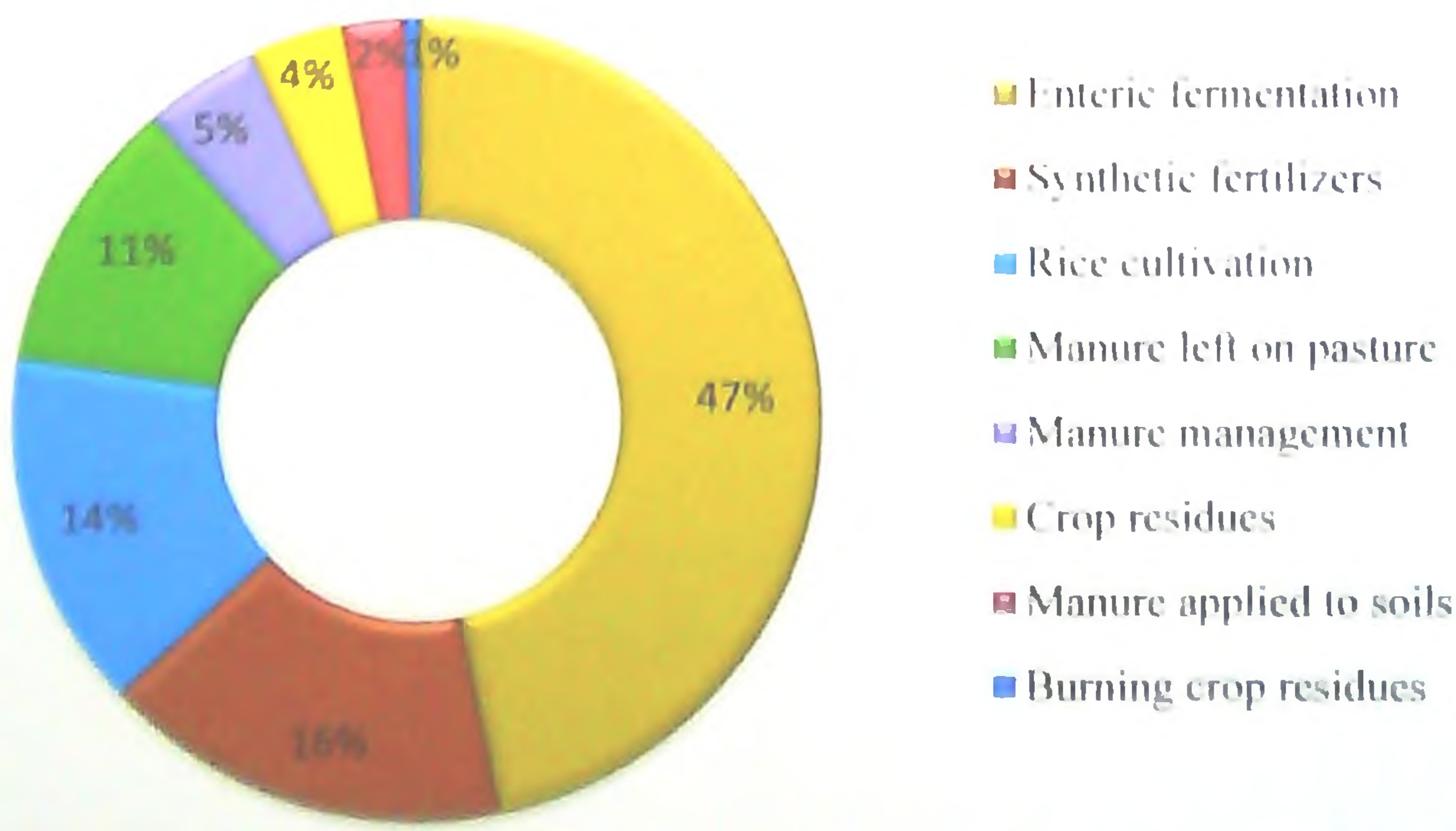
3. Agricultural sources of greenhouse gas emission

Emission from agricultural production is mainly classified into direct emission and indirect emission. As the name indicates, direct emission is the emission occurs in the field itself, e.g., N_2O from fertilizer applied in the soil. Indirect emission includes those emissions which may occur outside the field, but related to the production of various farm inputs, e.g., fuel combustion for fertilizer production.

Among the GHGs, methane is produced when organic materials decompose in oxygen deprived conditions, notably from fermentative digestion by ruminant livestock, stored manures and rice grown under flooded conditions (Mosier *et al.* 1998). Nitrous oxide is generated by the microbial transformation of nitrogen in soils and manures, and is often enhanced where available nitrogen exceeds plant requirements, especially under wet conditions (Smith and Conen, 2004). Major sources of CO_2 are burning and decaying of crop residue and by soil respiration. Small amount of CO, NMVOC and other oxides of nitrogen are emitted when burning of crop residues.

3.1 Green house gas emission from agricultural sources in India

Under Indian scenario of total GHG emission, major portion is from enteric fermentation followed by16 per cent contribution by synthetic fertilizers and 14 per cent by rice cultivation. Manure left on pasture, manure management and manure applied to soil altogether contribute 18 per cent. Other sources are decomposition and burning of crop residues (FAO, 2010).



(FAO, 2010)

Fig.2. Green house gas emission from agricultural sources in India

4. Carbon footprint

The term carbon footprint has become tremendously popular over the last few years. The word 'C-footprint' was the word of the year in 2006. Just like the actual footprint, it is the mark leave upon the environment. It is defined as measure of total amount of CO_2 and other GHG emissions for which an individual or organization is responsible. Footprints can also be calculated for events or products (Carbon trust, 2008). C footprint of agriculture is measured as the impact of agricultural activities on the amount of GHGs produced (Pandey and Agrawal, 2014).

4.1 Carbon footprint of various products from crops and animals

Carbon footprinting has potential as a tool for assessing and comparing GHG performances of different agricultural products along with identification of points to improve environmental efficiencies (Pandey and Agrawal, 2014). Carbon footprint can vary among different products and even within same product under different situations and processes. Among different crops, rice is having higher C footprint which is due to the high methane efflux from flooded condition of paddy field. Higher C footprint of animal products is due to the enteric fermentation.

Table 2. Carbon footprint of various products from crops and animals

Crop/animal product	GHG emission			C- footprint
	CH_4 (g/kg)	N_2O (g/kg)	CO_2 (g/kg)	(g CO_2 eq./kg)
Rice	43.0	0.2	75.0	1223.7
Wheat	0.0	0.3	15.0	119.5
Pulse	0.0	0.8	83.3	306.8
Oilseed	0.0	1.3	50.0	422.5
Milk	29.2	0.0	0.0	729.2
Mutton	482.5	0.0	0.0	12062.7

(Pandey and Agrawal, 2014)

4.2 Emission of GHG in life cycle of rice

Quantification of C- footprint requires 'cradle to grave analysis' or 'life cycle assessment'. Standard method was formulated by UK Govt. as Publically Available Specifications 2050 (PAS 2050). Pathak *et al.* (2012) has done life cycle assessment of rice in Indian condition. Emission of GHG during each activity from field situation till marketing was quantified and converted to corresponding GWP in terms of CO_2 eq. GWP of each activity were added together to find out C-footprint. It was found to be 1223.7 kg CO_2 eq. / t.

Table 3. Emission of GHGs in the life cycle of paddy in India

Activity	CO_2-C (kg/t)	CH_4 (kg/t)	N_2O-N (kg/t)	GWP (kg CO_2 eq./t)
Production	26.7	19.6	0.13	649.2
Drying	24.4	-	-	89.5
Parboiling	54.1	-	-	198.4
Steel huller milling	3.3	-	-	11.9
Transportation (100 km)	1.4	-	-	5.0
Packaging	15.3	-	-	56.1
Marketing	58.2	-	-	213.6
C-footprint				1223.7

(Pathak *et al.*, 2012)

5. Low carbon technologies

Low carbon technologies (LCTs) lead to lower the emission of GHGs, reduce GWP and thereby C-footprint. These technologies are with low input consumption, efficient recycling with improved input efficiency to create clean energy structure. It also helps to reduce resource and environmental pressure thereby leads to environmental protection along with productivity enhancement (Pathak and Aggarwal, 2012). Various components of the LCT are as follows:

- Low input consumption
- Recycling
- Clean energy structure
- Environmental protection
- Productivity enhancement

6. Classification of low carbon technologies

The techniques for mitigating GHGs in crop production fall into two broad categories based on underlying mechanisms which are emission reducing technologies and sequestering technologies (Singh *et al.*, 2014). Due to the complex nature of agricultural processes within the ecosystem one technique can be combination of mechanisms or one technique can mitigate more than one gas. Hence, the net benefit depends on the combined effects of more techniques.

6.1. Emission reducing technologies

Emission reducing technologies can reduce GHG by managing more efficiently the flows of C and N in agricultural ecosystem. Emission reducing technologies for crop production include broad techniques like land preparation, appropriate varietal selection, nutrient management, water management and residue management.

6.1.1 Land preparation

Land preparation has a pivotal role for a better crop production. Tillage is the basic activity for a good seedbed preparation. During intensive tillage activities, oxidation of C in soil to CO_2 is induced due to increased aeration. Soil compaction leads to anaerobic situation which induce denitrification and N_2O emission. Tillage activities also influence CH_4 emission. In order to obtain better yield with less GHG emission it is better to adopt optimum tillage practices. Agriculture, as practiced in the modern times is heavily dependent on various machineries a huge amount of CO_2 is emitted by combustion of fuels. So, Energy efficient machineries and carbon neutral fuel reduce CO_2 emission considerably during mechanized farming.

Lal (2004,*a*) reported equivalent carbon emission due to different type of tillage operations. Mouldboard ploughing and subsoiling lead to more carbon emission compared to the other tillage operations as deep and heavy ploughing requires more energy. Even though these different tillage operations have different purposes, choose tillage operations with low carbon emission under normal situations.

Table 4. Comparison of different tillage practices on GHG emission

Tillage operation	Equivalent C emission(kg C eq./ha)
Mouldboard ploughing	15.2 ± 4.1
Sub-soiling	11.3 ± 2.8
Chisel ploughing	7.9 ± 2.3
Heavy tandem disking	8.3 ± 2.5
Standard tandem disking	5.8 ± 1.7

Field cultivation	4.0 ±1.9
Rotary hoeing	2.0 ± 0.9

(Lal, 2004)

Farmers' participatory field trials at 40 sites for 3 consecutive years in 4 districts of Haryana were conducted by Aryal *et al.* (2014). They found that shifting from conventional till to zero till based wheat production reduces GHG emission by 1500 kg CO_2-eq ha^{-1}. Estimated CO_2 emission was significantly higher from conventional tillage. However, N_2O emission was not significant between conventional till and zero till based production system. Negative value indicates carbon sequestration in zero tillage. This difference in CO_2 emission mainly came from changes in soil carbon stock as influenced by reduced number of tillage operations and less consumption of fuel in zero tillage.

Table 5. Effect of zero tillage and conventional tillage on GHG emission

Treatment	CO_2 (kg CO_2 /ha)	N_2O (kg N_2O / ha)	Total GHGs (kg CO_2 eq. / ha)
CT wheat	615^{a}	3.74^{a}	1720^{a}
ZT wheat	-841^{b}	3.55^{a}	213^{b}

Values superscripted by different letters in a column are significantly different at 5% level

(Aryal *et al.*, 2014)

No-tillage leads to the mitigation of CO_2 emission, but may emit more N_2O as compared to the conventional tillage. Bhatia *et al.* (2010) conducted a field experiment on rice - wheat system at IARI to assess N_2O emission in wheat grown under conventional and no tillage and its mitigation using nitrification inhibitor, dicyandiamide (DCD). Cumulative emission of N_2O-N was higher under no-tillage compared to the conventional tillage. Under both situations total emission of N_2O-N reduced when urea was applied along with nitrification inhibitor. Application of urea along with nitrification inhibitor reduced cumulative emission by 9.5 per cent under conventional tillage and 16 per cent under no till over urea treatment and may be used to mitigate N_2O emission.

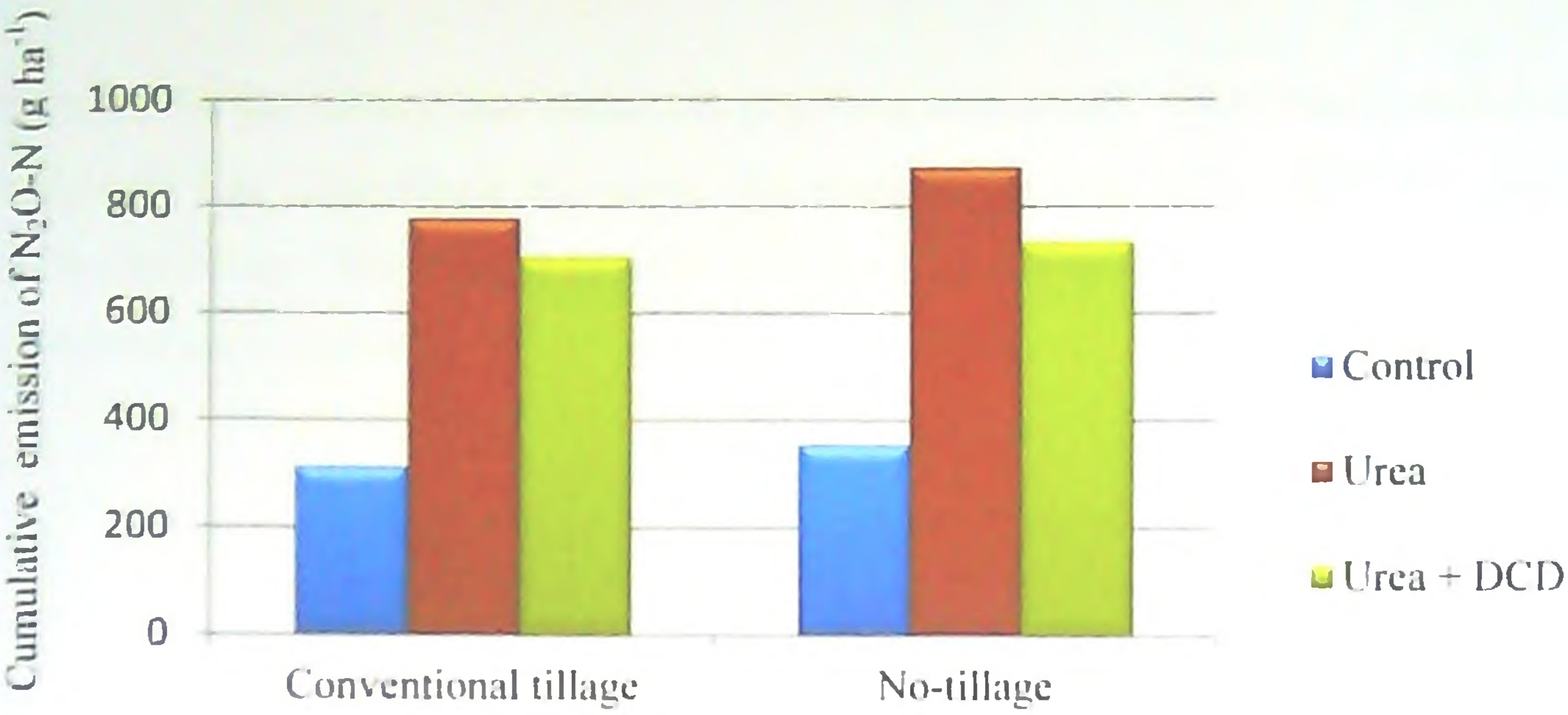


Fig.3. N_2O mitigation under conventional and no-tillage by nitrification inhibitor

(Bhatia *et al.*, 2010)

6.1.2 Selection of variety

Many varietal characters influence GHG emission, mostly in case of rice. Flooded situation in the rice field and several root exudates induce methanogenesis and thereby CH_4 emission. Rice plants act as a mediator for transport of CH_4 from soil to atmosphere. Some of the varietal characters like short duration, less number of unproductive tillers, low exudation and high yield contribute to low emission. Pest resistant varieties help to reduce pesticide application cycles thereby reduce pesticide production related indirect emission and application related direct emission.

An International group led by Su *et al.* (2015) at Swedish university of agricultural science developed a high starch low methane emission transgenic rice variety *SUSIBA2-77* by introducing a single gene from barley into rice favouring the allocation of photosynthates to above ground biomass mainly to sink over roots. Due to that it is having varietal characters like large grains, less number of unproductive tillers and low root volume. All these characters contribute to less methane production and emission.

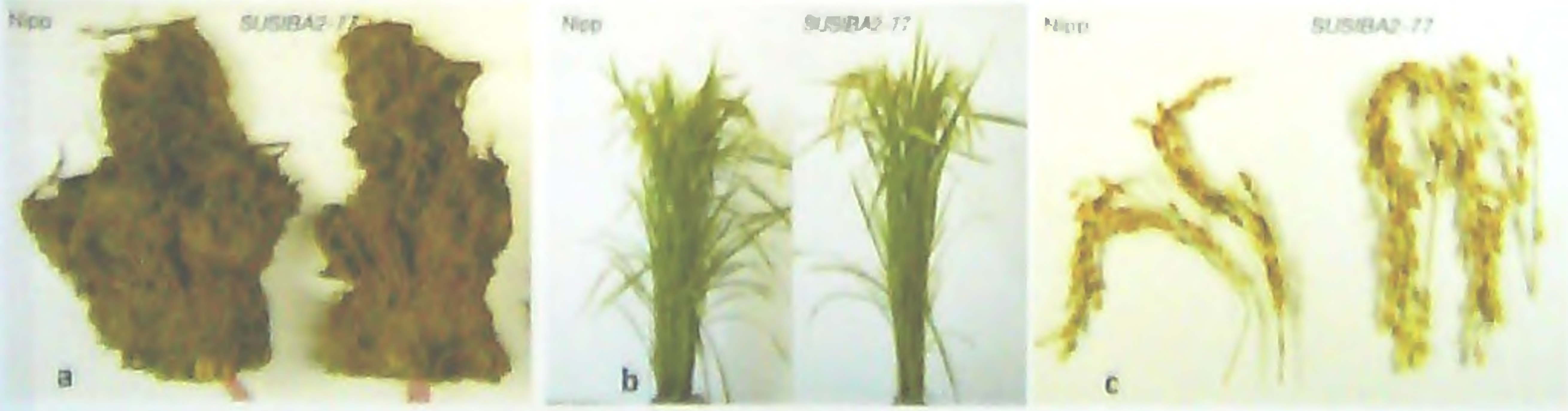


Plate 1. Varietal characters of *SUSIBA 2-77* and Nipponbare a. root b. above ground parts c. panicle

Nippon bare is the variety into which the gene was introduced. Field trial conducted at China showed that *SUSIBA2-77* can cut methane emissions to around 10 per cent before flowering, and almost to zero at 28 days after flowering. Dry weight of filled grains per plant was also higher for *SUSIBA 2-77* due to high starch accumulation in grains.

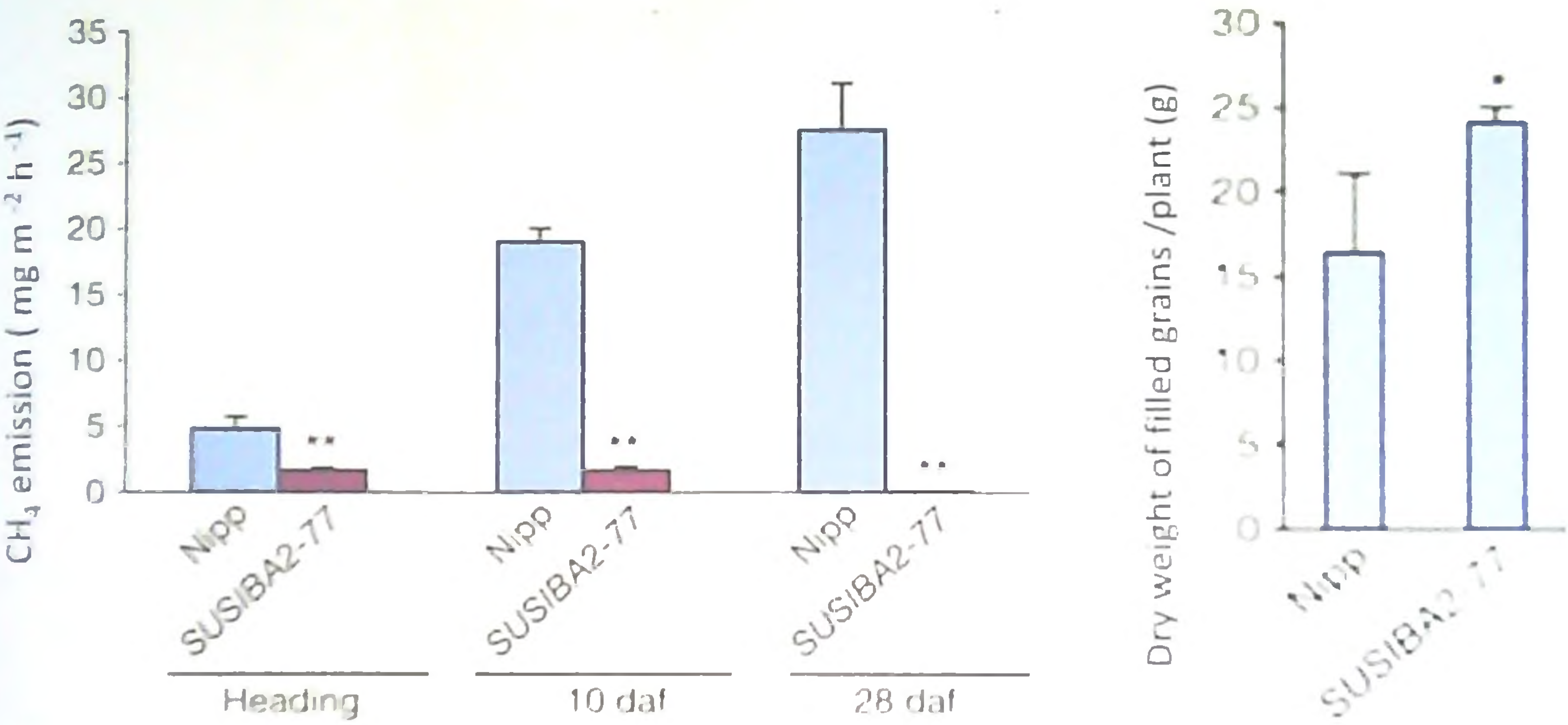


Fig.4. a. CH_4 emission from *SUSIBA 2-77* and Nipponbare **b. Dry weight of filled grains/panicle**

A study was conducted in KAU at Vellayani campus for comparing CH_4 efflux from different varieties of paddy. Four medium duration varieties such as Aishwarya, Uma, MAS 946-1 and PMK(R) 3 were used for the study. Aishwarya and uma are varieties from KAU. MAS 946-1, also known as Sharadha is the first aerobic rice variety from UAS Bangaluru and PMK (R) 3 is a variety from Tamil nadu. All the three varieties except PMK(R) 3 showed comparable CH_4 efflux and grain yield whereas PMK(R) 3 showed the highest CH_4 efflux with lower yield, which is undesirable. Higher yield and lowest CH_4 emission was reported for MAS 946-1. While considering N_2O, CH_4 efflux and grain yield Aishwarya and Uma were found to be better under Kerala condition (Jincy, 2014).

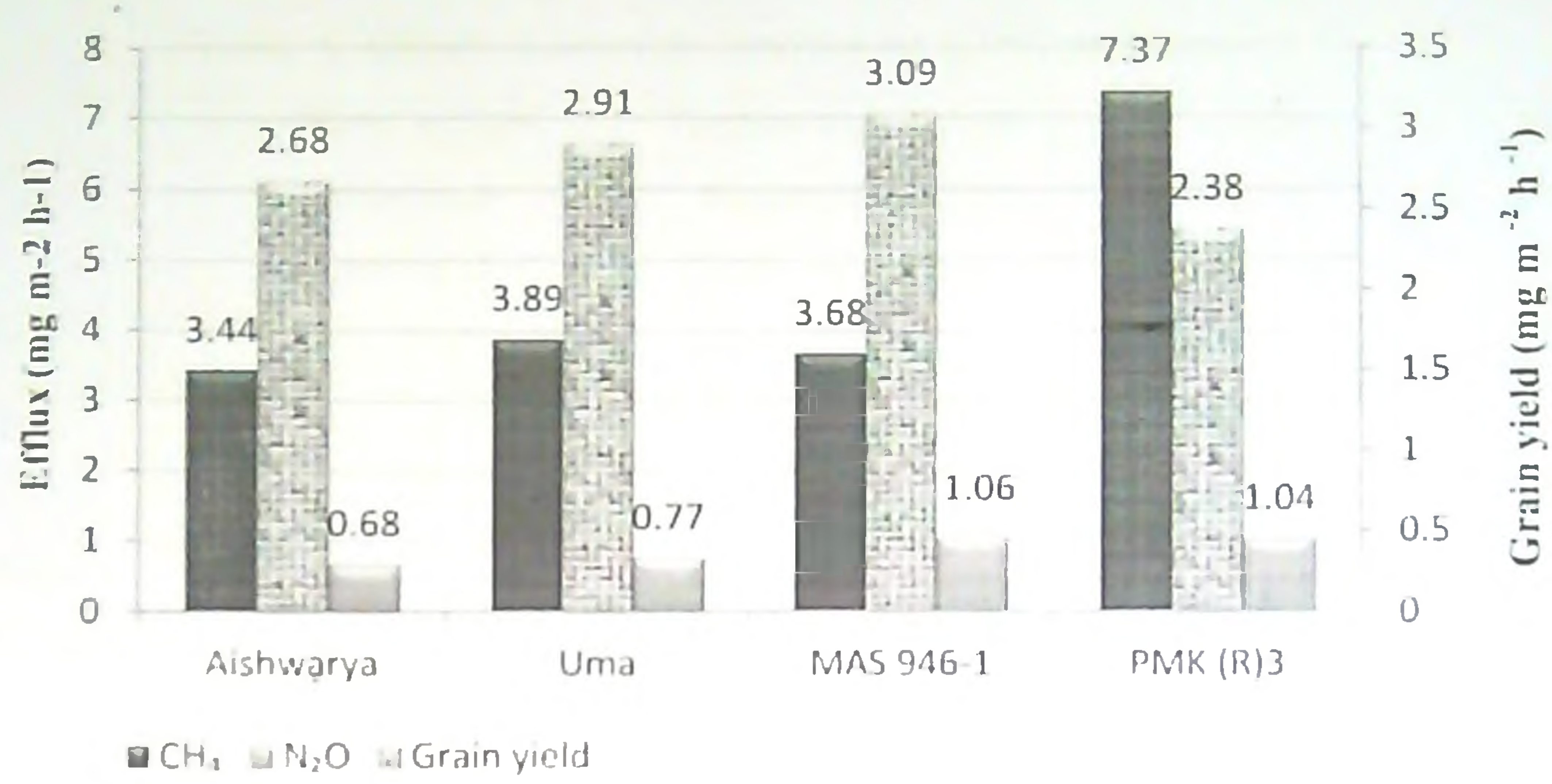


Fig. 5. Varietal variation on CH_4 and N_2O emission

(Jincy, 2014)

6.1.3 Nutrient management

N_2O is the major GHG that can be controlled by nutrient management. N_2O is generated by the microbial transformation of N in soil and manures i.e. nitrification and denitrification and is often enhanced where available N exceeds plant requirement. By selecting right type of fertilizers suitable for crop and soil characters and by adjusting time of application, there will be increase in crop uptake and thereby reduction in emission and increase in yield. Well decomposed manures induce mineralization and crop uptake. Site specific nutrient management (SSNM) is a concept of feeding the crop with nutrients as and when it is required. Adoption of SSNM and all the activities improving nutrient use efficiency reduce emission and increase yield.

Baruah and Baruah (2015) conducted an experiment to observe the effects of organic manures and crop residues on N_2O emission in paddy. Five treatments including inorganic fertilizer – NPK as control, cow manure, rice straw, poultry manure and sugarcane bagasse were applied in the field @ 10 t/ ha. As compared with control the seasonal cumulative emission decreased by 14 per cent for rice straw application. This is due to higher amount of lignin in rice straw reduces the available C supply and depresses the nitrification and denitrification processes. Carbon Efficiency Ratio (CER) is the grain yield per Carbon Equivalent Emission (CEE). Decreased values of CEE and high value of CER would be beneficial for rice productivity and an effective option for mitigating N_2O emission from rice ecosystem.

Table 6. Effect of nutrient sources on GHG emission

Treatment	Total N_2O-N emission (μ gm $m^{-2}h^{-1}$)	Carbon Equivalent Emission(CEE) (CO_2 eq. kg/ha)	Carbon - Efficiency Ratio (CER)	Yield (t/ha)
NPK(control)	2104	286 ^{d}	9.37 ^{ab}	2.79 ^{a}
Cow manure	2379	321 ^{c}	7.92 ^{a}	2.54 ^{a}
Rice straw	1814	245 ^{a}	11.39 ^{b}	2.73 ^{a}
Poultry manure	2068	282 ^{c}	9.42 ^{ab}	2.65 ^{a}
Sugarcane bagasse	1998	270 ^{b}	9.76 ^{ab}	2.66 ^{a}

Values superscripted by different letters in a column are significantly different at 5% level

(Baruah and Baruah, 2015)

Combination of organic manure along with fertilizer sources for paddy cultivation is an age old practice in our state. So selection of proper combination of nutrient sources with less GHG emission is important. Reena Mathew (2003) of Kerala Agricultural University conducted a study to observe CH_4 emission from paddy field influenced by interaction of organic manure and nitrogenous fertilizer. Study was conducted at Agricultural Research Station, Mannuthy with three sources of organic manures such as straw, gliricidia and FYM along with two sources of nitrogenous fertilizers i.e., urea and Factomphos. FYM along with both fertilizer sources showed reduced CH_4 emission among which combination of FYM and Factomphos was found to be more beneficial. This is because FYM is decomposed manure Factomphos contains sulphate which has methanogenesis inhibiting property.

Table 7. CH_4 emission influenced by interaction of organic manure and nitrogenous fertilizers

Source of N	CH_4 emission (mg m^{-2} hr^{-1})				
	Straw	Gliricidia	Farm yard manure	Control	Mean
Urea	7.84	6.85	2.92	1.75	4.84
Factomphos	7.01	3.44	2.04	1.06	3.38
Control	3.21	2.58	2.95	0.22	2.24

Mean	6.02	4.29	2.64	1.01	
CD(0.05)			2.13		

(Mathew, 2003)

Bos *et al.* (2014) estimated total GHG emission of different crops under conventional and organic practices. Wheat, Onion and winter carrot produced more GHG under organic cultivation practices than conventional whereas, organic cultivation of pea and sugarbeet reduced GHG emission. It suggests that all organic cultivation practices may not work as a driving force to reduce GHG emission all the time. So, adoption of those organic practices which reduce carbon footprint will provide a win-win benefit for the health of human and planet.

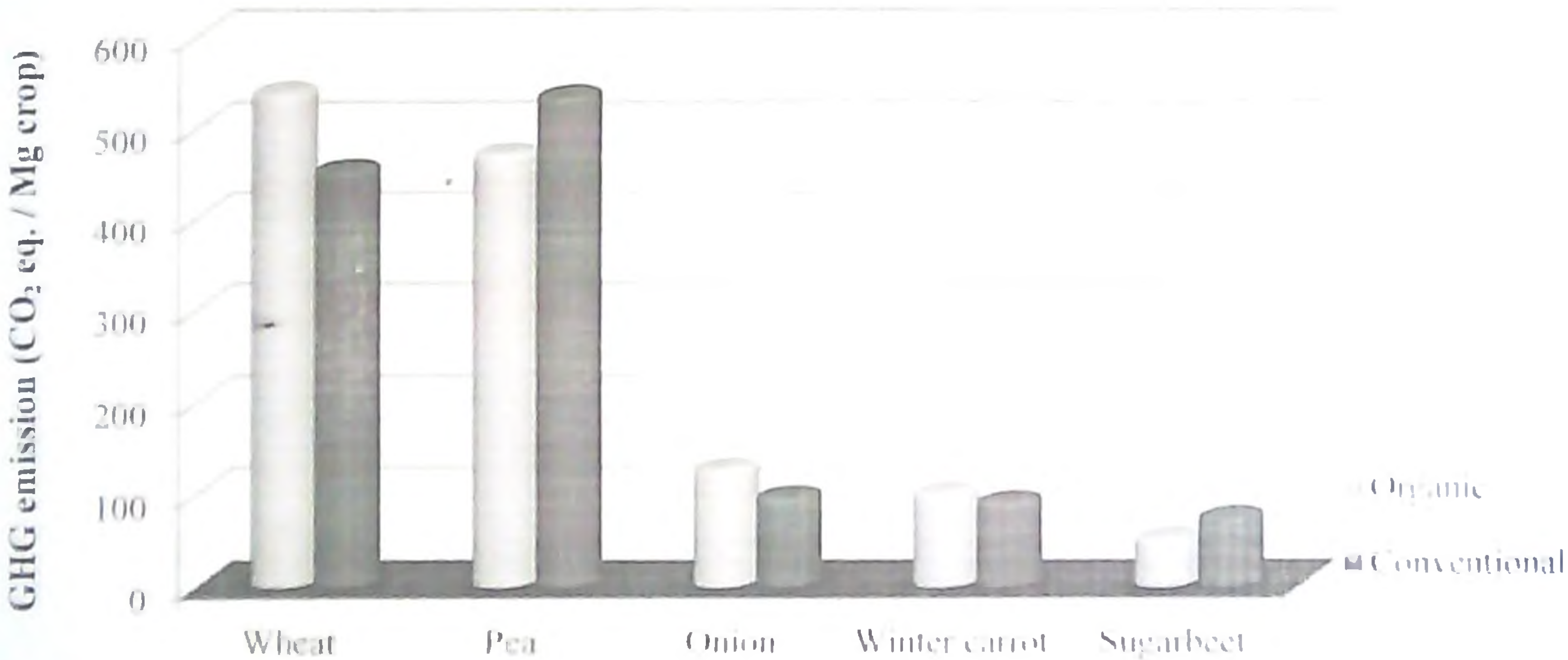


Fig.6. Total GHG emission from different crops under organic and conventional system

(Bos *et al.*, 2014)

6.1.4 Water management

Water management has a crucial role in GHG production as excess water in field will create anaerobic condition which is conducive for CH_4 production. So, GHG emission can decrease by reducing anaerobic situation in the field without reduction in the yield. This is mainly applicable to wetland paddy. Avoiding waterlogged situation in the field during offseason will helps to achieve the same objective. Less energy consumptive irrigation methods and high water use efficiency provide better yield and reduce both direct and indirect emission.

Water drainage is considered to be one among the important practices that reduces the CH_4 efflux from paddy fields. A study conducted by Tyagi *et al.* (2009) compared four different water management systems i.e., continuous flooding , water withdrawal at tillering stage, water withdrawal at mid-season and water withdrawal at multiple stages to find out best one to reduce CH_4 emission. Among all the four different water management systems applied, water withdrawal at mid-season and at multiple stages were found to be highly effective in mitigating methane efflux which will in turn lower GWP, by up to 37 per cent and 41 per cent respectively.

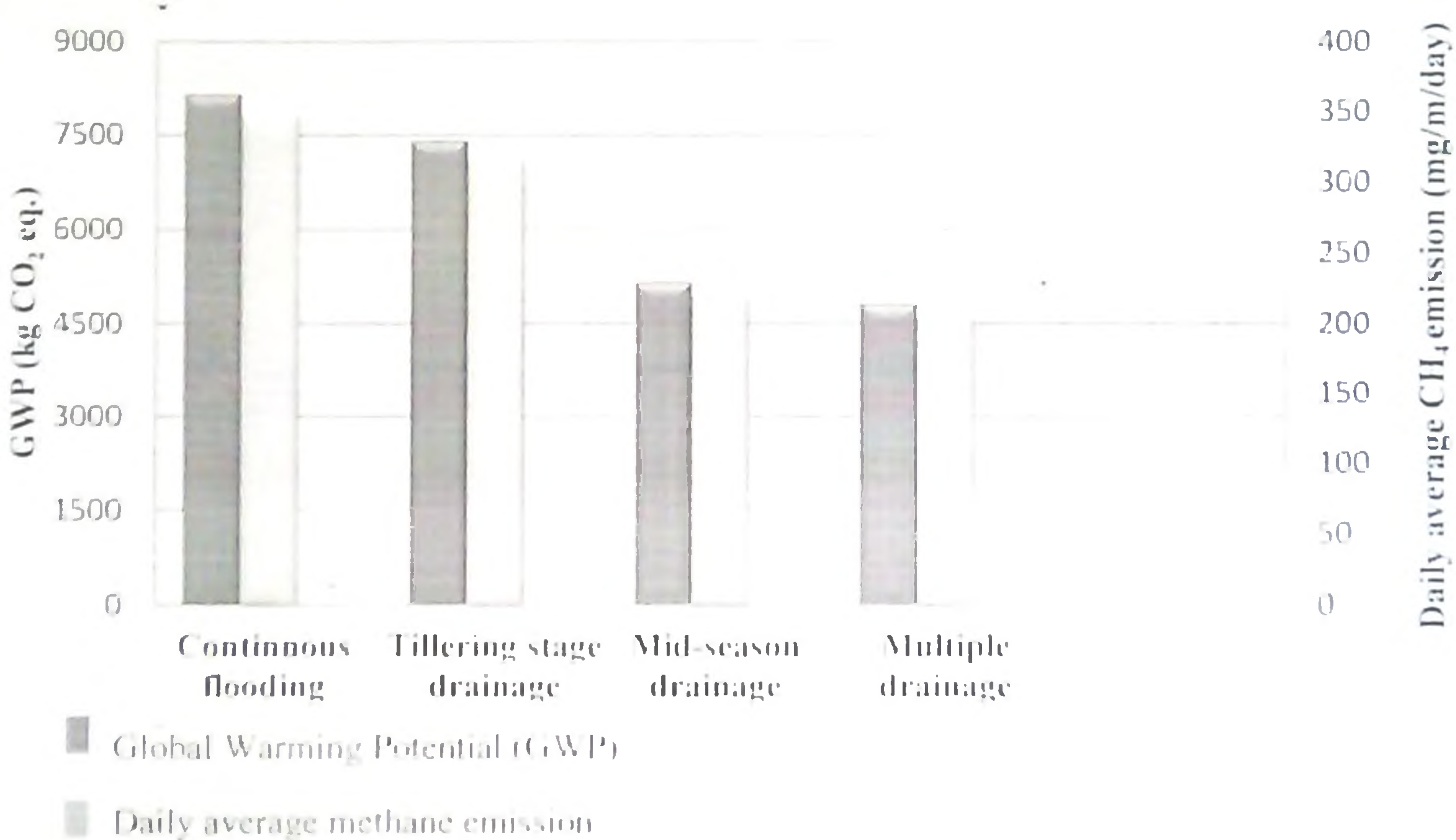


Fig.7. CH_4 emission and GWP from paddy field under different water management systems

(Tyagi *et al.*, 2009)

In aerobic rice, the crop is established in non-puddled, non-flooded and unsaturated field. Rice is grown like an upland crop with adequate input and supplementary irrigation. Study conducted by Jincy (2014) of KAU observed that methane efflux from aerobic rice was significantly less compared to the flooded situation. Aerobic situation in the field reduces methanogenesis and thereby methane emission.

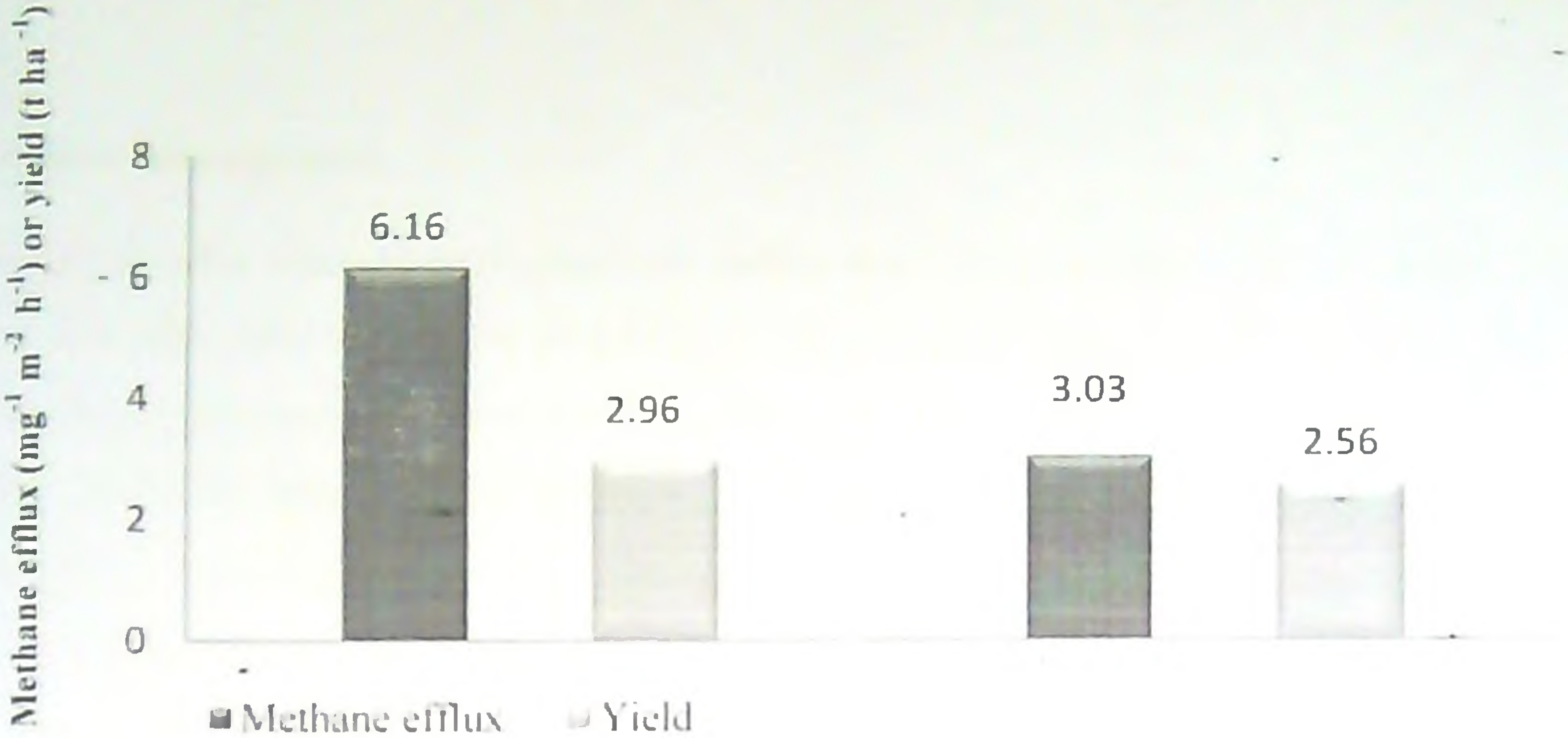


Fig.8. CH_4 efflux from paddy field under aerobic and flooded situation

(Jiney, 2014)

Every modification in current cultivation systems towards aerating the soil can suppress the methane production and emission from paddy fields. A study was conducted by Fazli and Man (2014) to compare diffeferent cultivation practices at Malaysia using a variety MR219. Three treatments include conventional practice and two type of modified method. 21-30 days old seedlings were transplanted with plant density of 125 plants /m^2. 12 days old seedlings were transplanted with plant density of 18 plants /m^2 for MC1 and 24 plants /m^2 for MC2. Methane emission was decreased by 64.15 per cent and 60.07 per cent from MC1 and MC2 respectively in comparison with C. Water management seems to be most determining parameter in this regard.

Fig.9. CH_4 emission from conventional and modified paddy cultivation

(Fazli and Man, 2014)

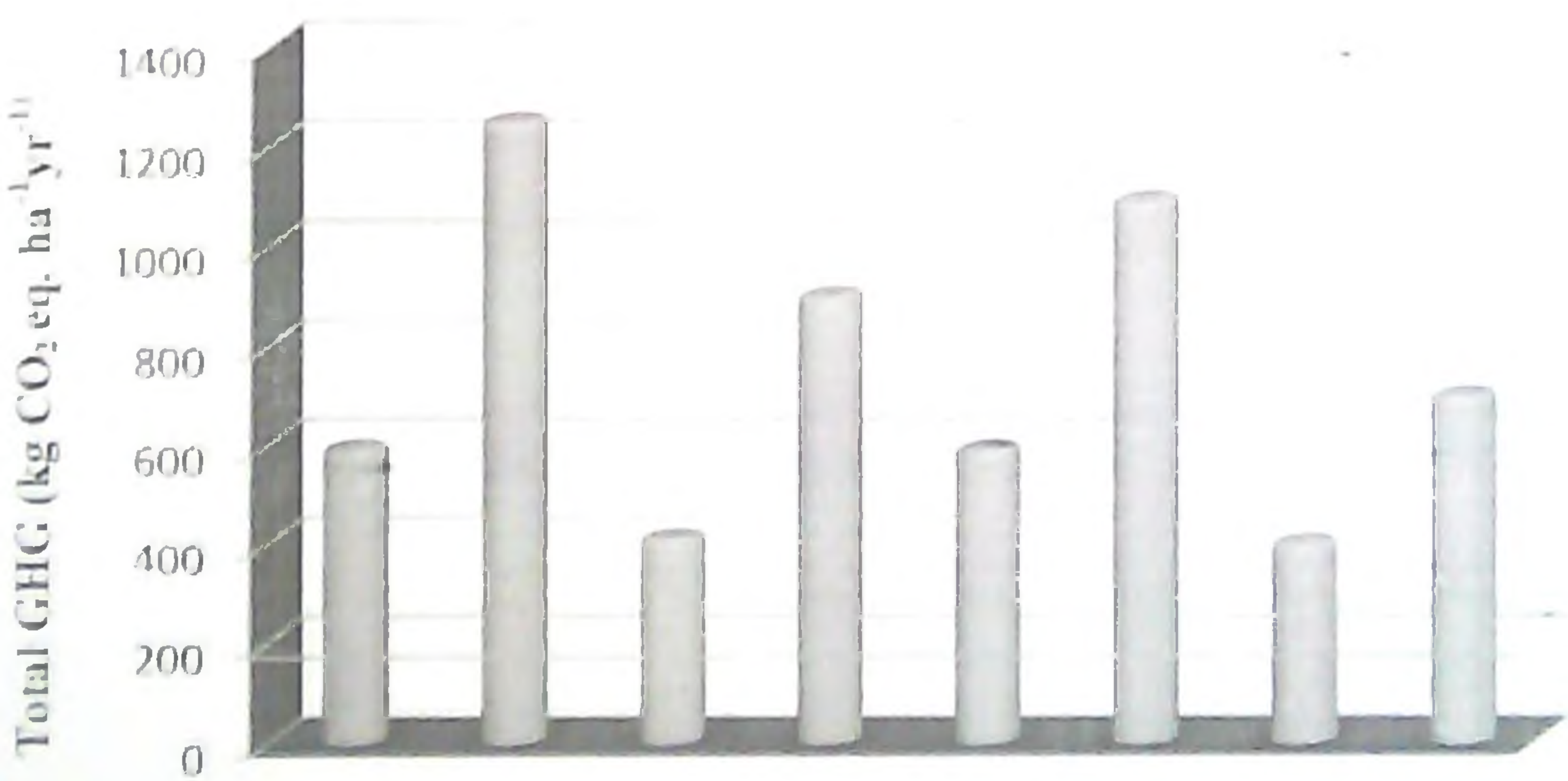
MC-1 – modified cultivation-1

MC-2 – modified cultivation -2

6.1.5 Residue management

Different residue management practices influences N_2O emission, CH_4 emission and SOC content. Retention of stubble after harvest or mulching of crop residues reduce GHG emission. This will also reduce weed infestation and conserve moisture. Composting is done to reduce C: N ratio and for easy availability of nutrients. This also reduces GHG emission.

In addition to an individual crop management practice, the combination of appropriate cultivation practices was also found to have profound influence on reducing GHG emission. Global warming impacts of no-till vs. conventional till, stubble retention vs. stubble burning, and N fertilization vs. no N fertilization in an Australian wheat cropping system were assessed by Wang and Dalal (2015). The results demonstrated all GHG emissions for assessing the global warming impacts of different management practices. The carbon footprints of wheat production were higher under nitrogen fertilization than no fertilization. Stubble retention produced less total emission than stubble burning in all cases. No till leads to less emission than conventional tillage. A combination of no till with stubble retention and no N fertilizer and conventional till with stubble retention and no N fertilizer were produced least field C-footprint.



-N	+N	-N	+N	-N	+N	-N	+N
SB		SR		SB		SR	
Conventional tillage				No-till			

-N – No N fertilizer +N – N fertilizer applied SR – Stubble Retention SB- Stubble

Fig.10. Effect of major farming practices on GHG emission

(Wang and Dalal, 2015)

6.2 Carbon sequestration technologies

Carbon sequestration involves the net removal of CO_2 from atmosphere and storage in long-lived pools of C. Such pools include the aboveground plant biomass, belowground biomass such as roots, soil microorganisms, and the relatively stable forms of organic and inorganic C in soils and deeper subsurface environments, and the durable products derived from biomass (Nair *et al.*, 2010).

6.2.1 Soil carbon sequestration

The sink capacity of soil organic matter for atmospheric CO_2 can be greatly enhanced by restoring degraded soils and ecosystems, converting agriculturally marginal soils to natural vegetation or replanted to perennial vegetation, and adopting recommended management practices on agricultural soils. Under these conditions, SOC can accumulate in soils because biomass production is enhanced on degraded soils, soil disturbance, and risks of degradation are reduced on highly erodible lands, and production is enhanced through agricultural intensification on prime lands. Recommended agricultural practices improve SOC by increasing the input of C through crop residues and biosolids with less intensive tillage (Lal, 2003).

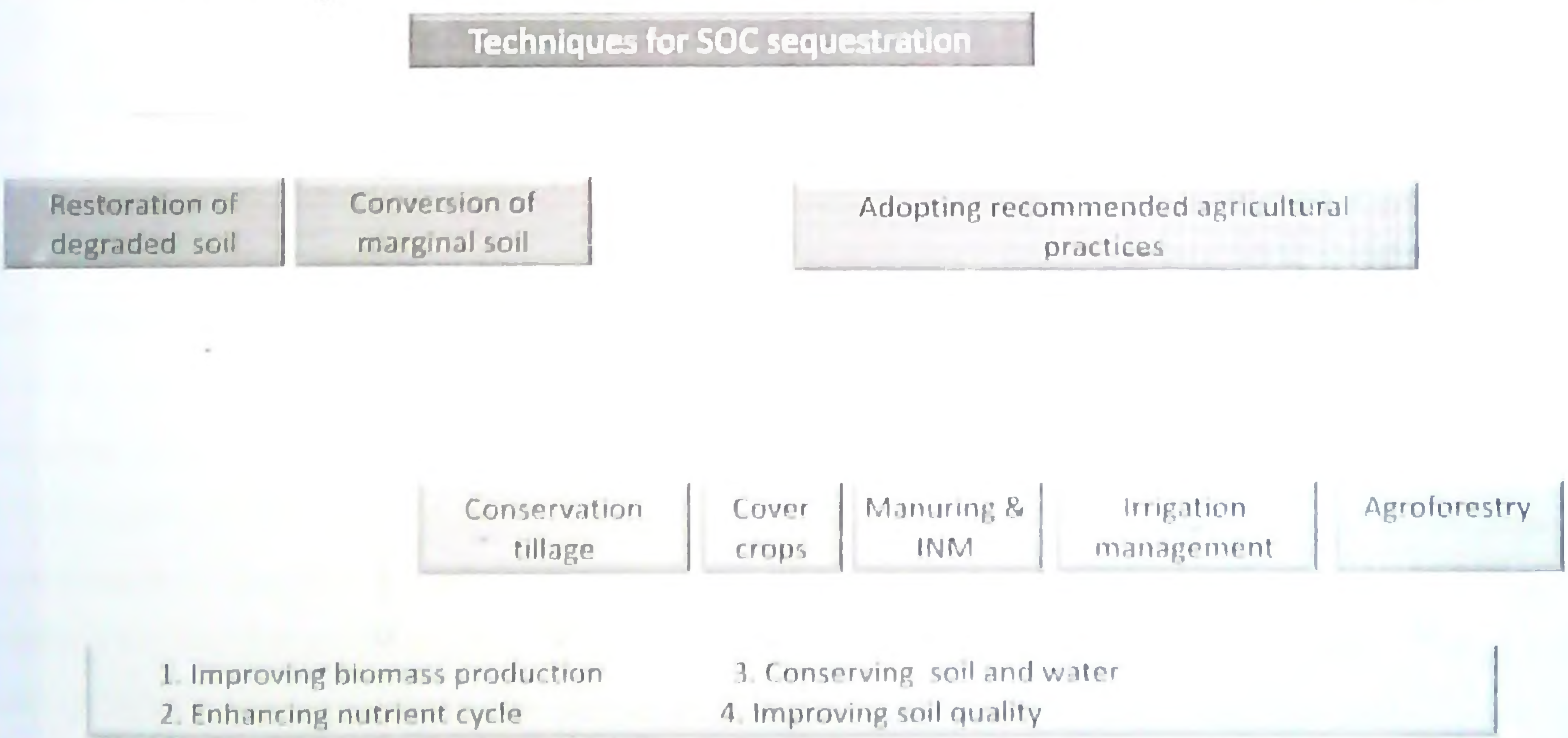


Fig. 11. Soil organic carbon sequestration (Lal, 2003)

Soil organic carbon sequestration decreases the rate of enrichment of atmospheric concentration of CO_2 and enhances of the SOC pool thus, improve soil quality and agronomic/biomass productivity. According to Lal (2004,*b*), Indian soils has the potential to sequester 39.3-49.3 Tg C/yr (table 8). Soil organic carbon sequestration can be improved by restoration of degraded soil and by agricultural intensification. Potential to form secondary carbonates is 21.8-25.6 Tg c/yr.

Table 8. Total carbon sequestration potential of Indian soil

Process	Potential (Tg C/yr)
a. Soil organic carbon	7.2 - 9.8
- Restoration of degraded soil	5.5 – 6.7
- Agricultural intensification	
b. Secondary carbonates	21.8 - 25.6
c. Erosion control	4.8 – 7.2
Total	39.3 – 49.3

(Lal, 2004)

6.2.2 Carbon sequestration potential of agricultural practices

Carbon sequestration potential of different agricultural practices varies. Lal *et al.* (1998) reported carbon sequestration potential of various agricultural practices (table 9). Soils can store carbon after conversion from intensive mechanical tillage to conservation tillage. Elimination of summer fallowing in arid and semiarid regions, and adoption of conservation tillage with residue mulching improves soil structure, lowers bulk density, and increases infiltration capacity (Shaver *et al.*, 2002). Drinkwater *et al.* (1998) observed that legume-based cropping systems reduce C and N losses from soil. Judicious nutrient management is crucial to humification of C in the residue and to soil C sequestration. Addition of organic amendments and conservation tillage is having more carbon sequestration potential. Adoption of more than one agricultural practice will enhance carbon sequestration potential of crop production system.

Table 9.Carbon sequestration potential of various agricultural practices

Recommended practices	C sequestration potential (Mg C ha^{-1} yr^{-1})
Organic amendments	0.20-0.30
Conservation tillage	0.10-0.40

Elimination of summer fallow	0.05-0.20
Winter cover crop	0.05-0.20
Forages based rotation	0.05-0.20
Soil fertility management	0.05-0.10
Use of improved varieties	0.05-0.10

(Lal *et al.*, 1998)

6.2.3 Agroforestry

Agroforestry refers to the practice of the purposeful growing of trees and crops, in interacting combinations, for a variety of benefits and services. As a GHG mitigation strategy under the Kyoto Protocol, it has earned added attention as a strategy for biological carbon sequestration. Agroforestry systems have a higher potential to sequester C than pastures or field crops. Tree incorporation in croplands and pastures would result in greater net aboveground as well as belowground C sequestration. Carbon sequestration potential of different agroforestry systems had reported by several researchers (Table.10).

Table 10. Soil carbon sequestration potential under agroforestry systems

Agroforestry system / species	Age (yr)	Soil depth (cm)	Soil C (Mg / ha)	Reference
Agrisilviculture (*Gmelina arborea* + field crops)	5	0-60	27.4	Swamy and Puri, 2005
Agroforestry (*Pseudotsuga menziesii* + *Trifolium subterraneum*)	11	0-45	95.9	Sharrow and Ismail, 2004
Tree based intercropping (Hybrid poplar+ *Hordeum vulgare*)	13	0-20	78.5	Peichi *et al.*, 2005
Silvopastoral system (*Acacia mangium* + *Arachis pintoi*)	13	0-100	173.0	Amezquita *et al.*, 2005
Gliricidia sepium + *Zea mays*	10	0-200	123	Makumba *et al.*, 2007

Kunhamu *et al.* (2011) quantified the carbon stock of 6.5 year old *Acacia mangium* in KAU under different tree density. When the density of trees decreased from 5000 to 625 there was proportional increase in carbon stock of both above ground and below ground and total carbon sequestered. This is due to the better growth of trees under increased spacing. Under increased spacing there is more provision for other crop incorporation.

Table 11.Carbon stock of 6.5 year old *Acacia mangium* in Kerala

No. of trees/ ha	Carbon stock (kg C/tree)		
	Above ground	Below ground	Total
5,000	13.28 [d]	3.08 [d]	16.37 [d]
2,500	21.47 [c]	4.38 [c]	25.84 [c]
1,250	42.50 [b]	6.95 [b]	49.50 [b]
625	57.54 [a]	8.68 [a]	66.22 [a]

(Kunhamu *et al.*, 2011)

4.2.2.2 Bioenergy crops

A bioenergy crop is considered as solar energy collector and thermo-chemical energy storage sysem. Biomass derived from bioenergy crops plays an important role in GHG mitigation (Karp and Shield, 2008). It acts as an agricultural option for carbon sequestration. These crops are having ability to produce large volume of biomass and high energy potential. Marginal and degraded soils are generally poor in organic carbon. These crops are very well adapted to marginal and highly degraded soils. Thereby improve the carbon sequestration in these soils. Energy produced from bioenergy crops either by combustion or by ethanol production will offset fossil fuel carbon emission. Bioenergy crops are of two types: perennial herbaceous crops and short rotation woody crops

Perennial herbaceous crops: Elephantgrass (*Pennisetum purpureum*), Switchgrass (*Panicum virgatum*)

Short rotation woody crops: Eucalyptus (*Eucalyptus* spp.), Poplar (*Populus* spp.)

Potential of a bioenergy crop depends upon its ability to produce biomass, biofuel and soil organic carbon sequestration. Biomass production and carbon per cent of Switchgrass, Poplar and Willow were reported by Lemus (2004) under U.S.situation. Biofuel production and carbon sequestration of these crops were accounted by Lal *et al.* (2004). According to them, Switchgrass is having higher potential than Poplar and Willow.

Table 12.Potential of bioenergy crops for CO_2 mitigation

Properties	Bioenergy crops			Reference
	Switchgrass	Poplar	Willow	
Biomass production (Mg $ha^{-1}yr^{-1}$)	15.0	11.3	9.1	Lemus, 2004
Carbon (%)	46.0	50.0	49.4	Lemus, 2004
Potential biofuel production (Tg yr^{-1})	447.0	162.6	130.1	Lal *et al.*, 2004
Potential SOC sequestration (Tg C yr^{-1})	23.8	15.7	12.9	Lal *et al.*, 2004

6.2.5 Biochar for GHG mitigation

Biochar is a recalcitrant form of carbon which slows the rate at which photosynthetically fixed carbon is returned to the atmosphere. Production of biochar and its storage in soils have been suggested as means of abating climate change by sequestering carbon, while simultaneously providing energy and increasing crop yields. Fig.12 shows inputs, process, outputs, applications of biochar and its impacts on global climate .CO_2 is removed from the atmosphere by photosynthesis to yield biomass. A fraction of these total biomass produced each year, such as agricultural residues, biomass crops and agroforestry products, is available to produce biochar. This fraction of biomass is converted by pyrolysis to yield bio-oil, syngas, process heat and biochar. The bio-oil and syngas are subsequently combusted to yield energy and CO_2 .This energy & process heat are used to offset fossil carbon emissions, whereas the biochar stores C for a longer period than would have occurred if the original biomass had been left to decay. In addition to fossil energy offsets and carbon storage, some emissions of CH_4 and N_2O are avoided by preventing biomass decay and by amending soils with biochar. Additionally, the removal of CO_2 by photosynthesis is enhanced by biochar amendments to previously infertile soils, thereby providing a positive feedback. CO_2 is returned to the atmosphere directly through combustion of bio-oil and syngas, through the slow decay of biochar in soils, and through the use of machinery to transport biomass to the pyrolysis, to transport biochar to its disposal site and to incorporate biochar into the soil. Even though CO_2 is emitted back to atmosphere, it is less than the amount sequestered. Hence, there is a net positive mitigation impact. In contrast to bioenergy, in which all CO_2 that is fixed in the biomass by photosynthesis is returned to the atmosphere quickly as fossil carbon emissions are offset. Biochar has the potential for even greater impact on climate through its enhancement of the productivity of infertile soils and its effects on soil GHG fluxes (Woolf *et al*., 2010).

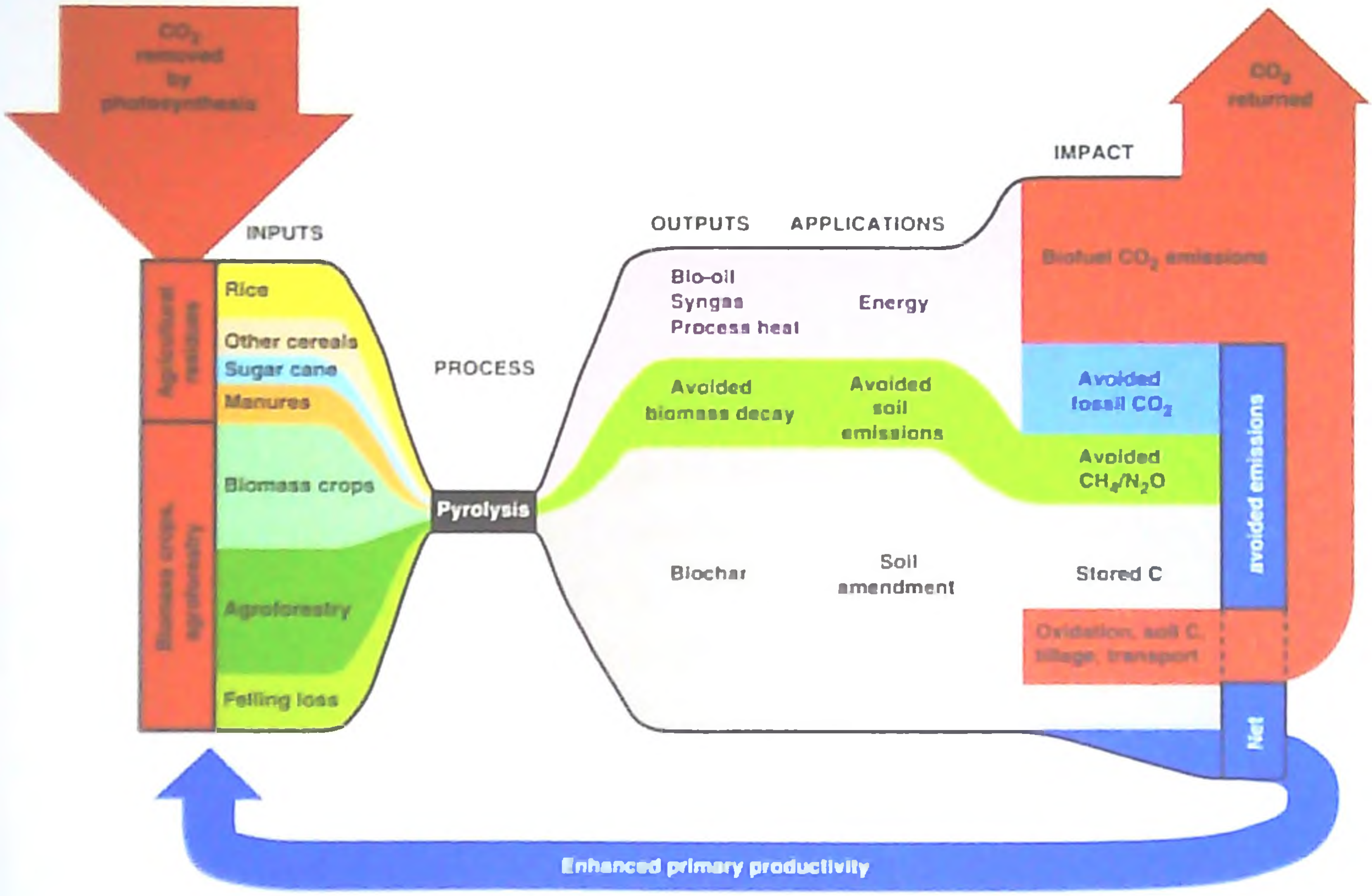


Fig.12. Carbon sequestering and reducing concept of biochar

A field experiment was conducted by Zhang *et al*. (2011) to investigate the effect of biochar on GHG emission in a calcareous loamy soil poor in organic carbon from Henan, China. Biochar was applied at rates of 0, 20 and 40 t ha^{-1} with or without N fertilization. Green House Gas Intensity(GHGI) is the GWP per grain yield of crop. Under no fertilizer application GHGI was reduced only at 40 t/ha of biochar application. Whereas, under N-fertilized condition reduction in GHGI showed a positive correlation with increased dose of biochar application. Overall, GHGI was decreased by 23.8% under BC_1+N and by 47.6% under BC_2+N compared to under BC_0+N, respectively. These results suggest that application of biochar to infertile dry croplands poor in soil organic carbon will enhance crop productivity and reduce GHGs emissions.

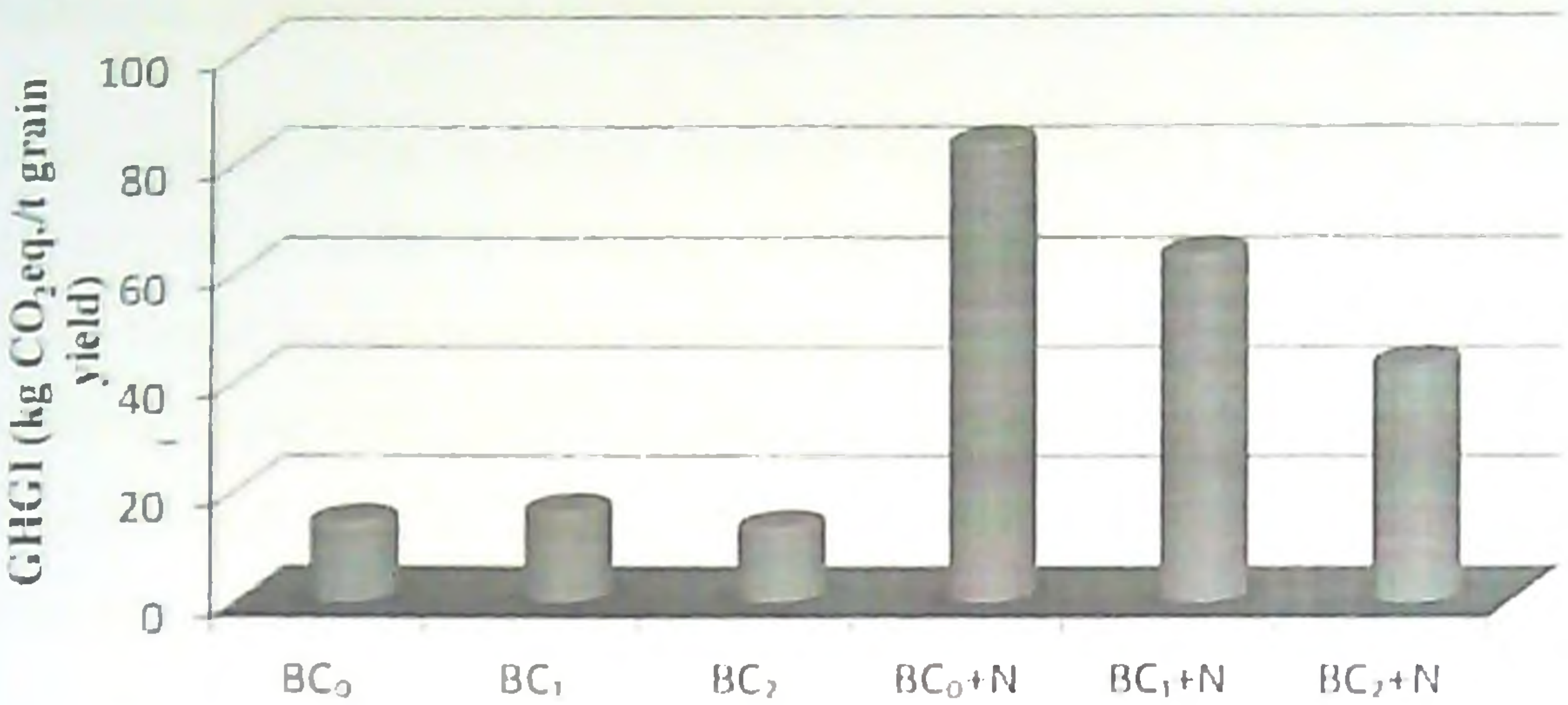


Fig.13. Effect of biochar amendment on green house gas intensity

(Zhang *et al.*, 2011)

4.3 Potential low carbon technologies

Pathak and aggarwal (2012) summerised the potential technologies for reducing GWP of wheat production in lower Indo-gangetic plane. According to them organic cultivation, integrated nutrient management and zero tillage had profound effect in reducing GHGs compared to conventional practices. They estimated the area required for 1000 t CO_2 mitigation.

Table 13. Potential low carbon technologies for wheat production under Indo-gangetic plane

Technology	GWP (CO_2 eq. /ha)	Change in GWP over conventional practices(%)	Area for 1000 t CO_2 mitigation (ha)
Conventional	1280		
Sprinkler irrigation	1085	-15	5128
Zero tillage	-61	-105	745
INM	-250	-119	653
Organic	-1952	-252	309
Nitrification inhibitor	1190	-7	11111
SSNM	1216	-5	15625

(Pathak and Aggarwal, 2012)

4.5 Challenges of low carbon technologies

Even though there is ample opportunities to reduce the GHGs emission from agriculture or to sequester carbon in soils by adopting alternative agricultural practices, the speed of its adoption in the developing world is not much encouraging. This might be due to the fact that farmers lack scientific understanding about GHG processes and LCTs. Knowledge on local adaptation and performance of such technologies which help mitigating climate change without compromising yields while producing higher economic gains. There are no governmental policies to encourage farmers for the adoption of LCTs in many countries. Establishment of mechanism for local adaptation of such technologies through active participation of farmers to disseminate this knowledge to other farmers and communities is important. Requirement of additional investment for some of LCTs such as use of nitrification inhibitors may discourage its acceptance. Moisture related risks and weed problems in field situation also act as major challenge.

Farmers may not voluntarily adopt GHG mitigation techniques unless they improve profitability. Some techniques, such as no-till agriculture or strategic fertilizer placement and timing, already are being adopted for reasons other than concern for climate change.

5. Carbon credit

Trading carbon credits is an important strategy to increase the income stream of farmers. Receiving additional income through trading of carbon credits is important to the resource poor farmers of developing countries.

Environmental protection authority of Victoria (2008) defined carbon credit as "Generic term to assign a value to a reduction or offset of GHG emissions, usually equivalent to one tonne of CO_2 equivalent"

Carbon credit is a marketing mechanism towards reducing GHGs. Farmers who adopt LCTs should be able to generate carbon credit and trade it in carbon markets. Thereby, carbon credit can act as a driving force for the adoption of these technologies. However, at present there is no institutional framework for carbon trading in agriculture in India. Furthermore, existing carbon markets have mostly focused on GHG emission reductions and offsets from the industrial and energy sectors.

6. Conclusion

Application of novel LCTs makes crop production economically and socially beneficial and help to protect the climate system. Agriculture has a potential to mitigate emission of GHGs by adopting LCTs. India had taken it's voluntary pledge to reduce GHG emission for the benefit of present and future generation of humankind. These technologies help to limit the temperature increase below 2°C. Climate friendly techniques and practices could serve as a blueprint for a re-design of the agricultural sector. So, low carbon technologies in crop production have to be develop and disseminate.

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8. Discussion

1. What is Keeling curve?

Keeling curve is a graph which plots ongoing changes in the atmospheric CO_2 level since 1958 in Mauna Loa observatory at Hawaii Island. It got its name as Keeling curve as it was initiated by Charles David Keeling.

2. What is the reason for fluctuation of Keeling curve?

Keeling curve is having a saw tooth appearance because of seasonal variation in the atmospheric carbon dioxide level. Winter fall of trees reduces the photosynthesis and thereby reduces CO_2 uptake. It leads to increase in atmospheric CO_2 level.

3. What is pyrolysis?

It is the thermochemical decomposition of organic materials under elevated temperature in the absence of oxygen.

4. What is the advantage of biofuel over fossil fuel?

Combustion of both of these fuels emits CO_2. Biofuels are carbon neutral. The amount of CO_2 released when they are used is the same as the amount absorbed by the plants as they grew.

5. What is global warming potential?

Global warming potential is a relative measure of how much heat a GHG traps in the atmosphere. It compares the amount of heat trapped by a certain mass of gas in question to the amount of heat trapped by a similar mass of CO_2.

6. About 63 per cent of N_2O emission is from agriculture sector. What are the major sources of N_2O from agriculture?

N_2O is generated by the microbial transformation of nitrogen in soils and manures, and is often enhanced where available N exceeds plant requirements, especially under wet conditions. Small amount of N_2O is emitted during crop burning.

7. At present is there provision to acquire C-credit from agriculture in India?

At present there is no institutional framework for carbon trading in agriculture in India. Existing carbon markets have mostly focused on GHG emission reductions and offsets from the industrial and energy sectors.

8. According to COP21, what are the regulatory measures taken to reduce GHG emission from agriculture sector?

COP21 is promoting an initiative called '4 per 1000 initiative' aims to protect and increase C stocks in soils. It is to increase the amount of CO_2 captured by the soil by 4g. per kilogram of soil. If the whole planet managed to do this, the world's CO_2 emission would be cancelled out in one year. 'Live beef carbon' is an initiative to reduce C-footprint of livestock. ASAP (Adaptation for Smallholder Agriculture Programme) is to invest climate finance in poor smallholder farmers in developing countries.

9. What is NICRA?

National Innovations on Climate Resilient Agriculture (NICRA) is a network project of the ICAR launched in February, 2011. The project aims to enhance resilience of Indian agriculture to climate change and climate vulnerability through strategic research and technology demonstration.

10. Whether LCTs can be adopted in Kerala? Suggest some of the low cost and easily adoptable LCTs for Kerala farmers?

Most of the LCTs are suitable for Kerala condition. Zero tillage, water withdrawal at multiple stages of paddy cultivation and stubble retention are easily adoptable LCTs. It doesn't require additional investment.

9. Abstract

KERALA AGRICULTURAL UNIVERSITY

COLLEGE OF HORTICULTURE, VELLANIKKARA

Department of Agronomy

AGRON 591: Master's Seminar

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Admission No. : 2014-11-125
Major advisor: Dr. A. Latha

Venue : Seminar hall
Date : 07-01-2016
Time : 11:30 a.m.

Topic: Low carbon technologies for crop production

Abstract

Global warming is an alarming environmental issue of the twenty-first century. The net emission of green house gases (GHGs) from India was reported to be 1728 million tons of CO_2 equivalent. Main sectors contributing to this emission are energy, industry and agriculture. Crop production contributes to global warming, primarily through emission of GHGs, viz. methane, nitrous oxide and carbon dioxide. Total emission from agricultural sector is 334.4 million tons of CO_2 equivalent (INCCA, 2010) of which contribution from crop production sector is 53 per cent (FAO, 2010). Therefore, it is highly pertinent to develop technologies that help in reducing GHG emission from crop production. Carbon footprint is a potential tool for assessing and comparing GHG emission of different agricultural products.

Low carbon technologies (LCTs) help to reduce GHG emission by enhancing input use efficiency and sequestering carbon. Singh *et al.* (2014) classified LCTs into two categories i.e., emission reducing and carbon sequestering technologies.

Adoption of optimum tillage with the use of energy efficient machineries and carbon neutral fuels reduces GHG emission. Use of nitrification inhibitors, decomposed manures, appropriate combination of nutrient sources including organic manures and fertilizers, site specific nutrient management, etc. will improve the nutrient use efficiency and thereby reduce emission. Improved water use efficiency and suitable residue management techniques can also pave way for reduction of GHGs.

According to Nair *et al.* (2010) carbon sequestration technologies involve the net removal of CO_2 from atmosphere and storage in long-lived pools of carbon. Carbon sequestration technologies in crop

production conserve water, improve biomass production and soil quality. Agroforestry systems, bioenergy crops and use of biochar are the agricultural options for carbon sequestration and GHG mitigation.

Continuous increase in the concentration of GHGs leads to climate change in the ecosystem causing destruction of livelihoods, economic activity and human health. Adoption of appropriate resource management and carbon sequestration technologies in crop production offers immense scope for climate change mitigation. Hence, various climate friendly initiatives such as enhancement of energy efficiency, use of renewable energy sources and introduction of environmental measures like LCTs will address the climate change issues effectively.

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SEMINAR REPORT

ORGANIC MULCHES

By

RESHMA N.
(2014-11-131)

Submitted in partial fulfilment of requirement of the course
AGRON 591- Master's Seminar (0+1)

DEPARTMENT OF AGRONOMY
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DECLARATION

I, RESHMA N. (2014-11-131) hereby declare that the seminar entitled '**Organic mulches**' has been prepared by me, after going through various references cited at the end and has not been copied from any of my fellow students.

Vellanikkara

25/11/2015

RESHMA N.

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CERTIFICATE

This is to certify that the seminar report entitled '**Organic mulches**' has been solely prepared by Reshma N. (2014-11-131), under my guidance and has not been copied from seminar reports of any seniors, juniors or fellow students.

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1. Introduction

The present status of our conventional farming system is alarming with several man made issues like soil degradation, water scarcity, heavy crop losses due to uncontrollable weeds, pests and diseases, food contamination and health injury to all living beings. So the need of the hour is sustainable cultivation and production of quality foods. The qualities of food we eat, water we drink and air us breathe – in fact the quality of all plant and animal life is determined by the quality of our top soil. So earth's crucial thin layer of soil must be protected, maintained, built and nourished. For that one of our own indigenous technologies has to be reintroduced into our agricultural fields and it is nothing but mulching.

2. Mulch

The word mulch is derived from the German word "*Molsch*" meaning soft to decay. A mulch is any material used at the surface of the soil primarily to prevent loss of water by evaporation, to keep down weeds, to dampen temperature fluctuations or to promote soil productivity (Jacks *et al.*, 1955).

3. Types of mulches

Generally mulches are classified into two types i.e. organic and inorganic mulches

3.1. Organic mulches

Organic mulches are those derived from plant and animal sources. They are more popular in cropping systems as they can suppress weed growth and reducing the need for tillage. They conserve soil moisture and enhance soil biological activities. The most frequently used organic mulches include plant residues such as straw, wood shavings, saw dust, grass clippings, tree leaves and paper mulches

3.2. Inorganic mulches

Inorganic mulches include those derived from inert materials of synthetic or natural origin. They are having a very low replacement frequency as they will not decompose in the soil over time. But they do not add nutrients or organic matter to the soil. Many of the inorganic mulches like rock and rubber mulches are mainly used for aesthetic purposes. Plastic, fabric, rock and rubber mulches come under this category

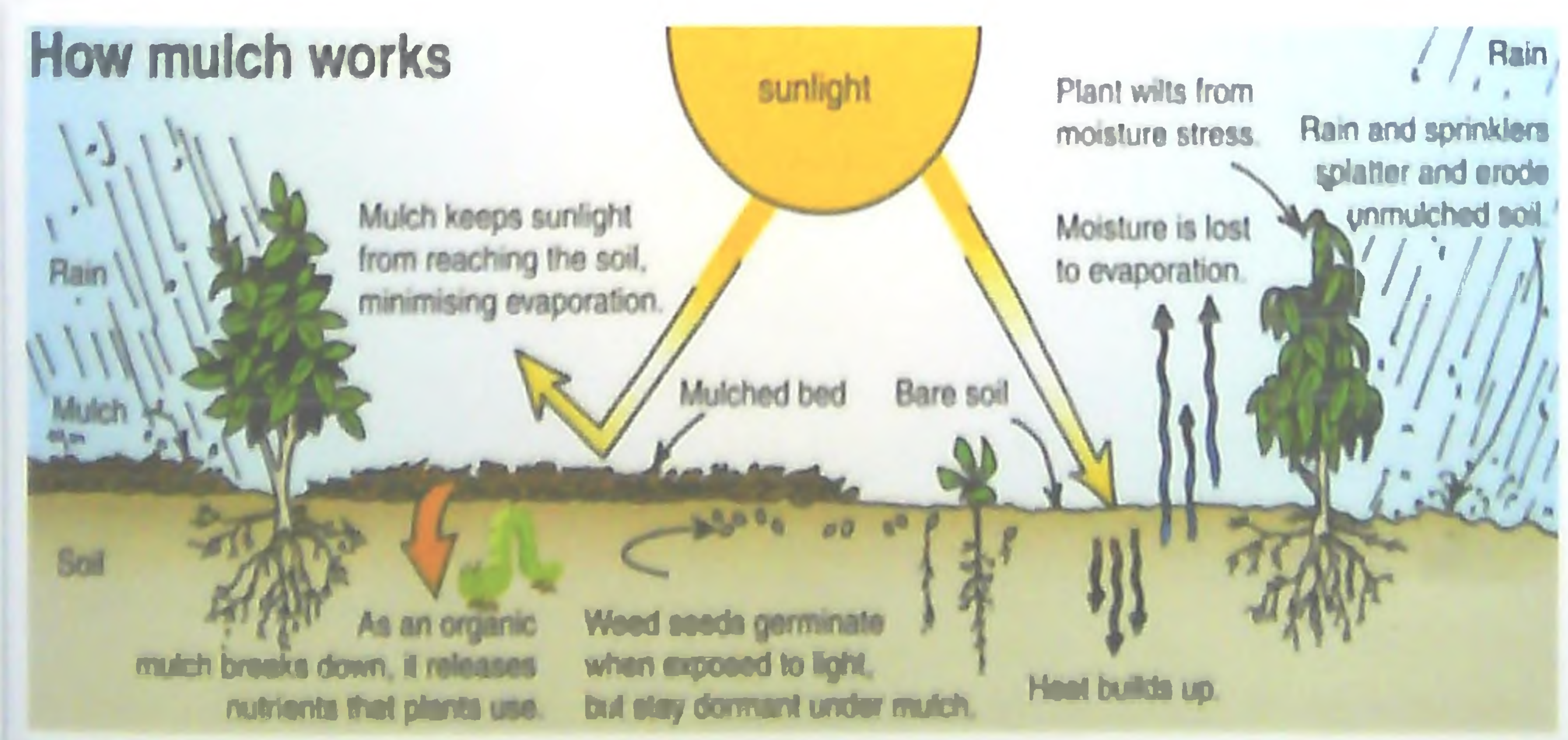
4. Why organic mulches?

Inorganic mulches	Organic mulches
No addition of organic matter	Add nutrients and organic matter
Do not decompose over time	Fast decomposition
High initial cost	Cost effective
Negative influence on soil plant micro climate	Positive influence on soil plant micro climate
Less root development	Better root development

Organic mulches are preferred over inorganic mulches, as they decompose at a faster rate and add nutrients to the soil. They improve soil physical properties, increase water retention, regulate soil temperature, prevent erosion, supply organic matter and take part in nutrient cycles. They suppress weed growth as well as increase the biological activity (Hooks and Johnson, 2003).

5. How mulch works

Figure 1.



Mulches protect the soil from incoming solar radiations which will help to reduce the excess loss of water by evaporation. As the weed seeds are not exposed to sunlight, they will remain dormant under the mulch. Mulches also prevent the erosion of soil by reducing the splashing effects of rain and irrigation water. As organic mulches decompose, it will release nutrients and organic matter, which can be utilized by the growing plants. Solar radiation will directly reach to bare soil resulting in the excess loss of water by evaporation and plants wilt from moisture stress. Also, a bare soil is always vulnerable to elements like rain and wind and causes the top soil to erode.

6. Organic mulching materials

6.1. Straw

Straw is the stalks and other residues of a mature grain left after harvest. It is highly effective in controlling weeds and conserving soil moisture. It is a readily available mulching material, however, lower in nutrient content. Straw provides cleaner and more persistent mulch that is slower to decompose and highly effective in conserving soil moisture and preventing weed growth in vegetables like pumpkin and other vine crops. Straw mulch has disadvantages like self sprouting, weed seed contamination and are easily carried away by heavy wind.

6.2.Bark (wood shavings)

Shredded hard wood and soft wood shavings can use as a mulch for trees and perennial beds. They are the byproducts of paper or timber industries. Their size can vary from shredded chips to large pieces of logs. Many of the studies have found that they can reduce the need for irrigation upto 50%.

6.3. Grass clippings

Grass clippings are obtained from lawn or other grass fields and form an excellent mulching material for vegetables and garden beds. It contains more than 70% of water. So they decompose quickly and add nutrients to the soil. Grass clippings are best to use as dry and if applied freshly spread loosely. Avoid grass clippings treated with pesticides as it may cause leaching of chemicals into the soil and also avoid seeded grass clippings in order to prevent the undesirable turf grass growing on garden beds.

6.4. Sawdust

Saw dust is the finely divided wood powder. It is highly efficient in conserving soil moisture by increasing infiltration and percolation. Aged sawdust is always preferable than fresh ones. Major drawbacks of sawdust mulch include chances for acidification and washing away by heavy rains in the slopping fields.

6.5. Leaf litter

Fresh leaves or naturally falling dry leaves can used as mulch in garden beds. They play an important role in nutrient recycling as they are rich in calcium and other micronutrients and also contain moderate amounts of N, P and K. However, there is high chance of contamination with weed seeds and we have to avoid leaf litter infected with pests and diseases.

6.6. Paper mulches

Paper mulches are low cost alternative to plastic and straw mulches. They eliminate the disposal concern associated with plastic mulches and there is no chance of carrying weed seeds along with it. Paper mulches are permitted to use in organic production excluding glossy or coloured sheets. Effectiveness of paper mulching for controlling weeds like purple nutsedge was reported by Cirujeda *et al.* (2012). Use of paper mulches should be according to our weather conditions as it will blow and tear away within 2-3 weeks. So avoid the use of paper mulches in windy or heavy rainfall areas.

6.7. Crop residues

Crop residues like rice hull, coconut husk, arecanut husk, banana pseudostem, cotton gin waste, peanut hull and maize stover can be used as an effective mulching material for resource poor soils as it contain substantial quantities of nutrients. The benefits are not only derived from nutrient recycling, they are also effective in conserving soil moisture and suppressing weed growth.

Table 1. N, P and K content in different crop residues

Crop/species	N (%)	P (%)	K (%)
Cowpea stem	1.07	0.14	2.54
Cowpea leaves	1.99	0.19	2.20
Rice straw	0.58	0.10	1.38
Coconut husk	0.31	0.02	1.30
Maize stover	0.59	0.31	1.31
Oil palm (processed fibre)	1.24	0.10	0.36
Sesbania	4.00	0.19	2.0
Crotalaria spp.	2.89	0.29	0.72
Tephrosia spp.	3.73	0.28	1.78
Water hyacinth	2.04	0.37	3.40
Azolla spp.	3.68	0.20	0.15
Typha spp.	1.37	0.21	2.38

From this table we can find that the highest nitrogen content is in sesbania residue, highest phosphorous content in water hyacinth and potassium content in cowpea stem residue.

6.8. Live mulch

Live mulch is a fast growing ground cover crop inter planted with a main crop and intended to serve the functions of mulch. Live mulches co-exist with the crops during the growing season continue to grow even the crop is harvested. Live mulches offer advantageous as they not only provide erosion control but also fix atmospheric nitrogen. They can increase soil organic matter which can improve the overall physical conditions of soil.

7. **Effects of mulches**
   - On crop
   - On soil
   - On microflora

7.1. Effects on crop

7.1.1. Increases seed germination and seedling survival

Organic mulches found to increase the seed germination and seedling survival. Mulching depth is an important parameter in this aspect. Deeper mulches are associated with improved weed control and are not the best choices for seeded areas rather than planted. So a thin layer of mulch or mulch applied post seeding is found to be benefited. Once seedlings have emerged, mulches are associated with improved seedling performance under field conditions.

Table 2. Effect of grass mulch on seed germination rate of okra

Treatment	Mean germination		% germination	
	2008	2009	2008	2009
Grass mulch	43.2	41.3	90	86
No mulch	21.6	32.6	45	68
CD (0.05)	0.95	1.02		

(Aniekwe, 2013)

The above study was conducted by Aniekwe (2013) in the experimental research farm of Nigeria to assess the effect of grass mulches on the seed germination rate of okra. He found out that the mean germination rate of okra seeds was higher under the grass mulched treatment compared to control plot and the germination per cent was double under the mulched treatment than that under no mulch treatment in the year 2008. This shows the modified microclimate of the seed environment under grass mulch.

7.1.2. Enhances root growth and establishment

Numerous studies have demonstrated that improved water retention and reduced weed growth are correlated with increased root growth and establishment. Mulches allow roots of trees and shrubs to extend and establish far beyond the trunk compared to bare soil.

Table 3. Effect of leaf litter mulch on root growth of Stevia

Treatment	Root dry biomass (g/plant)		Root volume (mm)	
	2010	2011	2010	2011
Leaf litter mulch @ 5t/ha	6.78	12.73	22.07	57.82
No mulch	4.26	8.99	13.84	43.00
CD(0.05)	1.65	2.39	3.96	14.52

(Kumar *et al.*, 2014)

A study was conducted to find out the effect of leaf litter mulch on the root growth of Stevia by Kumar *et al* (2014). He recorded the root biomass and volume of Stevia under mulched and no mulched treatments and found out that both root biomass and volume were higher under grass mulch compared to the bare soil. Grass mulch improves aggregation of soil through high amount of organic matter. Their quick decomposition and availability of nutrients is related with the better root growth under mulched treatment.

7.1.3. Improves plant growth and performance

ate 1.Capsicum under dried pine needles

Plate 2.Tomato under straw mulch

Plate 3.Strawberry under straw mulch

An increased seed germination rate and enhanced root growth leads to improved plant growth and performance. Most of the studies reveal that organic mulches are highly effective in optimizing the plant performance rather than stone or gravel mulches

Table 4. Effect of organic mulches on growth and yield of water melon

Treatments	Vine length(cm) at 60 DAS	Fruit yield (t/ha)
No mulch	117.49	20.59
Wheat straw mulch @ 5 t/ha	138.52	26.37
Dry leaves @ 5t/ha	140.08	27.56
CD(0.05)	19.34	3.03

(Parmer *et al.*, 2013)

A study was conducted by Parmer *et al.* (2013) to find out the effect of organic mulches on growth and yield of water melon, in Junagadh Agriculture University of Gujarat. They observed the fruit yield vine length of water melon under wheat straw, dry leaves and no mulch treatments. Both the characters were higher under mulched treatments compared to the no mulch treatment. Water melon grown under dry leaf mulch recorded a greater vine length and higher fruit yield compared to others. A favourable hydro thermal regime of soil and complete weed free environment leads to better crop performance under mulched conditions.

7.1.4. Reduction of weeds

Organic mulches have been proved to be suitable for soil moisture conservation and temperature regulation during summer and save the crops from early stage weed infestation (Goswami and Saha, 2006). Sherriff *et al.* (1998) reported wheat and oat straw as most efficient mulches for controlling weeds in cucurbits

7.1.4.1. How mulch control weeds?

- Physical barrier

  All types of mulches reduce light, which will stress existing weeds and prevent the germination of many weed species and this mulch barrier will not allow the weed seeds to come out of the soil layer.

- Allelopathic compounds

  Certain organic mulches especially wood chips may control weeds through the leaching of allelopathic chemicals. A study reveals that rye residues maintained on the soil surface release benzoxozinoids which strongly inhibited the germination of several dicot and monocot weed species.

- Beneficial organisms

  The protected soil habitat created by the use of mulches can increase beneficial organisms that prey upon weeds or eat their seeds.

- Competition

  Living mulches can reduce the weed problems through competition by limiting the light and moisture availability.

A study was conducted in Kerala Agricultural University by Muhammed *et al.* (2015) to find out the weed control efficiency of different organic mulches. He compared five different types of organic mulches with an un weeded control plot and pre emergent application of pendimethalin @ 1.0kg a.i./ha. He concluded that even though the weed dry weight was least under pendimethalin applied plots, the yield and B: C ratio of mango leaves and paper mulches were comparable with that of pendimethalin applied plots. So mango leaves and paper mulches can be used as effective alternatives to herbicides in organic farming without affecting the yield.

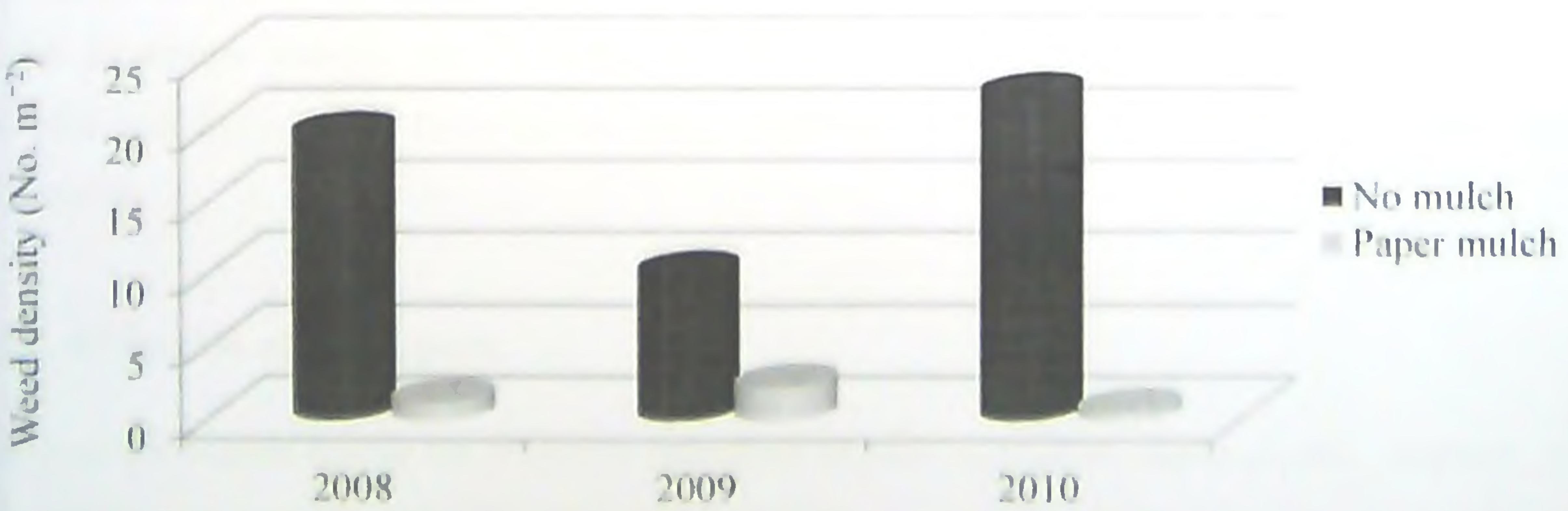
Table 5. Effect of different organic mulches on weed dry weight, yield and economics of okra

Treatments	Weed dry weight at 30 DAS (kg/ha)	Yield (t ha^{-1})	B:C ratio
Mango leaves	28.2	10.06	2.73
Coconut fronds	64.3	4.55	1.24
Fresh weeds	60.9	4.22	1.13
Paddy straw	41.3	5.01	1.11
Paper	22.8	9.37	2.49
Pendimethalin	16.7	9.56	2.72
UWC	90.1	1.05	0.30
CD(0.05)	17.1	1.71	

(Cirujeda *et al.*, 2012)

Another study conducted by Cirujeda *et al.* (2012) shows the effectiveness of paper mulches in controlling weeds like purple nut sedge. He conducted the experiment in the tomato fields of Spain. He used MG craft paper mulches for this experiment which of high quality. He found out that weed density under paper mulches was very less compared to the control plot.

Figure 2. Effect of paper mulches on controlling purple nutsedge (*Cyperus rotundus*)



7.1.5. Reduction of diseases

Physically, mulches will reduce the splashing effect of rain or irrigation water, which can carry spores of disease organisms up to the stems or leaves. Additionally, the populations of beneficial organisms, colonize under mulch materials can also prevent the diseases either through competition or chemical inhibition. A study was conducted by Kumar (2012) in the ICAR Sikkim centre to find out the effectiveness of mulches on disease reduction.

Table 6. Effect of mulches on disease severity in ginger

Treatment	Disease severity (%)		
	Bacterial wilt	Soft rot	Leaf spot
No mulch	38	48	40
Artemisia vulgaris @ 15t/ha	20	12	38
Eupatorium odoratum @ 15 t/ha	15	18	36
Datura spp. @ 15 t/ha	10	14	38
CD(0.05)	2.39	3.54	4.03

(Kumar, 2012)

He recorded the disease severity of bacterial wilt, soft rot and leaf spot under different mulch treatments and all the mulched plots were shown a lesser disease severity compared to the no mulch treatment. Ginger grown under Datura leaf mulch was shown the least severity of bacterial wilt and soft rot. These can be related with the anti microbial activity of the plants used as mulches.

7.1.6. Reduction of insect pests

Some of the studies reveal the effective reduction of pest population under organic mulches, as the densities of natural predators will be higher under an organic mulch. A study was conducted by Mochiah (2012) to find out the effect of mulches on pest reduction in Chilli. First he recorded the densities of natural predators in chilli under straw mulch and a no mulch treatment

Table 7. Effect of mulches on mean populations of natural predators on chilli

Mulch type	Mean ± (SE) number of predators / plant		
	Scutigera coleoptrata	*Argiope aurantia*	*Cheilomenes* sp.
No mulch	0. 8 ± 0.1	1.4 ± 0.3	1.6 ± 0.2
Straw	1.0 ± 0.2	1.7 ± 0.2	1.9 ± 0.3

He found out that mean number of insect predators was higher under straw mulch compared to the no mulch treatment. Subsequently he also studied the insect population on chilli.

Table 8. Effect of mulches on insect population on chilli

Mulch type	Mean ± (SE) number of insect pests plant		
	Aphis gossypii	*Thrips tabaci*	*Bemisia tabaci*
No mulch	3.0± 0.30	1.7 ± 0.30	2.6 ± 0.30
Straw	1.9 ± 0.30	0.7 ± 0.20	1.2 ± 0.30

(Mochiah, 2012)

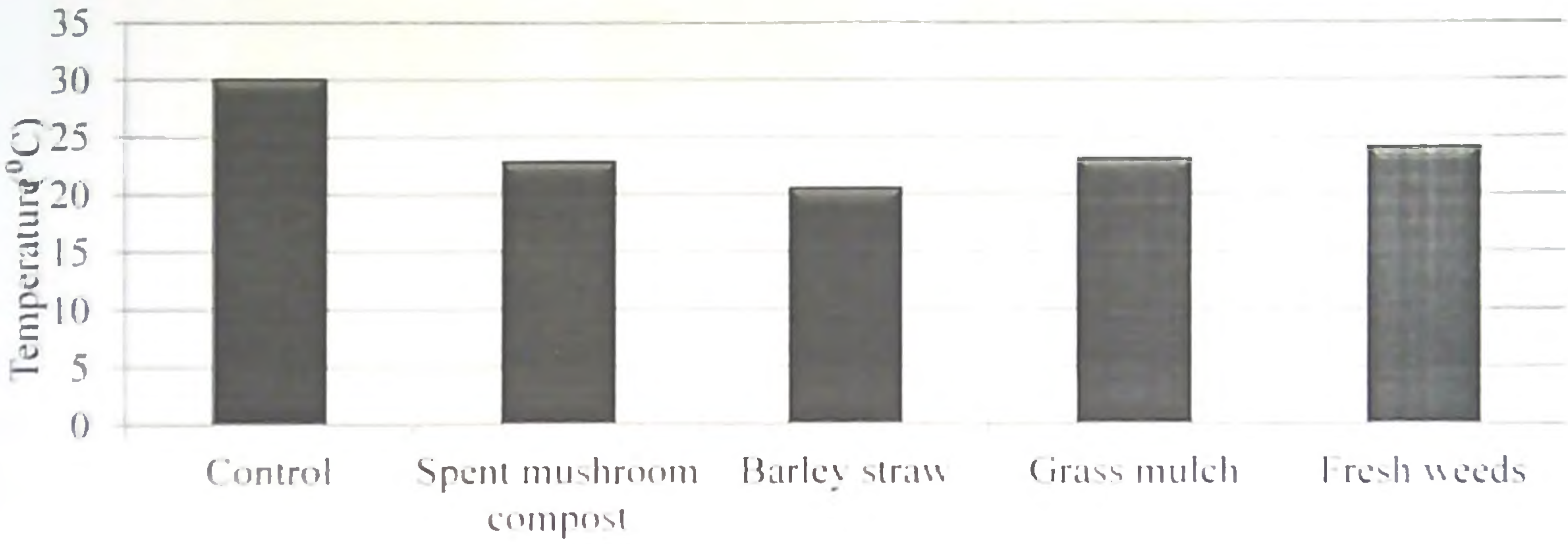
He recorded the populations of *Aphis gossypii. Thrips tabaci and Bemisia tabaci* under no mulch and straw mulched plots. The insect population was lower in straw mulch compared to the control treatment, which can be related with the greater densities of natural enemies under straw mulch.

7.2. Effects on soil

7.2.1. Effects on soil temperature

Organic mulches protect the soil from extreme temperatures by keeping it cooler in hotconditions and warmer in cold conditions. Coarse mulches are more temperature moderating than finely textured mulches. Live mulches also reduce surface soil temperature by evaporative cooling

Figure 3. Influence of organic mulches on surface soil (0 - 5 cm) temperature



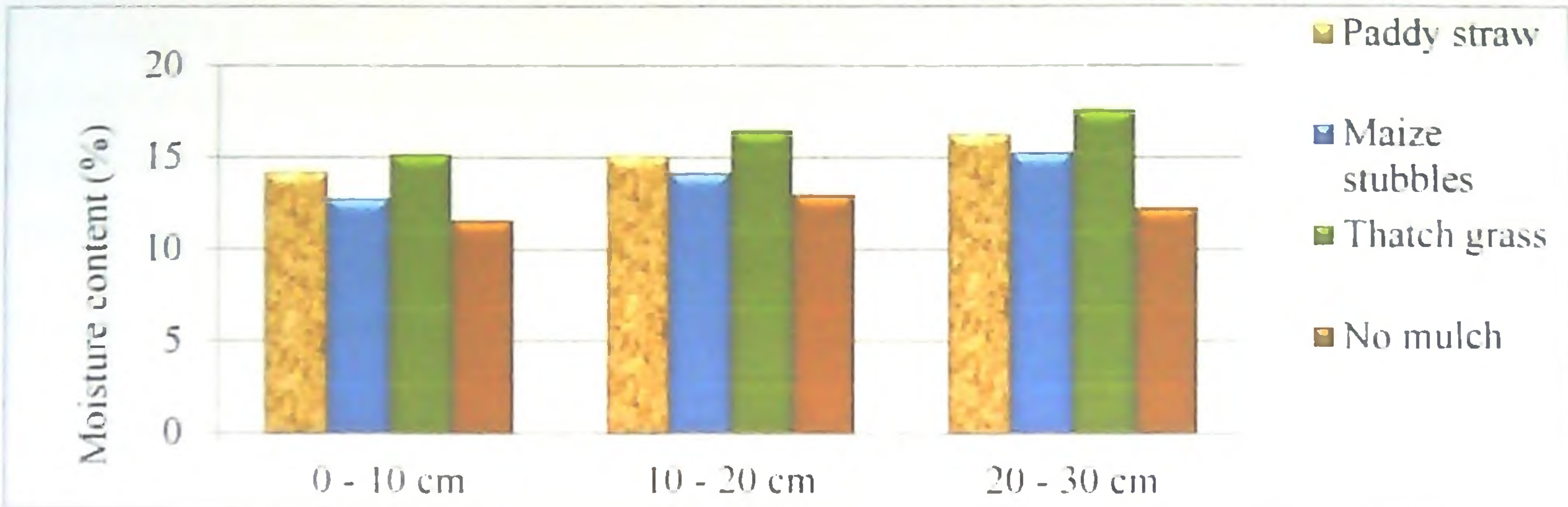
The above study was conducted by Yordanova (2015) to find out the effect of organic mulches on surface soil temperature. He used different organic mulches like spent mushroom compost, barley straw, grass mulch and fresh weeds and recorded the surface soil temperature. All the organic mulches were shown a lower soil temperature compared to the control plot. Lowest soil temperature was measured under barley straw mulch. This may be due to the bright surface of the barley straw reflects sun's rays, preventing over heating of soil surface.

7.2.2. Increases soil moisture retention

Studies reveal that weeds can increase evapotranspiration by 25% in a summer season and mulches reduce the rate of evapotranspiration by reducing weeds. They also help to increase moisture retention by increasing infiltration and percolation. Most of comparative studies among mulch types indicate that organic mulches conserve water more effectively than inorganic.

A study conducted by Choudhary (2015) reveals the effectiveness of organic mulches on conserving soil moisture in the experimental farms of ICAR, Arunachal Pradesh.

Figure 4.Influence of organic mulches on soil moisture content

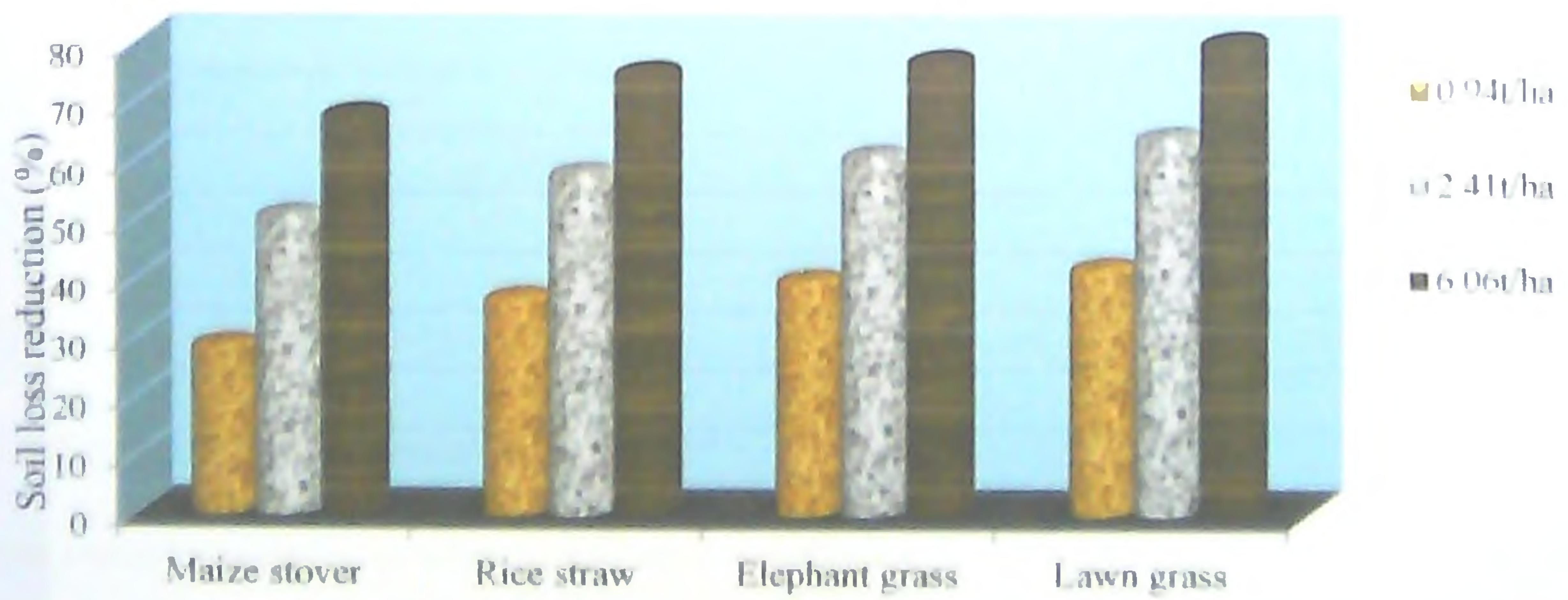


He used different organic mulches like paddy straw, maize stubbles, thatch grass and no mulch and measured the soil moisture content at three different soil depths. He found out that thatch grass is having the highest moisture retention capacity followed by paddy straw. This is because of the lignin and polyphenols content in thatch grass and silicon content in paddy straw. These characters make them slower to decompose and conserve soil moisture for a longer period of time

7.2.3. Controls soil erosion

Live mulches are more effective in reducing soil erosion and compaction by protesting the soil from wind and water erosion

Figure 5. Effect of mulch types on soil loss



The study was conducted by Asante (2011) in Ghana soils. He studied the effectiveness of different mulch materials at three different application rates. He found that the highest soil loss reduction value was under lawn grass at an application rate of 6.06t/ha. So a better soil erosion control can be achieved by increasing the application rate of mulching.

7.2.4. Effects on irrigation levels

As per the study of Agronomic Research Station (ARS), Chalakudy, organic mulches can effectively reduce the irrigation intervals without affecting the crop yield. This experiment was conducted with four levels of irrigation and two levels of mulching. Result of the study is given in table 9. From the table, it is clear that yield under all the levels of irrigation were higher under dry leaf mulch compared to the no mulch treatment. So we can reduce the level of irrigation by using dry leaf mulch without affecting the yield

Table 9.Effect of mulching and irrigation on fruit yield of pineapple

Treatments	Yield (t/ha)	
	No mulch	Dry leaves @ 6 t/ha
No irrigation	19.64	26.26
IW/CPE - 0.3	36.38	40.28
IW/CPE - 0.6	41.54	49.93
IW/CPE - 0.9	44.98	93.70
CD(0.05)	6.98	

(Annual report - ARS, chalakudy)

7.2.5. Effects on soil physical properties

The overall benefits of mulches in soil seem to influence the physical properties of soil. A study was conducted by Komariah (2002) in the pineapple plantations of Indonesia. He studied physical properties like bulk density and formation of water stable macro aggregate at two different soil depths under different mulch types.

Table 10.Effects on soil physical properties

Treatment	Depth (cm)	Bulk density (g/cm^3)		Water- stable macro aggregate (%)	
		Initial	Final	Initial	Final
No mulch	0 - 5	1.14	1.10	28.4	33.3
	5 - 10	1.17	1.16	34.2	45.7
Rice husk mulch	0 - 5	1.06	1.04	35.1	46.2
	5 - 10	1.22	1.10	36.8	48.5
Cassava bagasse mulch	0 - 5	1.13	1.08	28.5	53.3
	5 - 10	1.19	1.07	30.3	49.5

(Komariah, 2002)

The highest bulk density reduction and higher formation of water stable macro aggregate was observed under cassava bagasse mulch followed by rice husk mulch. The faster decomposition capacity of cassava bagasse mulch could have enhanced the physical properties of soil.

7.2.6. Effects on soil fertility

Organic mulches enhance soil fertility as they contain substantial quantities of nutrients and add organic matter by their faster decomposition. A field experiment conducted in Kerala Agricultural University shows the effectiveness of organic mulches for enhancing soil fertility. The study was conducted by Muhammed *et al.* (2015) and he analyzed the soil for different parameters under different mulch types. The data obtained were compared with that of no mulch plot and pre experiment data. All the mulched plot were shown a greater quantity of available nutrient and favourable pH.

Table 11. Effects of mulches on soil Fertility

Treatments	pH	Organic carbon (%)	N(kg/ha)	P(kg/ha)	K(kg/ha)
Mango leaves	5.26	1.71	205.33	23.73	240.78
Coconut frond	5.50	1.85	235.20	25.70	249.38
Fresh weeds	5.30	1.65	218.40	25.10	252.45
Paddy straw	5.53	1.82	237.20	23.63	268.80
Paper	5.30	1.80	252.00	23.33	244.65
No mulch	4.90	1.59	164.06	23.38	220.22
Pre experiment	4.80	1.48	195.30	15.17	232.70
CD (0.05)	0.58	0.21	14.8	5.21	18.52

(Muhammed *et al.*, 2015)

7.3. Effects on microflora

Organic mulches can have a direct effect on soil micro organisms as mulches are serving as a food source for them. Mulches increase the amount of organic matter and other nutrients in soil which leads to the buildup of micro organisms. An experiment was conducted by Muhammed *et al.* (2015) to find out the effect of different mulch types on the population of bacteria, fungi and actinomycetes. He found out that all the mulched soil types shown a higher number of microbial populations compared to the no mulch plot.

Table 12.Effect of different mulches on total microbial population

Treatments	Bacteria (cfu X 10^6) / g	Fungi (cfu X 10^3) / g	Actinomycetes (cfu X 10^4) / g
No mulch	8.6	40.3	60.6
Mango leaves	23.6	60.3	75.3
Coconut fronds	20.3	57.6	87.6
Paddy straw	27.3	56.6	76.0
News paper	20.6	73.3	94.3
CD(0.05)	7.3	22.4	18.1

(Jodaugiene, 2010)

An experiment was conducted by Jodaugiene (2010) in the pomological garden of Lithuanian University of Agriculture, to find out the influence of organic mulches on urease activity. He used different mulch types like straw, peat, sawdust and grass, and recorded the urease activity under these different mulch types. Among the mulches, sawdust was shown a higher urease activity compared to others and this can be related with the greater moisture retention capacity of sawdust

Figure 6.Effect of organic mulches on urease activity

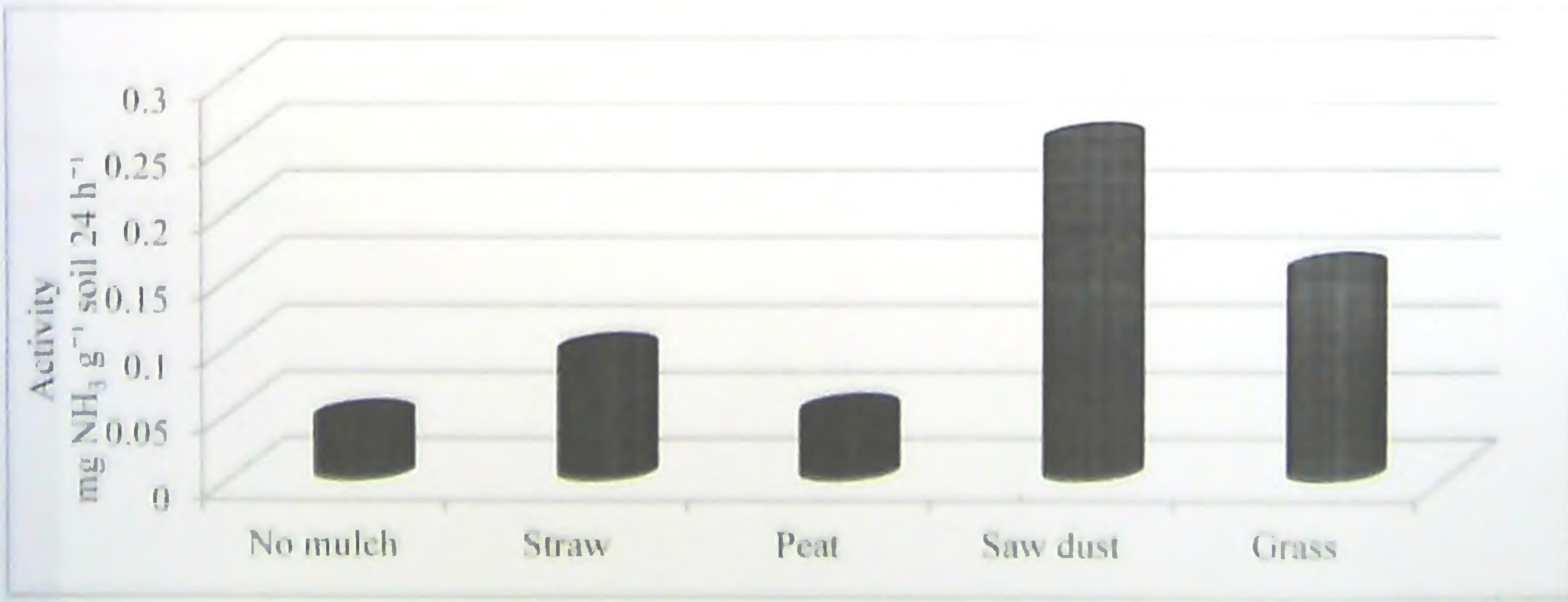
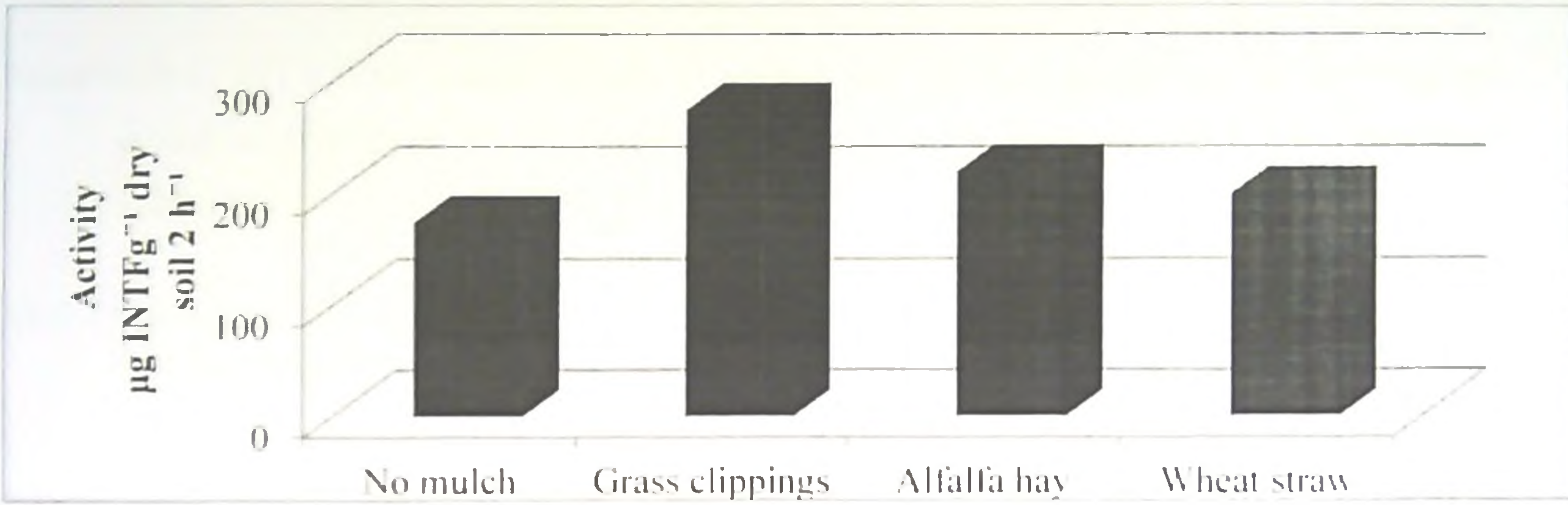


Figure 7.Effect of organic mulches on dehydrogenase activity



Organic mulches are found to have an enhancing effect on dehydrogenase activity. An experiment conducted by Robert *et al.* (2003) reveals a higher dehydrogenase activity under organic mulches compared to the bare soil. Among different mulches, grass clippings recorded a higher degydrogenase activity this may be due to the faster organic matter supplying capacity of grass clippings, which could have enhanced the dehydrogenase activity in soil.

8. Conclusion

Organic mulches are the best option in organic farming as they restore the soil health by adding substantial quantities of nutrients, conserving soil moisture, suppressing weed growth and by maintaining a good microflora. They are the best alternative to herbicides in organic farming without affecting the yield. In the present scenario of globalization and health consciousness, demand for organic products has increased world over. Excessive competition has compelled us to produce quality food in more quantities. So apart from using HYVs and depending on fertilizers and chemicals, there is a need to utilize environmental or biological energy for higher production. Mulching is such a healthy way for attaining food security without any environmental impact.

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10. Discussion

1. Explain the mechanisms of disease control by organic mulches?

Physically, mulches will reduce the splashing effect of rain or irrigation water, which can carry spores of disease organisms up to the stems or leaves. Additionally, populations of saprophytic fungi will be higher under mulches and these fungi produce exogenous cellulose enzyme which lyses the cell walls of fungi and prevent their sporulation.

2. Why aged sawdust is preferable?

Sawdust is having a wide C: N ratio which results in a slower decomposition rate. Ageing by composting will reeduce the C: N ratio as well as toxic effects of sawdust.

3. Is mulch is having any allelopathic effects on crops?

Allelopathy is the inhibition of seed germination and through the release of chemicals. Allelopathic activity is confirmed by the inhibition of seed germination rather than how it affects mature plants. So established plants are not affected by the allelopathic effects of mulches.

4. Which one is more cost effective? Organic mulch or inorganic mulch?

While considering the persistence, inorganic mulches are more cost effective. But if are using using organic mulching materials produced from our farm, we can reduce the cost of purchase and it will be more economical.

5. What is soil mulching?

Soil mulch/ dust mulches are created by intensively hoeing the soil surface, creating a finely textured layer of soil which help to prevent the evaporation from the underlying soil layer.

6. Which organic mulch is originated from animal materials?

Compost. But it is having a limited application as a mulch.

7. What is the concept of vertical mulching?

It involves drilling holes at regular spaces and these holes are filled with organic materials, which found to improve the soil aeration, percolation and more availability of nutrients to the roots.

8. Why sawdust is having acidifying effect?

Sawdust releases phenolic acids during its decomposition process which causes acidification to the soil environment.

9. Name commercially available organic mulch?

Coir pith

10. Relevance of using sawdust in polyhouses?

Sawdust effectively reduces nematode population under protected cultivation.

11. Abstract

KERALA AGRICULT URAL UNIVERSITY

COLLEGE OF HORTICULTURE, VELLANIKKARA

Department of Agronomy

AGRON 591: MASTER'S SEMINAR

Name: Reshma N. Venue: Seminar Hall

Admission number: 2014-11-131 Date: 19.11.2015

Major advisor: Dr. Sindhu P. V. Time: 10.45 a.m.

Organic mulches

Abstract

The practice of applying mulches to soil is possibly as old as agriculture itself. The word mulch has been derived from the German word "*Molsch*" meaning soft to decay. Any material used at the surface of the soil primarily to prevent loss of water by evaporation, to keep down weeds, to dampen temperature fluctuations or to promote soil productivity is generally designated as a mulch (Jacks *et al.*, 1955).

Mulches can be either organic or inorganic. Organic mulches are those derived from plant and animal sources. The most frequently used organic mulches include plant residues such as straw, wood shavings, saw dust, grass clippings, tree leaves and paper mulches. Inorganic mulches include those derived from inert materials of synthetic or natural origin. Plastic, fabric, rock and rubber mulches come under this category. Organic mulches are preferred over inorganic mulches, as they decompose at a faster rate and add nutrients to the soil.They improve soil physical properties, increase water retention, regulate soil temperature, prevent erosion, supply organic matter and take part in nutrient cycles. They suppress weed growth as well as increase the biological activity (Hooks and Johnson, 2003). To achieve optimum advantage from organic mulches, they should be applied either after germination of crop or after transplanting seedlings (Bhardwaj, 2013).

Organic mulches have been proved to be suitable for soil moisture conservation and temperature regulation during summer and save the crops from early stage weed infestation (Goswami and Saha, 2006). Mulches control weeds by acting as a physical barrier, secreting allelopathic compounds, promoting beneficial organisms and competing with weeds. Sherriff *et al.* (1998) reported wheat and oat straw as most efficient mulches for controlling weeds in cucurbits. Mulches from wood shavings are generally used around trees and in perennial beds. Paper mulches can be a low cost alternative to straw and plastic mulches and are permitted to use in organic production excluding glossy or coloured sheets. Effectiveness of paper mulching for controlling weeds like purple nutsedge was reported by Cirujeda *et al.* (2012). Uses of live mulches enhance nutrient availability for the main crop and increase crop yield. Chances for allelopathy, acidification, competition and spread of pests and diseases through mulch materials are some of the problems associated with mulching.

Organic mulches improve soil health and create favourable environment for the crops and associated microorganisms. They provide more stable landscape, which is sustainable and resistant to stress.

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SEMINAR REPORT

AQUATIC WEEDS – PROBLEMS AND POTENTIAL

By

ATHEENA A.
(2014-11-134)

Submitted in partial fulfilment of requirement of the course
AGRON 591- Master's Seminar (0+1)

DEPARTMENT OF AGRONOMY
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DECLERATION

I,Atheena A. (2014-11-134) hereby declare that the seminar entitled '**Aquatic weeds- problems and potential**' has been prepared by me, after going through various references cited at the end and has not been copied from any of my fellow students.

Vellanikkara

20/11/2015

Atheena A.

(2014-11-134)

CERTIFICATE

This is to certify that the seminar report entitled '**Aquatic weeds – problems and potential**' has been solely prepared by Atheena A.(2014-11-134), under my guidance and has not been copied from seminar reports of any seniors, juniors or fellow students.

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1. Introduction

Aquatic weeds are those plants growing in or near water and complete at least a part of their lifecycle in water resources. Any aquatic plant that causes adverse effects physical, chemical or biological on water bodies, resulting in economic losses is called aquatic weed. The infestation of aquatic weeds results in critical problems in agriculture, navigation, irrigation, pisciculture and public health. A lot of resources are required to control infestations of aquatic weeds because of their fast growth, which interfere with use of water, increase the risk of flooding, slow the water flow in canals and river, favour the development and growth of mosquitoes which threaten public health. The menace of water weeds is reaching alarming proportions in many parts of the world. The problem is global, but more pronounced in tropical and subtropical zone, where warm weather supports profuse growth of aquatic plants. In India large irrigation projects have been reported to be adversely affected by profusely growing aquatic weeds. Today a large part of inland water-area in this country is threatened by the invasion of noxious aquatic weeds. Nearly 2,100 km of the Bhakra Canal in the Hissar district is so badly infested with weeds that it has to be cleaned many times in a year to sustain the flow of water (Kumar and Babu, 2015). Keeping in view the loss of water through weeds, it has become essential to manage weeds to save water for human use. Kerala, bestowed with inland water resources and wetlands is facing serious problems due to alien invasive aquatic weeds like water hyacinth, salvinia, alligator weed *etc.* and management of these weeds are a major concern in many parts of the state.

The scientists and technologists has now changed their destructive attitude towards these apparently troublesome plants, and trying to put them to productive use. Limited research so far being carried out in this line, has yielded encouraging results. It has been found that aquatic weeds constitute plants of great potential value. These water weeds have been found to have potential for use as animal feed, human food, soil additives and fuel.

2. Classification of aquatic weeds

Aquatic weeds in general can be classified into algae, ferns and angiosperms. Algae are again classified as macroscopic algae and filamentous algae. *Chara* spp. is an example of macroscopic algae and Spirogyra is an example of filamentous algae. *Salvinia molesta* is an example of fern. Angiosperms can be again classified as emergent, floating and submerged.

3. Major aquatic weeds

Kumar and Babu (2015) enlisted some of the major aquatic weeds found in India. *Eichhornia crassipes, Ipomoea aquatica, Hydrilla verticillata, Salvinia molesta* are the major weeds of Kerala.Out of 160 aquatic weeds reported world over, *Eichhornea crassipes, Salvinia molesta, Nymphaea stellata, Nelumbo nucifera, Hydrilla verticillata, Alternanthera philoxeroides, Vallisneria spiralis, Typha angustata, Chara* spp., *Nitella* spp. are of primary concern to India. Among these *E. crassipes, S. molesta, H. verticillata, A. philoxeroides, P. stratiotes* are five primary aquatic weeds of the world and qualify the status of worst weeds in India too.

Table I. Major aquatic weeds in India

State	Weed species
Assam, Orissa, West Bengal	*Chara* spp., *Eichhornia crassipes, Hydrilla verticillata, Salvinia molesta*
Andhra Pradesh, Kerala, Karnataka, Tamil Nadu	*E. crassipes, Ipomoea aquatic, H. verticillata, S. molesta*
Punjab, Bihar, Haryana, Uttar Pradesh	*Cyperus aquatica, E.crassipes, H. Verticillata, Ipomoea carnea,*
Gujarat, Madhya Pradesh, Rajasthan	*Chara* spp., *E. crassipes, H. verticillata, Ipomoea carnea*
Jammu and Kashmir	*Lemna minor, Salvinia natans*

(Kumar and Babu, 2015)

Eichhornia crassipes, commonly known as water hyacinth is a free floating fresh water plant of family pontederacia that has proven to be a significant economic and ecological burden to many subtropical and tropical regions of world. It has its origin in tropical South America , but has become naturalised in many warm areas of the world. So it is listed as the world's worst weed and also one of the most productive plants on the earth. It was first introduced to India as an ornamental plant in 1896 from Brazil.

Salvinia molesta, commonly known as giant water fern is a free floating aquatic weed of Brazilian origin. It reached India perhaps through introduction into botanical gardens. It was first observed in 1950's in Veli lake, Trivandrum and assumed pest status since 1964. Now it is a major problem in Africa and South East Asia also.

Pistia stratiotes, commonly known as water lettuce is a free floating aquatic fern of South American origin. It was introduced to India in 1960. Now it is widely distributed in Africa and South East Asia.

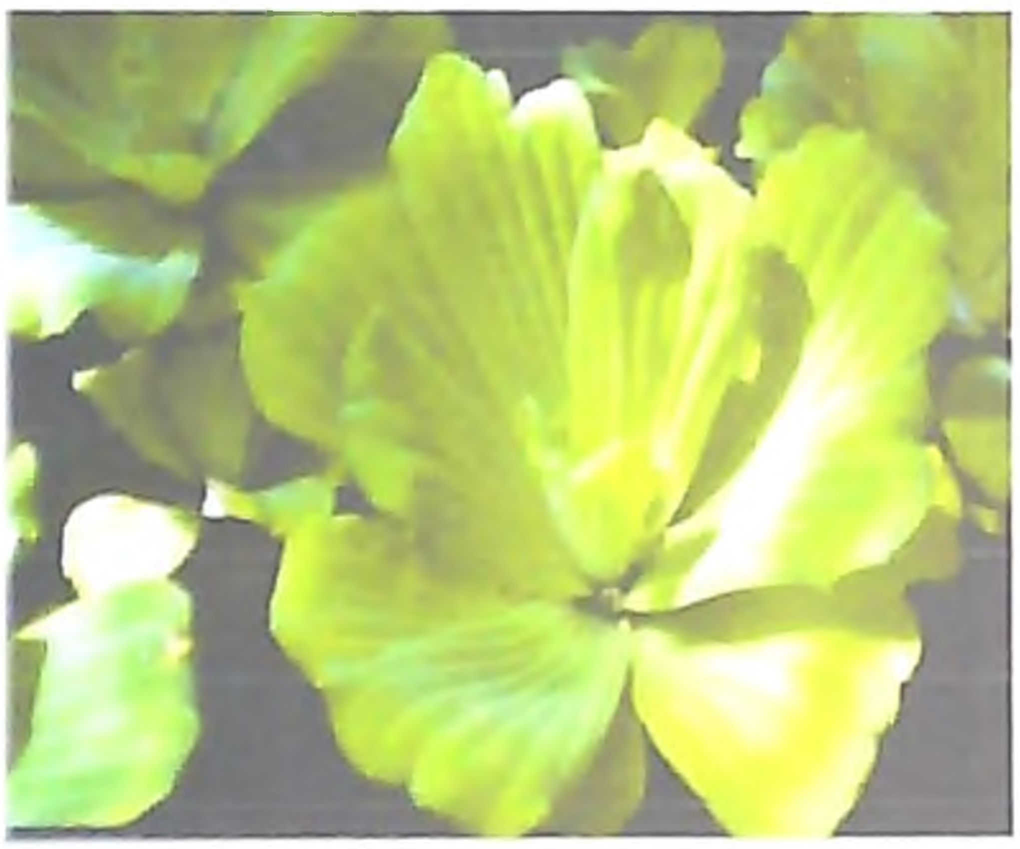
Alternanthera philoxeroides, commonly known as alligator weed is an emergent aquatic plant of South American origin, but has spread to many parts of World. It was first reported in India in West Bengal and Bihar in 1964. It is a recent introduction to Kerala. The ability of alligator weed to persist in terrestrial, semi-aquatic and aquatic environments and ability for vegetative propagation contribute to it's success as an invasive species.

Hydrilla verticillata, commonly known as hydrilla is a submerged perennial aquatic plant. Among the five primary aquatic weeds reported, hydrilla is the only aquatic weed of Indian origin. It is found throughout India, Srilanka, Malaysia, China and US.

Plate 1.Worst aquatic weeds in India

Water hyacinth(*Eichhornia crassipes*)

Water fern (*Salvinia molesta*)



Water lettuce (*Pistia stratiotes*)

Hydrilla (*Hydrilla verticillata*)

Alligator weed(*Alternanthera philoxeroides*)

4. Adverse effects of aquatic weeds

In a balanced ecosystem aquatic plant population is kept under check through interaction of several physical, chemical and biological factors operating both within and outside the water body. But for some reason this balance is disturbed, rapid changes in the entire web of life is inevitable, including the rampant growth of aquatic plants. The three major reasons for the occurrence of aquatic weeds in water bodies in India and elsewhere are

a) Over enrichment of water bodies with plant nutrients reaching there through run-off from agricultural lands, as well as through release of town sewage loads in them.
b) Heavy silting of water bodies from eroded soils of catchment areas usually caused by felling of trees and no- adoption of land capability classification norms.
c) Introduction of extraneous aquatic plant species from distant continents.

When aquatic plants change its status to aquatic weeds, it creates several critical problems which are discussed below.

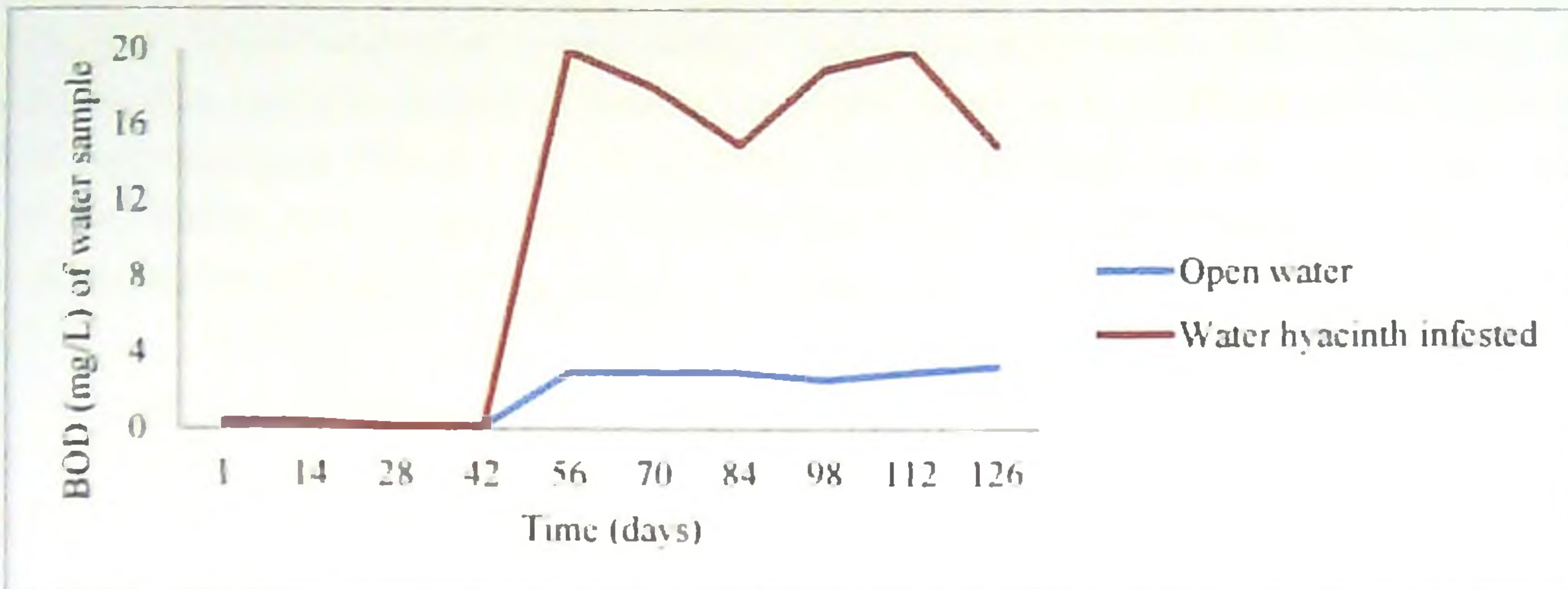
4.1. Impair fish production

Among edible animals, fish is the most efficient user of water in terms of conversion of plant proteins to animal proteins. Aquatic weeds are responsible for the loss of tonnes of such protein-efficient animals in varied ways. In India, also in many other countries, the weedy floating mats of water hyacinth, water lettuce and salvinia are most damaging to fisheries. Of the 8 lakh hectare of fresh water available in India for pisciculture, about 40% is rendered unsuitable for fish production because of invasion of aquatic weeds.

In Assam in Beel fisheries water hyacinth has been considered as a major problem. Fish production was found drastically reduced in beels. Beels are the low land regions of Assam which is predominantly meant for fish production.

When aquatic weeds cover the water surface, it cause darkness underneath and adversely affects the limnology of water and prevents normal gaseous exchange between the water and atmosphere. In darkness the phytoplanktons cannot grow normally nor the fish can locate their food. The water becomes cooler than usual and its dissolved oxygen content is disturbed under the cover of weeds. The decomposition of worn-out roots and leaves of other noxious aquatic vegetation raise Biological Oxygen Demand (BOD) of water body.

Figure 1. Change in BOD as result of aquatic weed infestation



(Chukwuka *et al.*, 2012)

In a study conducted by Chukwuka and co-workers at South Western Nigeria, to determine the Influence of persistent presence of water hyacinth on specific physicochemical properties of freshwater body, it was found that BOD values for water hyacinth infested areas were relatively higher ranging from 0.38 ppm to 20 ppm than those of open water with 0.13 ppm to 4.6 ppm. There was no observable difference between both samples in early period of observation till first 42 days. How ever there was a sharp and pronounced increase in the following days with peak between 42nd day and 84th day. These results indicate rapid depletion in dissolved oxygen concentration in the infested areas and steady build up of organic matter sediments probably caused by decaying and decomposing mats on of older water hyacinth plants.

4.2. Covering and blocking of water courses

Excessive aquatic vegetation impedes the flow of water in all kinds of water ways. In India weeds have already cut the water flow in many canals by 20-95% (Kumar and Babu, 2015). The direct effect of this is inadequate water supplies at the distal ends. Indirectly the impediment of water flow initiates the seepage process which turns vast areas of otherwise productive land around weedy canals water logged and subsequently saline. Silting of water ways induces floods in rivers. The too slow moving weedy water is subjected to accelerated evaporation in comparison to the fast moving one due to its longer exposure to atmosphere.

4.3. Hindrance to navigation

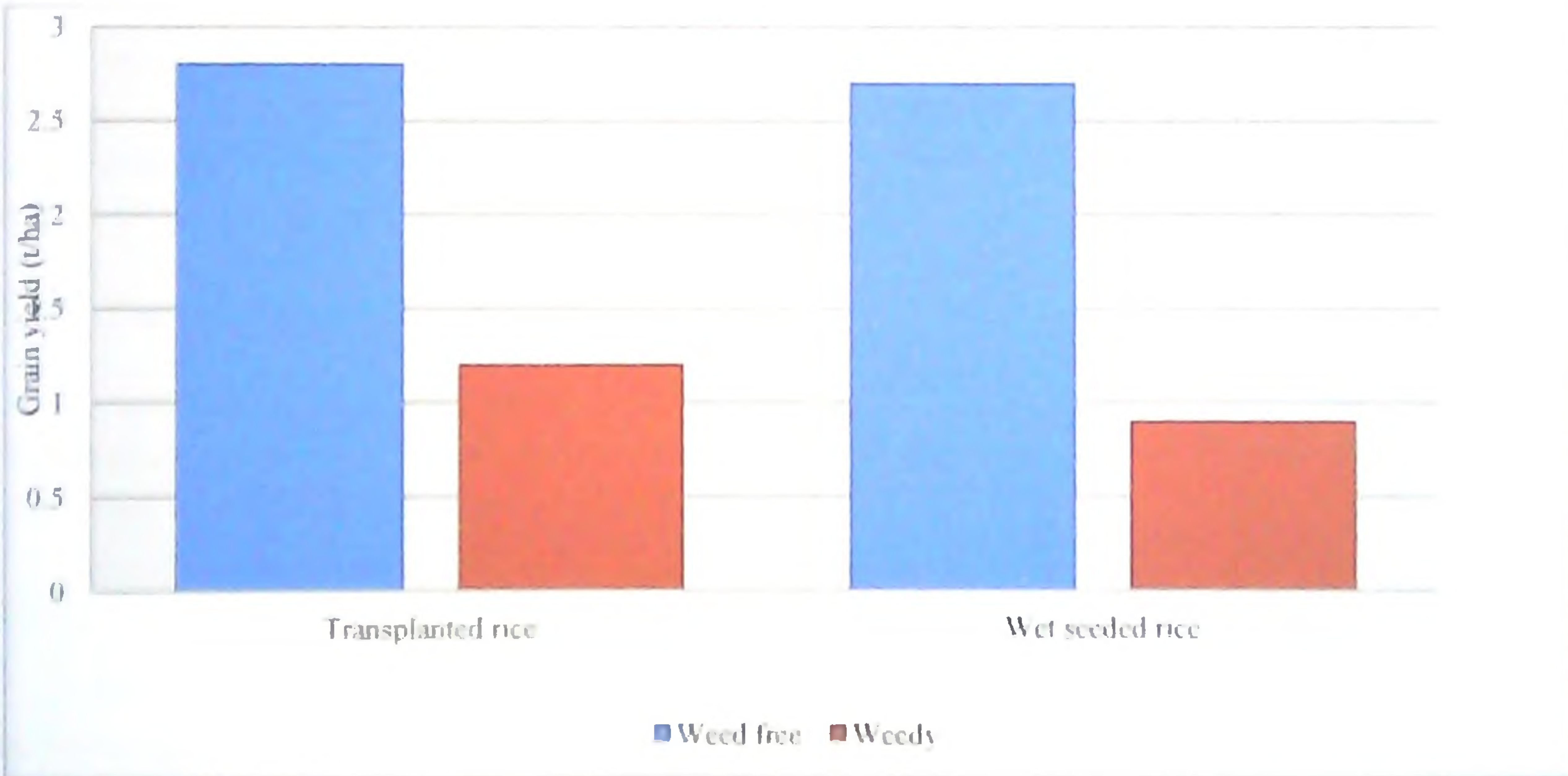
In rivers and large lakes, aquatic weeds keep back the pleasure of navigation and boating. The smooth sailing of tourist boats in Ashtamudi canal and Veli lake is hindered by the massive growth of water hyacinth, and thus has adversely affected the tourism.

4.4. Adverse effect of aquatic weeds on crop production

Aquatic weeds invade and obstruct the growth of thousands of hectare of low land paddy in West Bengal , Kerala and other coastal parts of India. Water hyacinth, salvinia and scum algae cause problems in rice fields by attaching themselves to the young crop seedlings and by forming mats that blanket new emerging rice shoots. These weeds cause huge reduction in crop yields, increases the cost of cultivation, reduce input efficiency, interfere with agricultural operation, impair quality and act as alternate host for several insect pests, diseases and nematodes.

In a study conducted at Uttar Banga Krishi Viswavidyalaya, West Bengal to determine the effect of aquatic weed infestation on rice grain yield, Mukherjee *et al* (2008) found that in transplanted rice, weedy situation throughout the crop growth caused yield reduction to the tune of 57 to 61% in comparison to complete weed-free condition. In wet seeded rice, weed growth throughout the season caused yield reduction of 64 to 66 % as compared to complete weed-free situation as shown in figure 2.

Figure 2 Effect of aquatic weed infestation on rice grain yield



(Mukherjee *et al.*, 2008)

4.5. Adverse effects on human health

Aquatic weeds foster mosquito and snail-borne human and animal diseases. Small sheltered pools formed between aquatic plants like water hyacinth, water lettuce provide perfect breeding habitats for mosquitoes that are vectors of malaria, dengue fever, encephalitis. In drinking water bodies, certain snails like *Pila* spp., inhabit aquatic weeds and act as alternate host of helminthic worms of human and domestic animals.

The more invasive species such as water hyacinth and salvinia affect biodiversity by replacing native flora and fauna, often causing irreversible changes to habitats. The dense mat formations by aquatic weeds interrupt hydro power generation.

5. Management of aquatic weeds

Considering the losses caused by aquatic weeds, their management is of utmost importance. Management of aquatic weeds can be grouped as

5.1. Preventive

The troubles that weeds create in crops, soil and water can be summed up in an adage 'one year of seeding is seven years of weeding'. To avoid such situation a wise step is to follow the principle 'prevention is better than cure'. So appropriate measures are to be taken to prevent the introduction of new aquatic lants from different continents.

5.2. Physical/mechanical

Physical control of aquatic weeds primarily consists of removing the weeds physically from the water body. This can be done manually by hand/ using hand tools. Mechanical methods often reduce massive nutrient load of eutrophic water bodies. Several techniques like dredging, drying, netting, mowing, chaining, burning can be employed for physical removal of aquatic weeds.

5.3. Cultural method

Aquatic weeds can also be controlled by manipulating of water level, light intensity, nutrient availability and competitive displacement. Growth of the aquatic plants in small tanks and ponds can be checked by reducing light reaching the water level.

5.3.1. Drying/ water level manipulation

This method is simple and effective way of controlling submerged weeds. Most of the aquatic weeds respond quickly to changes in water level. Control is achieved by either dehydration of the vegetation or by exposure to low temperature. This method is not effective for controlling emergent weeds.

5.3.2. Light

Growth of submerged aquatic plants in small tank and ponds can be checked by reducing light penetration. Use of fibre glass screen is popular in some countries. Planting of trees on the banks of canals may create shade to reduce light intensity hence checking the weed growth. However care should be taken that trees or their appendages do not impede water flow. Light intensity can also be checked by adding dyes to the water. This type of control is more effective in static water such as ponds or tanks where dye remain suspended for a longer time.

5.3.3. Competitive displacement

Planting of Paragrass (*Brachiaria mutica*) in drainage ditches in the Chambal Irrigation Project eliminated *Typha angustata* after 10 to 12 months and yielded green fodder (Mehta and Sharma, 1975). Besides direct competition, growth is also suppressed by some plants by shading effect.

5.4. Chemical control

Chemical control through use of registered aquatic herbicides and algicides is a technique that is widely employed by aquatic plant managers in both private and public water bodies throughout the world. No one chemical has been developed so far which would control all aquatic weeds. The use of chemicals to control aquatic weeds has resulted in severe toxicity to both water quality and aquatic fauna and degradation in water quality.

Table 2. Mortality of *Cardina nilotica* (Decapod shrimp) exposed to different concentration of glyphosate

Glyphosate exposure rate (mg/L)	Percentage mortality		
	24 h	48 h	72 h
20	1.23	3.75	8.75
40	3.75	8.75	16.25
80	8.75	21.25	38.75
160	12.50	30.00	53.75

(Deepananda *et al.*, 2011)

Several researches has being carried out in this line and many are in progress. In such an experiment conducted at Matara by Deepananda and co-workers on assessing the acute toxicity of a glyphosate herbicide on fresh water crustaceans. The bioassay with *C. nilotica* was performed in glass aquaria (23x23x35 cm) with a 4 L capacity. Test chambers were filled with 2 L of dechlorinated tap water having the following physicochemical characteristics: temperature, 27.5 ± 0.5 °C; pH, 6.8 - 7.3; dissolved oxygen, 8.3–8.9 mg/L; and conductivity, 167– 229 mS. Groups of experimental animals, each consisting of 20 individuals, were selected at random and placed into aerated aquaria. The toxicity test consisted of a control and four concentration groups with four replications per group, resulting in a total of 80 individuals for each concentration. The different concentrations of Roundup® (20, 40, 80 and 160 mg/L) were added to the experimental aquaria. Mortality was assessed at 24, 48, 72 and 96 h after the start of the test. Test solutions were renewed every day, so the animals were transferred to new aquaria containing fresh medium every 24 h. Animals were not fed during the 48 h adaptation period and throughout the experiment. Controls were treated in the same way but without adding of pesticide to the test water. It was found that the percentage mortality in the shrimp exposed to glyphosate showed a progressive increase from the lowest to the highest concentration group. Mean mortality rates in the shrimp exposed to all concentrations at 72 and 96 hours were significantly higher than that of controls. The study indicates that even low concentration levels of Roundup® may have a deleterious effect on a very important structural group of aquatic ecosystems.

5.5. Biological control

Biological control can be an economically sustainable, environmentally safe, long-term option to manage certain targeted aquatic weeds in multi-use waters. Invasive aquatic weeds that colonize vast areas of water bodies in monotypic stands are ideal targets for biological control. However, biological control is not meant to eradicate a target weed, but merely suppress the weed populations substantially, allowing native species to return. When used in an integrated approach with other control techniques, biological agents can stress their host plants, making them more susceptible to other controlling forces. Two forms of biological control are practiced: 1) introduction of non-native organisms that function in a self-maintaining, host-density dependent manner with their target weeds (the classical or inoculative biocontrol strategy) and 2) augmentation or manipulation of indigenous organisms that, with human intervention, can be made to incite weed-suppression (the augmentative, inundative, or bioherbicide strategy). The most widely used biocontrol organisms with a proven record of success are fish and insects. Among insects *Neochetina eichhorniae* and *Cyrtobagus salvinae* are successful biocontrol agents of water hyacinth and salvinia respectively.

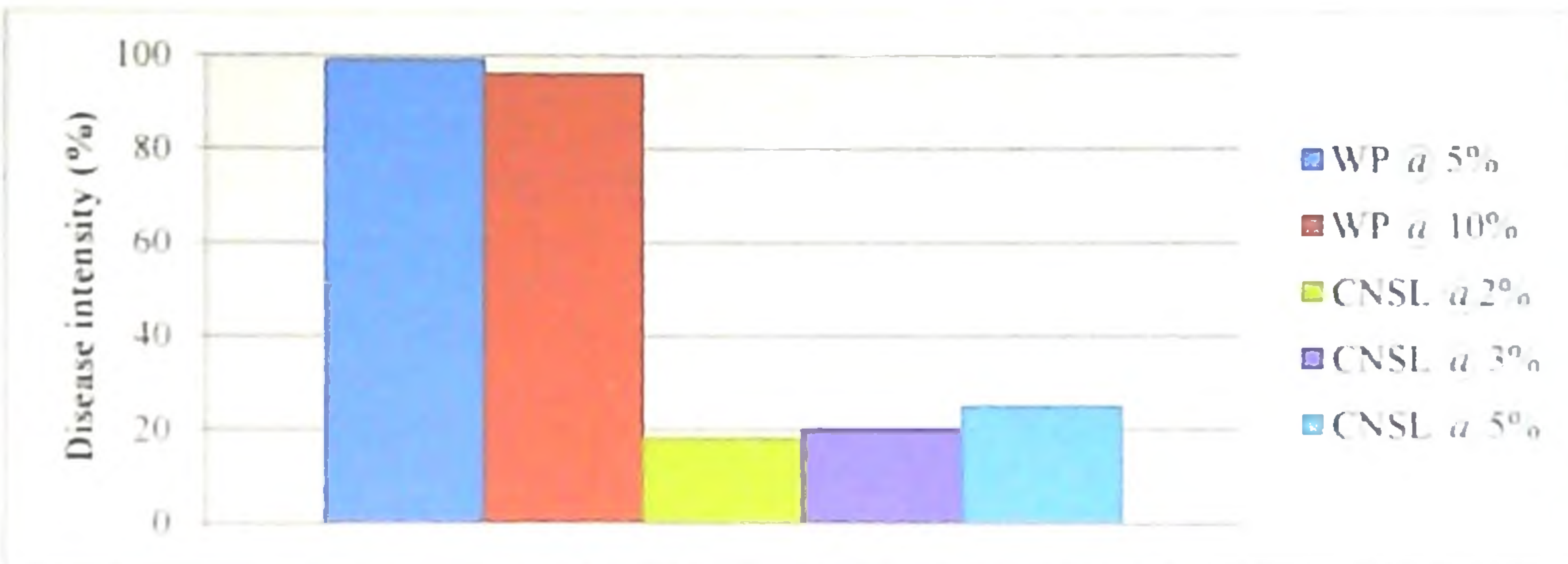
Table 3. Notable examples of aquatic weeds managed fully or partially by biological control

Aquatic weed	Insect bio agents
Water hyacinth (*Eichhornia crassipes*)	*Neochetina eichhorniae*
	N. bruchi
	Orthogalumha terebrantis
	Sameodes albiguttalis
Salvinia (*Salvinia molesta*)	*Cyrtobagus salvinae*
	Paulinia acuminata

(Kumar and Babu, 2015)

Studies conducted in the Department of Plant Pathology, College of Agriculture, Vellayani, indicated that *Fusarium pallidoroseum*, a wilt-inducing pathogen isolated from water hyacinth could restrict the multiplication and thus cause reduction in the population of the weeds. The initial symptom produced by the pathogen is brown spots with prominent yellow halo towards the tip and margins of the leaves, which later enlarged to form large brown, irregular lesions spreading from the tip downwards, covering a major area of the leaves and resulting in the blighting and drying up of the leaves. Similar symptoms were observed on the petiole and swollen portion, resulting in the drying and sinking of the whole plant to the bottom of the lake. *F. pallidoroseum* was formulated as a wettable powder (40%) and was tested on water hyacinth plants under glasshouse condition, in tanks and in an infested lake (Akkulam) at Thiruvananthapuram. Wettable powder formulation @ 5 % showed maximum disease intensity on water hyacinth (Naseema *et al.*,2004)

Figure 3. Effect of *Fusarium pallidoroseum* formulation on water hyacinth



(Naseema *et al.*, 2004)

Control of salvinia by *Cyrtobagus salvinia* is a classical example of biological control of aquatic weeds.

6. Utilization of aquatic weeds

Attempts to control aquatic weeds with physical, cultural , biological measure have generally failed on long term basis (Bindu and Ramasamy, 2012). These methods succeeded only in keeping weed infestation on check at enormous costs. So an alternative control strategy to overcome problematic aquatic weeds is to make optimum use out of it. The aquatic weeds are highly productive than conventional terrestrial crops and possess great potential and economic value. When grown on waste they donot compete with conventional crops for fertilizer, water/ land. Their natural profuse growth in humid tropical and subtropical areas of the world make them a promising source of multipurpose raw material. As a matter of fact these plants have been proved to be good sources of livestock feed, human food, fish feed, organic/biofertilizer, energy, fibre and paper. Further more aquatic weeds have the capacity to purify wastewater through the uptake of dissolved heavy metals.

6.1. Organic manure

Aquatic weeds can be used as a green manure, compost and vermicompost. For the yield of good and healthy crops. Micronutrient deficiencies have also been widely reported in some soils. For high crop yields addition of nutrients particularly N, P, K must be sufficient. Aquatic weeds have been reported to be a good source of available plant nutrients. Many aquatic weeds contain appreciable amount of N, P, K (Table 4)

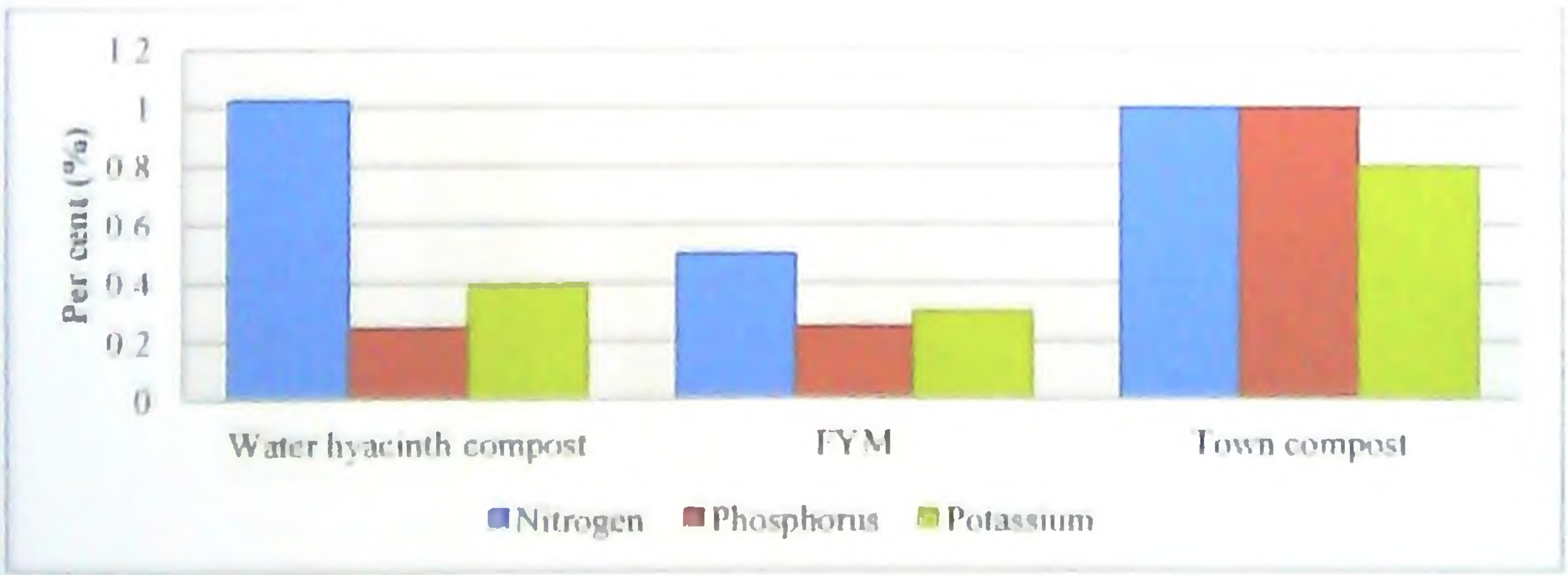
Table 4. Nutrient composition of aquatic weeds

Plant	Nutrient content (%) on dry weight basis		
	N	P	K
Water hyacinth	2.15	0.56	3.32
Duck weed	3.75	0.23	0.18
Water lettuce	2.21	0.89	2.39
Salvinia	2.05	0.67	3.30
Ghricidia	2.76	0.28	4.60
Pongamia	3.31	0.44	2.39

(Majid, 2010)

The simplest and least cost conversion which can be accomplished is merely to compost the aquatic weeds. While comparing the N,P,K content of compost prepared out of water hyacinth is four times richer than FYM (figure 4).

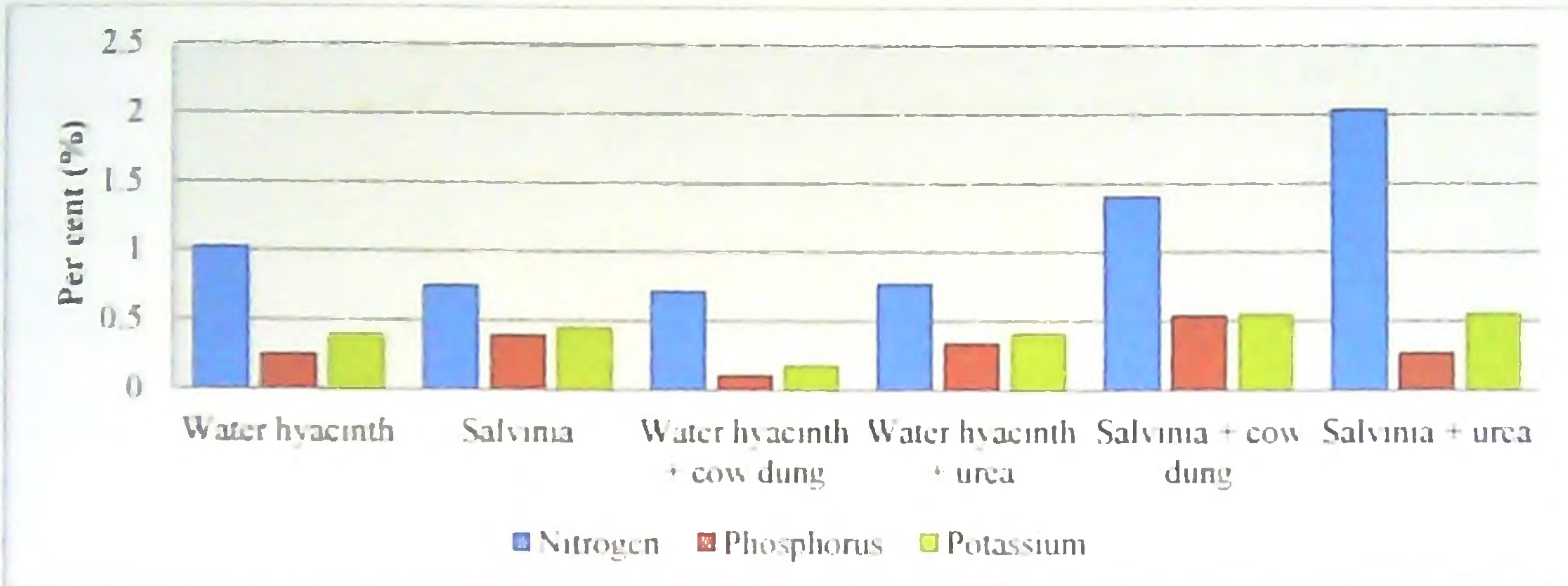
Figure 4. Comparison of N,P,K content in water hyacinth compost, town compost and FYM



(FAO, 2012)

Various studies have been conducted to hasten the composting process and nutrient value of compost prepared out of aquatic weeds. Research at RARS, Kumarakom showed that water hyacinth produce a good compost , when composted alone rather than with addition of additives, while the nutritive value of salvinia compost was found to increase by the use of additives. The addition of urea enhanced the nutritional value of compost (Geetha,2009).

Figure 5. Effect of additives on composting of aquatic weeds

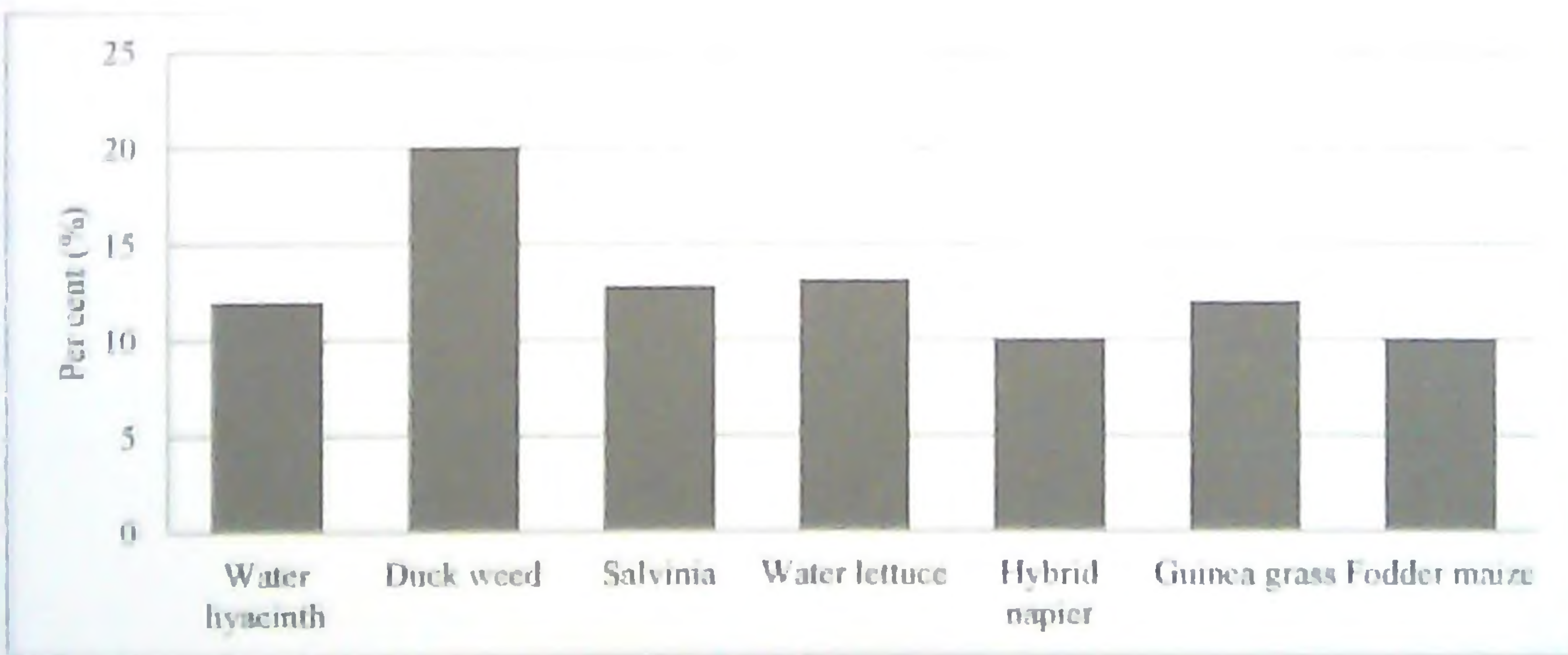


(Geetha, 2009)

6.2. Live stock feed

Aquatic weeds are good sources of protein. These may be as such incorporated into the diet of herbivorous livestock's. Water buffaloes consume aquatic plants, such as, water hyacinth. This weed is also consumed by cattle, but for good consumption it has to be mixed with right proportion of other feeds.

Figure 6. Crude protein content - aquatic weeds vs. fodder grass



(Mandal and jayasankar, 2011)

Ducks, geese and swans are commonly known to be herbivorous, although they also consume insects, snails etc. Water weeds may serve as a feed for those herbivorous water-birds, which provide man with meat and eggs. In developing countries they are promising for the use in small farms.

Processed animal feed such as silage can also be prepared out of aquatic weeds. Aquatic weeds in combination with conventional forage crops yield better quality silage.

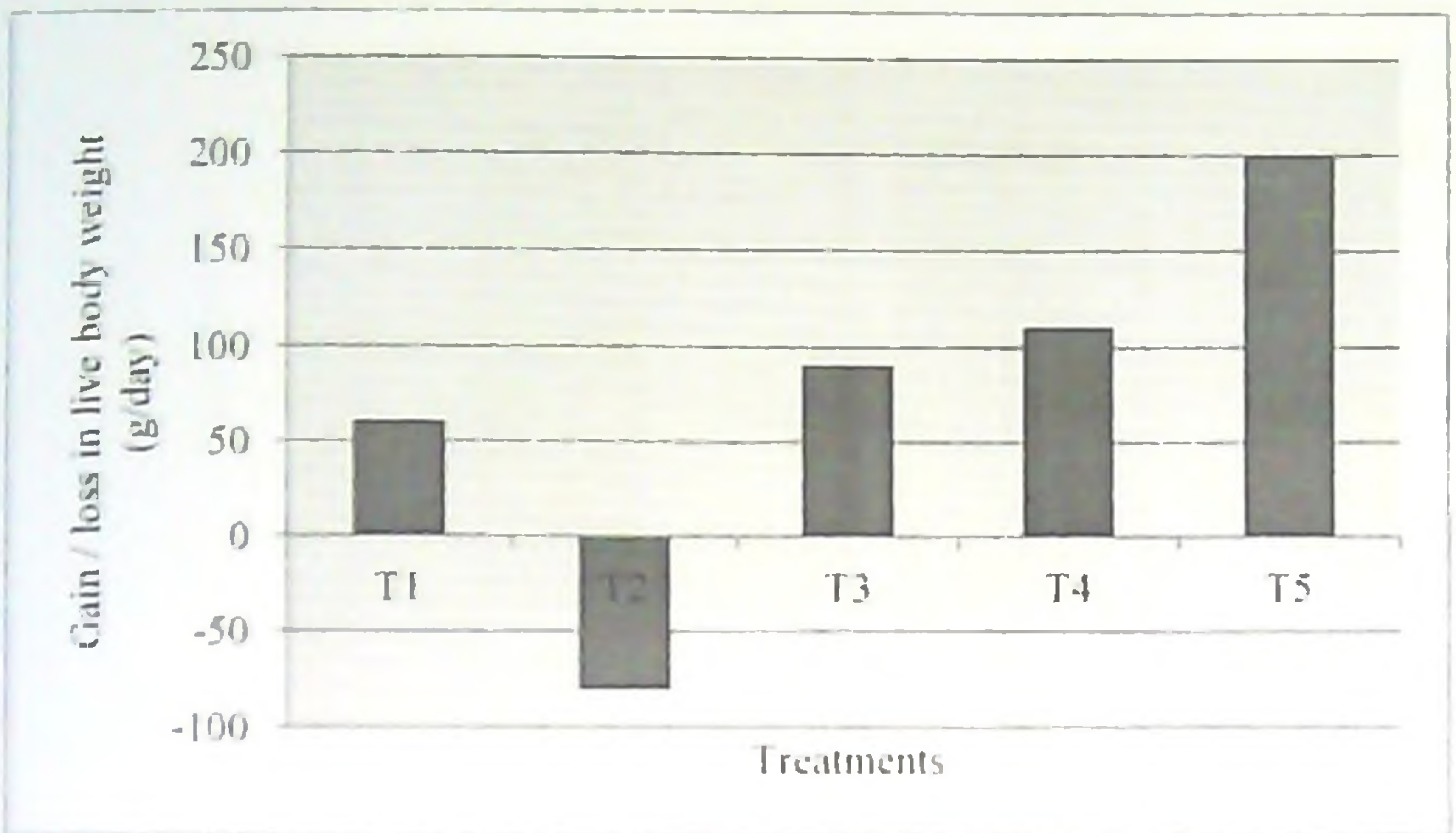
Table 4. Proximate analysis of silage from water hyacinth and para grass

Source	Moisture(%)	Crude protein(%)	Carbohydrate(%)	Crude fat(%)	Ash(%)
Para grass	77.94	1.57	9.16	1.22	3.31
Water hyacinth	90.65	0.85	3.93	0.39	2.01
Para grass + water hyacinth (1:1)	80.33	1.42	7.48	1.56	2.92

(FAO, 2012)

Aquatic weeds can be fed as such or a processed feed to livestock. Various studies being carried out in this line has reported to increase the live weight of animals fed with aquatic weeds. In such an experiment conducted at Mohanpur, Forty four male cross-bred (Jersey xHaryana) calves (6-9 m; 72-120 kg) were used to study the palatability of water hyacinth in fresh, wilted and its silage with paddy straw for a period of 6 weeks. The quantities of feed offered were @ 2.5% body weight for roughage and 1/3rd requirements of dry matter through concentrate. The amount of feed offered was adjusted every fortnightly as per live weights of the animal recorded. The experimental animals were provided with fresh and clean drinking water daily. Water hyacinth collected from pond was removed off roots and rhizomes, chopped to a size of 2.5 to 4 cm and wilted for 48 h. Wilted water hyacinth was ensiled along with paddy straw (4:1 on weight basis), urea (0.5%) and molasses (5%) on dry matter basis. It was found that Water hyacinth silage with paddy straw was more palatable than its fresh or wilted forms. Addition of molasses while ensiling increased palatability. However, fresh and wilted forms were equally good in promoting growth at all levels studied.

Figure 7. Change in live body weight of cattle



T_1 - Paddy straw (PS)

T_2 - Para grass (PG)

T_3 - Fresh water hyacinth

T_4 - Wilted water hyacinth

T_5 - Water hyacinth-paddy straw silage

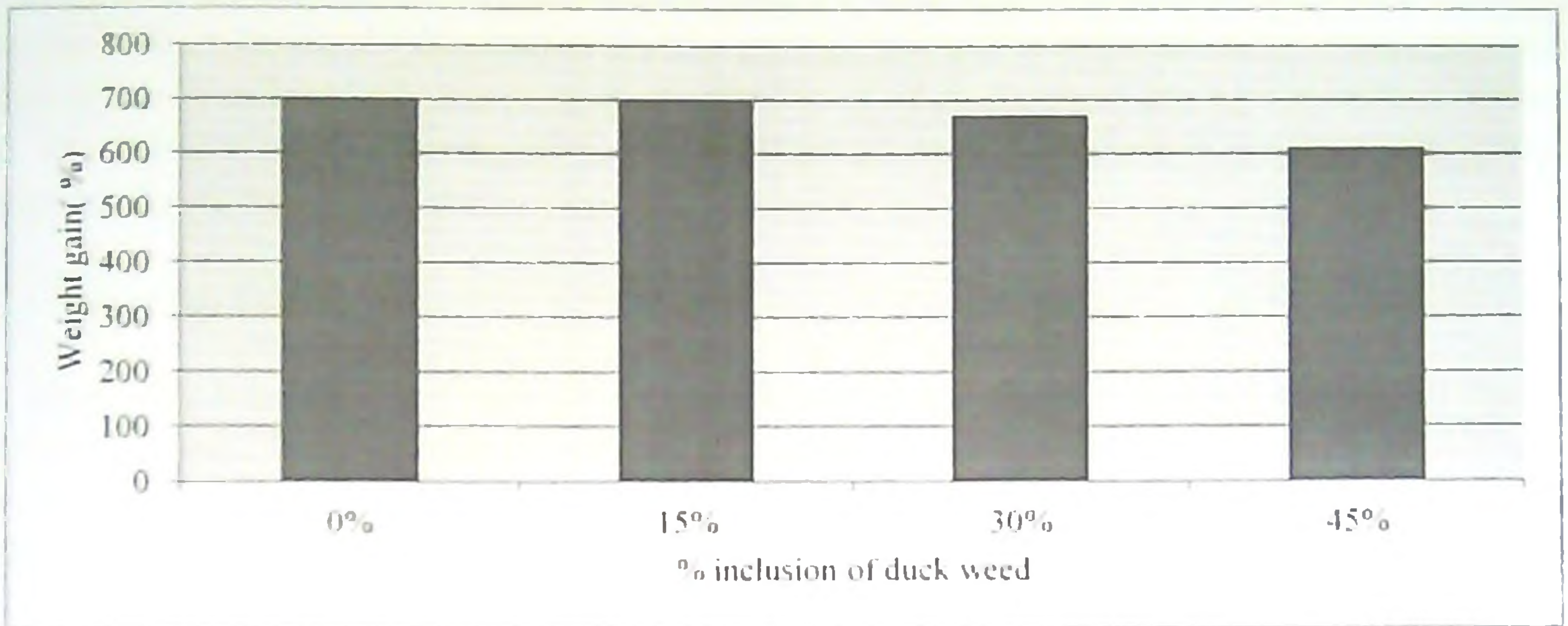
(Poddar, 1990)

6.2.1. Fish feed

Fish nutritionists have tried since years to replace the expensive fish meal component of fish feeds with less expensive plant protein feed stuffs. For maximum growth of fish, optimum protein content in the feed is necessary. Generally, protein is recognized as a frequent limiting factor for growth of cultured fish. Studies pertaining to nutrition in freshwater aquaculture had resulted in the development of new feed formulations for carps. Duck weed and water spinach with a high crude protein content can be utilised as fish feed.

Mohapatra and Patra (2013) conducted an experiment at Cuttack, to assess the acceptable nutritional value of Lemna as an ingredient in diets for *Cyprinus carpio* (L.) under aquarium culture system for 120 days. For that purpose fry of approximately equal weight were distributed in groups of 15 to each four aquaria at 0%, 15%, 30% and 45% inclusion levels of Lemna. The fry were fed at 5% body weight twice daily morning and evening. It was found that the three inclusion levels of duckweed supported the growth of *Cyprinus carpio* but growth performance, weight gain growth rate was favoured by low inclusion of duckweed meal. The study clearly showed that fry fed diet 15% duckweed dietary inclusion perform best result and fishmeal was non replaceable but can be supplemented with duckweed up to an optimum level to produce cost effective feed.

Figure 8. Effect of partial replacement of fishmeal with duck weed feed on growth of common carp

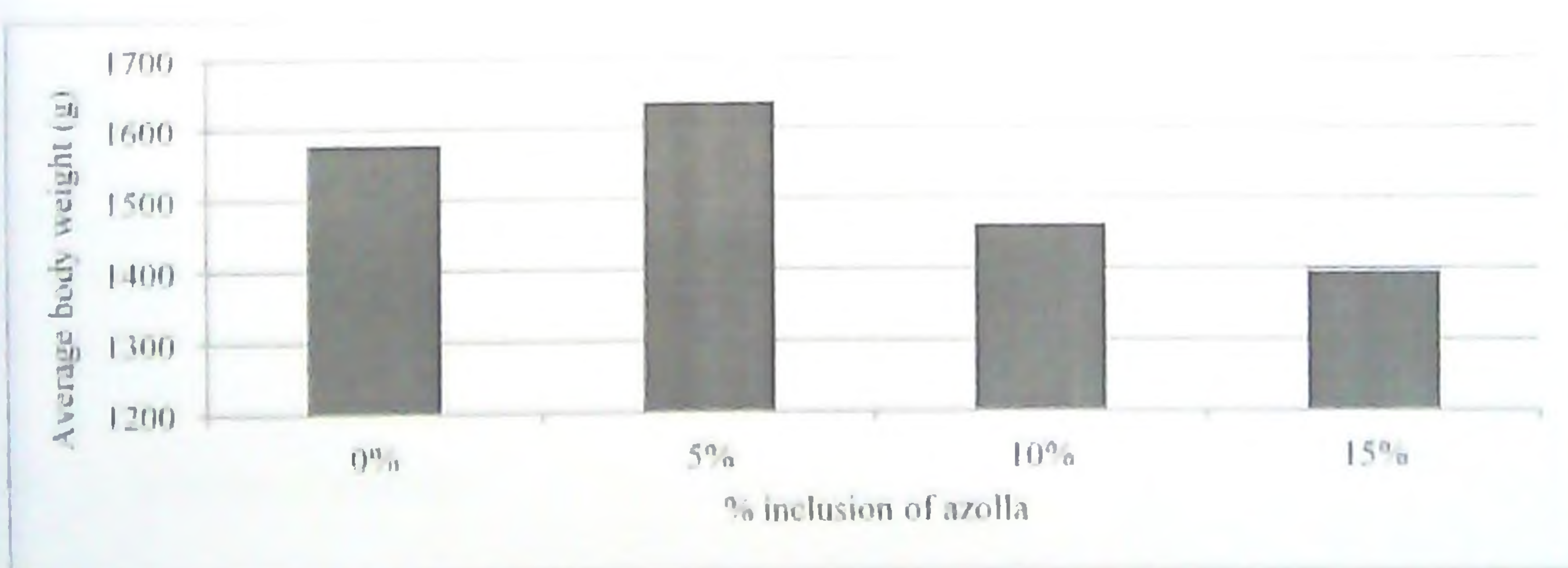


(Mohapatra and Patra, 2013)

6.2.2. Poultry feed

Now a days, poultry industry as one of the most profitable business of agriculture in India that provides nutritious meats and eggs for human consumption within the shortest possible time. Recently, broiler industry has become a rapidly developing enterprise among the other sector of poultry production. Large numbers of farms are being established in different parts of the country, which create employment opportunities to the peoples. But they are facing some problems. The two major problems are higher price and non-availability of feed ingredients to the growth of commercial poultry enter price. So in order to reduce the cost incurred in feed , unconventional feed can be utilised. Aquatic weeds with high crude protein content serve as a best alternative.

Figure 9. Average body weight of the broilers at different dietary inclusion of azolla



(Basak *et al*., 2002)

Basak *et al.* (2002) conducted an experiment at Bangladesh Agricultural University (BAU) with seven days old vencobb commercial broiler chicks and continued up to forty two days of age to determine the feasibility of azolla (*Azolla pinnata*) as a feed ingredient in broiler ration. The broilers are randomly allotted to four dietary treatments: T1 (control diet without azolla meal), T2 (diet with 5% azolla meal), T3 (diet with 10% azolla meal) and T4 (diet with 15% azolla meal) diets replacing sesame meal by azolla meal. The weekly body weight of broilers at different dietry treatments were recorded. It was found that the diet containing of 5% level of azolla meal was best in respect of body weight. The use of higher percentage of azolla meal had a deleterious effect, resulted in poor growth, this might be due to high level of non dietry fibre in azolla meal.

6.3. Paper and fiber

Increasing concerns for future fiber supplies in pulp and paper industries has shifted interest in non wood sources from agriculture residues and aquatic plants. Aquatic plants with short growth cycles, in abundance, and with low lignin are a potential fiber source. Fiber characteristics, short and thin fibers, Slenderness ratio >60, flexibility coefficient within 50–75, and runkel ratio <1, are suitable for papermaking. Handmade paper industry is an environmental friendly and very promising industry for local entrepreneurship. Papers made from aquatic plants have multiple uses. They can be used for writing, food wrapping, tissue paper, and book mark and can be commercialized as value added materials for handmade crafts.

Table 5. Comparison of fibre dimensions and lignin content

Source	Part used	Fibre length (mm)	Fibre diameter(μm)	Lignin content(%)	Slenderness ratio
Cattail (*Typha angustata*)	Stem	0.83	10.01	20.00	83.72
Bulrush (*Scirpus grossus*)	Stem	0.83	12.11	13.00	64.01
Waterhyacinth (*Eichhornia crassipes*)	Leaf	1.60	5.50	10.00	290.00
Bamboo (*Bambusa tulda*)	Stalk	1.89	7.00	25.70	111.20
Plantain(*Musa paradisiaca*)	Stem	1.55	22.00	18.21	70.50

(Bidin *et al.*, 2015)

6.4. Source of energy

A major source of energy for our dynamtic society is the burning of fossil fuels such as coal, petroleum and natural gas. These sources of energy have been found to have limited amounts available, and therefore are said to be depleting resources. Scientists are continuously looking to find alternatives to fossil fuels. One such alternative is using vegetable oils to make fuel. There are number of vegetable oils are available, like *Jatropha curcas*, *Pongamea glabra*, *Salvalora oleoides*, *Madhuca indica*, *Azadiracta indica*, *Piper nigram*, castor, coconut, sunflower, ground nut, palm trees etc. But all these have their own medicinal values and other important uses rather than the production of biodiesel. So, while selecting the best one, it should be considered that such a raw material is to be selected which is abundantly available in all times at any place and which is not useful for other purpose rather than the production of bio-diesel. As the search for alternatives to fossil fuel intensifies in this age of modernization and industrialization, fuelled by increasing energy costs, water hyacinth holds a strong promise in the 21st century biofuel industry.

Bioethanol has been produced from waste biomass produced by agricultural and forest industries such as corn cobs, sugar cane bagasse, wheat straw, and wood chip. Instead of terrestrial plants, aquatic plants are the next promising renewable energy resource. Aquatic plants have many advantages such as growing on and in bodies of water without competing against most grains and vegetables for arable land.

Mishima and co-workers in 2008 evaluated water hyacinth and water lettuce for bioethanol production. The sugar contents, aside from arabinose, in water lettuce resembled those in water hyacinth leaves. Water lettuce had slightly higher contents of starch and lower contents of cellulose and hemicelluloses. The ethanol yields per unit biomass from the two aquatic plants were comparable to those from the other agricultural wastes. It can be concluded that aquatic plants are a promising biomass for ethanol production when the fermentation process is fully optimized.

Table 6. Ethanol production potential of aquatic weeds

Biomass	Ethanol yield / unit biomass (g /g - biomass)
Water hyacinth leaves	0.17
Water lettuce leaves	0.29
Sugarcane bagasse	0.18

(Mishima *et al.*, 2007)

Aquatic weeds can also be converted to biogas by methane producing anaerobic bacteria. The high moisture content of aquatic weeds is an advantage in this process. Production of biogas removes carbon from the ferment, but other elements are hardly lost. The remaining liquid sludge is an organic fertilizer, soil conditioner equivalent to compost.

Ntengwe and co-workers in 2010 studied the production of biogas from cow dung, pig and chicken manures and from water hyacinth-cow dung mixture in cone-closed gas collector 1.5 mm thick and 0.7 m wide placed in a brick-walled batch-anaerobic digester 1.5 m deep and 0.8 m wide. Samples containing substrate (S) were mixed with water in the ratios of 1:3, 1:4 and 1:5 and left to react with bacteria-dependent enzyme (E) in the digester for hydraulic retention times (HRT) of 10 to 40 days.

Table 7. Composition of biogas

Parameter	Cow dung	Pig manure	Water hyacinth + cow dung (1:4)
Methane (%)	50 - 58	40 - 60	40 - 50
Hydrogen sulphide (%)	-	0.06 - 0.12	trace
Carbondioxide (%)	42 - 50	59 - 94	40 - 45
pH	6 - 8	6 - 9	6 - 8
Calorific value (MJ/m^3)	18 - 21	17 - 24	16 - 18

(Ntengwe, 2010)

The composition of biogas was found to be mainly methane and carbon dioxide. There was a little or trace of hydrogen sulphide. The percentage of CH_4 in biogas from cow dung was 50-58 % while the rest was CO_2. The composition of CH_4 in biogas from chicken manure, pig manure and water hyacinth was 70-85 %, 40-60 % and 45-55 % respectively at pH range of 6-8 and 27°C.

6.5. Phytoremediation

Disposal of polluted water often create health problems in densely populated countries. It has been reported that some aquatic weeds can scavenge inorganic and some organic compounds from waste water. These weeds are capable of absorbing and incorporating the dissolved materials into their own structure. The clean water produced in most situations are suitable for re-use in irrigation and industry.

The contamination by heavy metals is serious concern for surface water and ultimately for animal and human health. Heavy metals, unlike organic pollutants can not be destroyed or changed to forms that are harmless. Treatments for remediation of polluted waters, should therefore aim at extracting these substances from water and concentrating them before final disposal. Among macrophytes, weeds are more suited to remove heavy metals from water due to its fast growth resulting high biomass. Therefore, phytoremediation of heavy metals using locally available potential weeds get more attention as remedial measures in present context. Among the aquatic plants, *Eichhornia crassipes*, (water hyacinth) is a common aquatic weed in many tropical countries which has the ability to take up and accumulate elements from water and has been successfully used as indicator of heavy metal pollution. *Alternanthera philoxeroides* (alligator weed) is also a serious weed grown both in aquatic and terrestrial environment which were also found to be the potential scavengers of heavy metals from aquatic environment. Roots usually show higher heavy metal content than shoots as they come into contact with the toxic metals (Table 8).

Table 8. Heavy metal removal by aquatic weeds

Aquatic weed	Plant part	Heavy metal (mg/kg)				
		Ni	Cd	Cu	Fe	Mn
Alligator weed	Shoot	441	16	2,448	3,586	1,666
	Root	149	12	2,839	569	1,196
	Total	**590**	**28**	**5,287**	**4,155**	**2,862**
Water hyacinth	Shoot	57	2	552	2,645	1,014
	Root	253	22	2,868	6,576	6,624
	Total	**310**	**24**	**3,420**	**9,221**	**7,638**

(Khankhane *et al.*, 2014)

Khankhane *et al.* (2014) studied the heavy metal extracting potential of common aquatic weeds in Madhya Pradesh. Different aquatic weed species and water samples were collected from various pond sites such as Ranital, Gullowa, Mansingh, Mahanadda, and Adhartal in Jabalpur, during winter 2008 and 2009. Five composite water samples were collected randomly from the ponds on which the test plants were growing. The five water samples were mixed, filtered through 0.45 micron membrane filter for analysis. For each plant species, five plants were collected randomly at the maturity stage. The plant samples were thoroughly washed and dried at 70 0C for 48 hours, ground and mixed for metal analysis. Weed samples (1 g) were digested in concentrated nitric and perchloric acid (5:1) till a clear solution was obtained. The solution was filtered, reconstituted to the desired volume and analysed by atomic absorption spectrophotometer. It was reported that water hyacinth accumulated higher concentration of, Cd, , Fe and Mn, whereas alligator weed accumulated greater concentration of Cu and Ni.

6.6. Source of human food

Wild rice, taro, swamp taro , arrow head, cattail etc are, carbohydrate rich aquatic plants consumed by man. Water spinach and chinese water chestnut are valued as vegetable in some tropical countries. Some aquatic weeds are even cultivated and used as human food. But a good number of aquatic weeds are not cultivated at all, but their products are harvested and consumed as human food in many parts of the world. Some examples are furnished in Table 10.

Table 9. Aquatic weeds as a source of food

Aquatic weed	**Edible part**
Taro (*Colocasia esculenta*)	Tubers , leaves
Swamp taro (*Cyrtosperma chamissonis*)	Corm
Chinese water chestnut (*Eleocharis dulcis*)	Corm
Water spinach (*Ipomoea aquatica*)	Young leaves and stem
Lotus (*Nelumbo nucifera*)	Petiole, peduncle, rhizome, seed
Water lilly (*Nymphaea nouchali*)	Petiole, peduncle, rhizome, seed
Water cabbage (*Lymnocharis flava*)	Young leaves, stem, inflorescence
Azolla (*Azolla pinnata*)	Whole plant

(Mandal and Jayasankar, 2011)

The nutritive value of edible aquatic weeds are comparable to that of conventional terrestrial food crops (Table, 11)

Table 10. Comparison of nutritive value of tubers of taro and cassava

Source	Protein (%)	Carbohydrate (%)	Energy (Kcal)
Taro (*Colocasia esculenta*)	3	21	97
Swamp taro (*Cyrtosperma chamissonis*)	0.5	18	58
Cassava (*Manihot esculenta*)	1.36	38	160

(Mandal and Jayasankar, 2011)

Some of the aquatic weeds are also a rich source of carotene, which is a precursor of vitamin A. Azolla contain highest amount of carotene compared to any other commonly used leafy vegetable (Table 12)

Table 11. Carotene content of aquatic weeds

Source	Carotene content (µg/100g)
Azolla	63200
Taro leaves	10278
Ipomoea leaves	1980
Amaranth	14190
Curry leaves	7560

(Mandal and Jayasankar, 2011)

6.7. Therapeutic value

Many of the aquatic weeds were used as source of medicine in traditional knowledge system . *Pistia stratiotes* was used in Egypt for healing skin diseases and wounds. In India it is used after boiling the leaf juice in coconut oil. A preparation from the leaves in sugar and rosewater is taken for coughs and asthma. The roots provide a laxative and diuretic. The decoction prepared out of flowers of *Nelumbo nucifera* is used against Diarrhoea, cholera, fever, piles, dysentery and dyspepsia. Leaf extract of *Pistia stratiotes* is used for Eczema,leprosy, ulcer, piles and syphilis.

6.8. Other uses

Aquatic weeds have many other uses apart from the uses discussed above . They are being used as a substrate for bio plastic production, for phyto degradation of textile dyes, manufacture of essence sticks and handicrafts, as bedding media for mushroom, as beds for floating garden , for thatching *etc*.

7. Conclusion

Eradication of aquatic weeds has been proved to be impossible inspite of the sincere efforts of the scientists and technologists. Therefore, there is a need to divert research activities towards their utilisation and it is essential to design national-level policy for their proper utilisation. Abundantly available aquatic weeds should be used as organic fertilizer, livestock feed, human food, source of biogas, fibre and pulp. These should also be employed for purifying waste water. Measures should also be taken to prevent further introduction and spread of invasive aquatic weeds.

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9. Discussion

1. What do you mean by Beel fisheries?

   Beel fisheries is the low land areas of Assam, which is solely used for fish production.

2. Can you explain the use of dyes in controlling aquatic weeds?

   Blue coloured dyes are used in small ponds as a control measure for aquatic weeds. The addition of dye reduces the light intensity and there by controls the weed multiplication.

3. Para grass is also a weed, how it can be used to displace Typha?

   In competitive displacement, a more competitive plant is used to displace the aquatic weeds. In Chambal irrigation project para grass was used to control typha. At that time para grass was utilised as a fodder crop.

4. Which is the classical example of aquatic weed control in Kerala, especially in kuttanad?

   The classical example of aquatic weed control in Kerala and which is widely adopted in Kuttanad is the biological control of salvinia by *Cyrtobagus salvinia.*Over 29,000 hectares of paddy field infested with salvinia was recovered by release of the biocontrol agent.

5. What do you mean by bioplastics?

   Bioplastics are biodegradable plastic derived from biological substances rather than petroleum.

6. How bioplastic is obtained from water hyacinth?

   To make poly hydroxyl butyrene, researchers dried and crushed water hyacinth into a fine powder and subjected it to acid and enzyme treatment in the presence of water. The end product was used to grow *Cupriavidus necator*, a bacterium known to produce PHB, in the presence of organic and inorganic nitrogen sources. As the bacteria grew, PHB was found to accumulate inside them. Researchers ruptured the bacterial cells using an alkaline solution and extracted the PHB. Maximum PHB, 4.3 grams per litre, was obtained from the bacteria cultured using the products of enzymatic breakdown of water hyacinth powder.

7. What is the economic advantage of utilisation of aquatic weeds over the conventional control measures?

   Utilisation of aquatic weeds as livestock feed, organic manure, energy source etc. reduces the cost incurred.

10. Abstract

KERALA AGRICULTURAL UNIVERSITY

COLLEGE OF HORTICULTURE, VELLANIKKARA

Department of Agronomy

AGRON 591: MASTER'S SEMINAR

Name: Atheena A. **Venue:** Seminar Hall

Admission number: 2014-11-134 **Date:** 12-11-2015

Major advisor: Dr. P. Prameela **Time:** 10.45 a.m.

Aquatic Weeds – Problems and Potential

Abstract

Aquatic weeds, the vigorously growing plants completing their life cycle in water, are a serious menace to the environment and agriculture. In India, out of about 160 aquatic weeds, *Eichhornia crassipes* (Water hyacinth), *Ipomoea aquatic* (Water spinach), *Typha angustata* (Cattail), *Nymphaea stellata* (Water lilly), *Salvinia molesta* (Water fern), *Nelumbo nucifera* (Water lotus), *Alternanthera philoxeroides* (Alligator Weed), *Hydrilla verticillata* (Hydrilla), *Vallisneria spiralis* (Eel grass), *Chara* spp. and *Nitella* spp. are of primary concern (Kumar and Babu, 2015). Kerala, bestowed with inland water resources and wetlands is facing serious problems due to alien invasive aquatic weeds like water hyacinth, salvinia, alligator weed *etc.* and management of these weeds are a major concern in many parts of the state.

Infestation of aquatic weeds affects drainage, navigation, aesthetics, fish production, irrigation, biodiversity and recreational and land values (Pimentel *et al.*, 2010). Attempts to eradicate or control aquatic weeds with physical, cultural, biological and chemical measures have generally failed throughout the world on a long term basis (Bindu and Ramasamy, 2012).

The aquatic plants are generally more productive than terrestrial crops and most of these species can be exploited for varied uses which can be a better alternative for managing the problems caused by them. A number of aquatic weeds such as alligator weed, water spinach , swamp taro, water chestnut, water lettuce *etc.* are used as human food. The high protein content of aquatic weeds makes it a valuable livestock and poultry feed. Aquatic weeds also have been reported to be a good source of organic manure, as many aquatic weeds contain appreciable amount of nitrogen, phosphorus and potassium (Majid, 2010). Bulrush (*Scirpus grossus*) and Cattail (*Typha angustifolia*) are suitable aquatic plant species for papermaking based on their fibre characteristics, chemical composition and physical properties (Bidin *et al.*, 2015). Water hyacinth is a good feedstock and can be utilized as an energy source. The aquatic weeds are well known for accumulating and concentrating heavy metals, and this property is being utilized in phytoremediation. Some weeds have medicinal properties and have therapeutic value.

Aquatic weeds are generally regarded as a menace, because we are not aware of the potential uses of these highly productive plants. So there is a need to divert research activities and it is essential to design national level programmes for their proper utilization. Strict laws may also be enforced to prevent further introduction and spread of invasive aquatic plants.

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SEMINAR REPORT

MIRACLE MARINE ALGAE AND THEIR POTENTIAL IN AGRICULTURE

By

ARCHANA C.R.
(2014-11-136)

Submitted in partial fulfilment of requirement of the course
AGRON 591- Master's Seminar (0+1)

DEPARTMENT OF AGRONOMY
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DECLARATION

I, ARCHANA C. R. (2014-11-1316) hereby declare that the seminar entitled '**Miracle marine algae and their potential in agriculture**'has been prepared by me, after going through various references cited at the end and has not been copied from any of my fellow students.

Vellanikkara

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CERTIFICATE

This is to certify that the seminar report entitled '**Miracle marine algae and their potential in agriculture**' has been solely prepared by Archana C.R. (2014-11-136), under my guidance and has not been copied from seminar reports of any seniors, juniors or fellow students.

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1. Introduction

Agar was discovered in 1658 in Japan by Mino Tarozaemon, an innkeeper who was said to have discarded some surplus seaweed soup and noticed that it gelled later after a winter night's freezing.

Agar was first used in microbiology in 1882 by the German microbiologist Walther Hesse, an assistant working in Robert Koch's laboratory, on the suggestion of his wife Angelina Fannie Eilshemius Hesse. He discovered that it was more useful as a solidifying agent than gelatin, due to its better solidifying temperature.

Agar was first subjected to chemical analysis in 1859 by the French chemist Anselme Payen, who had obtained agar from the marine algal seaweed species *Gelidium corneum*. So far our knowledge about marine algae is restricted to its potential in agar production only. However, there are immense uses of marine algae in various other fields like agriculture, pharmaceuticals, cosmetics and food industry.

2. Marine algae

Marine algae can be broadly classified as marine microalgae and marine macroalgae. Marine microalgae(phytoplanktons) are further subdivided into diatoms(Bacilliorophyta), green algae(Chlorophyta), golden brown algae(Chrysophyta),blue green algae(Cyanophyta), eustigmatophytes(Eustigmatophyta), prymnesiophytes(Prymnesiophyta). Marine macroalgae **(seaweeds)** are further subdivided into green algae/green seaweeds (Chlorophyta), brown algae/brown seaweeds (Phaeophyta), red algae/red seaweeds (Rhodophyta).

3. Seaweeds

Seaweeds refer to any large marine benthic algae that are multicellular, macro-thallic, and thus differentiated from most algae that are of microscopic size (Smith, 1944).

4. Classification of seaweeds

Seaweeds are classified into three based on the pigments present in their cell wall.

Green seaweeds	Brown seaweeds	Red seaweeds
Chlorophyta	Phaeophyta	Rhodophyta
Chlorophyll a, b	Chlorophyll a, c, fucoxanthin	Chlorophyll a, d, phycoerythrin
Closer to shores	Cold waters	Deeper waters

4.1 Green seaweeds

Some of the green seaweeds are shown here

Plate 1. *Ulva lactuca*

Plate 2. *Codium fragile*

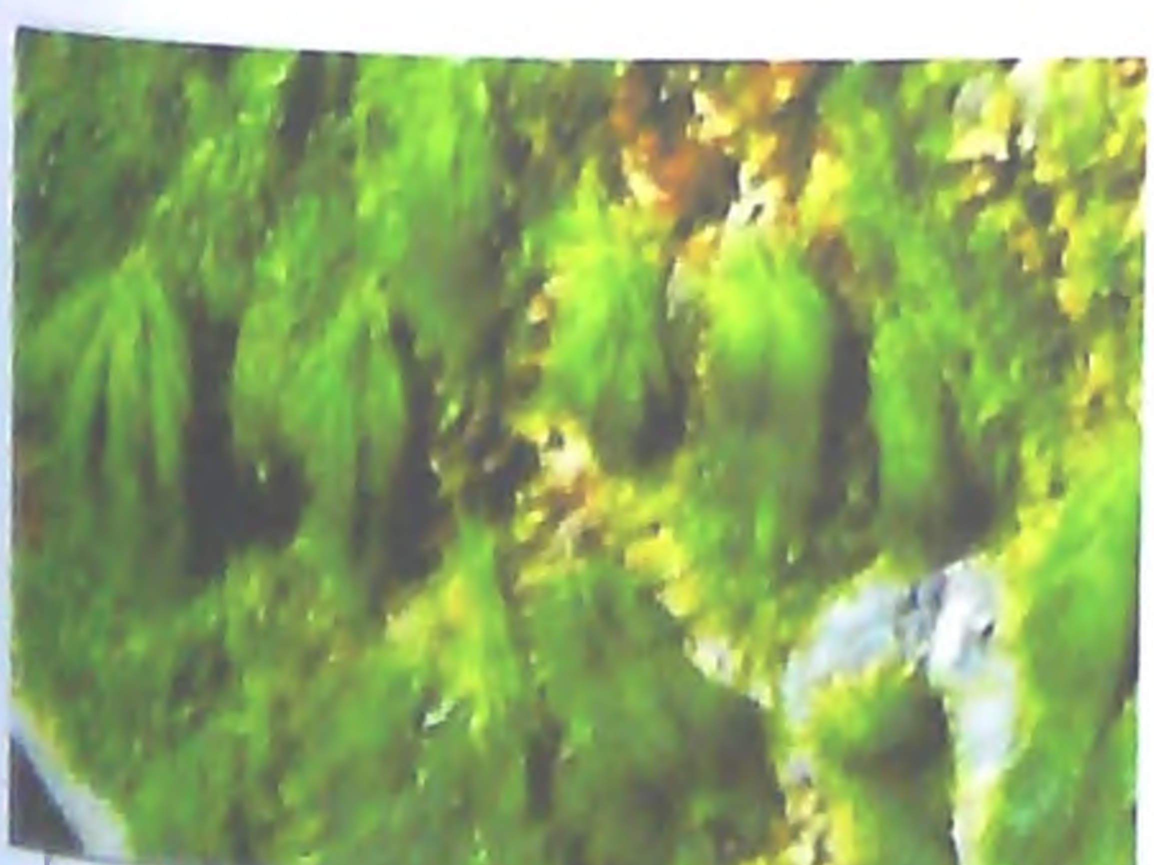


Plate 3. *Spongomorpha aeroginosa*

Plate 4. *Prasiola stipitata*

4.2 Brown seaweeds

Some of the brown seaweeds are shown here

Plate 5. *Ascophyllum nodosum*

Plate 6. *Himanthalia elongata*

Plate 7. *Fucus serratus*

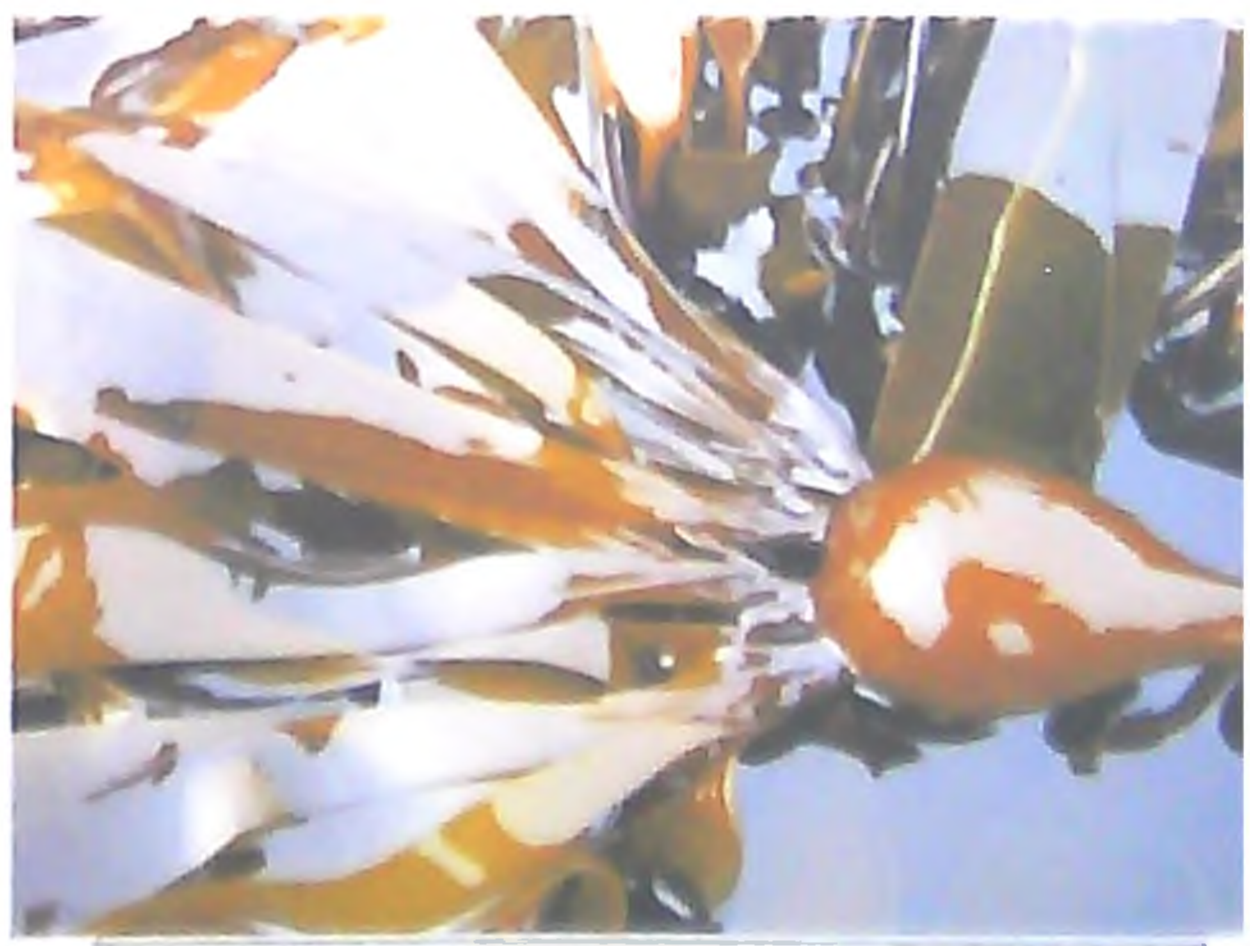


Plate 8. *Laminaria digitata*

4.3 Red seaweeds

Some of the red seaweeds are shown here

Plate 9. *Porphyra umbilicalis*

Plate 10. *Palmaria palmata*

Plate 11. *Gracilaria verrucosa*

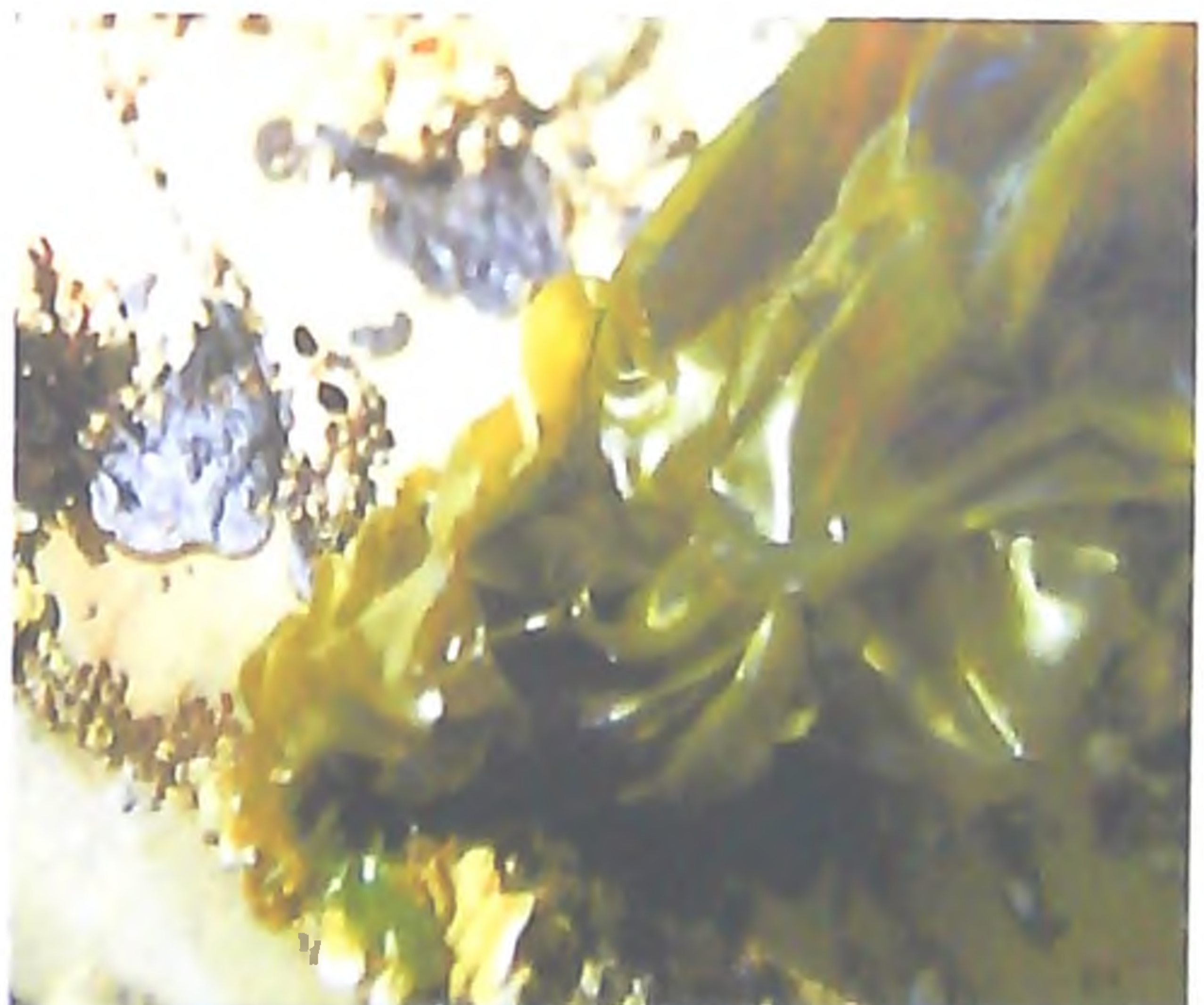


Plate 12. *Chondrus crispus*

5. Structure of a typical seaweed

This is a very diverse group of organisms. Although they lack true leaves, stems and roots, they have got some structures similar to terrestrial plants. The entire body of seaweed is known as thallus, no matter the growth form. Each part of the thallus can photosynthesize.

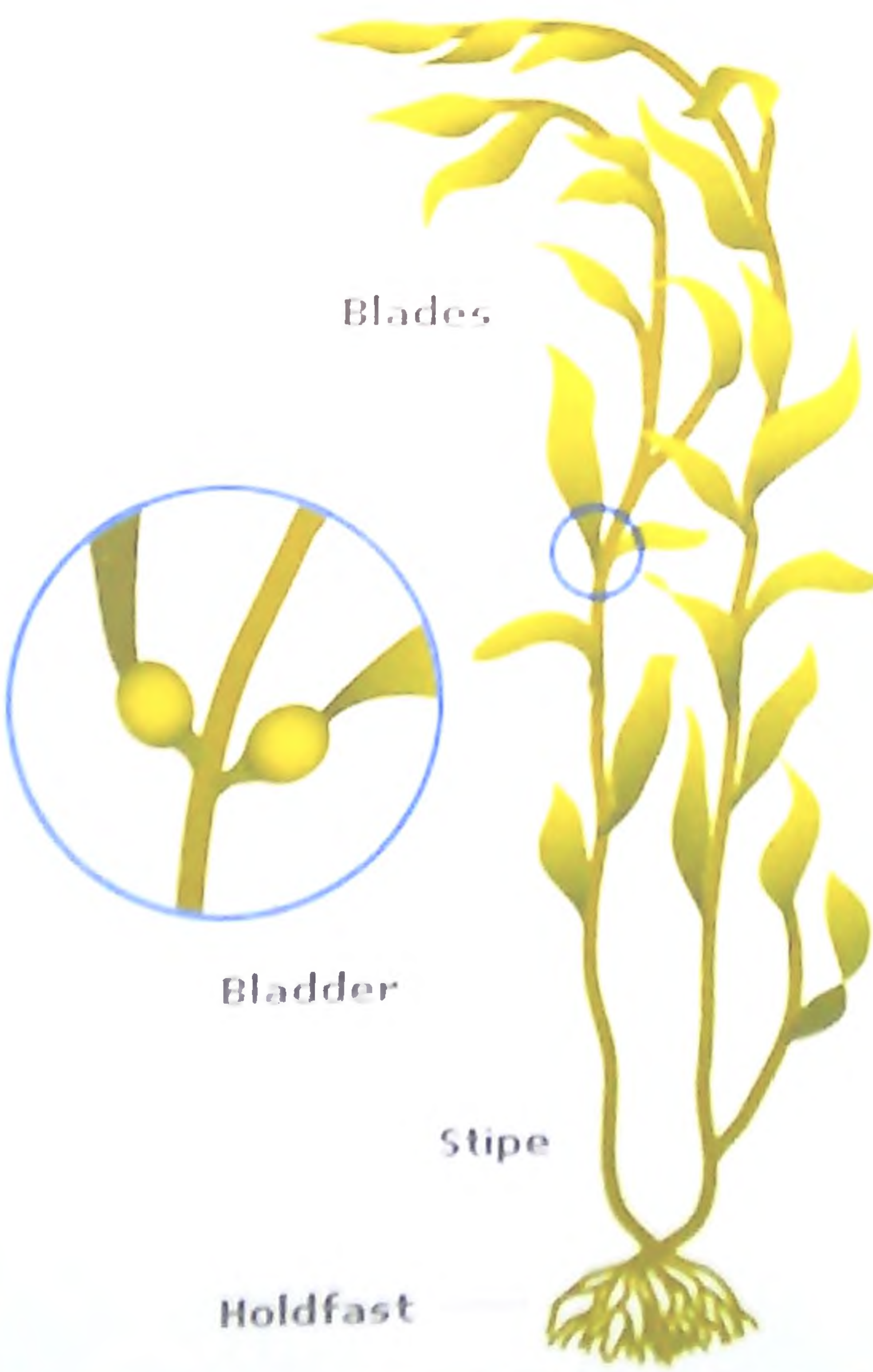


Figure 1. Structure of seaweed

(Kempanna, 2009)

5.1 Blades

Blades are the leaf like structures found in seaweeds. Their function is to absorb sunlight and conduct photosynthetic activity. They are not true leaves since they lack veins. Certain seaweeds have only single blade. Some others have many blades.

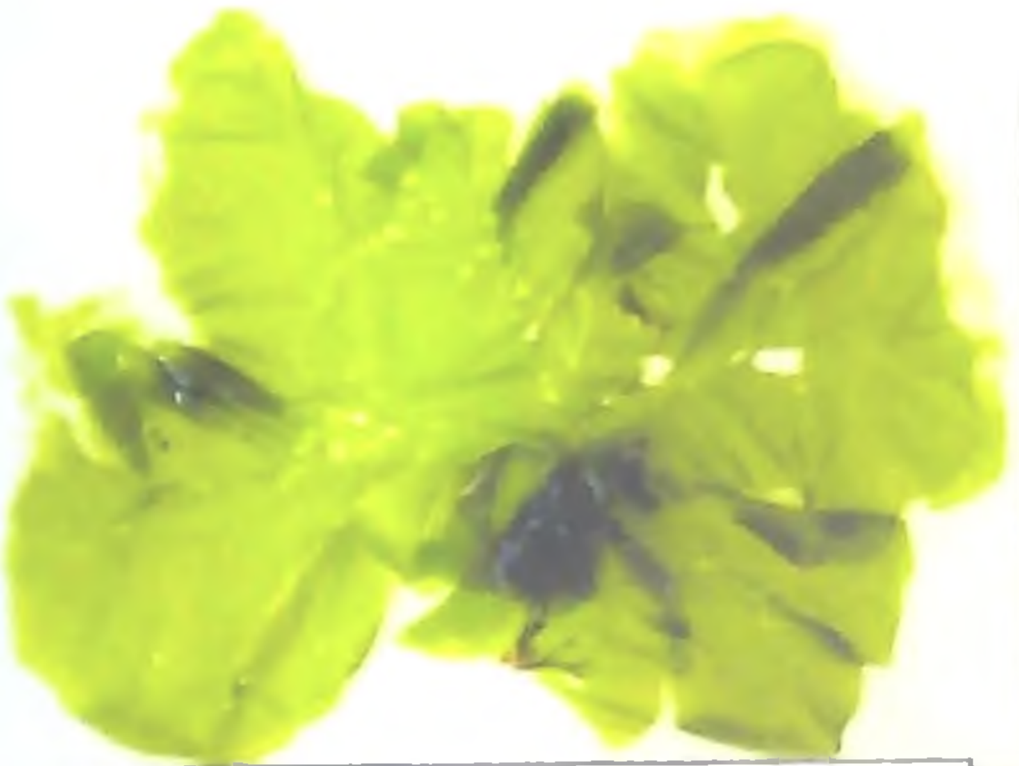


Plate 13. Single blade

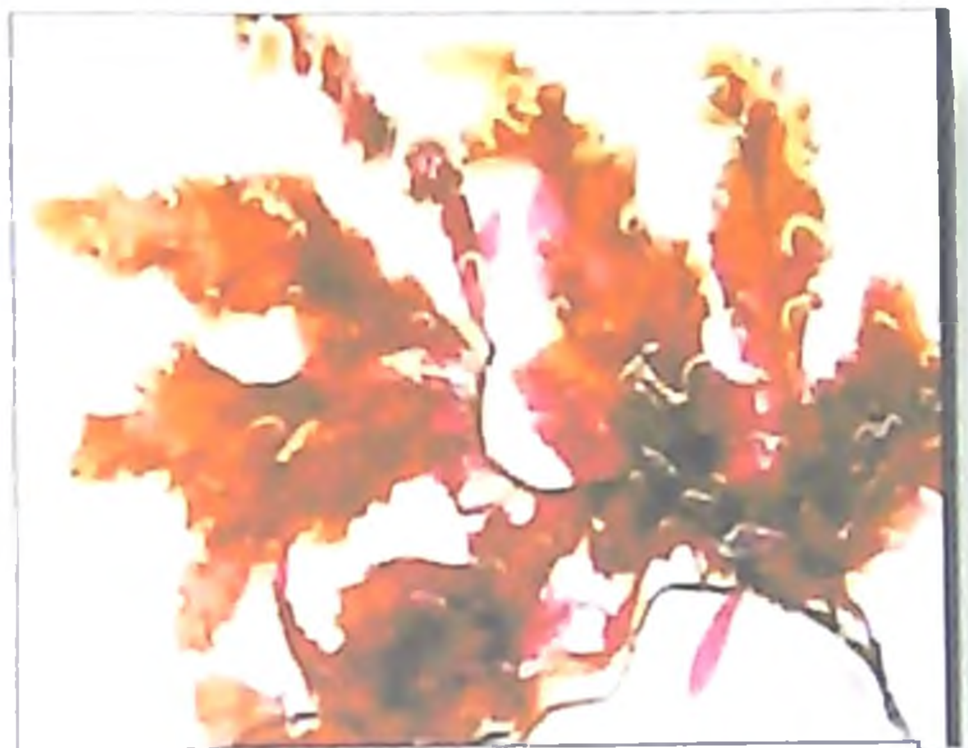


Plate 14. Multiple blades

5.2 Floats

Floats are the air filled sacs present in seaweeds. Floats are also known as bladders or pneumatocysts. It helps the blades to float on water. Maximum photosynthesis takes place in the floats. Certain seaweeds have only single float. Some others have many floats. Sometimes floats may be absent in some species.

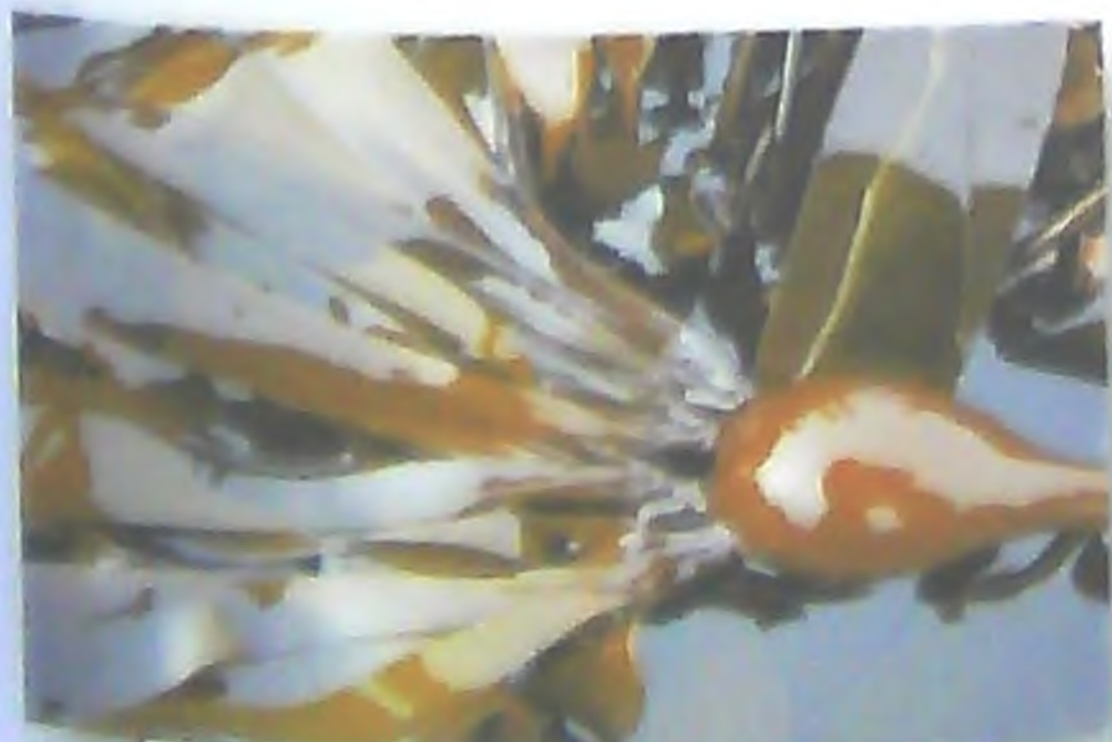


Plate 15. Single float

Plate 16. Multiple floats

5.3 Stipe

Stipes is the stem like or stoke like structures in seaweeds. Their function is to provide support for the seaweeds structure of stipe varies from seaweed to seaweed. They can be solid, rigid, flexible, hollow, long or short.

Plate 17. Long and rigid stipes

Plate 18. Short and flexible

5.4 Holdfast

Holdfasts are the root like structures. They help the seaweeds to attach to bottom seafloor or to rocks or to any other substratum. They serve more as an anchor. They does not aid in nutrients absorption. The finger like projections seen in holdfast is known as 'haptera'. Since all parts of seaweeds are either partially or completely in contact with sea water, they are able to take nutrients, fluids or water directly. As such they do not need any internal conducting system.

Plate 19. Holdfast attached to

Plate 20. Holdfast attached to rocks

6. Size and distribution

Sizes of seaweeds vary from tiny Irish moss to large kelps. Seaweeds can be seen attached to rocks in the intertidal zone or floating on ocean surface or washed up on the beach or can be seen as giant under water forest.

Plate 21. Irish moss

Plate 22. Kelps

7. Chemical constituents in seaweeds

7.1 Polysaccharides

Table1. Polysaccharides present in seaweeds

Chlorophyceae	Rhodophyceae	Phaeophyceae
Amylose, amylopectin	Agars , agaroids	Alginates
Cellulose	Carrageenans	Cellulose
Complex hemicellulose	Cellulose	Complex sulfated heteroglucans
Glucomannans	Complex mucilages	Fucose containing glycans
Mannans	Furcellaran	Fucoidans
Inulin, pectin	Glycogen	Glucuronoxylofucans
Laminarin xylans	Mannans ,xylans	Laminarans

(Khan *et al.*, 2009)

Polysaccharides. laminaran and fucoidan exhibit a widerange of biological activities. Direct effects of fucoidan on plants have not yet been reported, but sulfated fucoidans from brown algae have evinced biological activities in mammalian systems .Laminarin has been shown to stimulate natural defense responses in plants and is involved in the induction of genes encoding various pathogenesis–related (PR) proteins with antimicrobial properties. Alginates play an important role in soil moisture retention. Agars and carrageenans are having many industrial applications.

7.2 Growth hormones

The concentration of mineral nutrient elements present in commercial seaweed concentrates (SWCs) alone cannot account for the growth responses elicited by seaweed extracts. Beneficial effects observed in various plant growth bioassays have led to speculation that SWCs contain plant growth-regulatory substances. Furthermore, the wide range of growth responses induced by seaweed extracts implies the presence of more than one group of plant growth-promoting substances/hormones. Cytokinins have been detected in fresh seaweeds and seaweed extracts (Stirk *et al.*, 2003). Marine algae are also reportedly rich in auxins and auxin-like compounds (Crouch *et al.*, 1993). The water-soluble growth inhibitors extracted from *Laminaria digitata* and *A. nodosum* resulted in marked inhibition of lettuce hypocotyl growth (Hussain and Boney, 1973). One of these substances seemed to be similar to ABA as revealed by bioassay, thin layer, and gas liquid chromatography analysis.

7.3 Betaines

Ascophyllum nodosum extracts contain various betaines and betaine-like compounds (Blunden *et al.*, 1986). In plants, betaines serve as a compatible solute that alleviates osmotic stress induced by salinity and drought stress; however, other roles have also been suggested, such as enhancing leaf chlorophyll content of plants following their treatment with seaweed extracts. This increase in chlorophyll content may be due to a decrease in chlorophyll degradation. Yield enhancement effects due to improved chlorophyll content in leaves of various crop plants have been attributed to the betaines present in the seaweed. It has been indicated that betaine may work as a nitrogen source when provided in low concentration and serve as an osmolyte at higher concentrations (Naidu *et al.*, 1987).

7.4 Sterols

As with many other eukaryotic cells, sterols are an essential group of lipids. Generally, a plant cell contains a mixture of sterols, such as sitosterol, stigmasterol, 24-methylenecholesterol, and cholesterol. Brown seaweed chiefly contains fucosterol and fucosterol derivatives, whereas red seaweeds primarily contain cholesterol and cholesterol derivatives. Green seaweed accumulates mainly ergosterol and 24-methylenecholesterol (Khan *et al.*, 2009).

8. Uses of seaweeds

8.1 Industrial uses

Polysaccharides present in cell walls of seaweeds are known as phycocolloids. These phycocolloids are having many industrial applications. Some of the industries involved in the phycocolloid extraction and its applications are given in Table 2.

Table 2. Industrial applications of seaweeds

Seaweeds	Phyco - colloides	Industries	Industrial applications
Red	Agar	Marine chemicals (Madurai, Kerala) Golden agar agar (Madurai)	Gel capsules, food industry
Brown	Alginate	SNAP Natural and Alginate Products Ltd. Ranipet Best Chemicals, Madurai Rajaganapathy Chemicals, Madurai Algae Organic Chemicals, Kerala Hariharamatha, Kerala	Pharmaceuticals, cosmetics, paper, cardboards, cloth dyes, processed foods
Red	Carrageenan	Best Chemicals, Madurai Perumal, Madurai	Ice-creams, adhesives for paper bags, additives in pesticides

8.2 Medicinal uses

Table3.Medicinal uses of seaweeds

Seaweeds	Chemical	Treatment
Laminaria digitata	Mineral content	Goiter
Laminaria angustata	Laminine	Blood pressure
Sargassum muticum	Fucosterol	Antihyperlipidaemic activity
Gelidium sp., *Gracilaria* sp.	Agar	Blood anticoagulant
Eucheuma cottonii	Carrageenan	Cough
Ecklonia cava	Fucoidan	Leukaemia
Codium pugniformis	Inulin	Anticarcinoma activity

(Gupta and Pandey, 2007)

Chemical constituents present in seaweeds are having therapeutic values. Chinese have been using seaweeds for medicinal purposes as early as 3000 BC. The phycocolloids present in seaweeds and their corresponding treatments are given in Table 3.

8.3 Seaweeds as vegetables

Seaweeds often referred as vegetables, have been in use as a vegetable in many European and East Asian countries like China, Japan, Korea etc. although seaweeds as a vegetable is not so popular in India, there are some stray reports mentioning its use as a food ingredient in Kanyakumari sector. Here they used to prepare a special food 'gangi' out of *Hypnea* sp. It is good for curing stomach disorders. Presently 11 seaweed species (Table 4) are authorized as seaweed vegetables and condiments in the world market.

Table 4. Seaweeds authorized as vegetables and condiments in the world

Type	Species	Common name
Brown	*Ascophyllum nodosum*	
	Fucus vesiculosus	
	Fucus serratus	
	Himanthalia elongata	
	Undaria pinnatifida	Wakame, quindai cai
Red	*Porphyra umbilicals*	Nori, amanori, hoshinori, zicai, laver bread
	Palmaria palmata	Dulse, dillisk, sol
	Gracilaria verrucosa	
	Chondrus crispus	Irish moss, carrageenan
Green	*Ulva* spp.	
	Enteromorpha spp.	

(Gupta and Pandey,2007)

8.4 Biostimulants in Agriculture

There are several seaweed based available in the market having agricultural and horticultural applications. The benefits of seaweeds as sources of organic matter and fertilizer nutrients have led to their use as soil conditioners for centuries. Some 15 million metric tons of seaweed products are produced annually, a considerable portion of which is used for nutrient supplements and as biostimulants or biofertilizers to increase plant growth and yield. A number of commercial seaweed extract products are available for use in agriculture and horticulture (Table5).

Table 5.Commercial seaweed products used in agriculture and horticulture industries

Product name	Seaweed name	Company
Acadian.Stimplex	*Ascophyllum nodosum*	Acadian Agritech
Agri-Gro Ultra		Agri Gro Marketing Inc.
Alg-A-Mic		BioBizz Worldwide N.V.
Biovita		PI Industries Ltd.
Guarantee		Marine Stream Organics
Kelp Meal		Acdian Seaplants Ltd.
Maxicrop		Maxicrop USA Inc.
Soluble Seaweed Extract (SSE)		Technoflora Plant Products Ltd.
Kelpak	*Ecklonia maxima*	BASF
Profert	*Durvillea antarctica*	BASF
Seasol	*Durvillea potatorum*	Seasol International Pvt. Ltd.

9. Seaweed cultivation

As the demand for seaweed and seaweed based products grew over the years, it was felt that this might lead to over harvesting and eventually led to depletion of natural stocks very soon. Large scale removal of seaweeds from shores will endanger the lives of many aquatic plants and animals. Moreover it may cause erosion of shores also. In order to conserve the genetic diversity of seaweeds naturally along with meeting is demand for various purposes, there arise the concept of seaweed farming or seaweed cultivation. The methods of seaweed cultivation rare greatly varied. A seaweed species for cultivation is chosen according to the location of a farm and cultivation facilities (in the open sea, on the land, in the cold waters of a temperate zone, or in warm waters of the tropics) and on the productivity and availability of a species. At present, there are eight major types of seaweed cultivation.

9.1 Net method

The net method is suitable for thin seaweed such as *Ulva, Monostroma and Porphyra* which are cultivated in open areas. The method mostly starts from spore collection in nature. It was called two-step farming: nursing and cultivating. In the first step, an overlapping net is placed in shallow waters, where most seaweed crops are grown, to collect spores for several days. After the germlings grow 2-3 cm long, the net is separated to transfer in a cultivation area. In the cultivation area, the net is fixed with a bamboo pole in the intertidal zone, which will expose the net to the air during low tidal levels.

9.2 Off-bottom method

Off bottom method is also known as Post and Line method. The general approach is to suspend series of lines of 10 m length between two posts, which are usually made of wood. This technique is best suited for lagoons, where there is relatively shallow water at low tide and for small scale initiatives.

9.3 Long line method

Long line method is preferred for growing large seaweeds such as the kelps *Laminaria* and *Undaria*, in which seedling lines of 1-4 m long hang on cultured lines 70-140 m long and place in deep water zones.

9.4 Monoline method

This method is applied in shallow waters for red seaweeds such as *Eucheuma* and *Kappaphycus* species. The propagation by thallus fragment is a commercial way. Reef areas with depth of 0.61 meter a good locality for growing these seaweeds. Stocking density of 50-100 g is tied to the monoline of 10.5 m long. Their growth rates are higher above 5 percent per day.

9.5 Raft method

Raft method is followed in Kerala for cultivating *Gracilaria* sp. Here the seaweeds are cultivated using racks made of bamboo poles, with ropes stretched between poles. Branches of Gracilaria are cut and tied to the main ropes. The entire structure is then placed on the sea.

9.6 Rock based farming

Cuttings are initially attached to a rock, roughly the size of a large fist with an elastic band, although after a few weeks the seaweed establishes its own fixation points. Then the rocks are placed on the beach. However there is one major constraint to the application of this technique and that is the requirement for a site well protected from potentially rough sea conditions.

9.7 Pond method

Species which are vegetating all year round like Gracilaria are cultivated using this method. Pieces of seaweed thalli are spread to the bottom. Only *Gracilaria* sp can thrive in pond condition (low water motion). Salinity of water should be 2.5 percent and temperature 20-25°C. . ½ or one-third of seaweed crops are harvested every 4-6 weeks.

9.8 Tank method

Tank method is done only in special valuable seaweeds in pharmaceutical or premium food species of *Ulva, Gracilaria and Porphyra.* This type of culture has not attracted private investors because it is not profitable due to higher cost of additional pumping nutrients and carbon dioxide. However cultivation in the tank has role for reproductive cell collection and spore stimulation of *Laminaria/Ulva, Porphyra* etc. Co culture of fish can turn the whole system both economically and ecologically profitable.

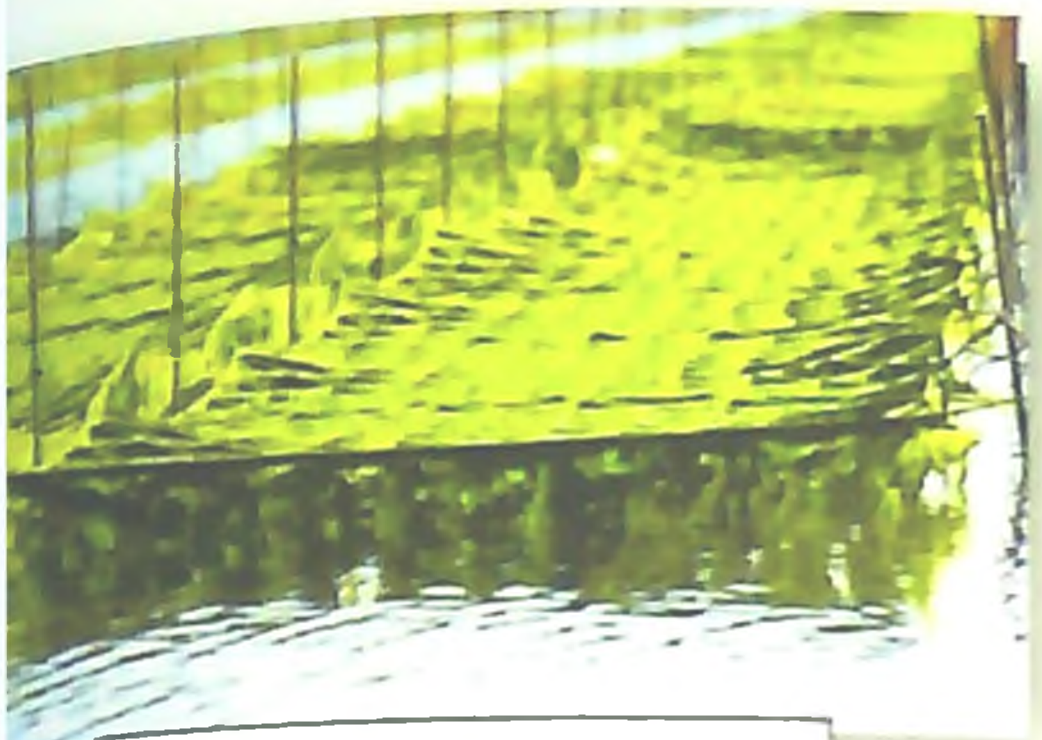


Plate 23. Net method

Plate 24. Off bottom method

Plate 25. Long line method

Plate 26. Mono line method

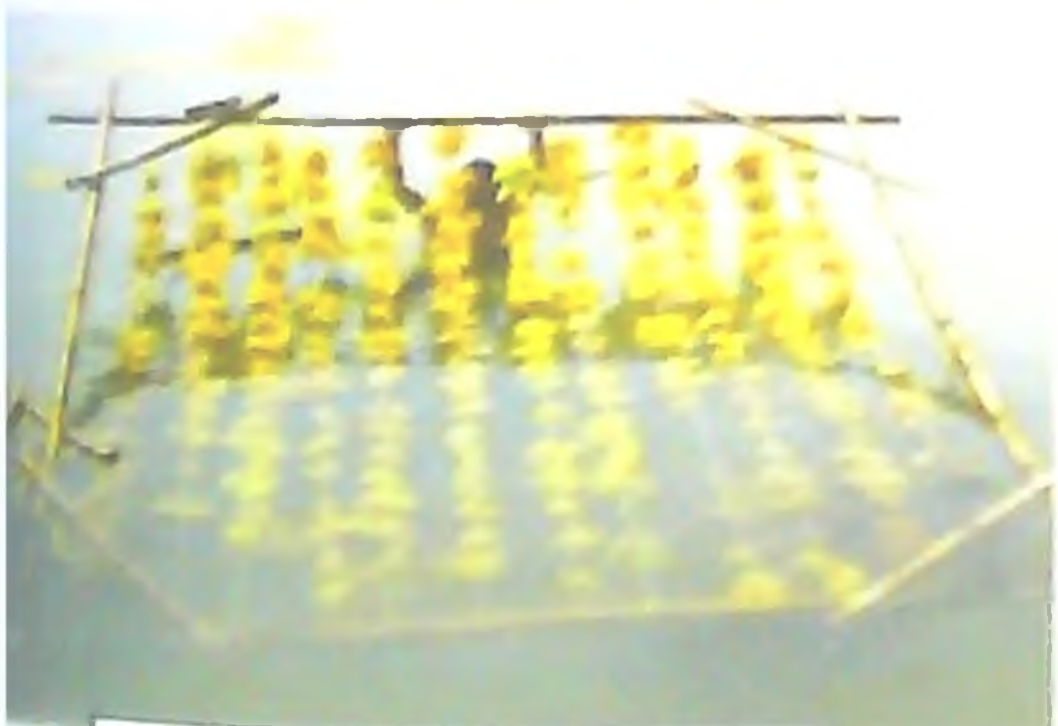


Plate 27. Raft method

Plate 28. Rock based method

Plate 29. Pond method

Plate 30. Tank method

10. Applications of seaweeds in

- **Soil management**
- **Crop management**
- **Alleviation of environmental stress**

10.1 Effects on soil health

10.1.1 Soil structure and moisture retention

Seaweeds affect the physical, chemical, and biological properties of soil which in turn influence plant growth. Seaweeds and seaweed extracts enhance soil health by improving moisture-holding capacity and by promoting the growth of beneficial soil microbes. Brown seaweeds are rich in polyuronides such as alginates and fucoidans. Alginate occurs in the cell walls of seaweeds as a mixed salt with the major cations being Na, Ca, Mg and K. Salts of agonic acid combine with the metallic ions in the soil to form high-molecular-weight complexes that absorb moisture, swell, retain soil moisture, and improve crumb structure. This results in better soil aeration and capillary activity of soil pores which in turn stimulate the growth of the plant root system as well as boost soil microbial activity.

Table6. Effect of seaweeds on water holding capacity

Source	Weight of dry sample (g)	Weight of saturated sample (g)	Percent increase in moisture
Seaweed	15	67	345
Soil	96	143	49

(Chbani *et al.*, 2013)

The above study was conducted by Chbani and his co-workers in the Doctoral School for Sciences and Technology, Lebanon. They assessed the moisture holding capacity of two supports, one made of brown seaweed *Padina pavonica* with agar source as a plasticizer and the other support made of 100% soil. They found out that water holding capacity of seaweed support was seven fold higher than soil support. Increased WHC was attributed to the higher moisture absorption capacity of phycocolloids present in the cell walls of seaweeds.

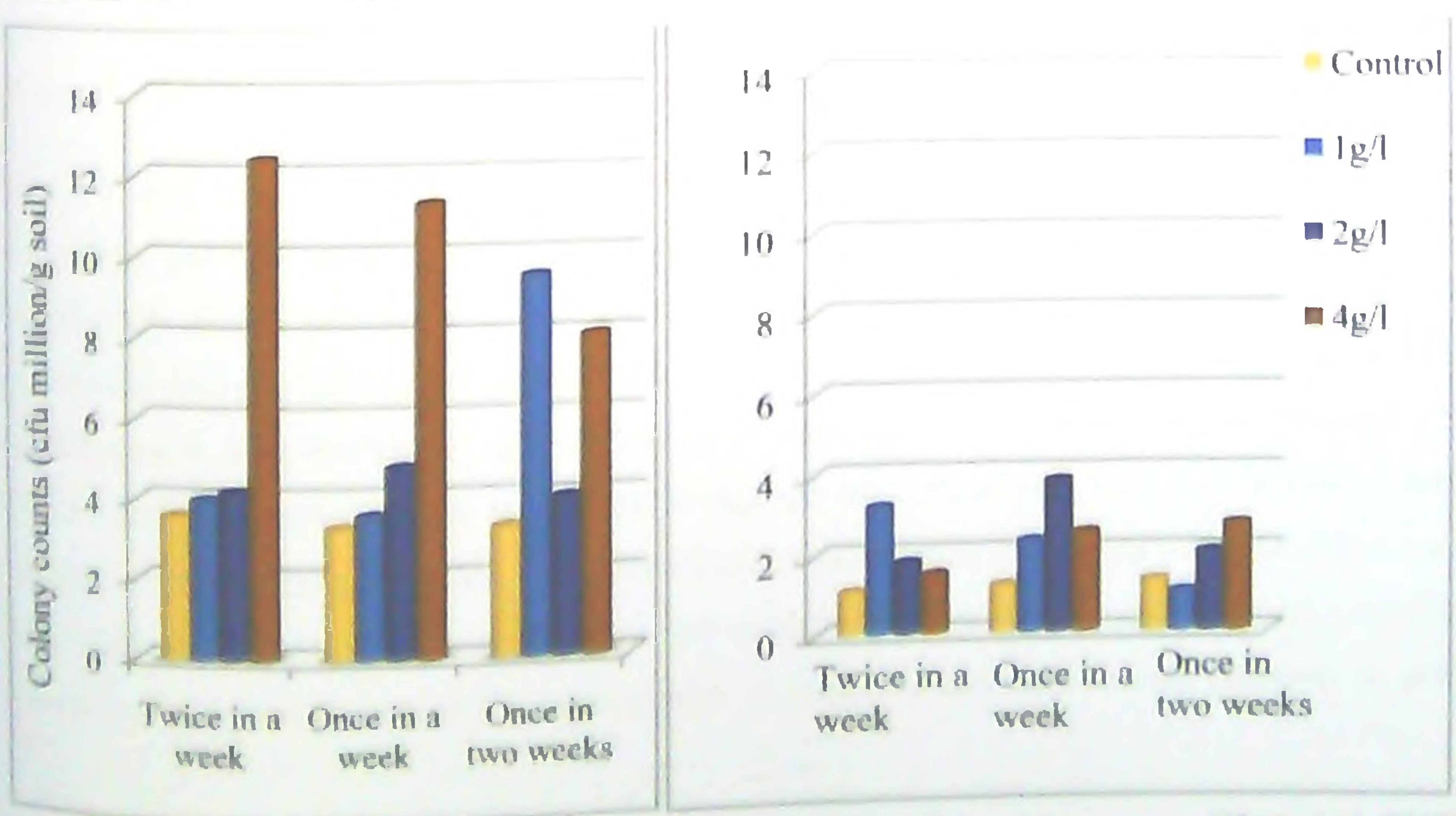
10.1.2 Effect on rhizosphere microbes

Application of seaweeds and seaweed extracts triggers the growth of beneficial soil microbes and secretion of soil conditioning substances by these microbes. As mentioned, alginates affect soil properties and encourage growth of beneficial fungi. Extracts of various marine brown algae [*Laminaria japonica* and *Undaria pinnatifida*] could be used as an AM fungus growth promoter by significantly stimulating hyphal growth and elongation of arbuscular mycorrhizal (AM) fungi (Kuwada *et al.*, 2006).

A study was conducted by Alam and his co-workers (2013) to find the effect of Soluble Ascophyllum Extract Powder (SAEP) on beneficial soil microbes of strawberry both under green house and field condition (Figure2) in the Atlantic Food and Horticulture Research Centre, Canada.

Figure2. Effect of seaweed extracts on growth of beneficial microbes

Green house Field



(Alam *et al.*, 2013)

They found out that Microbial colony development varied in response to different SAEP rates and application timings under greenhouse and field conditions. At 4 g /LSAEP, the number of colonies was significantly higher under greenhouse conditions compared with water-treated controls, irrespective of application timings. Total colony counts were four- and sevenfold greater in the greenhouse than those in the field. This difference is probably related to ambient temperature differences between the two growing conditions and soil sampling in the green house and field. Greenhouse day and night temperatures ranged between17 and 30°C during the entire growth period, while in the field, day and night temperature ranged between 11 and 25°C. Cooler soil temperatures, in the field plot study may have reduced bacteria in soil relative to the warmer greenhouse environment.

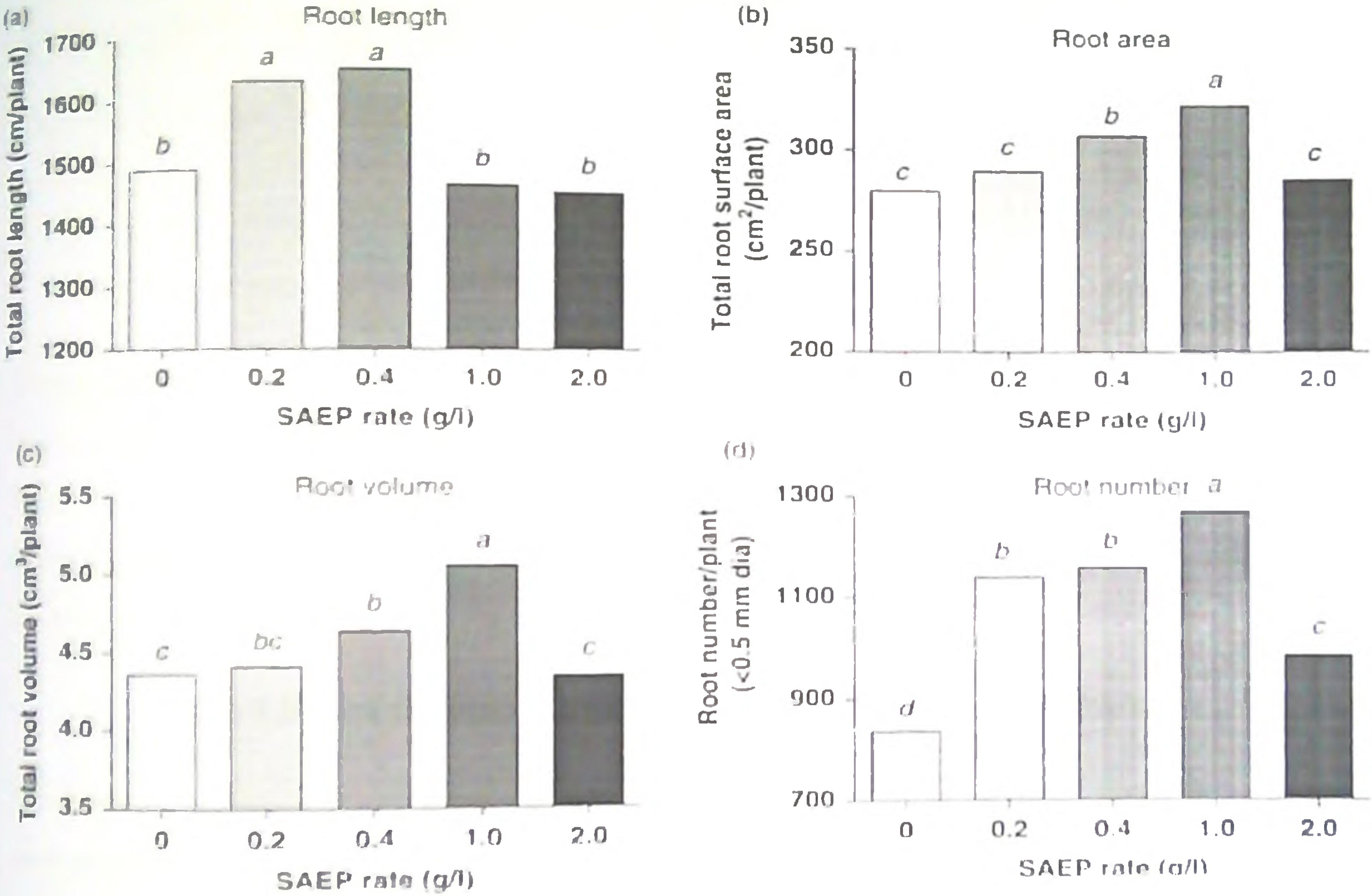
10.2 Effect on plant growth and health

10.2.1 Root development and mineral absorption

Seaweed products promote root growth and development. The root growth stimulatory effect was more pronounced when extracts were applied at an early growth stage, and the response was similar to that of auxin, an important root growth promoting hormone. An improved root system could be influenced by endogenous auxins as well as other compounds in the extracts. Seaweed extracts improve nutrient uptake by roots, resulting in root systems with improved water and nutrient efficiency, thereby causing enhanced general plant growth and vigor.

Alam and his coworkers (2013) observed positive effects of SAEP on root length, root surface area, root volume and root numbers in the greenhouse at rates between 0.2 and 1 g /L (Figure3). Soluble Ascophyllum extract powder at 2 g/L led to a negative impact on root characteristics. Growth responses to Ascophyllum extracts have been shown to be similar to those induced by plant growth regulators such as a cytokinins and auxins. In general, cytokinins are known to stimulate cell division and differentiation. In turn, root elongation and expansion may be associated with endogenous gibberellin production, the more vigorous root system associated with seaweed extract application may provide a larger surface area for nutrient and water uptake and allow for improved mineral nutrition and growth. As a consequence of improved nutrition and the presence of plant growth-promoting substances mentioned above in seaweed extracts, seaweed extract-treated plants often have more vigorous growth and yield

Figure 3. Effect of *Ascophyllum* on root growth of strawberry plant in greenhouse



10.2.2 Chlorophyll content

Seaweeds and seaweed products enhance plant chlorophyll content. This increase in chlorophyll content was a result of reduction in chlorophyll degradation, which might be caused in part by betaines in the seaweed extract. Glycinebetaine delays the loss of photosynthetic activity by inhibiting chlorophyll degradation. A field experiment was carried out by Akila and Jeyadoss in the Department of Chemistry and Biosciences, Sastra University, Kumbakonam to study the effects of foliar applications of different concentrations of seaweed liquid fertilizer (SLF) of *Sargassum wightii* on pigment content of sunflower leaves (Table7). Seaweed extract application significantly increased the chlorophyll content in leaves.

Table7. Effect of seaweed extracts on chlorophyll content

Treatments	Chlorophyll a	Chlorophyll b	Carotenoid
Control	1.65±0.005	0.65±0.02	2.72±0.05
SLF (2.5%)	2.07±0.005	0.74±0.01	3.12±0.05
SLF (5.0%)	1.90±0.07	0.66±0.01	3.01±0.05
Chemical Fertilizer	1.92±0.01	0.64±0.05	3.04±0.01

(Akila and Jeyadoss, 2010)

10.2.3 Shoot growth

Seaweed extracts increase shoot growth and overall performance of the crop. A field experiment was conducted by Dogra and Rakesh in the Regional Horticultural and Forestry Research Station, Himachal Pradesh to study the effects of soil applications of different concentrations of seaweed extract (prepared from *Ascophyllum nodosum*)on shoot growth and yield of onion(Table8). Maximum shoot growth and yield was obtained at an application rate of 2.5g/m².

Table8. Effect of seaweed extracts on shoot growth and yield of onion

Seaweed extract(g/m²)	Plant height (cm)	Shoots/plant	Yield (kg/m²)
1.5	38.52	5.7	3.56
2.0	41.74	6.2	3.83
2.5	58.47	8.9	5.84
3.0	55.20	8.4	5.37
3.5	56.38	8.7	5.00
Control	22.37	4.5	2.66
CD (0.05)	5.1	1.2	0.7

(Dogra and Rakesh, 2012)

10.2.4Crop yield

Seaweed concentrate triggers early flowering and fruit set-in a number of crop plants. In many crops yield is associated with the number of flowers at maturity. As the onset and development of Flowering and the number of flowers produced are linked to the developmental stage of plants, seaweed extracts probably encourage flowering by initiating robust plant growth. Yield increases in seaweed-treated plants are thought to be associated with the hormonal substances present in the Extracts, especially cytokinins. A field experiment was conducted in summer to study the effect of liquid seaweed fertilizer (LSF) applied as a foliar spray by Zodape and his coworkers (2007) in the Central Salt And Marine Chemicals Research Institute , Bhavnagar. The increase in yield due to seaweed fertilizer application (Table9) was attributed to the cytokinins present in the extract.

Table9. Effect of seaweed extracts on crop yield

Treatments	Length of fruit (cm)	Diameter of fruit (cm)	No. of fruits/plant	Fruit yield(t/ha)
Control	7.27	1.15	11.60	5.79
2.5%	9.58	1.36	16.30	6.97
5.0%	8.91	1.31	15.40	6.47
7.5%	8.53	1.27	14.70	6.13
10.0%	8.08	1.23	13.80	5.70
CD(0.05)	0.60	0.02	1.60	4.19

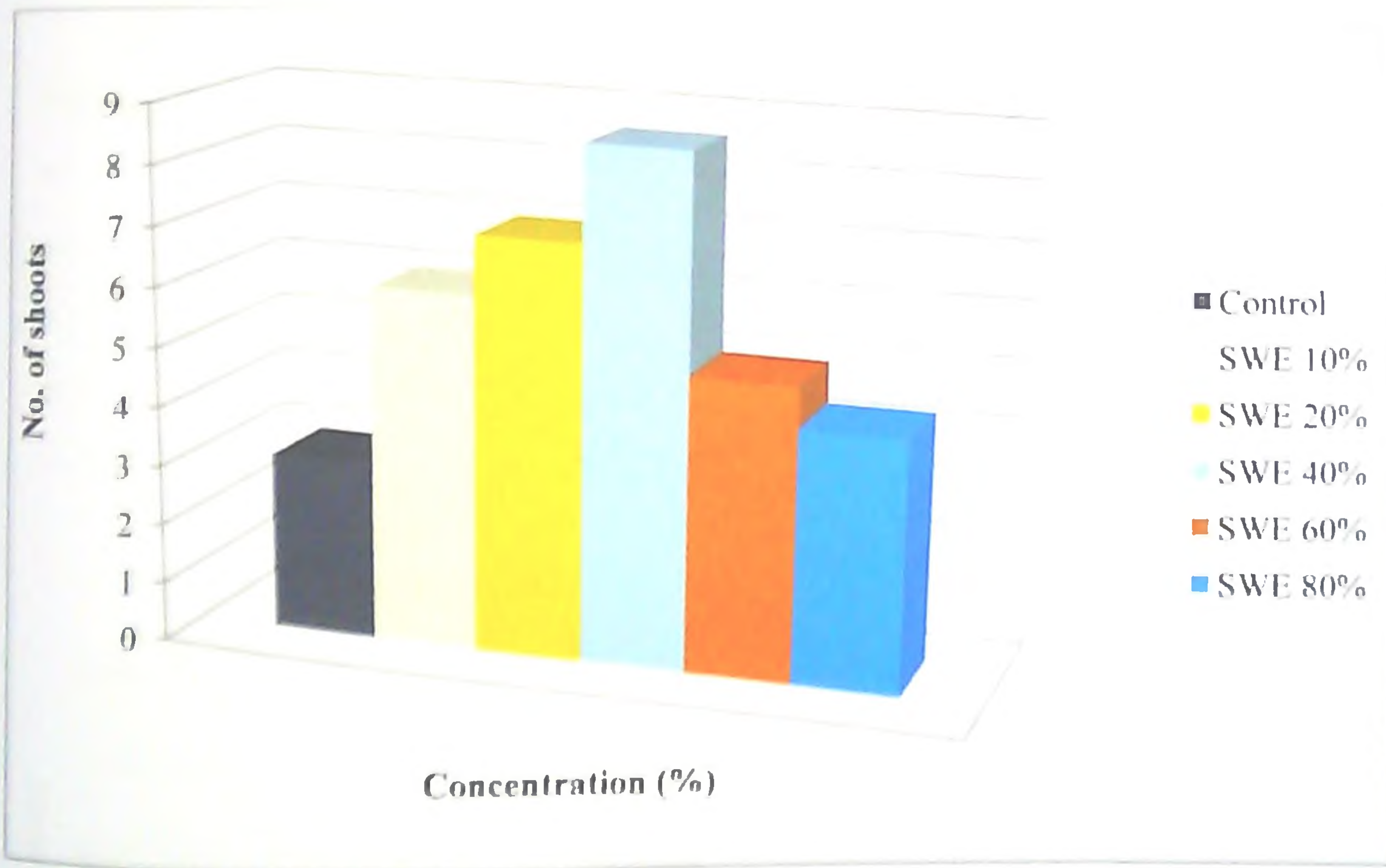
(Zodape *et al.*, 2007)

10.2.5 Vegetative propagation

Seaweed products are exploited in conventional vegetative propagation in many crop species. This is due to the presence of plant growth hormones present in seaweed extracts. An invitro mass propagation study was conducted by Sathees and his coworkers (2014) in the Department of Botany, A.V.C. College, and Tamil Nadu. The study was aimed to develop a cost-effective and efficient protocol for mass propagation of high-quality seedlings of *Withania somnifera*

(Aswagandha) through tissue culture by using seaweed extract as biostimulants instead of synthetic chemicals. MS media containing different concentration of seaweed extract (10, 20, 40, 60, 80 and 100 %) were tested individually for shoot induction (Figure4). The medium supplemented with 40 % seaweed extract exhibited maximum number of shoots with about 8.6 shoots/ callus and 80 % seaweed extract exhibited 4.3 shoots/ callus. It is evident from this study that seaweed extracts can be used as substitute for synthetic growth hormones for micro propagation of medicinally important plant *W. somnifera* for clonal propagation and conservation.

Figure 4. Effect of Seaweed extract on in vitro shoot multiplication of *Withania somnifera*



(Sathees *et al.*, 2014)

10.3 Effects on alleviating environmental stresses

10.3.1 Abiotic stress

Abiotic stresses such as drought, salinity, and temperature extremes can reduce the yield of major crops and limit agricultural production worldwide. Many abiotic factors such as drought, salinity, and temperature are manifested as osmotic stress and cause secondary effects like oxidative stress, leading to an accumulation of reactive oxygen species (ROS) such as the superoxide anion and hydrogen peroxide. These are known to damage DNA, lipids, carbohydrates, and proteins. Seaweed extracts increases antioxidant capacity by increasing the activity of antioxidant enzymes and thus scavenging ROS (Chandini *et al.*, 2008). Also seaweed products elicit abiotic stress tolerance in plants and that the bioactive substances derived from seaweeds impart stress tolerance and enhance plant performance. The chemistry of bioactive compounds in the seaweed and the physiological mechanism of action of the compounds that impart this tolerance are largely unknown. However, a number of reports suggest that the beneficial antistress effects of seaweed extracts may be related to cytokinin activity. However, it has also been reported that Kelpak seems to mediate stress tolerance by enhancing K uptake.

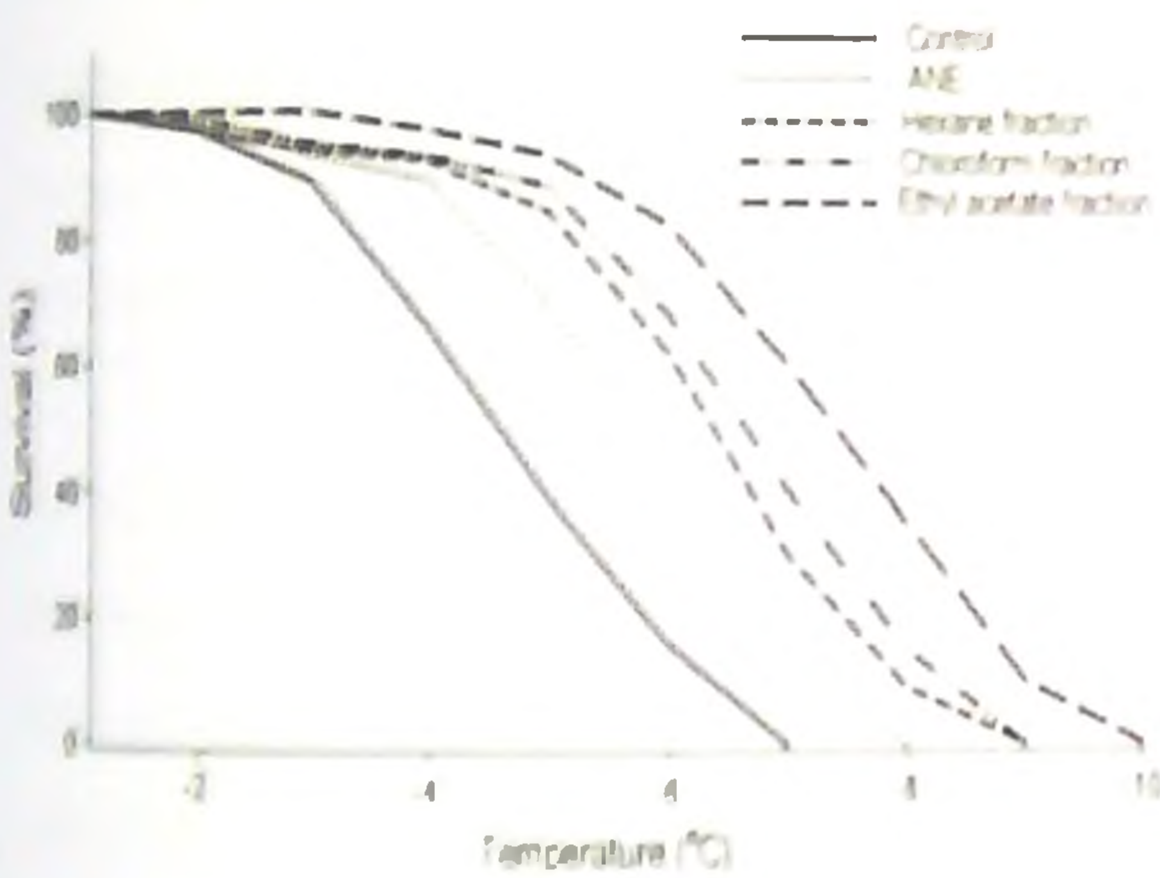


Figure 5. Extent of survival

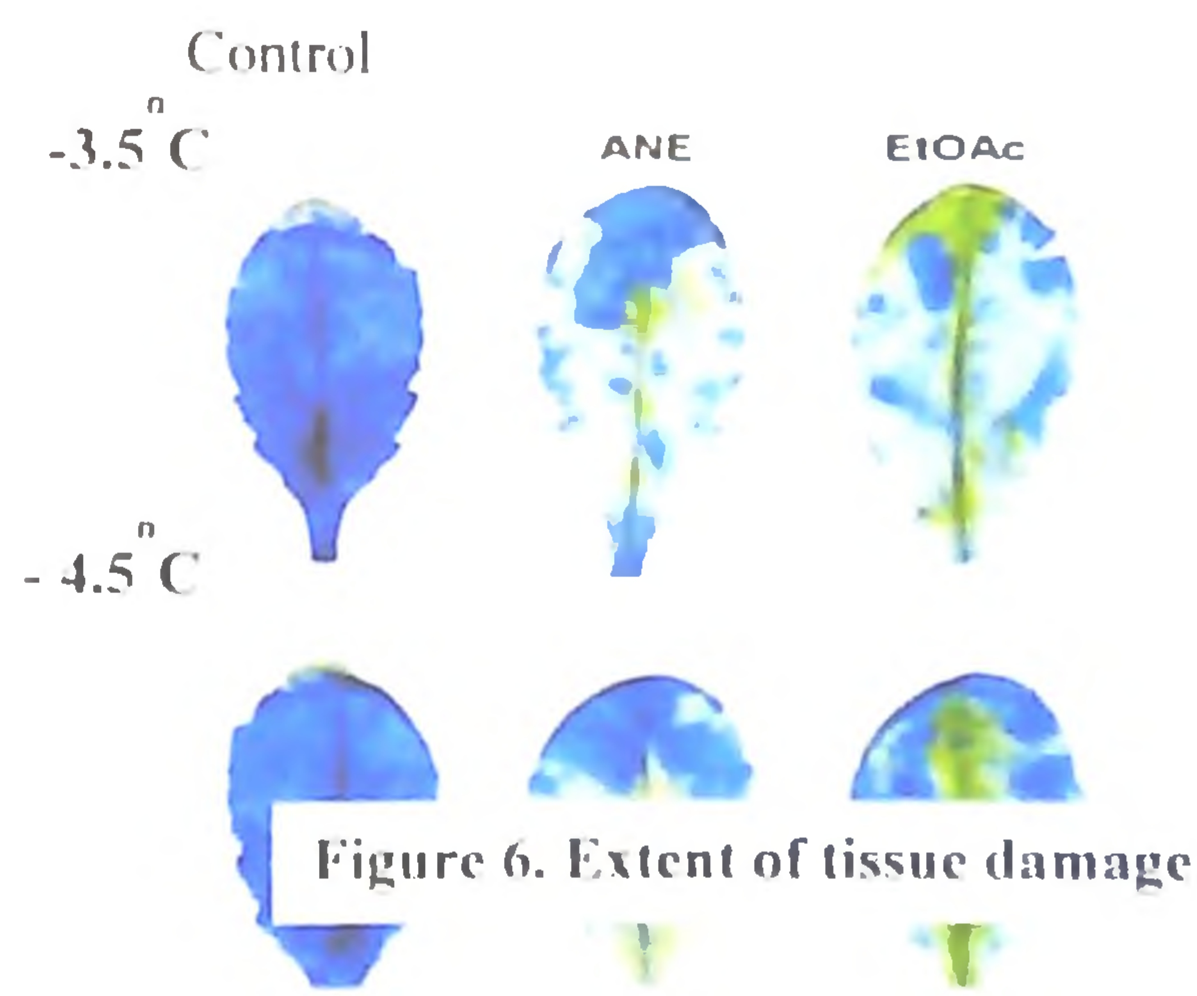


Figure 6. Extent of tissue damage

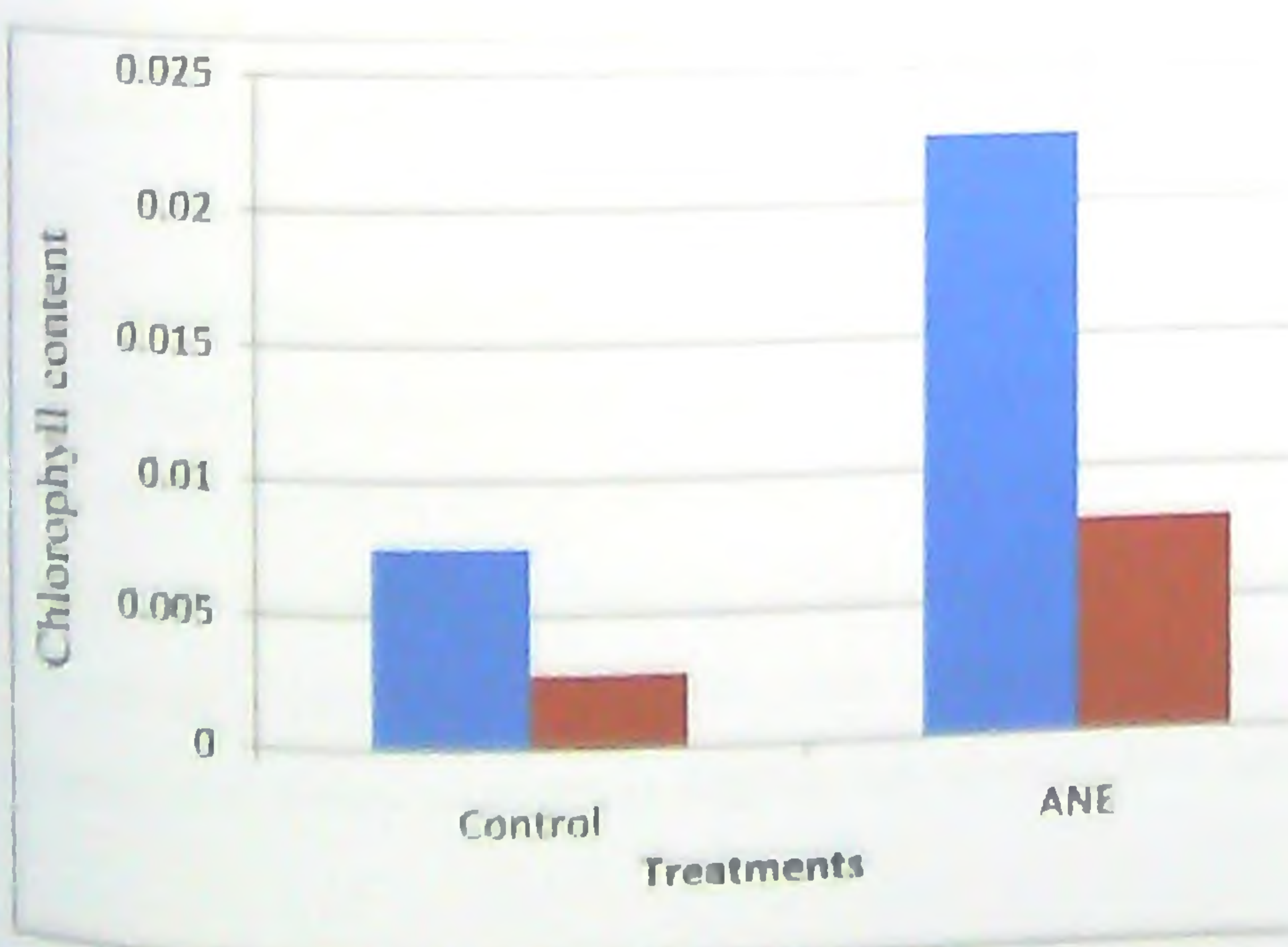


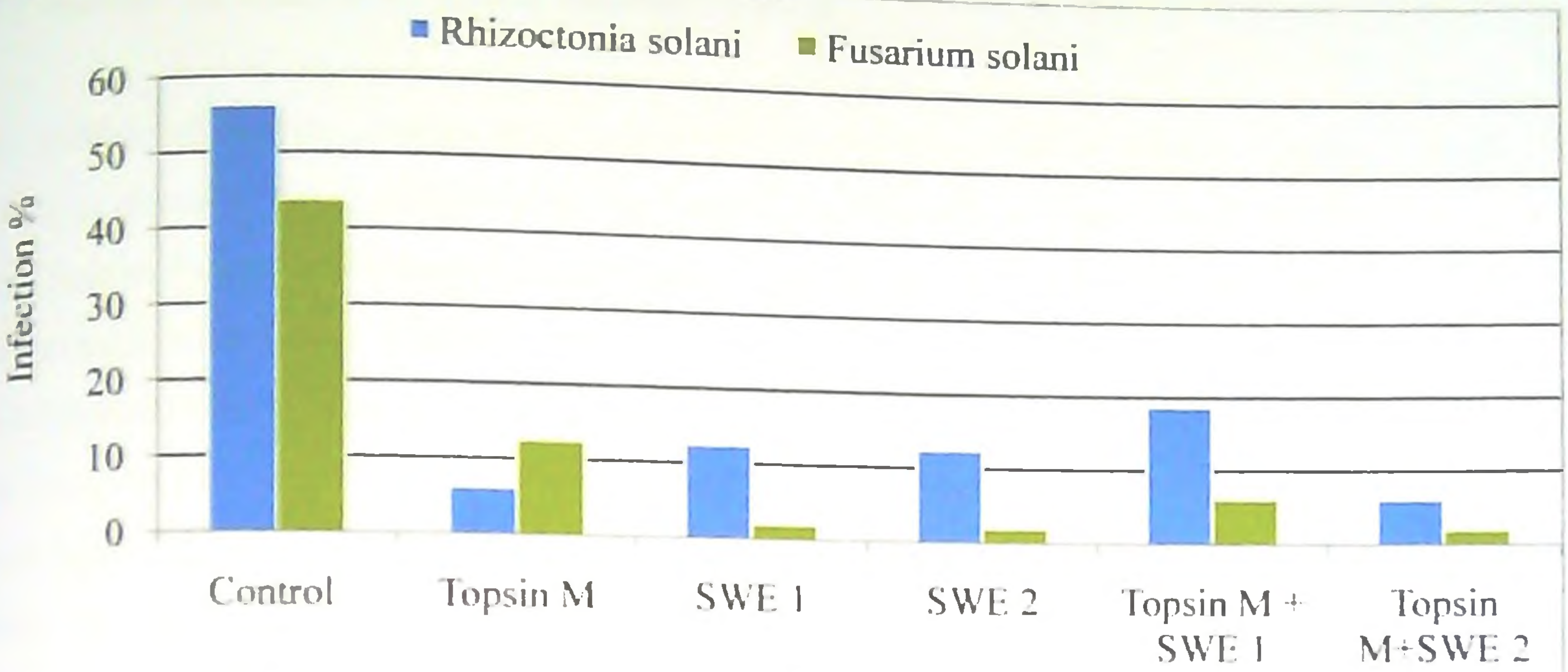
Figure 7. Extent of chlorophyll degradation

Extracts of the brown seaweed *Ascophyllum nodosum* enhance plant tolerance against environmental stresses such as drought, salinity, and frost (Rayirath *et al.*, 2009). They investigated the effect of *A. nodosum* extracts and its organic sub-fractions on freezing tolerance of *Arabidopsis thaliana*. *Ascophyllum nodosum* extracts and its lipophilic fraction significantly increased tolerance to freezing temperatures in vitro and in vivo assays (Figure 5). Untreated plants exhibited severe chlorosis, tissue damage(Figure 6), and failed to recover from freezing treatments while the extract-treated plants recovered from freezing temperature of -7.5°C in vitro. Treated plants exhibited 70% less chlorophyll damage (Figure 7) during freezing recovery as compared to the controls, and this correlated with reduced expression of the chlorphyllase genes *AtCHL1* and *AtCHL2*. Further, the *A. nodosum* extract treatment modulated the expression of the cold response genes, *COR15A*, *RD29A*, and *CBF3*, resulting in enhanced tolerance to freezing temperatures. Taken together, the results suggest that chemical components in *A. nodosum* extracts protect membrane integrity and affect the expression of stress response genes leading to freezing stress tolerance in *A. thaliana*.

10.3.2 Biotic stress

Seaweed extracts have been shown to enhance plant defense against pest and diseases. Besides influencing the physiology and metabolism of plants, seaweed products promote plant health by affecting the rhizosphere microbial community. Marine algae can serve as an important source of plant defense elicitors. A variety of polysaccharides present in algal extracts include effective elicitors of plant defense against plant diseases. Soil application of liquid seaweed extracts to stimulate the growth and activity of microbes that were antagonistic to fungal pathogens. Sultana and his co-workers (2013) studied the efficacy of two seaweeds *Spatoglossum variabile* and *Melanothamnus afaqhusainii* compared with the fungicide Topsin-M and a nematicide Carbofuran in tomato under field condition(Figures8 &9).Seaweed and pesticides showed more or similar suppressive effect on root pathogens of tomato by reducing fungal root infection(Figure8). Seaweed also showed inhibitory effect on *Meloidogyne javanica* (Figure9). Highest reduction in nematode's penetration in roots was achieved by the mixed application of *S. variabile* and carbofuran. Seaweed extracts affects the reproductive capacity of nematodes also.

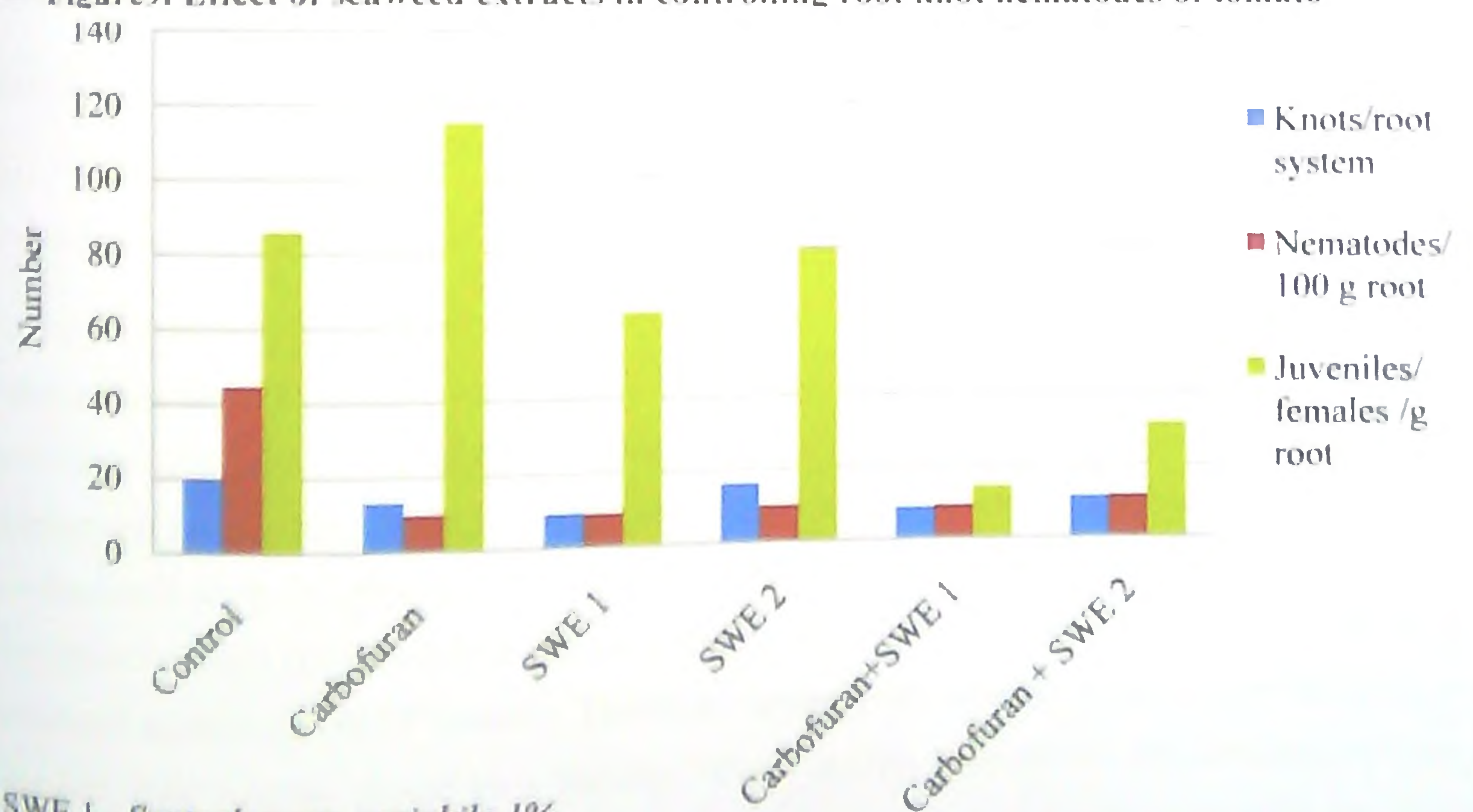
Figure 8. Effect of seaweed extracts in controlling fungal root pathogens of tomato



SWE 1 - *Spatoglossum variabile 1%*

SWE 2 - *Melanothamnus afaqhusainii* 1%

Figure9. Effect of seaweed extracts in controlling root knot nematodes of tomato



SWE 1 - *Spatoglossum variabile 1%*

SWE 2 - *Melanothamnus afaqhusainii* 1%

(Sultana *et al.*, 2013)

10.3.3 Seaweed farming as a climate resilient strategy

In the context of climate change and its impacts on global as well as regional levels, it is of necessity to develop effective climate resilient strategies. Zacharia and his coworkers (2015) at Central Marine Fisheries Research Institute Kochi focused on the scope of seaweed farming along Indian coastal waters as a climate resilient strategy. Carbon sequestration ability of seaweed (Table 10) makes its farming an option to combat ocean acidification and further bulk conversion of the substrate into stable biochar offers additional long term soil C sequestration means. Climate change had negatively affected the rural livelihoods of fishermen community in several coastal villages. Seaweed farming, its harvest and processing requires manpower and provides opportunity to enhance the rural livelihood.

Table 10. Carbon sequestration by seaweeds of Indian waters

Seaweed species	Weight of seaweeds (t)	CO2 sequestered (t/day)	Sequestration efficiency (mg CO2/g seaweed / hour)
Green	1,82,613	7487	4.10
Brown	41,740	981	2.35
Red	36,523	584	1.60

(Zacharia *et al.*, 2015)

11. Conclusion

Marine algal seaweed species are often regarded as an underutilized bio resource, although they have been used as a source of food, industrial raw materials, and in therapeutic and botanical applications for centuries. Moreover seaweeds and seaweed products are increasingly used in crop production. The recent challenges to food production due to the increasing occurrence of biotic and abiotic stresses is likely due to climate change and will further reduce yields and/or will have an impact on crops in the 21st century. Therefore, research into developing sustainable methods to alleviate these stresses should be a priority. Recent studies have shown that seaweed extracts protect plants against a number of biotic and abiotic stresses and offers potential for field application. Further, seaweed extracts are considered an organic farm input as they are environmentally benign and safe for the health of animals and humans.

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13. Discussions

1. What is the cost of seaweed based products? Whether any products are available in market? What is its taste?

   The cost will vary depending on the type of products. For cosmetic seaweed products the cost vary from Rs.500 to 1000/-. For china grass the cost varies from Rs.30/- to 150/- for 50g. Seaweed tastes savory and salty.

2. Can we use seaweed as an animal feed?

   Seaweeds are used as feed for pigs and buffalos to increase their body weight. It is also used as a fish feed.

3. Among three types of algae, which is beneficial?

   Three groups are having its own importance. Brown algae are having numerous applications in horticulture and agriculture. Red algae are mostly used for agar production, which is an important constituent of laboratory works. Green algae are mostly used for biofuel production. Moreover, green algae have the highest carbon sequestration efficiency.

4. Can we grow seaweeds in fresh water?

   Freshwater alone is not suitable for seaweed farming. Fresh water and seawater together can be used for seaweed cultivation. For the proper growth of seaweeds 2.5% salinity and temperature in the range of 20-25°C is required.

5. Why marine algae are 'miracle'?

   Fifty percent of photosynthesis on earth is carried out by marine algae. Sometimes, every second molecule of Oxygen we inhale might have come from marine algae.

6. Any toxic effects of marine algae are reported?

   Seaweeds sometimes contain CO in their bladders which are harmful for aquatic organisms. Marine microalgae may sometimes create algal blooms.

7. How can we improve the production of agar?

By large scale cultivation of red algae *Gelidium* sp. Exploration of new species having phycocolloid agar in their cell wall.

8. Difference between holdfast and stipe?

Holdfast is a root like structure. Stipe is a stem like structure.

9. Where in Kerala are the seaweeds cultivated commercially?

Kochi

10. Which are the growth hormones present in seaweeds?

Auxin , Cytokinin and ABA.

KERALA AGRICULTURAL UNIVERSITY

COLLEGE OF HORTICULTURE, VELLANIKKARA

Department of Agronomy

AGRON 591: MASTER'S SEMINAR

Name: Archana C. R.

Admission number: 2014-11-136

Major advisor: Dr. LalithaBai E. K.

Venue: Seminar Hall

Date: 18.12.2015

Time: 10.45a.m.

Miracle marine algae and their applications in agriculture

Abstract

Marine algae are vital components of the marine ecosystem, and are broadly classified into micro and macro algae. Among these marine macro algae are generally referred as seaweeds. The term 'seaweed' refers to any large marine benthic algae that are multicellular, macro-thallic, and thus differentiated from most microscopic algae (Smith, 1944). Structural components of seaweed include blades, bladders, stipes and holdfasts. Seaweeds are further classified into three major groups; green algae (Chlorophyta), brown algae (Phaeophyta), and red algae (Rhodophyta).

Seaweeds are globally popular for their value as food, feed and nutraceuticals. The benefits of seaweeds as sources of organic matter and fertilizer nutrients have led to their use as soil conditioners. A number of commercial seaweed products are available for use in agriculture (Khan *et al.*, 2009).The extensive use of seaweeds for diverse market products lead to over harvesting and depletion of their natural stocks. Seaweed farming is recently initiated to check biodiversity loss.

Seaweed products exhibit growth stimulating activities, and the use of seaweed formulations as biostimulants in crop production is well established. Chemical components of seaweeds that promote plant growth include polysaccharides, growth hormones, betaines and sterols. Seaweeds and seaweed extracts enhance soil health by improving moisture holding capacity and by promoting the growth of beneficial soil microbes. It also promotes root growth and development

(Jeannin *et al.*, 1991).The seaweed products also enhance plant chlorophyll content. Seaweed concentrates trigger early flowering and fruit set in a number of crop plants (Arthur *et al.*, 2003). It is feared that aggravating biotic and abiotic stresses due to climate change will further reduce crop yield and will have an impact on food production. Therefore, research into developing sustainable methods to alleviate these stresses should be a priority. Recent studies have shown that many seaweed extracts can protect plants against a number of biotic and abiotic stresses and offers scope for field application.

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Hydrogel: A nascent approach for soil water conservation

By

Yansing Luikham

(2014-11-215)

M. Sc. Agronomy

Seminar report

Submitted in partial fulfilment of requirement of the course

Agron. 591 Seminar (0+1)

DEPARTMENT OF AGRONOMY

COLLEGE OF HORTICULTURE

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CERTIFICATE

Certified that the seminar report entitled **'Hydrogel: A nascent approach for soil water conservation'**, is a record of seminar presented by Yansing Luikham (2014-11-215) on 31st October, 2015 and is submitted for partial requirement of the requirement of the course Agron. 591.

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DECLARATION

I, Yansing Luikham (2014-11-215), hereby declare that the seminar report entitled **'Hydrogel: A nascent approach for soil water conservation'**, has been completed by me independently after going through the reference cited herein and I have not copied from any of the fellow students or previous seminar reports.

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2014-11-215

Vellanikkara

Date: 07.11.2015

CERTIFICATE

Certified that the seminar report entitled **'Hydrogel: A nascent approach for soil water conservation'** for the course Agron.591 has been prepared by Yansing Luikham (2014-11-215), after going through various references cited herein under my guidance, and she has not copied or borrowed from any of her fellow students.

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1. Introduction

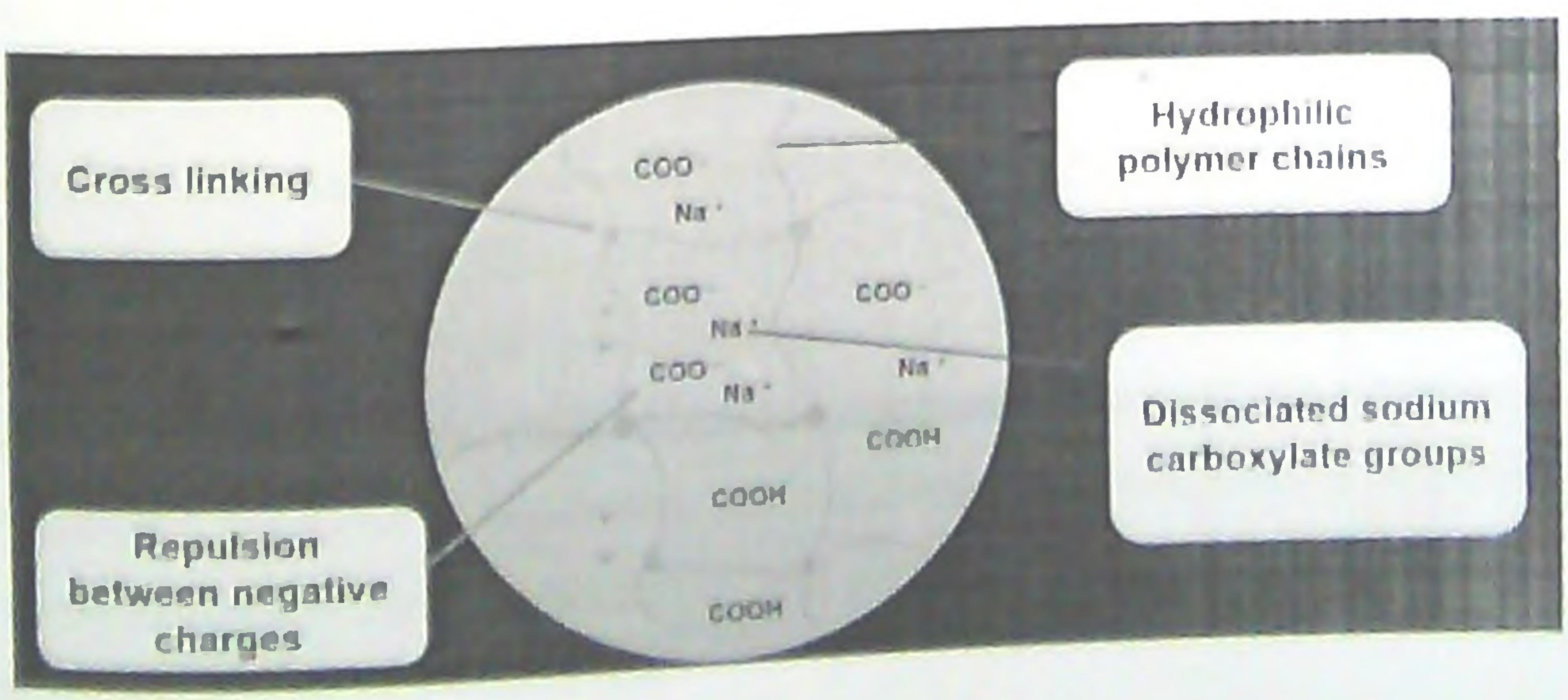
As agricultural sector is one of the largest consumers of water and the demand is constantly increasing due to the population growth. Prolonged periods of drought can cause environmental, agricultural and economic problems leading to social unrest and humanitarian crisis. Usage of peat moss, coir pith as soil conditioners to conserve soil moisture at field is a traditional method being practised over time. With the rapid loss of water from the soil due to evaporation and leaching, these methods are found to be less affective especially in arid and semi-arid regions. The development of non-traditional new technologies to conserve water is becoming important for attaining a sustainable economic growth in agricultural countries. The use of hydrogel is gaining importance due to its high water retention capacities and biodegradability.

2. Hydrogel (Gel-forming polymers)

Hydrogel is defined as "three dimensional cross-linked network structure obtained from a class of synthetic and natural polymers which can absorb and retain significant amount of water" (Rosiak and Yoshii, 1999). Agricultural polymer can absorb water more than 400 times its weight.

Cross-linking occurs when polymerisation is carried out in the presence of a small amount of a divinyl compound. Cross linking will prevent infinite swelling and provides mechanical strength which is interconnections of hydrophilic polymer chains (Plate 1).

Plate 1. Polymer network of hydrogel



Depending on synthetic conditions, type and density of covalent bonds that form cross-links, these polymers can absorb up to 1000 times their weight in pure water and form gels. The dissociated sodium carboxylate groups helps in maintain of electrical neutrality of the polymer.

3. Functional features of an ideal hydrogel

According to Zohuriaan-Mehr (2006), the functional features of an ideal hydrogel material are as follows:

a) The highest absorption capacity (maximum equilibrium swelling) in saline.
b) Desired rate of absorption (preferred particle size and porosity) depending on the application requirement.
c) The highest absorbency under load.
d) The lowest soluble content and residual monomer.
e) The highest durability and stability in the swelling environment and during the storage.
f) The highest biodegradability without formation of toxic species following the degradation.
g) pH- neutrality after swelling in water.
h) Colourlessness, colourlessness and non-toxic.

4. Classification of hydrogel

The hydrogel is classified based on its source, polymeric composition and network electrical charge.

4.1. Based on source

Ahmed (2015) categorise hydrogel based on sources as follows:

4.1.1. **Natural**: Hydrogel-forming natural polymers include proteins eg. Collagen, gelatine and polysaccharides such as starch, alginate, and agarose.

4.1.2. **Semi synthetic**: Semi-synthetic polymers are derived from cellulose, which is chemically combined with petrochemicals. One of the first hydrogels specifically designed for horticulture was a polyethylene polymer combined with sawdust.

4.1.3. **Synthetic**: Synthetic polymers that form hydrogels are traditionally prepared using chemical polymerization methods.

4.2. Based on polymeric composition

Hydrogel is further classified as homopolymeric, coplymeric and multipolymeric interpenetrating polymeric hydrogel.

4.2.1 **Homopolymeric hydrogels:** Polymer network derived from a single species of monomer, which is a basic structural unit comprising of any polymer network.

4.2.2. **Copolymeric hydrogels:** It comprised of two or more different monomer species with at least one hydrophilic component, arranged in a random, block or alternating configuration along the chain of the polymer network.

4.2.3. **Multipolymer interpenetrating polymeric hydrogel:** It is made of two independent cross-linked synthetic and natural polymer component, contained in a network form.

4.3. **Based on network electrical charge**

The network electrical charge is important which determines the activity of hydrogel in the nature of the medium. The hydrogel is classified as:

4.3.1. **Nonionic:** Neutral

4.3.2. **Ionic:** Including anionic or cationic

4.3.3. **Amphoteric electrolyte (ampholytic):** Containing both acidic and basic groups.

4.3.4. **Zwitterionic (polybetaines):** Containing both anionic and cationic groups in each structural repeating unit.

5. Cross linking behaviour of hydrogel

Cross linking id the important property of hydrogel that helps to absorb water, prevents infinite swelling and provides mechanical strength. Esposito *et al.* (1996) investigated cross linking density, presence of ionic groups on the backbone of hydrogels as well as the macroscopic morphology detected by electron scanning microscopy. Hence optimal water retention by the superabsorbent polymer (SAP) investigated suggested that it optimized when 2.3% $Al_2(SO_4)_3.18H_2O$ was used in the crosslinking. It was observed that when less than 2.3% $Al_2(SO_4)_3.18H_2O$ was used the SAP was under-cross linked, indicating that the complex does not have enough connections to create the appropriate sized void spaces for optimal water absorbance; while more than 2.3% $Al_2(SO_4)_3.18H_2O$ indicated that the polymer was over-cross linked and the complex had too many connections making the void spaces too small for optimal water absorbency. There are different methods to obtain cross linking behaviour.

5.1. Methods to obtain cross linking in hydrogel

Cross-linked networks of synthetic polymers such as polyethylene oxide (PEO), polylactic acid (PLA), polyacrylic acid (PAA), polymethacrylate (PMA), polyethylene glycol (PEG) or natural biopolymers such as alginate, chitosan, carrageenan, hyaluronan, and carboxymethyl cellulose (CMC) are commonly used hydrogel. The general methods to produce physical and chemical gels are described below.

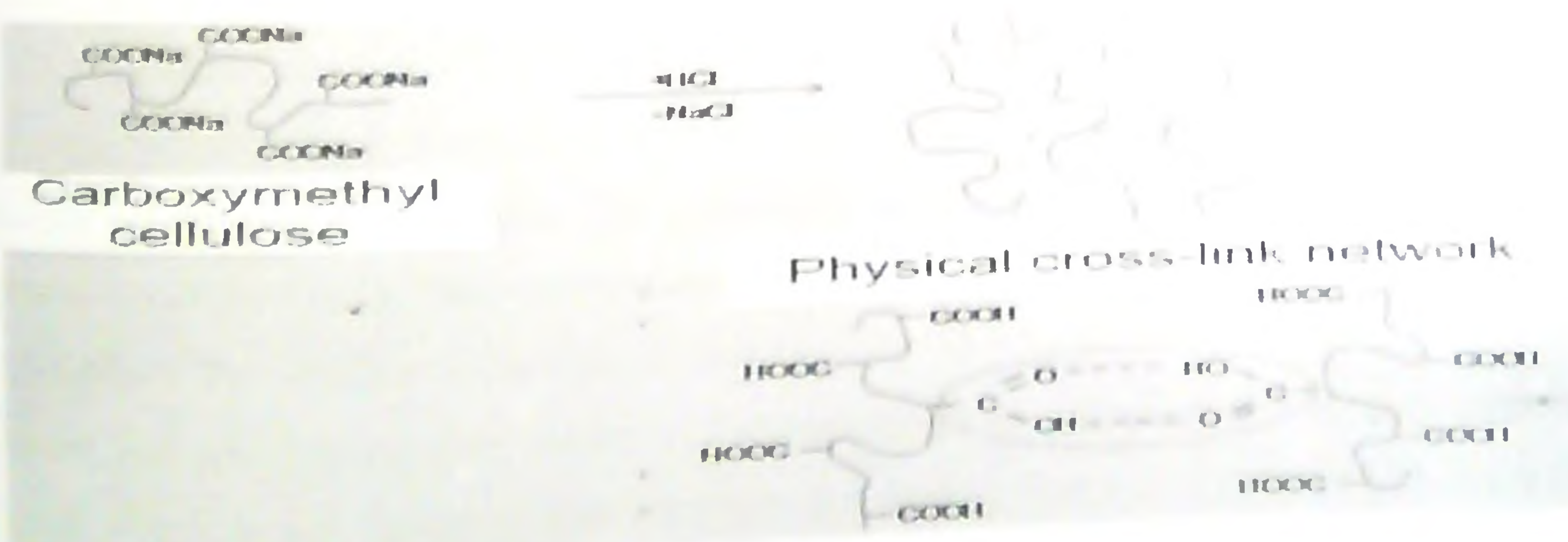
5.1.1. Physical cross-linking

There has been an increased interest in physical or reversible gels due to relative ease of production and the advantage of not using cross-linking agents. These agents affect the integrity of substances to be entrapped (e.g. cell, proteins, etc.) as well as the need for their removal before application. Careful selection of hydrocolloid type, concentration and pH can lead to the formation of a broad range of gel textures .

5.1.1.1. H-bonded hydrogel

It can be obtained by lowering the pH of aqueous solution of polymers carrying carboxyl groups. Such hydrogel is a hydrogen-bound CMC (carboxymethyl cellulose) network formed by dispersing CMC into 0.1M HCl (Takigami et al., 2007). The mechanism involves replacing the sodium in CMC with hydrogen in the acid solution to promote hydrogen bonding (Figure ---). The hydrogen bonds induce a decrease of CMC solubility in water and result in the formation of an elastic hydrogel.

Plate 2. Physical cross linking

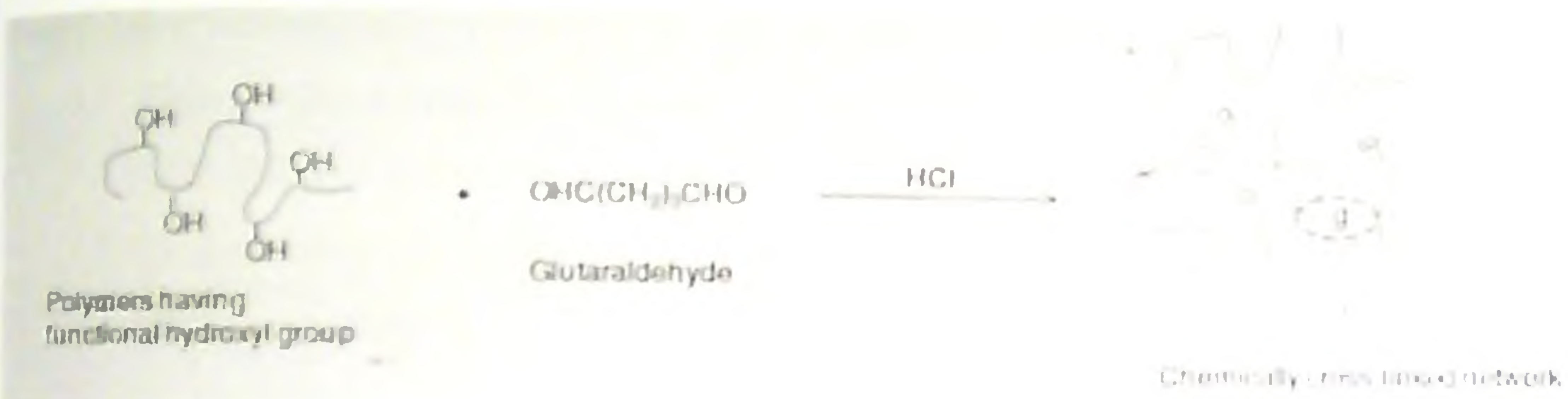


5.1.2. Chemical cross-linking

Chemical cross-linking covered here involves grafting of monomers on the backbone of the polymers or the use of a cross-linking agent to link two polymer chains. The cross-linking of natural and synthetic polymers can be achieved through the reaction of their functional groups (OH, COOH and NH_2) with cross-linkers such as glutaraldehyde, adipic acid and dihydrazide.

Among other chemical cross-linking methods, IPN (polymerise a monomer within another solid polymer to form interpenetrating network structure) and hydrophobic interactions (Hennink & Nostrum, 2002) by incorporating a polar hydrophilic group by hydrolysis or oxidation followed by covalent cross-linking are also used to obtain chemically cross-linked permanent hydrogels.

Plate 3. Chemical cross linking



5.1.2.1. Preparation of cassava based hydrogel using chemicals as cross linker

The preparation of the superabsorbent polymer (SAP) follows a procedure described by Suo et al. (2007). Carboxymethyl cellulose sodium salt (20 g) was mixed with 2.0 L of distilled water in a large beaker using a magnetic stirrer. Cassava starch (1.2 g) was gelatinized in 50 mL of distilled water at 80°C for 45 min. The gelatinized starch was added to the CMC solution and allowed to mix for 1 hour. Then varying amounts of aluminum sulfate were added to the beaker to investigate the optimum crosslinkage, and the solution was allowed to mix for another 30 minutes. The solution was then spread on Teflon baking pans and dried at 70°C until a film is formed. The film was shredded with a blender and then ground into a powder with a mortar and pestle.

6. Desirable characteristics of hydrogel for agriculture

For agriculture purpose, hydrogel will reserve different amount of water in itself and ultimately increases the soil ability of water retention and preserving and at last in water deficiency. The desirable characteristics which made hydrogel applicable in the field of agriculture are as follows:

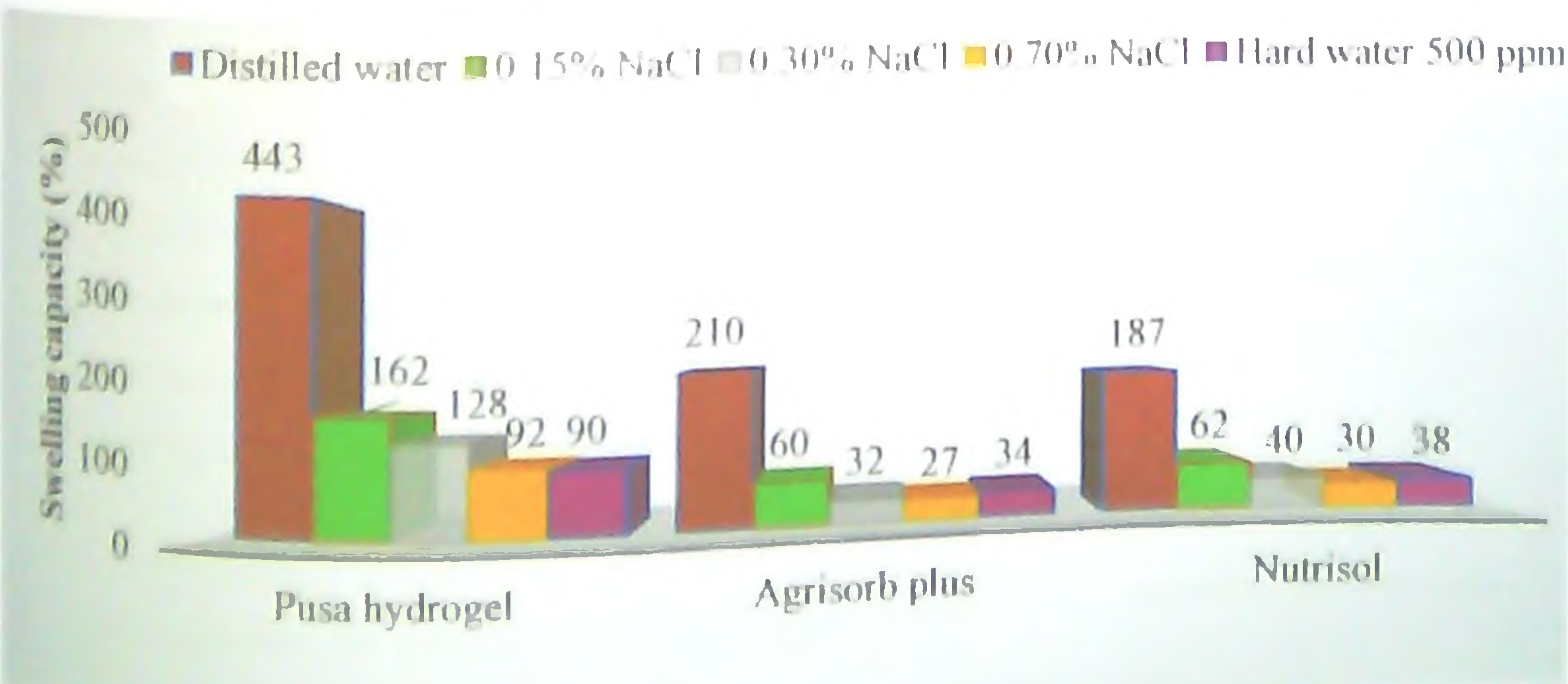
The elasticity and rigidity of hydrogels are governed by their chemical structures and affect their mechanical properties, such as the modulus of elasticity, degree of swelling, permeability and diffusion, and optical properties, which can be governed by the polymerization technique and conditions, the diluents, monomer structure, crosslinking density and hydrogen bonding structures, ionic and polar interchain forces, and the water-binding properties of the hydrogel.

6.6.1. Swelling behaviour of hydrogels in different medium

The water-holding capacity drops significantly at sites where the source of irrigation water contains high levels of dissolved salts (e.g effluent water) or in the presence of fertilizer salts (Wang and Gregg, 1989). The amount of water retained is also adversely affected by chemicals or ions (Mg^{2+}, Ca^{2+}, Fe^{2+}) present in the water (Johnson 1984). The performance of different hydrogels differ on its swelling capacity of hydrogel (Figure 1).

James and Richards (1986) suggested that these divalent cations develop strong interactions with the polymer gels and are able to displace water molecules trapped within the polymer. Even though monovalent cations (Na^{+}) can also replace water molecules, the effect is not as pronounced as with the divalent counterparts as the process is fully reversible by repeated soaking with deionised water

Figure 1. Effect on swelling capacity of different hydrogels



(Singh, 2011)

7. Mode of action of hydrogel in soil

The polymer consists of a set of polymeric chains that are parallel to each other and regularly linked to each other by cross-linking agents, thus forming a network. When water comes into contact with one of these chains, it is drawn into the molecule by osmosis. Hydrogels are characterized by negative (anionic), positive (cationic) or neutral charge. These charge classes are found in both linear and cross-linked polyacrylamide hydrogels (Narjary *et al.*, 2013). The charge determines how they will react with solid and solutes. Cationic hydrogels generally binds to the clay components and acts as flocculants. Anionic hydrogels can bind with the clay and other negatively charged particles through ionic bridges such as calcium and magnesium.

The stronger the attraction between the gel and surrounding solutes and soil particles, the greater the ability of the gel to absorb water, create aggregates and stabilize soil structure. The more the polymer is cross-linked, the tighter the network. Thus absorption capacity decreases but the polymer remains more stable over time.

8. Applications of hydrogel in agriculture

Hydrogel has a varied applications in agriculture which are amended along with fertilizers to improve nutrient use efficiency, to improve plant growth and also used as a additives with chemical. Its application are cited below as:

8.1. Nutrient release: Hydrogel polymeric fertilizer prepared from cross linking of hydroxyl ethyl cellulose with conventional fertilizers, urea and liquid super phosphate ([illegible] *et al.*, 2006). Nutrient-amended polymers serve as effective seedling growth media for short-term seedling production, reduce nutrient leaching losses and improve soil fertility.

8.2. Soilless cultivation: Plants are cultivated on a hydromembrane composed of water-soluble polymer and hydrogel. This hydromembrane absorbs water and nutrients from the culture medium. Accordingly, the plant develops a lot of fine and dense roots closely attached to the hydromembrane surface.

This technology saves 90% of water consumption, uses 80% less fertilizer, protects crops from diseases via pathogens as bacteria and viruses cannot penetrate the membrane material.

8.3. Weed control: Hydrogel is blended with water to create a gel formulation and then mixed with Diquat Reglone ® to give a 50/50 mix. Hydrogel mix is most active against undesirable broadleaf aquatic weeds. It also breaks down rapidly in natural water and presents no hazard to fish life when used as recommended. Because of the chemical properties of the gel, Hydrogel sticks to submerged aquatic plants. This means the active ingredient, which is added to Hydrogel prior to application remains in the target zone, ensuring optimum herbicidal activity.

8.4. **Waste management**: The biodegradable hydrogel with high water absorbability was applied to the disposal of livestock excreta. In the case of disposal of livestock excreta, 1 to 1.5-fold amount of sawdust against livestock excreta are usually required to composting of livestock excreta. However, the reduction of the amount of sawdust was achieved by adding 0.2% dry hydrogel to livestock excreta, and therefore the amount of sawdust became one-sixth. The advantage of using hydrogels is not only reduction of sawdust but also decrease of mixture volume, reduction of work-load and easily transporting of livestock excreta.

8.5. Soil water conservation

Superabsorbent has been shown to improve water-retention capacity of the soil,improve soil cluster structures, and enhance the absorption of water. Clay soils inhibit plant development by inadequate oxygen levels, excess of carbon dioxide, and lack of drainage. Hydrogel can be employed to improve the structure characteristics of clay soils, where the swelling of the polymer particles breaks apart the structure of the soil and leads to an improvement in aeration, better drainage, and provide a stable aggregate in the soil thus reducing the crusting effect.

8.5.1. **Improves water holding capacity:** Application of hydrogels has an influence on improvement of aggregate content and increase in water retention in the soil at all suctions (from 0 - 15 atm), and the available water is significantly increased (El-Hady and Abo-Sedera, 2006). Water storage properties of different soil conditioners are significantly affected by the nature and concentrations of dissolved salts in irrigation waters (Johnson, 1984).

8.5.2. **Increase water use efficiency**: Produced yields by the unit of irrigation water added to the beneficial effects of the examined hydrogel for reducing water consumption and increasing both water and fertilizers use efficiency by plants (El-Hady and Wanas, 2006).

8.5.3. Improves soil permeability and infiltration rate: Hydrogel allows the formation of synthetic network that improve both soil cohesion and water infiltration providing better hydrophilic properties of the soil

8.5.3. Reduction of irrigation frequency: Hydrogel influences the increase of efficiency of water usage and decrease of irrigation frequency (Sivapalan, 2006). The use of hydrogels increases the amount of available moisture in the root zone, thus implying longer intervals between irrigations.

8.5.4. Soil erosion: Super absorbent polymers affect water penetration rate, density, structure, compactness, aggregate anchorage, soil's water tension, available water, soil crispiness and finally cause better water management practices in soil. (Helalia and Letey, 1989) Soil-porosity is improved as the suspended fine particles flocculate at the surface and this considerably reduce soil-erosion by stabilizing soil structure. Hydrogel aids in ncreasing soil strength by aggregating the soil particles, absorbing the impact of raindrop energy and increasing soil moisture.

9. Factors affecting superabsorbent polymer performance

Many researchers have documented increased waterholding capacity, reduced irrigation frequency, greater water use efficiency, enhanced infiltration rates, reduced compaction tendency and increased plant performance with hydrogel use. A critical assessment of the variables that affect hydrogel performance will help explain the factors that contribute to its efficiency. These variables include polymer type, rate and grind size, method of application, salinity of the soil solution, soil texture, temperature, intended use etc.

9.1. Type of polymer: Hydrogels differ widely in their total absorbency, time needed to hydrate, structural integrity and longevity in the soil. Starch-graft co- polymers may take up to a few hours to hydrate completely. However, starch graft co-polymers do not possess the gel strength or longevity that cross linked acrylamide-acrylate co-polymers does (Grula and Huang, 1982). Activity of starch- graft co-polymers is usually limited to a single season, whereas, the cross linked acrylamide-acrylate co-polymers remain active for five to seven years or longer.

9.2. Particle size of polymer: Water absorbing polymers are available in various particle sizes, from powders to coarse granules greater than 2 mm in diameter. The effect of powders versus coarse granules on root zone characteristics such as oxygen diffusion rate and water absorption may be very different. The aim is to amend the soil to substantially increase the water-holding capacity without decreasing the ability for gaseous exchange. If a continuous layer of powder is applied, gas exchange to the roots may.be severely reduced.

9.3. **Soil texture**: Potential benefit of polymers on water storage also depends on the soil texture. Coarse textured soils with large pores tend to retain less water than fine textured soils. Thus, the amount of water that may be retained by incorporating a polymer would be greater in coarse textured soils (sandy soil) than in fine textured soils (clay soil).

9.4. **Salt concentration in water and soil solution:** Water holding properties of polymers are significantly affected by nature and dissolved salts concentration in water of irrigation. Saline water reduces absorption and conservation of water. Increase in water salinity in amount of more than 2.5 dS m^{-1} caused reduction in polymer effectiveness in loamy sandy soils and the plants irrigating with 5 dS m^{-1} used 42% more than that of with 1.6 d S m^{-1} (Bhat *et al.*, 2009).

9.5. **Rate of application of polymers:** Polyacrylamide (PAM) rates applied to soil may need to be adjusted based on soil properties, slope and type of erosion targeted (Table 1). PAM with newer longer-chain polymers is more effective even in lower rates (Wallace and Wallace, 1986). In some cases, overusing of hydrogels causes reverse results, because it reduces soil air followed by filling vacant spaces and gel swelling. The main reason as mentioned is due to occupation of many vacant spaces of soil resulting in sever soil ventilation (Abedi-Koupai and Mesforoush, 2009). Sarvas *et al.* (2007) in an experiment on *Pinus sylvestris* L. seedlings observed that by over using of super absorbent in soil, plants were more likely to be exposed to *Fusarium* diseases.

Table 1. Recommended dosage of hydrogel

Sl.No.	Dosage	Usage
1	4 to 6 g/ kg of soil	Arid and semi-arid region
2	0.2, 0.4 and 0.8% of soil	Delays permanent wilting point
3	0.5 to 2.0 g/pot	Improve relative water content
4	2 to 4 g/plant pit	Save irrigation water up to 15 to 50 %
5	225 to 300 kg/ha	To prevent water stress in extreme arid condition

9.6. **Method of application of polymers**: The performance of the gel on plant growth depends on the method of application as well. It was shown that spraying the hydrogels as dry granules or mixing them with the entire root zone is not effective (Flannery and Busscher, 1982). Better results seemed to be obtained when the hydrogels are layered, preferably a few inches below soil surface.

9.6.1. **Dry method to subsoil:** Dry polymer is applied to the subsoil by mixing with the sandy soil into depths of about 15–25 cm and then subjecting to wetting for swelling prior to cultivation (Plate 5). After the polymer has swollen the soil structure is improved and the water penetration and retention capacity increases, decreasing water runoff and erosion. This method is applied for long-term intentions as the polymer has to absorb water prior to becoming beneficial, it is not recommended for immediate sowing.

9.6.2. **Wet method to topsoil**: The polymer solution is sprayed onto initially wetted topsoil, followed by drying to create water-stable aggregates that resist erosion. This method is particularly well adapted to sowing immediately afterwards and can also be adopted to reduce water consumption in irrigation systems where water losses occur due to the soils' poor ability to retain moisture. These wet polymer methods can also decrease soil erosion by being applied to topsoil or to driveways of irrigation.

9.6.3. **Root dip**: When applied as a root dip, hydrogels coat fine roots and protect them against desiccation. One potential benefit is that hydrogel dips may function similarly to the natural polymeric mucilages produced by healthy roots (Plate 6). Mucilage weakens the drop in water potential at the root soil interface, increasing the conductivity of the flow path across soil and roots and reducing the energy needed to take up water.

Plate 5. Dry method to subsoil

Plate 6. Root dip

9.6.4. **Irrigation water**: The hydrogel in irrigation water will adhere on the soil particles in furrows. Many researchers found that application of 20 kg ha-1 PAM prior to sprinkler irrigation increased infiltration rates and reduced runoff and erosion (Stern et al., 1992).

9.7. **Biodegradation of polymer:** The persistence of a particular polymer in the soil may affect its usefulness as a device to delay the release of water and nutrients. In general, naturally occurring polymers are readily degraded by soil microorganisms, while synthetic polymers are more resistant to biological breakdown. The applied hydrogels influence the production of CO2, disintegration of cellulose and enzymatic activity and may be used as eco-friendly water- saving materials (Sarapatka, 2004).

9.7.1. **UV radiation**: Exposure to ultraviolet radiation, chemical oxidizers, fertilizer salts, mechanical abrasion, and freeze-thaw events will degrade the polymer, breaking it up into smaller fragments. These smaller fragments do not have the same properties as the larger polymers, and thus the hydrogel's water-retaining capacity and other functions are reduced and ultimately lost. Intense UV radiation in the open is known to increase the breakdown rates.Gels that are applied to soil surfaces experience these environmental stresses most frequently and will degrade most rapidly, especially in soils with high levels of solar ultraviolet. Polyacrylamide polymers degrade at rates of at least 10% per year as a result of physical, chemical, biological and photochemical processes (Tolstikh *et al.*, 1992).

9.7.2. **Microbial action:** A number of naturally occurring soil microbes have been identified as active decomposers of both soluble and cross-linked polyacrylamide gels. Decomposers include bacterial species (*Bacillus sphaericus* and *Acinetobacter spp.*) and white rot fungi (*Dichomitus squalens*, *Phanerochaete chrysosporium* and *Pleurotus ostreatus*). The fungal species dissolve the polymer, which is then susceptible to further degradation by many other soil microbes. It is found that the average size of the polymer to be less than 25 percent of the original in only 14 days of microbial action. It thus becomes much more sensitive to the aerobic and anaerobic processes of microbiological degradation. It degrades naturally in soils (up to 10% to 15% per year) to CO_2, H_2O and nitrogen compounds.

9.7.3. **Temperature**: In soil, polyacrylamide polymers degrade at rates of at least 10% per year as a result of physical, chemical, biological and photochemical processes (Tolstikh et al., 1992). At high Variable Ambient temperature (VAT), the polymer will be gradually degraded.

9.7.4. **Enzymatic action**: Natural polymers contain chemical bonds that may be broken through common enzymatic hydrolysis in soils eg. Proteases, collagenases. Many of the natural polymers contain chemical bonds that may be broken through common enzymatic hydrolysis in soils. The synthetic polymers typically demonstrate much greater resistance to biological attack, since soil microbes have not yet developed the polymer- specific enzymes required for rapid decomposition.

10. Commercial products of hydrogel

There are various products which are available in both inorganic form and also starch based polymer which are processed out of natural starches from cassava, corn and potato etc. The products are also available along with adjuvants such as in Bio-organics where mycorhiza is present as bio-stimulants. The common products available are listed (Table 2).

Table 2. Commercial products available

Brand name	Chemical class
Pusa hydrogel	Inorganic polymer
Bio-Organics	Inorganic polymer
Soil Moist	Polyacrylamide
Stockosorb	Polyacrylamide
Zeba	Starch polymer

10.1. Pusa hydrogel

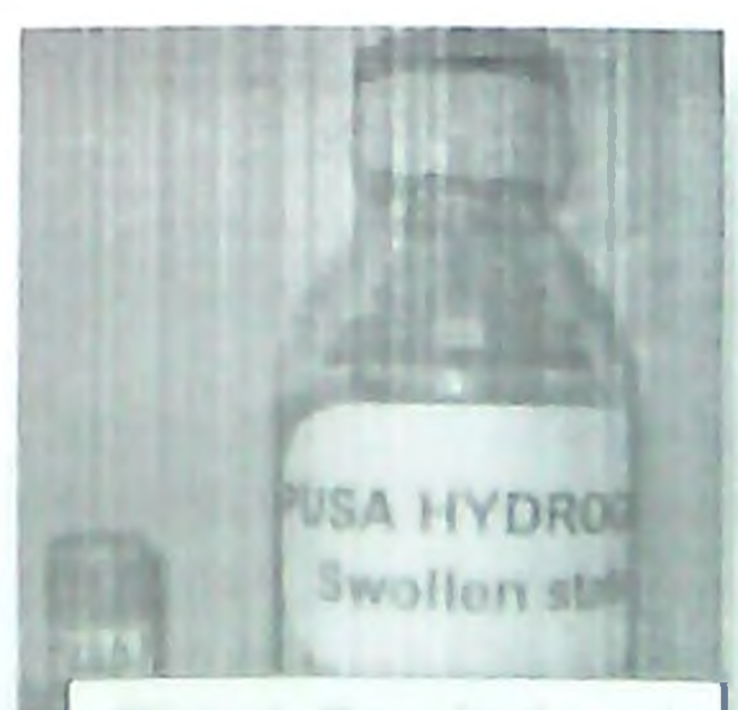


Plate 4. Pusa hydrogel

- Reduces leaching of herbicides and fertilizers by improves physical properties of soil and soilless media.
- Improves seed germination and seedling emergence rate
- Improves root growth and density (Plate 7).
- Helps plants withstand prolonged moisture stress by delaying the onset of permanent wilting point
- Reduces nursery establishment period. ie. 18 days as compared to 28 days in control in vegetables).

- Reduces irrigation and fertigation requirements of crops
  ie. Decrease in no. of fertigation booms required to raise nursery and the crop of tomato in field (37 as compared to 52 in control).
- Promotes early and dense flowering and fruiting and tillering (Plate 8).

Plate 7. Effect of Pusa hydrogel root growth pattern

Plate 8. Effect of pusa hydrogel on fruit

10.2. Starch polymer

There has been increased interest in developing countries for the conversion of starchy agricultural produce into hydrogel which is more environmental friendly as it is widely available and is considerably cheaper than the chemically synthesized ones. **Ekebafe (2012)** studied the physico-chemical properties of cassava based hydrogel (Table 3).

Table 3. Properties of starch based hydrogel

Colour	White
Form	Granules
Odour	Odourless
pH	6.9
Solubility in water	Insoluble
Absorbency (g/kg)	42500
Nature	Partially hygroscopic

11. Research studies of hydrogel for soil water conservation

Various studies has been conducted to prove the effectiveness of hydrogel to conserve soil water. The utility of hydrogel in sandy soil is found to be more efficient than that of sandy soils. The cation exchange capacity of the soil increases with the application of hydrogel.

11.1. Hydrogel for turf management

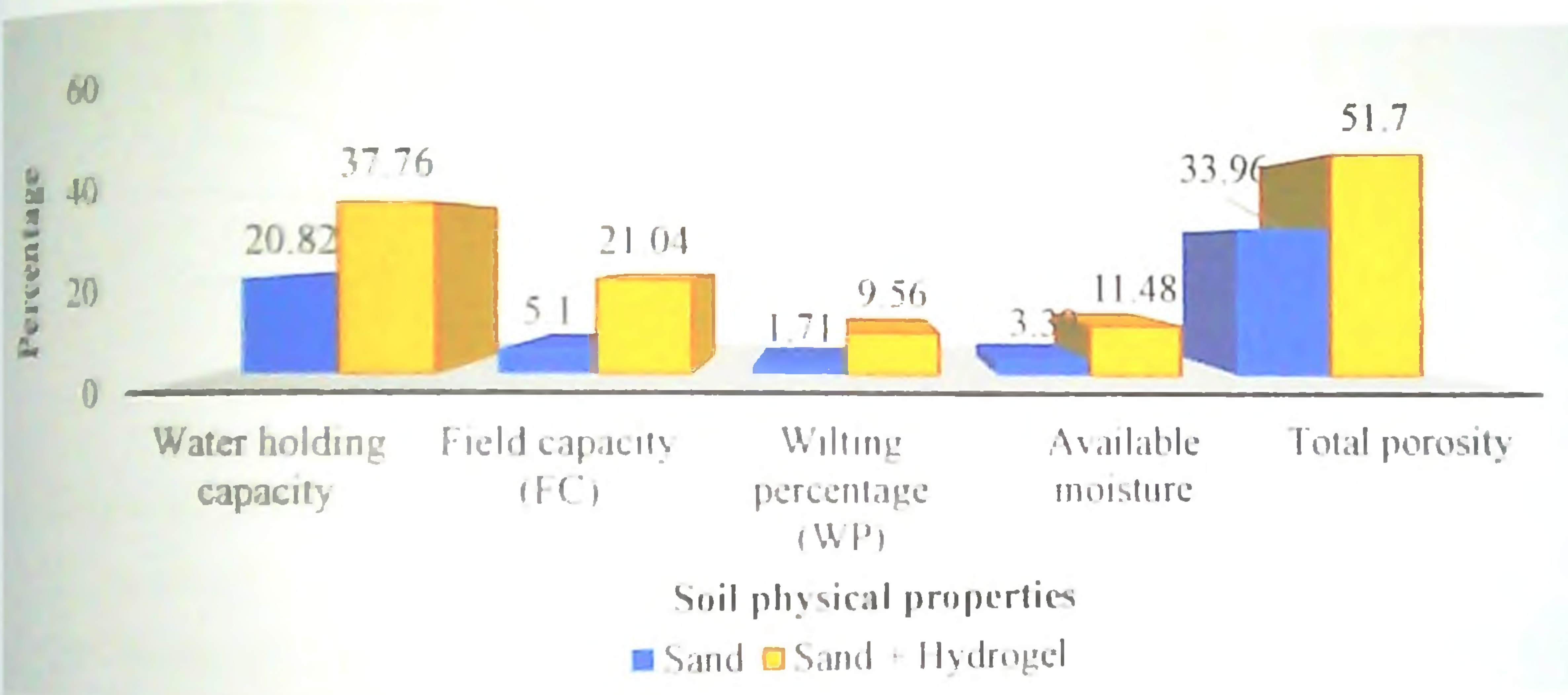
Deep-rooted grass transplants receiving adequate moisture exhibited high survival rates on arid rangelands. Starch-based hydrogels in embedded irrigation tubes described here provided moisture sufficient to ensure plant growth and reproduction beyond a single growing season.

Acrylic gels also supported plant growth, but the hydration ratio of 1 part hydrogel to 10 parts water applied in this study limited growth and reproduction. Ratios of 1:200 (hydrogel: water) should provide initial water potentials near 0.05 MPa (Rowe *et al.*, 2005), which would significantly improve plant performance. Transplants irrigated with fully hydrated acrylic gels are expected to produce the best restoration outcomes at the lowest cost.

11.2. Hydrogel for improving physical properties of soil

By adding the potassium polyacrylate to the concentration of 0.5% and at pressure of 1.5 MPa there is a great difference. There is a considerably greater quantity of water at the hydrogel retained after exposure to the pressure of 1.5 MPa. The quantity of available water was increased at the hydrogel variety by 3.38 times. (on dry weight basis). With the addition of hydrogel along with sand , there is significant increase in water holding capacity, field capacity, wilting percentage, available moisture and total porosity (Figure 2).

Figure 2. Effect of hydrogel on physical properties of soil



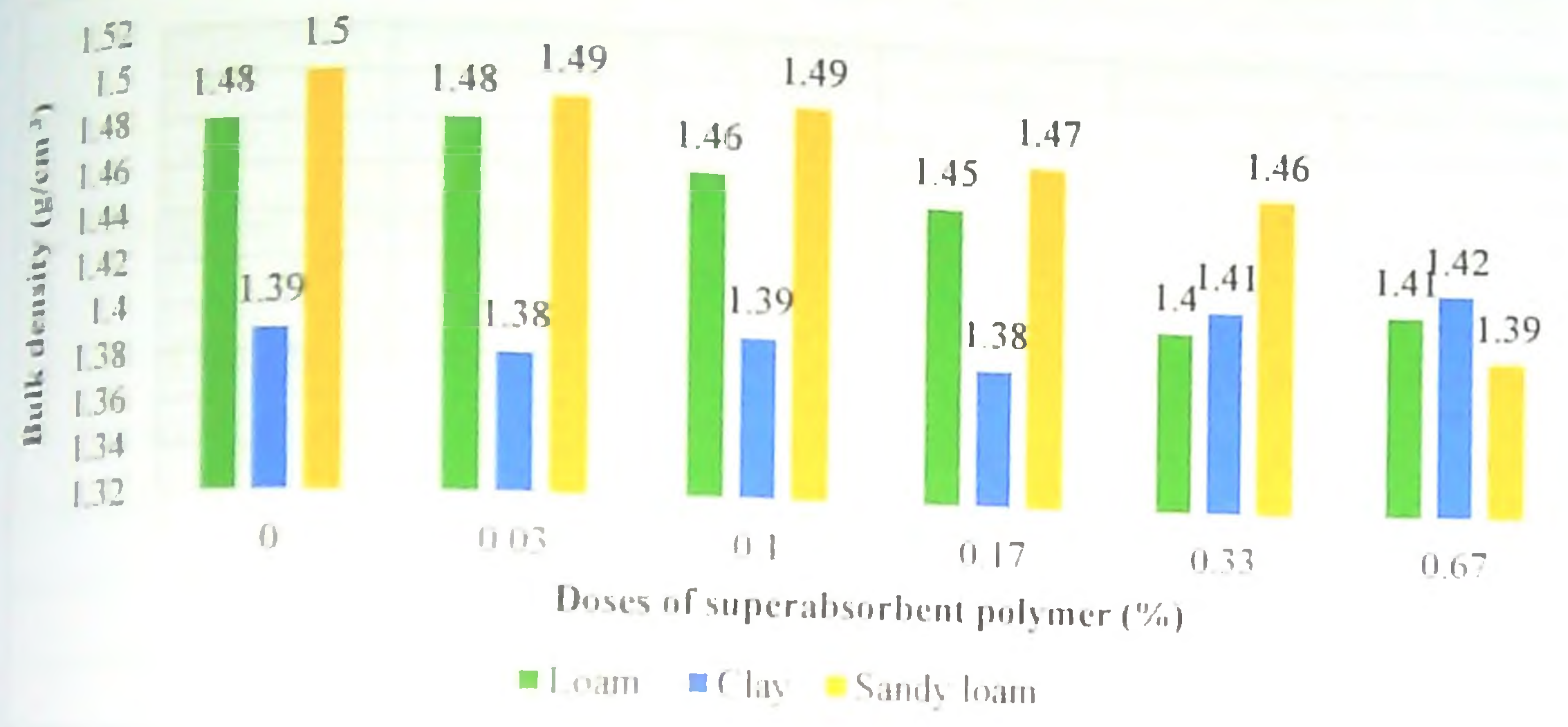
(Djurovic *et al.*, 2011)

Sivapalan, (2006) states that by adding the polyacrylamide, water holding capacity of the soil exposed to 0.01 MPa pressure was increased by 23 and 95% by adding 0.03 and 0.07% of polyacrylamide to the soil, respectively, but that at greater pressures (1.5 MPa) these differences are not pronounced.

II.3. Hydrogel on bulk density of soil

The bulk density of loamy and sandy soils reduced with polyacrylamide (PAM) addition compared to the control while there was a small increase in bulk density of clayey soil. Conversely, porosity increased with increasing hydrogel rates for clay loam and sandy soil (Figure 3). However, macro pore size increased in clay soil while it decreased in clay loam and sandy loam soils. Bulk density of soil is important to determine the soil compactness and soil health.

Figure 3. Effect of superabsorbent polymer on bulk density of loam, clay and sandy loam



(Uz *et al.*, 2008)

Available water contents of loamy and clay soils showed highly significant increase (108% and 105%, respectively) with the highest 0.67% PAM rate applied due to increase in water content at Field Capacity (FC) and decrease in water content at Wilting Point (WP). Meanwhile, plant available water content of sandy soil increased by 55% since water content at WP increased.

When polyacrylamide gels are mixed with sandy soils the maximum water absorption is substantially reduced compared with the gel alone; the swelling of the gel is limited by confinement by the soil matrix (Bhardwaj et al., 2007)

II.4. Hydrogel on chemical properties of soil

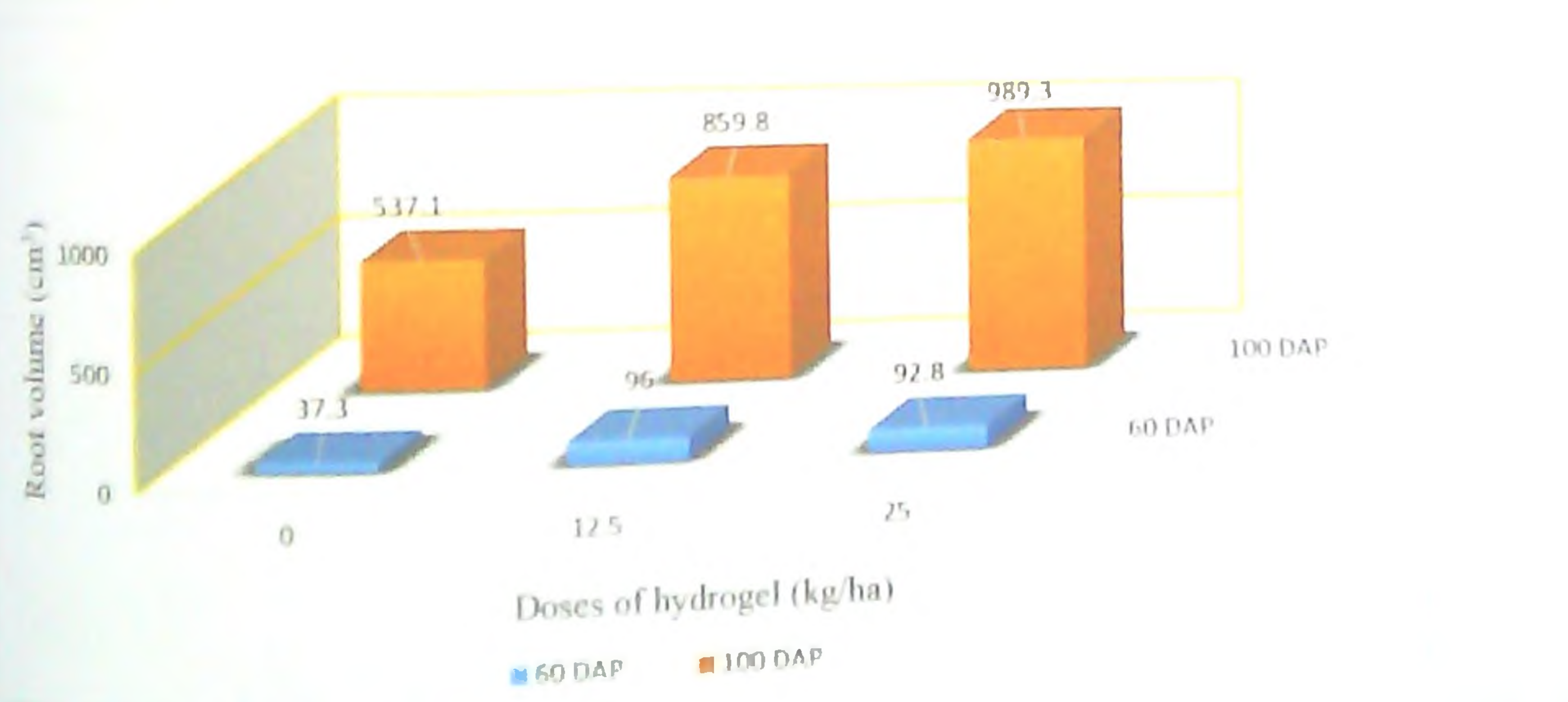
The CEC increases significantly with increase in dose showing the soil ability to reduce leaching of cations from the topsoil due to the application of the hydrogel. The use of the hydrogel to enhance water retention capacity also increases the nutrient holding capacity of the medium. The increase can also be interpreted in terms of the counter ions exchange capacity of the hydrogel which increases the soil's, Ca2+, Mg2+, K+ and Na+ ions which constitute the CEC (Table 4). The increase also is a reflection of the ability of the applied hydrogel to create microcosms that are rich in water and nutrients (counter ions).

The increased water availability with hydrogel amendments is known to improve seed germination and seedling growth, however there are variations in the response of different species to polymer (hydrogel) products (Ahmad and Verplancke, 1994). Seedling emergence and growth of crop plants increased in soil amended with hydrogel (Wallace and Wallace, 1986).

II.6. Hydrogel on root volume

The effect of hydrogel on the root volume was highly significant ($P < 0.01$), compared with the control, mainly during the first 60 DAP, because at 100 DAP only the highest dose of hydrogel (25 kg ha-1) was capable to maintain this effect. The low hydrogel dose (12.5 kg ha-1) was similar to control That means that the root volume is affected at the beginning and this effect is maintained only in the high hydrogel dose (Figure 5). The soil moisture retention in the soil increases thereby shows positive correlation with the increase in root volume.

Figure 5. Effect of hydrogel on soil moisture retention in the root volume of forage corn



(Yanez- Chavez *et al.*, 2014)

The results of this study are consistent with those reported by Taban and Movahedi (2006) where an evaluation of hydrogel and organic compost for soil moisture retention in maize grown with copolymer exhibited greater root weights and amounts of other root components

This is attributed to an increase in the soil temperature and water content due to hydrogel application. Dufault and Hair (1991) found that the use of the copolymer at a dose of 3.5 g L^{-1} of water to grow chili pepper seedlings, produced higher fresh and dry root weights in the treated plants.

11.7. Hydrogel with Azotobacter on soil water status

Soils amended with hydrogel were able to store much more water than those of control soil without hydrogel treatment. The Azotobacter inoculation gave an additional improvement to the soil and made it store more water. It was obvious also that the high concentrations of the polymer were much better than the low concentrations in storing water by the soil. The pot was inoculated or not with the free living nitrogen fixing bacteria *Azotobacter vinelandii*, in a rate of 3 kg bacteria per hectare There were significant differences between soils treated with 0.4% and 0.2% in their capacity to absorb water in the absence of Azotobacter, but there was a significant increase in soil water content at 0.4% in the presence of Azotobacter (Table 5).

Table 5. Stockosorb polymer (HG) amendment and *Azotobacter* (AZ) inoculation on soil-water status

HG doses (%)	AZ	Soil water content (kg/pot)	Time of 50% water loss (days)	% water loss
Control	-	03.75±0.88	05.2±1.11	87.2%
	+	03.88±0.93	06.4±1.24	85.2%
0.1	-	04.38±1.22	07.4±1.87	75.3%
	+	05.46±1.71	08.7±2.01	72.4%
0.2	-	06.76±1.63	10.2±2.12	70.3%
	+	07.65±1.95	12.2±2.23	66.7%
0.4	-	09.97±1.48	19.3±2.54	58.8%
	+	11.14±1.91	22.2±2.65	56.3%

(Qados, 2015)

Azotobacter is to prime the plants defense systems for increased stress tolerance involving different signalling pathway required for the recruitment of osmolytes (Beniwal, 2010). The polysaccharides on the cell wall of prokaryotic bacteria have the capacity to retain water and nutrients. Azotobacter was found to improve the level of nitrogenous compounds in soils, which may have facilitated water uptake (Hayat *et al.*, 2010).

12. General applications of hydrogel

Hydrogel of many synthetic and natural polymers have been produced with their end use mainly in tissue engineering, pharmaceutical, and biomedical fields. Due to their high water absorption capacity and biocompatibility they have been used in wound dressing, drug delivery, sanitary pads as well as trans-dermal systems, dental materials, implants, injectable polymeric systems, ophthalmic applications, hybrid-type organs (encapsulated living cells). The general applications are listed as follows:

12.1. **Drug delivery**: Hydrogel scaffold provides extracellular matrix and provides cell adhesion sites. It allows the flexibility of cells to rearrange in 3D orientation. This can also help immobilizing different proteins at the same time. Microgels in suspension contains several immobilized molecules for tissue regeneration. PEG-pH sensitive hydrogel is a biocompatible water soluble non- toxic and rapid disintegration from the body .Eg. Diltiazem

12.2. **Wound dressing:** Porosity provides channels the chemicals to be delivered. It can regulate therapeutic drugs by diffusing through the polymers network depending on the drug properties. Eg. Vigilon and hypol.

12.3. **Contact lens**: Soft contact lenses are produced due to higher wettability and permeability than those of hard contact lenses.

12.4. **Aesthetics**: Water beads available for decorartive purposes and to grow herbs indoors with wide range of colours.

12.5. **Cosmetics**: It is use to soothe the skin to prevent dark circles in eyes and to cure pigmentation.

12.6.. **Hygienic products**: Disposable diaper is a polyacrylate type produced by polymerizing with acrylic acid into a long molecular chain. Methyl acrylate monomer is polymerised in bulk in presence of cross linker and initiation via a radiation technique (UV & IR).

13. Reason for low adoption of hydrogel in agriculture

Research regarding hydrogel prove its effectiveness is limited. The starch based hydrogel which is preferred more by the farmers has low mechanical strength due to lower cross linking capacity than that of the synthetic hydrogel. Due to excessive use of chemical fertilizers in the agriculture has led to soil sickness and is easily affected by dissolved salts. Lack of awareness by Indian farmers and low risk bearing ability of farmers hindered the adoption of hydrogel for agricultural purposes.

14. Summary

Hydrogel is a cross-linked insoluble water absorbing polymer which can be synthesized naturally and synthetically. The important ideal features of hydrogel are water holding capacity, permeability and biodegradability. It is known to improve physical and chemical properties of soil. Hydrogel in the soil can be biodegraded by UV radiation, microorganisms, temperature and enzymatic action. It has wide uses in agriculture and biomedical fields.

15. Conclusion

Hydrogel amended soil prolongs plants survival and can be utilized effectively in arid and semi-arid regions since there is variability in monsoon over the years. It can be used to mitigate the effect of drought stress and as an input for contingent crop planning. Starch based polymer from yam, potato, cassava and corn can be processed to produce environmental friendly hydrogel at large scale.

The water use efficiency of various crops on different soil conditions can be studies and also to prove its efficiency in clayey soil. Further studies can be done for long term applications for landscape purpose.

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7. Discussion:

1. How does soil texture and salt concentration affect the hydrogel performance in the soil?

   The amount of water that may be retained by incorporating a polymer would be greater in coarse textured soils (sandy soil) than in fine textured soils (clay soil) allowing a void spaces to form an optimum interconnections to absorb water.

   Water holding properties of polymers are significantly affected by nature and dissolved salts concentration in water of irrigation. Saline water reduces absorption and conservation of water. Increase in water salinity in amount of more than 2.5 dS m^{-1} caused reduction in polymer effectiveness in loamy sandy soils.

2. What is the cost effectiveness in using hydrogel?

   The common hydrogel used in India are relatively affordable. The price of pusa hydrogel is Rs. 2000/kg and its effectiveness in the soil last for more than a year. For indoor purposes to grow plants, hydrogel products such as terrasorb are available in packs of 100 g, 200 g and 500 g.

3. Is the usage of hydrogel efficient in high rainfall areas?

   The hydrogel can absorb water up to 400-500 its weight and retain for long intervals. So on high rainfall areas it will act as a reservoir of water which will prevent the loss of water retain in the soil through leaching and environment. About 95% of water from hydrogel will be available. During the summer season this water can be effectively utilised by the plants.

4. How is hydrogel used for drug delivery?

   Poly ethylene glycol hydrogels (strong and elastic polymer allowing high chances of survival in the body) mimics collagenase(found in extracellular proteins) substrates found in natural proteins. Fibrous hydrogel allows for arrangement in structure of cell. Porous hydrogel allows permeability of chemicals to reach the target organ.

5. How does method of application affect the hydrogel performance in soil?

Hydrogel when applied on the subsoil region performs better than those applied over the top soil. The rate of exposure of hydrogel to the UV rays and temperature will be higher on the surface which leads to faster disintegration. For trees the root dip method for seedlings prevents the seedling roots from rapid desiccation.

6. The scope of using hydrogel for pest management?

Hydrogel is available as Nemagel which is a formulation obtained from *Sternemema thermophilum*, a nematode which has the potential to kill wide range of pest such as pod borer, diamonth back moth and boll worm. The mixture has longer shelf life than those of commercial formulation.

7. What is the effect of hydrogel in extreme dry conditions like in Rajasthan?

The activity of the hydrogel will be degraded at very high temperature at above 45 degree celcius. Since Rajasthan comes under arid condition and is below the said temperature, application of hydrogel will be resourceful be obtaining water from the atmospheric humidity by reducing the loss of evaporation from the soil.

8. What is the stability of hydrogel in soil?

The stability of hydrogel in soil differs based on the sources used. The starch graft polymer has lesser mechanical strength so it will be stable in soil for one season or a year while the synthetic polymer has the capacity to retain moisture for over 4-5 years.

18. Abstract

Hydrogel: A nascent approach for soil water conservation

Agricultural sector is one of the largest consumers of water and the demand of water has been consistently increasing over the years. The supply of water to plants during the period of water stress is essential for continued growth and survival for which proper soil water retention is a prerequisite. Superabsorbent have been used as soil additive to increase the water retention of soils, which can replace peat, the traditional moisture retention aid for soil (Barbucci *et al.*, 2000). The use of superabsorbent polymer for soil water conservation is gaining momentum in this context.

Insoluble water-absorbing polymers were first introduced for agricultural use in the early 1980s. Hydrogel is described as three dimensional network structures obtained from a class of synthetic and natural polymers which can absorb and retain significant amount of water (Rosiak and Yoshii, 1999). The polar hydrophilic groups are the first to be hydrated upon contact with water which leads to the formation of primary bound water. Hydrogels can absorb water approximately 400 times of its weight to form gels and can be synthesized by physical and chemical cross linking.

Hydrogel has a wide range of uses in biomedical applications and agriculture. The desired features of hydrogels for agricultural purposes include high swelling rate, stability and biodegradability which can be effectively utilized for its use in soil water conservation. These features are dependent on structure of the polymer network, particle size, rate and method of application, and temperature. The larger surface area of swollen particles can provide more voids in the soil matrix which can enhance soil aeration.

Pusa hydrogel, a commercial superabsorbent having properties of delaying the onset of permanent wilting point, gradual biodegradability and less affected by dissolved salts is found to reduce the irrigation frequency when applied in soil. This soil conditioner is effective in correction of aggregation, prohibiting capillary water soar, decreasing cumulative evaporation and improving growth in vast range of plant species (Sivapalan, 2006).

Superabsorbent polymers with a complex of carboxymethyl cellulose and starch based products from cassava, corn, potato and yam are promising eco-friendly amendment in soil (Nnadi and Brave, 2011). Qados (2015) reported that the inoculation of *Azotobacter vinelandii* in the presence of superabsorbent polymer enhance the ability of soil to hold more water and

prolong the time of water loss from soil. Hydrogel can be readily degraded by soil microorganisms and enzymatic in soil.

The usage of hydrogel in agriculture is limited since most of the superabsorbent polymers that are currently in the market are acrylate-based products which take longer time for degradation and raising some concerns about toxicity. Researches on finding out fast biodegradable hydrogel-based products in large scale are on the way.

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Soil Science and Agrl. Chemistry

Electrokinetic remediation of heavy metals in soil

By

Beena S. George

(2014-11-126)

MSc. Soil Science and Agricultural Chemistry

Seminar report submitted in partial fulfilment for the requirement of the course

Soils. 591 Seminar (0+1)

DEPT. OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

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DECLARATION

I, Beena S. George (2014-11-126), hereby declare that the seminar report 'Electrokinetic remediation of heavy metals in soil', has been completed by me independently after going through the reference cited herein and I have not copied from any of the fellow students or previous seminar reports.

Vellanikkara

Date: 13/11/2015

Beena S. George

2014-11-126

CERTIFICATE

This is to certify that the seminar report entitled 'Electrokinetic remediation of heavy metals in soil' has been solely prepared by Beena S. George (2014-11-126), under my guidance and has not been copied from seminar reports of seniors, juniors or fellow students.

Vellanikkara

13/11/2015

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1. Introduction

Soil contamination is a serious environmental problem all over the world. Main causes of soil contamination are industrialisation, urbanisation, mining, agricultural activities, land filling etc. Heavy metalsis one of the main soil contaminant. A number of industrial activities, including coal-fired power production, electroplating, leather tanning, smelting, fly ash, timber treatment, pulp production and mineral ore and petroleum refining, generate solid and aqueous waste products that are enriched with various heavy metals. Heavy metal contamination not only affects living organisms in the subsurface but also affects the plants that accumulate contaminants as they grow. Thus, contaminants enter the food chain with a potential impact in public health. On the other hand, contaminants can be washed out the soil by rain and groundwater, resulting in the dissemination of the contamination. The contaminants cause severe health hazards to the human being. Most of them are carcinogenic, many causes allergy, skin diseases, softening of bones.

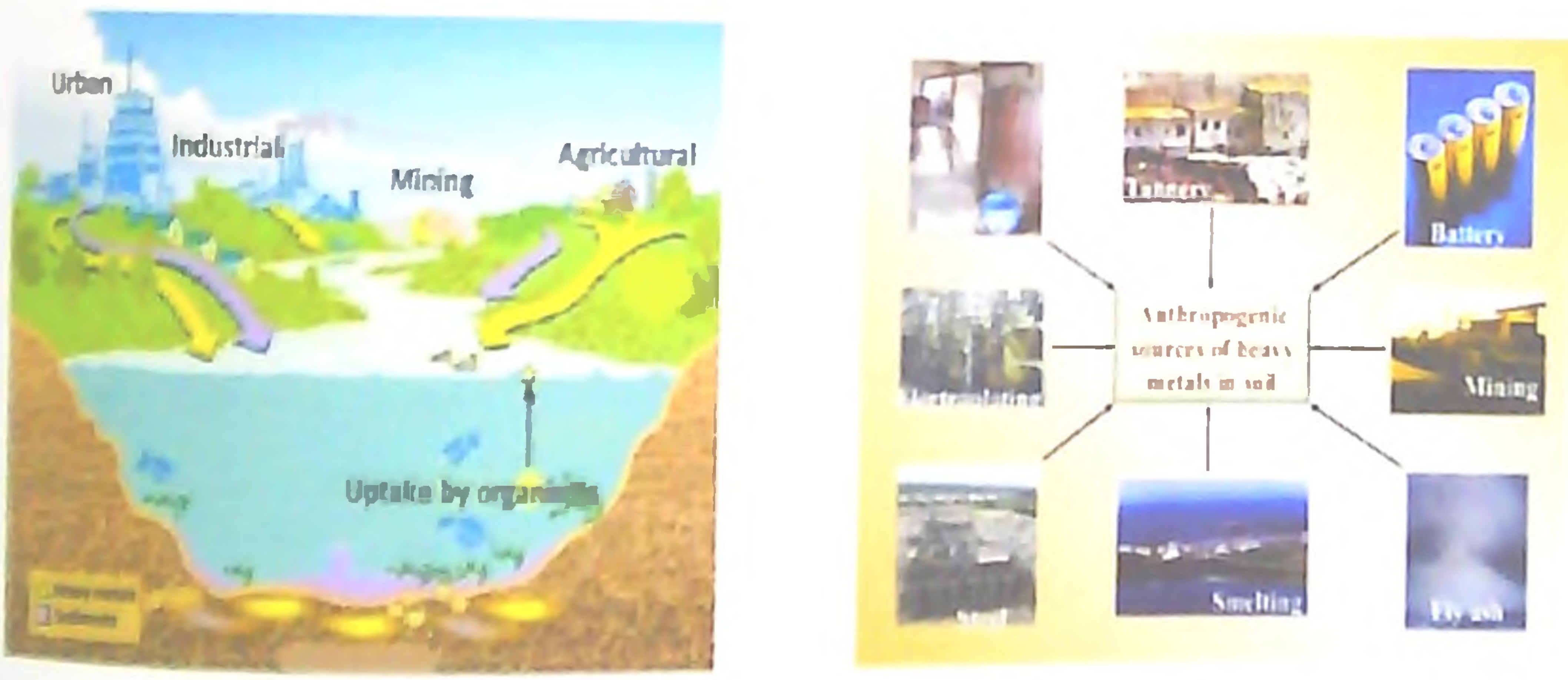

Plate 1. Sources of contamination

The present situation of soil contamination is the result of bad practices in the past. This process is not desirable because the area affected by the contaminants is bigger and bigger and the possible remediation is more difficult and costly as the affected area grows. Therefore, soil contamination is a serious problem that requires a rapid solution in order to prevent more environmental damages. Prevention is the best "technology" to save our soils from the contamination.

1. Introduction

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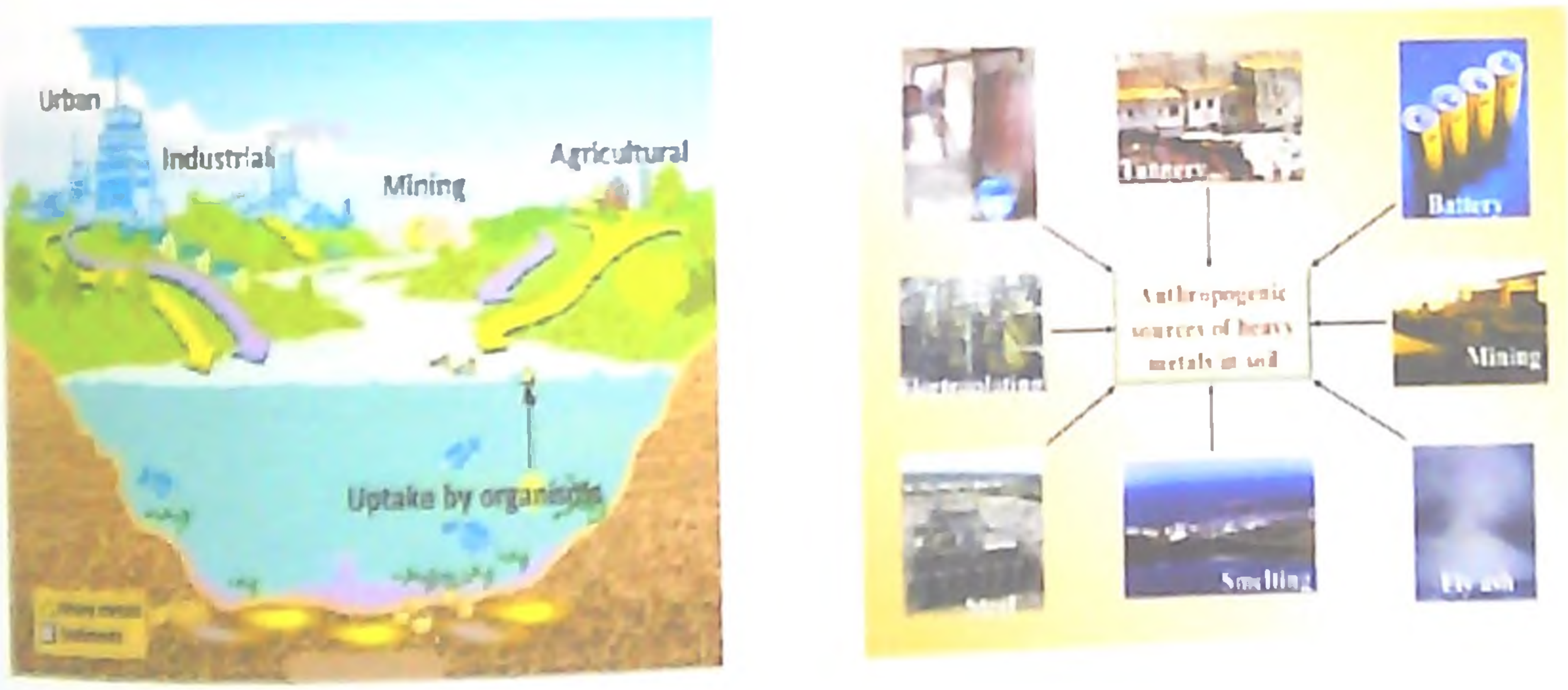

Plate 1. Sources of contamination

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Several technologies have been developed to remediate contaminated sites (Sharma and Reddy, 2004). Commonly used remediation technologies include soil flushing, solidification and stabilization, thermal desorption, bioremediation, and phytoremediation.

The inadequate performance of the remediation technologies may be attributed to complex site conditions, such as: (1) clayey soils are difficult to remediate because of their low permeability and complex composition (mineralogy and organic content); (2) many common technologies fail under heterogeneous subsurface conditions (e.g., clay lenses within sand formation); (3) hydrophobic organic contaminants such as PAHs and PCBs are difficult to treat; (4) very few technologies are available to cleanup sites contaminated with heavy metals; and (5) very few technologies exist that can remediate sites contaminated by mixed contaminants (e.g., organic compounds combined with heavy metals and/or radionuclides). There is an urgent need to develop new technologies that can overcome these challenges as well as be cost-effective (Reddy, 2010). Electrokinetic remediation has great potential to fill this need. Electroremediation is emerging as a viable, cost effective in-situ technique for cleaning heavy metal contaminated soils (Niroumand *et al*., 2012)

Reddy and Chinthamreddy (2002) suggests at least three general conclusive ideas about electroremediation. First, the technology is applicable to metal and organic contaminants removal. Second, it indicates that electrokinetic works well under unsaturated and saturated soil conditions. Third, low permeability soil can be treated successfully by this technology.

. Electrokinetic remediation

Electrokinetic remediation is an environmentally safe technique especially developed for the removal of contaminants in soil, sediments and sludge, although it can be applied to any solid porous material (Reddy *et al*., 2006). Initially electrokinetic remediation was applied to remove salt or alkali from soils (Puri and Anand 1936). Its application to the removal of heavy metals was first attempted in the early 1980s (Segall *et al*., 1980). The first successful demonstration of the use of electrokinetics for soil remediation was performed in the Netherlands in 1986.

. Components of electrokinetic system

A basic electrokinetics remediation system contains an external direct current source, positively charged electrode (or anode) and a negatively charged electrode (or a cathode) placed into the ground. Placement of electrodes are based on size and shape of known contaminant plumes. The removal of contaminants and prevention of plume migration are big influences in determining the arrangement of electrodes. Each electrode is encased in a reservoir well in which an electrolytic solution can be injected (Sharma and Reddy, 2004). The electrolytic solutions serve both as a conducting media (or pore fluid) and as a means to extract contaminants and introduce chemicals or biological entities (Acar *et al.*, 1995). Another use of the electrolytic solution is for control and/or depolarization of electrode reactions. By pumping, processing and testing the electrolytic solution at each electrode site, the life and efficiency of the system can be extended.

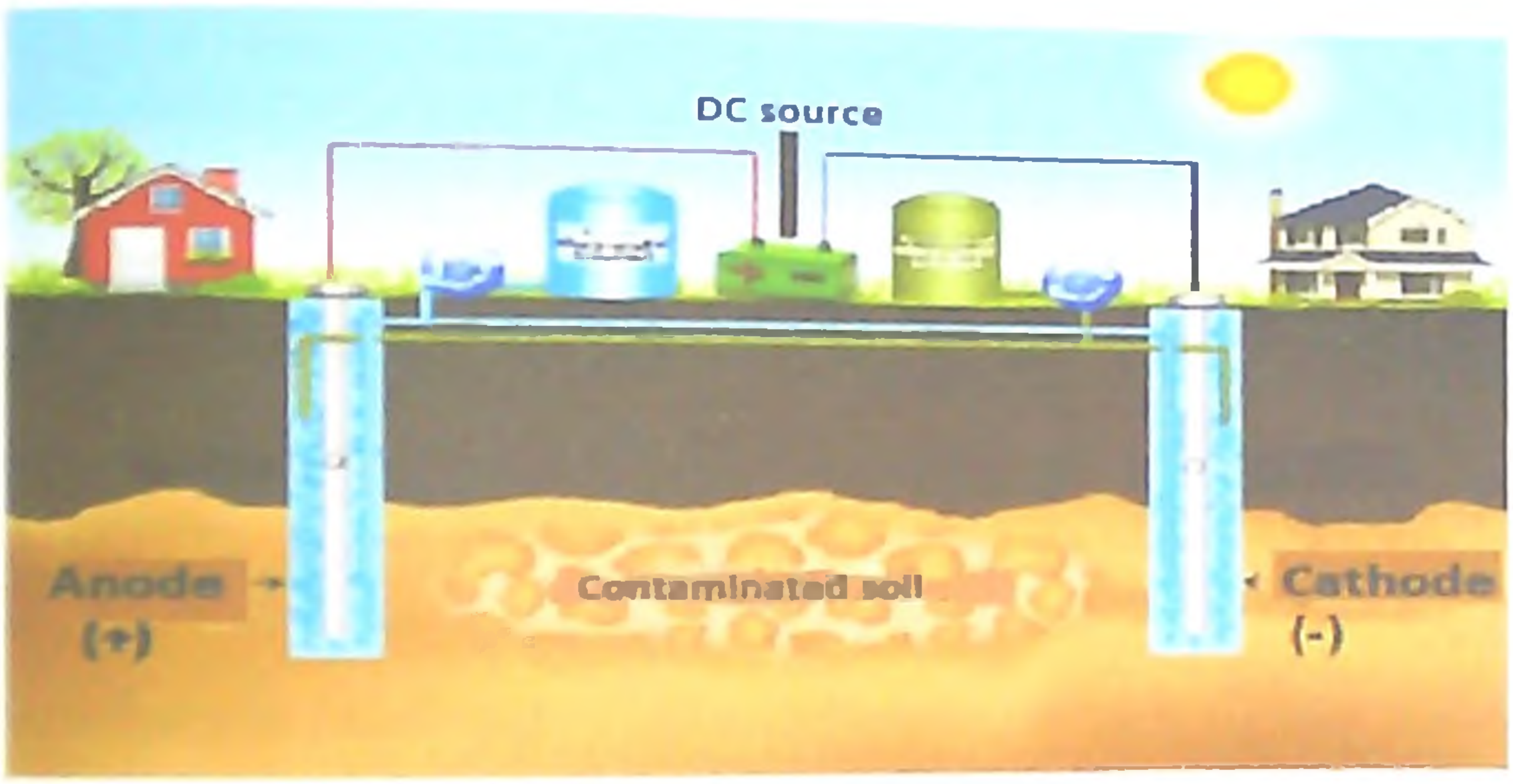


Plate 2. Components of electrokinetic system

4. Principle of electrokinetic remediation

Electrokinetic remediation is based on the application of a direct electric current of low intensity to the porous matrix to be decontaminated (Acar 1993). The effect of the electric field induces the mobilization and transportation of contaminants through the porous matrix towards the electrodes. The contaminants within the electric field are transported to the anode or to the cathode where they are removed by one of the following methods: electrodialysis into electrolyte solutions, adsorption onto the electrode, precipitation or co precipitation at the electrode, pumping next to the electrode, complexing with ion exchange resins, or capturing in permeable reactive barriers. Main electrodes, anode and cathode, are inserted into the soil matrix, normally inside a chamber which is fill with water or the appropriate solution to enhance the removal of contaminants.

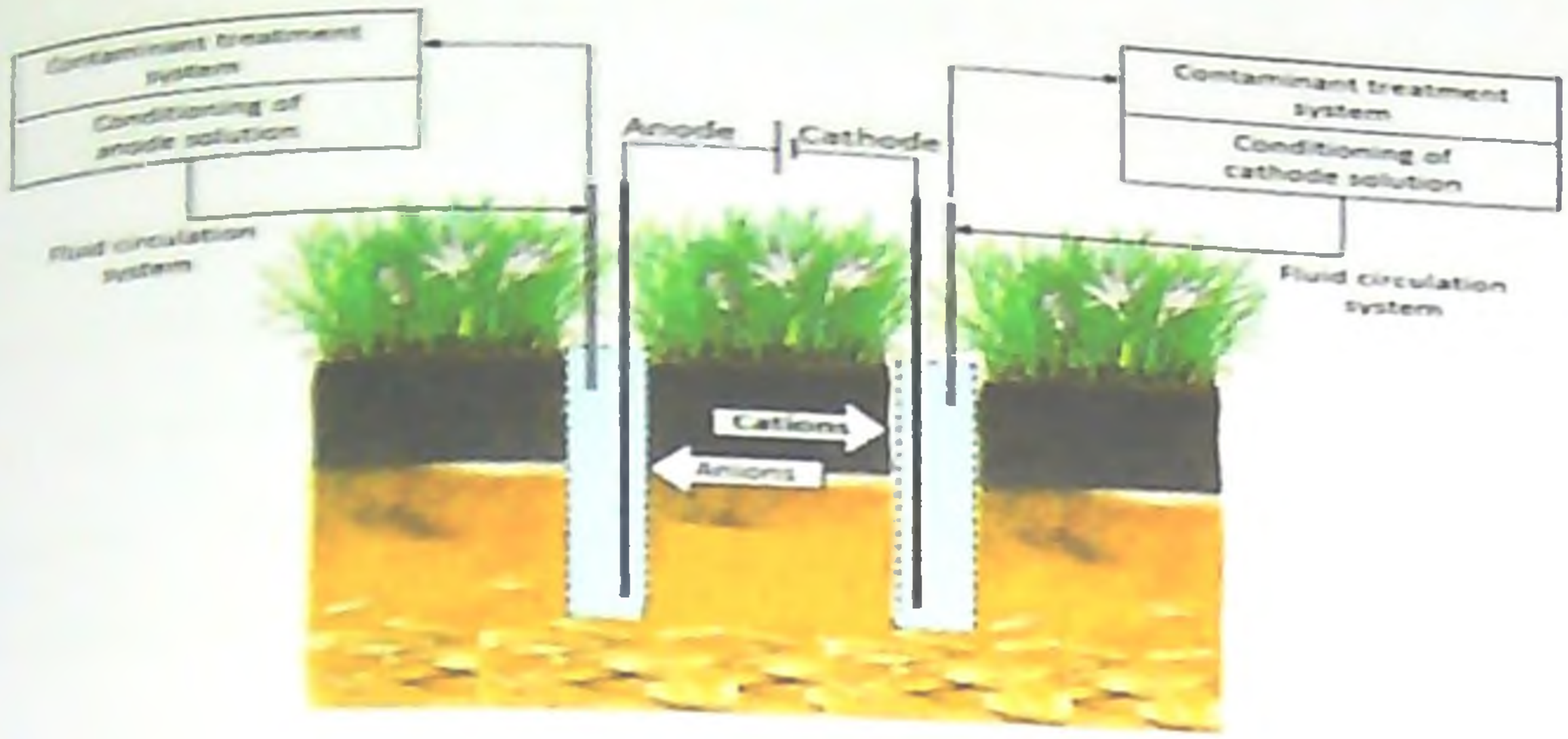


Plate 3. Principle of electrokinetic remediation

(Cameselle and Reddy 2012)

5. Contaminant transport mechanisms

Contaminants are transported out of the soil due several transportation mechanisms (Kim *et al.*, 2002) such as electromigration, electroosmosis and electrophoresis.

5.1 Electromigration

Electromigration is defined as the transportation of ions in solution in the interstitial fluid in the soil matrix towards the electrode of the opposite charge (Yeung and Gu, 2011). Cations move towards the cathode (negative electrode), and anions move towards the anode (positive electrode).

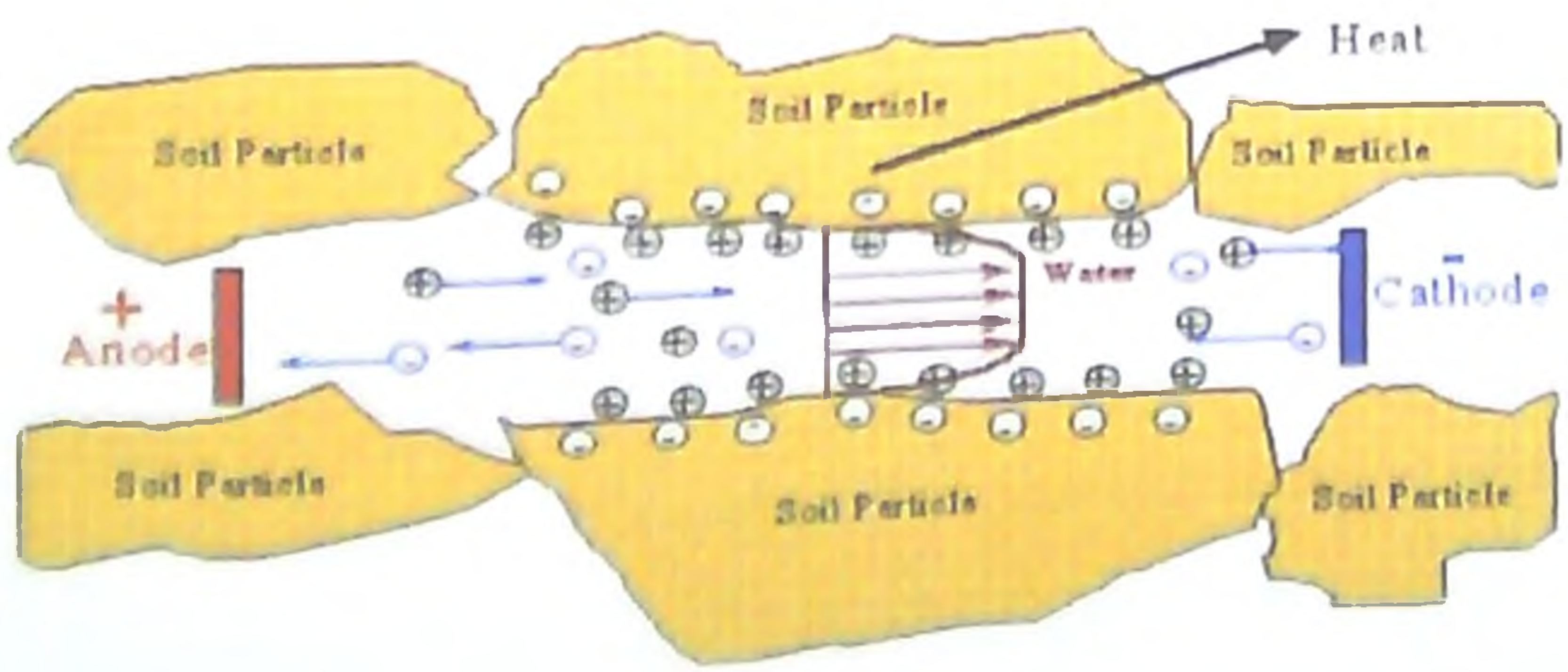


Plate 4. Electromigration

The ionic migration or electromigration depends on the size and charge of the ion and the strength of the electric field. It is the most important transport mechanism aiding electrochemical remediation (Lageman,1993). Because of electromigration, ions tend to concentrate near the opposite charged electrode (Reddy *et al.*, 2006). The electromigration of cations and anions towards the electrode opposite in charge is proportional to the ion concentration in the pore water solution and to the electric field strength (Kim *et al.*, 2005). The ionic mobility is a term used to describe the rate of migration of a specific ion species under a unit electric field. In soils, the rate of ionic migration can be better defined by the effective ionic mobility, which also accounts for soil porosity and tortuosity, which can significantly affect ion migration.

5.2 Electro-osmosis

Electro-osmosis is the net flux of water or interstitial fluid induced by the electric field. It is a bulk transport of water, which flows through the soil as a result of the applied electrical field (Lynch *et al.*, 2007). The fluid migration occurs mostly from the anode to the cathode, due to the predominance of a negative charge on the soil particle surfaces. The electro-osmotic flow is caused by the fact that when an electric field is applied to a soil, the excess of cations close to soil particles surface (double layer) tend to move towards the cathode. The movement of these ions and of the water molecules associated with these species (hydration shells), impart a net strain on the pore fluid surrounding the hydrations shell. This strain is transformed into a shear force because of the viscosity of the pore fluid. In sum, as there is usually an excess of cations close to soil particles, the electric fields leads to a net force towards the cathode which results in a pore fluid flux in this direction (Acar, 1995). Hence, the electric field causes the pore fluid to flow from the anode compartment to the cathode, producing a flux and forcing the water table to arise in the cathode compartment. Electro-osmosis is a complex transport mechanism that depends on the electric characteristics of the solid surface, the properties of the interstitial fluid and the interaction between the solid surface and the components in solution. The electro-osmotic flow transports out of the porous matrix any chemical species in solution. Soils and sediments are usually electronegative (solid particles are negatively charged), so the electro-osmotic flow moves towards the cathode. In the case of electropositive solid matrixes, the electro-osmotic flow moves towards the anode.

5.3 Electrophoresis

Electrophoresis is the transport of charged particles of colloidal size and bound contaminants due to the application of a low direct current or voltage gradient relative to the stationary pore fluid. When a direct current (DC) electric field is applied across a colloidal suspension, charged particles and colloids that are suspended in the pore fluid are electrostatically attracted to one of the electrodes and repelled from the other. Compared to ionic migration and electro-osmosis, mass transport by electrophoresis is negligible in low permeability soil systems. However, mass transport by electrophoresis may become significant in soil suspension systems and it is the mechanism for the transportation of colloids (including bacteria) and micelles.

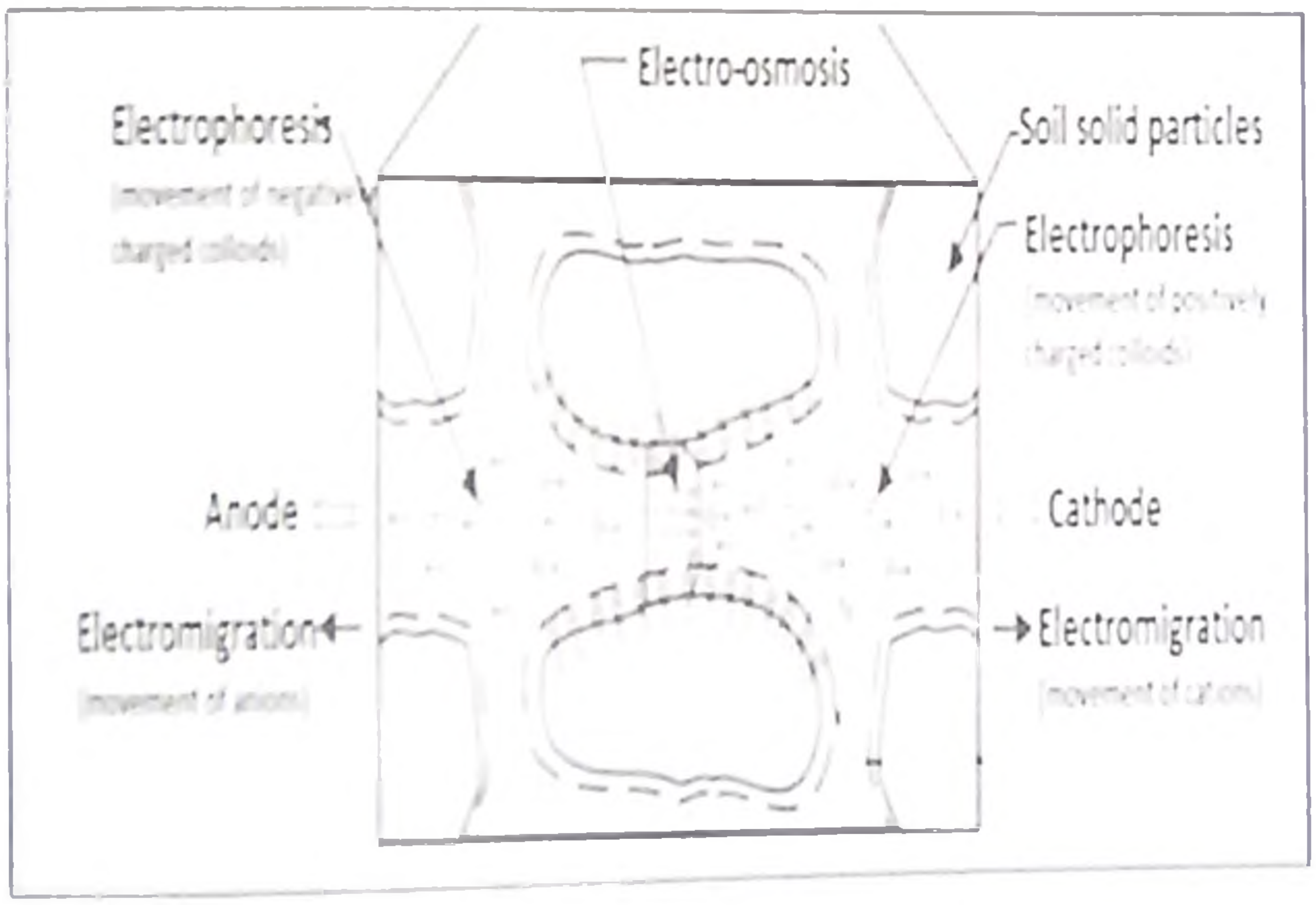


Plate 5. Overview of mechanism involved in electrokinetic remediation (Reddy 2010)

6. Processes involved in electrokinetic remediation

The physical and chemical processes involved are electrolysis, diffusion, adsorption-desorption, precipitation-dissolution and oxidation-reduction.

6.1 Electrolysis

The electrolysis of water occurs at the electrodes according to the following reactions

At the anode: $2H_2O \rightarrow O_2(g) + 4H^+ + 4e^-$

At the cathode: $4H_2O + 4e^- \rightarrow 2H_2(g) + 4OH^-$

Electrolysis is the decomposition of water molecules into hydrogen and hydroxyl ions (Cameselle and Reddy,2012).Theoretically, in an electrochemical reactor, equal amounts of current are carried by anions and cations in solution. The concentration of anions and cations decreases closer to the electrodes, compared to the bulk concentration. When the concentration reaches zero, the limiting current density has been reached. Operation at current densities higher than the limiting current results in the water splitting phenomenon (formation of H+ and OH-). The limiting current is lower at the anode than at the cathode, thus an acidic front is formed desorbi ng metals and transporting them with water and soil particles towards the cathode. For metals of concern that are not mobile at low pH (eg. As or Cr (VI)), surfactants and complexing agents have been used to assist in the migration (Ottensen, 1997). Surfactants have also been used to assist transport of organic contaminants in electrochemical remediation (Elektorowicz and Lin, 2001).

The electrolysis reactions greatly affect the remediation process because the ionic products (H+ and OH−) may electromigrate and/or be transported by electroosmotic advection towards the oppositely charged electrode location. Thus, an acidic (H+) front of solution may move from the anode towards the cathode, and/or an alkaline (OH−) front of solution may move from the cathode towards the anode. The rate of electromigration may also be affected by ionic mobility, and, since hydrogen ions are smaller and have a greater mobility than hydroxyl ions, the acidic front generally moves faster through the soil (Acar and Alshawabkeh, 1993). The reaction kinetics, or the rate of the electrolysis reactions at the electrodes, may also affect the generation and movement of the hydrogen and/or hydroxyl ions.

6.2 Diffusion

Diffusion is the process where the contaminants move due to difference in concentration gradient. This usually does not contribute to a significant amount of contaminant transport in remediation. This depends on the tortuosity and porosity of the medium and the concentration of the species (Sharma and Reddy, 2004).

6.3 Adsorption-desorption

Adsorption involves the movement of contaminants from pore water to the soil particles. Generally soils are negatively charged but it would depend on the pH of the soil (Reddy , 2010). The net charge in soil will be zero for a particular value of pH and that is called the point of zero charge (PZC). If the pore water falls to a pH less than PZC then adsorption of anions will be predominant and when pH rises above PZC the adsorption of cations are significant. Thus adsorption is dependent on factors including soil type, soil charge, contaminant, organic matter and pore water characteristics.

Desorption is the reverse of adsorption and involves the transport of contaminants from soil to pore water. When pH falls below PZC desorption of cations are significant and vice versa. Due to extreme pH differences between the regions near the electrodes, the cationic absorption and anionic desorption occurs near cathode. The anionic adsorption and cationic desorption occurs near anode. The area of the PZC is known as the slippage plane and beyond this, free pore water is present in the soil.

6.4 Precipitation-dissolution

Precipitation is the formation of solid that results when the concentration of compound exceeds its solubility. Dissolution is the reverse where compound forms a solution. Both processes are highly pH dependent and would occur depending on their location. The contaminants could be precipitated or dissolved during remediation. The dissolved contaminants would be easier to remove than the precipitated contaminants in soil.

6.5 Oxidation-reduction

Redox reactions take place during the remediation process. Area near Anode experiences oxidation since electrons are lost and the cathode area experiences reduction since there is addition of electrons. Some metal cations precipitate near cathode. The valence of the metal ions decides on their solubility and thus might impact removal (Sharma and Reddy, 2004).

7. Factors affecting electrokinetic remediation

There are many practical aspects of the technology that needs to be considered carefully before the technology can be successfully implemented in the field.

7.1 Soil type

This technology can be successfully applied to clayey to fine sandy soils. It appears that soil type does not pose any significant limitation on the technology. However, contaminant transport rates and efficiencies depend heavily on soil type and environmental variables. Soils of high water content, high degree of saturation, and low activity provide the most favorable conditions for transport of contaminants by electro-osmotic advection and ionic migration. However, soils of high activity, such as Illite, montmorillonite, and impure kaolinite, exhibit high acid/base buffer capacity and require excessive acid and/or enhancement agents to disrobe and solubilize contaminants sorbed on the soil particle surface before they can be transported through the subsurface and removed. Moreover the high sorbtive capacity of the clayey soil for contaminant would further aggravate the problem by retarding contaminant transport.

7.2 Contaminant type and concentration

Available experimental datas indicate that removal of heavy metals, radio-nuclides, and selected organics by electrokinetics is feasible. It is anticipated that pollutant, such as PbO, may dissolve and advance through the soil. The process helps in migration of different contaminants in the soil simultaneously. Therefore, the type of contaminant does not pose a significant limitation on the technology, provided the contaminant does not exist in the sorbed phase on the soil particle surface or as precipitates in the soil pore. However a high concentration of ions in the pore fluid will increase the electrical conductivity of soil and thus reduce the efficiency of electro-osmotic fluid flow. More the strength of the electric field applied may have to be reduced to prevent excessive power consumption and heat generation during the process. Nonetheless the concentration of the contaminant does not pose any insurmountable hurdle to the application of the process.

7.3 Electrolyte composition

Changes to the electrolyte composition occur when dissolved substances are removed from the soil sample, by entering the catholyte/anolyte, by depositing on the cathode as is the case for many metal ions, such as Pb (Hamed et al. 1991) and Cd (Acar et al. 1994), or by evolution of, for example, chlorine from saline soil at the anode. So metals from the exhausted electrolyte must be extracted and removed.

7.4 pH gradient across the electrokinetic cell

The process of electrolysis leads to changes in the soil pH near the electrodes. The region near anode develops a low pH of about 2 whereas near the cathode it increases up to 11 or 12 (Figure 1). The hydrogen and hydroxyl ions move both due to electromigration and diffusion. The hydrogen ions being smaller than the hydroxyl ions tend to travel faster leading to rapid acid front migration at almost twice the speed of the base front migration. The acid front migration is even easier in low buffering capacity soils compared to high buffering capacity soils since the hydrogen ions get consumed to neutralize soil constituents (Sharma and Reddy, 2004). The acid dissolves the usual cations in the soil or precipitates and helps cation removal. If the contaminants are anionic, the acid front would increase adsorption and reduce contaminant removal. Both the acid and base front will in turn have an effect on the zeta potential of the soil influencing the flow.

Figure 1. Variation in pH with distance from anode

7.5 Voltage and current levels

The electric current densities used in most studies are in the order of a few tens of mA cm^{-2}. Although a high current intensity can generate more acid and increase the rate of transport to facilitate the contaminant removal process, it increases power consumption tremendously, as power consumption is directly proportional to the square of electric current. An electric current density in the range of 1 - 10 A m^{-2} has been demonstrated to be the most efficient for the process. However appropriate selection of electric current density and electric field strength depends on the electrochemical properties of the soil to be treated, in particular the electric conductivity. The higher the electric conductivity of the soil, higher will be the required electric current density needed to maintain the required electric field strength. Electric field strength of the order of 50 V / m can be used as an initial estimate for the process. An optimum electric current density or electric field strength should be selected based on soil properties, electrode spacing and time requirements of the process.

7.6 Electrical conductivity and field strength

As a result of the changes in pH and ionic strength, which arise during electroremediation, non uniform electrical conductivity and voltage profiles quickly develop (Bruell *et al.*, 1992). The most noticeable drop in conductivity and therefore rapid change in field strength are generally observed near the cathode (Figure 2). These appear to correspond to the sharp pH jump and to the precipitation of heavy metal ion contaminants as solid hydroxides (Hamed *et al.*, 1991). The resultant steep potential gradient near the cathode initially causes a higher rate of electro-osmotic flow in this region by the high negative value of the zeta potential near the cathode (Eykholt and Daniel 1994). As the acid front produced at the anode passes through the soil, the overall flow is reduced. Eventually, the very high resistance of precipitated metal hydroxides and bubbles of gases, such as hydrogen, produced by electrolysis, cause fluid flow to become minimal. As long as the concentration of ions in solution is sufficient, electromigration results in significant removal of ions even when electro-osmosis has declined or ceased. However, as ions are removed, by means of water formation, precipitation, adsorption, and complexation, conductivity falls especially in the region of the pH jump. Electromigration and therefore the rate of removal of contaminant ions become slow.

Figure2. Variation in electrical potential with normalised distance from anode

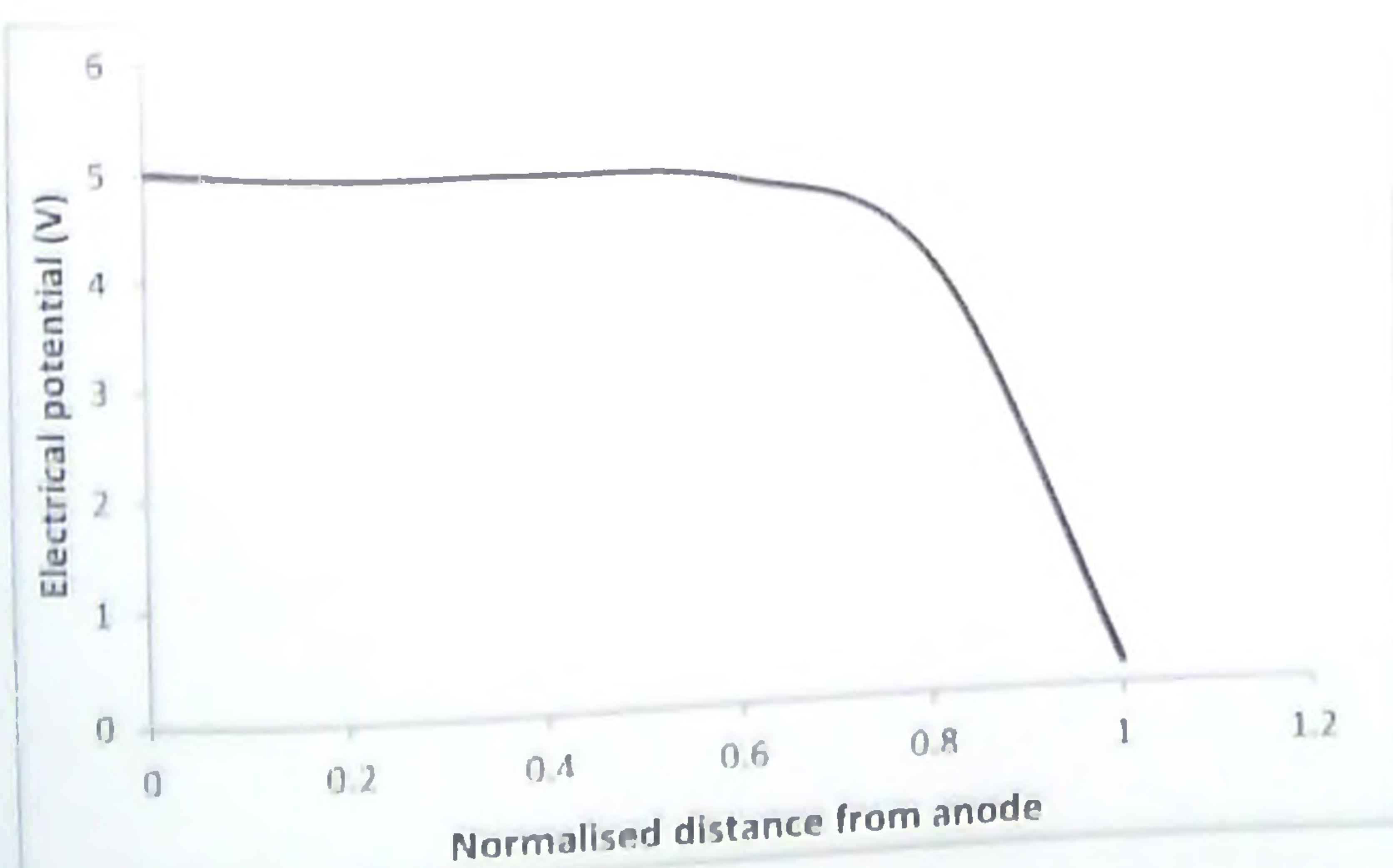


Figure 2 (Hamed *et al.*,1991) shows variation in electrical potential with normalised distance. Normalised distance is the ratio of distance from anode to a specific point to the distance from anode to cathode. There is a steep drop in electrical potential near the cathode

region due to pH jump and precipitation which leads to electro-osmotic flow towards cathode initially.

7.7 Nature and arrangement of electrodes

The choice of electrode material affects the electrode process but is limited in practice by cost considerations, ease of manufacture, and robustness. Generally, inert electrodes are preferred as they avoid introducing contamination from dissolution of the anode material though, in some cases, reactive anodes, such as iron, have been employed (Ho et al., 1997). They need to have porous casings and open access to the electrode compartments so that solutions and gases can flow through them. A common choice of material for both electrodes in laboratory studies is graphite while, in field applications, materials such as activated titanium with an electrocatalytic coating of mixed oxides or conductive ceramics are sometimes used. The size, shape, and arrangement of electrodes and the distance between them will also affect rates of decontamination. Very little research has been carried out into optimum values for these parameters.

8. Application of electrokinetic remediation

Electrokinetic Remediation can be implemented for the remediation of soils, sediments and any porous material. This technique is used on both saturated and unsaturated soils though it works better on saturated soils. It can also be implemented on heterogeneous soils and used to treat a wide range of contaminants (Acar et al., 1995). The method is very effective in removal of strontium and cesium from high water content soil. pH control at the electrodes and the use of enhancement agents would broaden the range of contaminants that can be treated with this process such as lead, mercury and cobalt. Thus, Electrokinetic remediation is a developing technology which intends to separate and extract radionuclides, heavy metals and organic contaminants from saturated or unsaturated soils, sludges, sediments and groundwater.

8.1 Field Applications

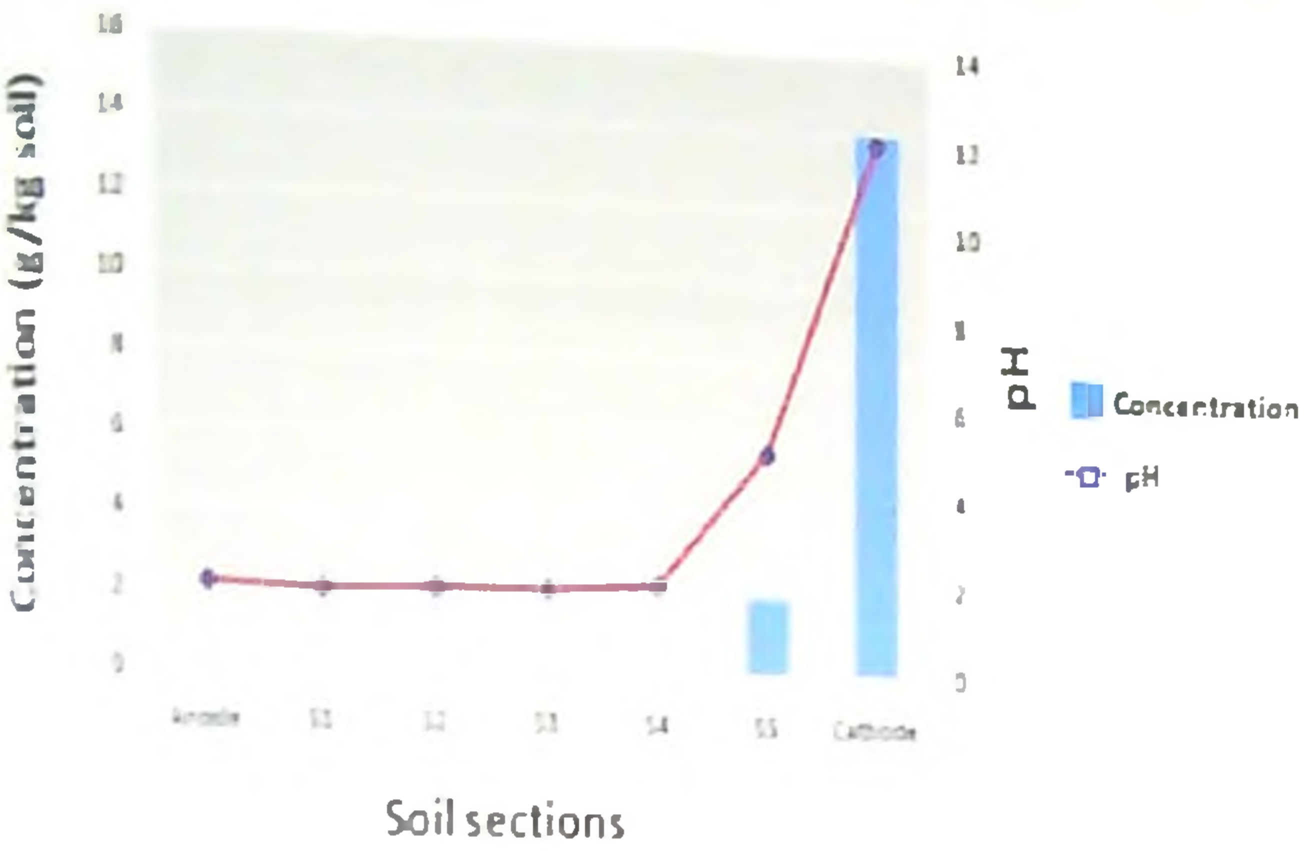
In most practical applications of electrokinetics, the anodes are iron or aluminum rods and the cathodes are steel tubes. Sometimes graphite electrodes are also used for both anodes and cathodes. Lageman, (1993) reported the results of field applications in the Netherlands. These studies demonstrated about 60 % of Zn removal at a concentration of 70 g g-1 from sandy clay soils; 80 % of As removal at a concentration of 90g g -1 from heavy clayey soils and 75 % of Pb removal at a concentration of 340g g -1 from dredged sediment. The energy expenditure ranged from 60 to 220 kWh m-3 of soil processed. Page and Page (2002) applied the electrokinetic extraction process in conjunction with the pump-and-treat method in a abandoned industrial hard-chrome plating facility superfund site in Corvallis, Oregon, USA. Their study demonstrated that chromium removal slightly increased, but they didn't provide any numerical value of removal efficiency. They primarily concluded that ion migration plays a significant role in the de-contamination process. In another field study conducted at Stadskanaal, Netherlands, it is reported that at an energy expenditure of 20 kWh m -3 of soil, Pb concentration reduced to 120 mg kg-1, Cd 150 mg kg-1 , and Zn 320 mg kg-1; at 65 kWh m-3 of soil, Pb concentration reduced to 90 mg kg-1, Cd 50 mg kg-1, and Zn 120 mg kg-1; and at 180 kWh m-3 of soil, Pb and Zn concentrations reduced to less than 10 mg kg-1and Cd less than 2 mg kg -1. In all cases the initial concentrations of Pd, Cd and Zn were 210 mg kg-1, 300 mg kg-1, and 480 mg kg-, respectively. However, a number of problems not encountered in the laboratory studies arose in the field trails.

9. Case studies

In 1995 at the Paducah site, in Kentucky, USA a new technique was developed for fore removing heavy metals form soils called the Lasagna Process (Ho *et al.*, 1991), simply is the creation of several horizontal permeable zones used to provide treatment through the contaminated soil matrix by adding different admixtures to the electrolytic solution. Admixtures like sorbents, catalytic reagents, buffering solutions, oxidizing agents in this system are applied through a vertical system with the anode near the bottom and the cathode near the top. The orientation of vertical anode and cathode system make recycling of fluid and system treatment easier. The formation if the lasagna layers is due to fracturing in over-consolidated clays because of horizontal electrodes. Coupling of the horizontal electrodes with a vertical pressuring system make this method especially effective in removing contaminants from deeper layers of the soil. The pioneer test of this process proved 98% effective of removing contaminants from the Paducah site.

The figure 3 shows the migration and removal of lead during electrokinetic remediation. The experiment was conducted by Virkutyte *et al.*(2002) in pb contaminated kaolinite soil using electrokinetic remediation. After the process the soil was divided into five equal sections and analysed for pb. It was noted that about 85 % of the initial Pb added was recovered. The remaining Lead that was desorbed during the experiment gets accumulated close to the cathode.

Figure3. Migration and removal of lead during electroremediation (Virkutyte *et al.*,2002)



Another experiment with hexavalent Chromium also shows 75-80 per cent efficiency during electrokinetic remediation. Hexavalent Chromium accumulated towards anode because it will form oxy anions that move towards anode under the influence of electric field (figure 4)

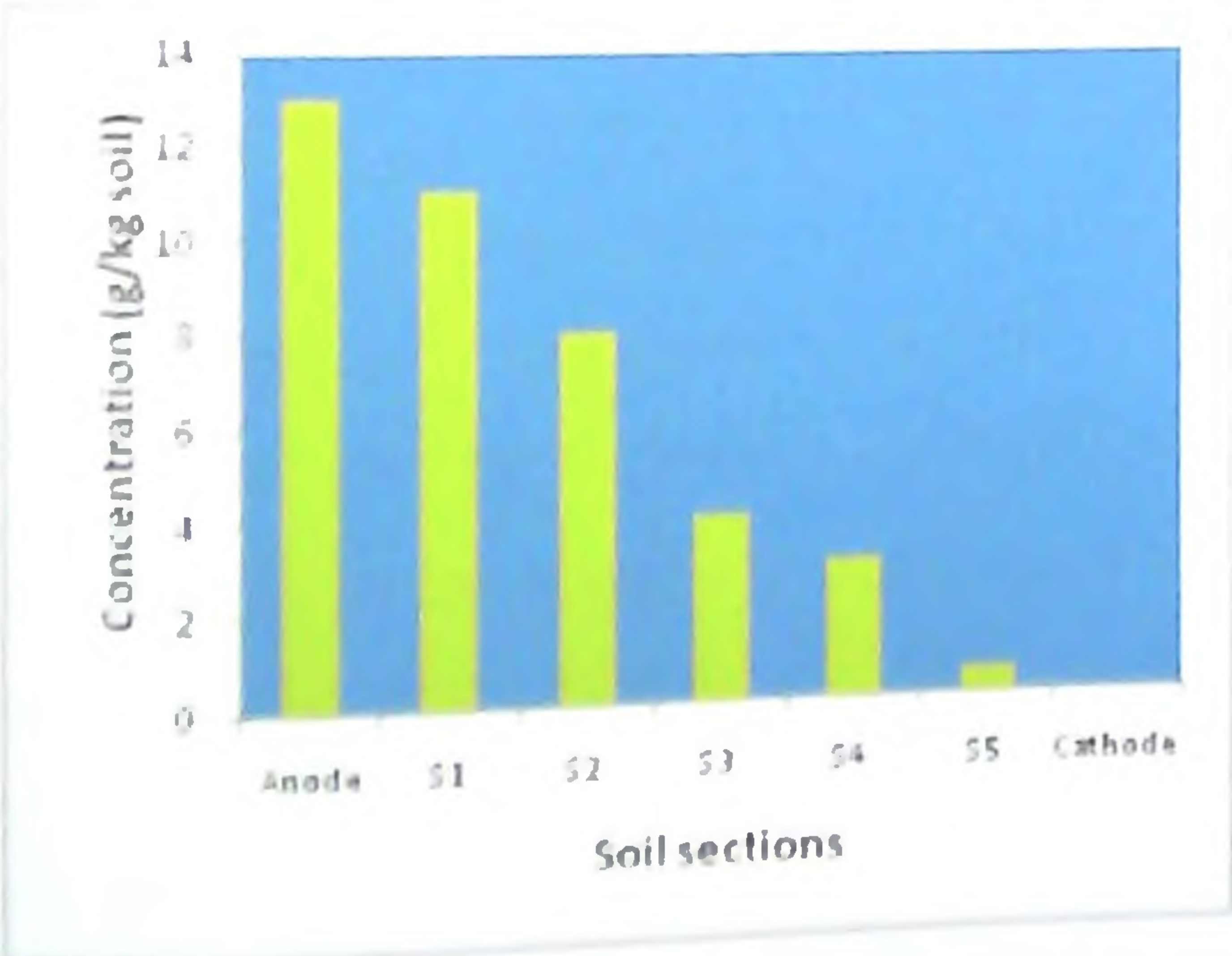


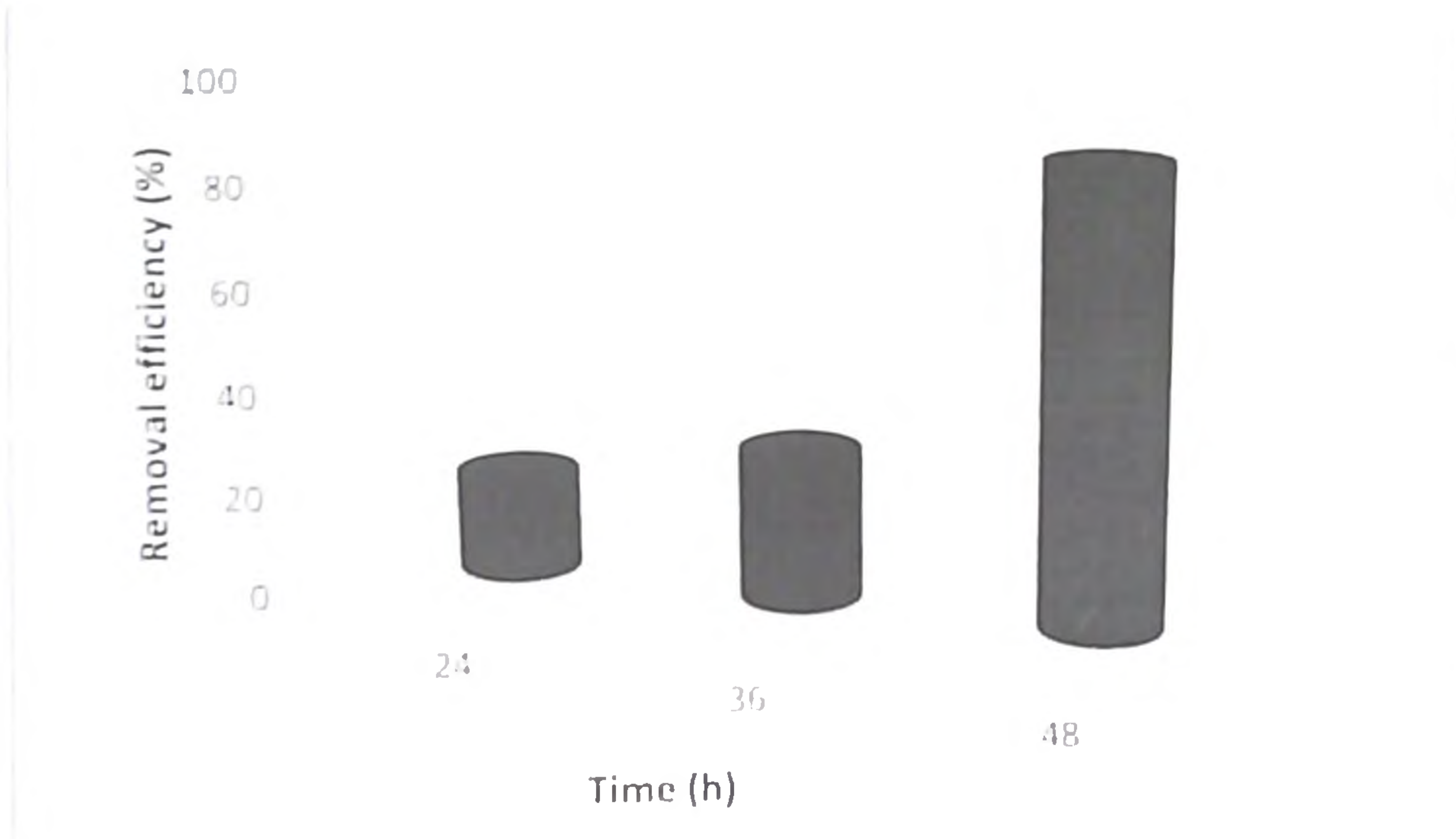
Figure 4. Migration and removal of hexavalent Chromium

10. Enhancement strategies to increase the efficiency of electrokinetic system

10.1 Increasing treatment duration

Figure 5 shows the effect of treatment time on the efficiency of electrokinetic remediation. As the duration of treatment increases from 24 to 48 hours the efficiency increases to 90 per cent.

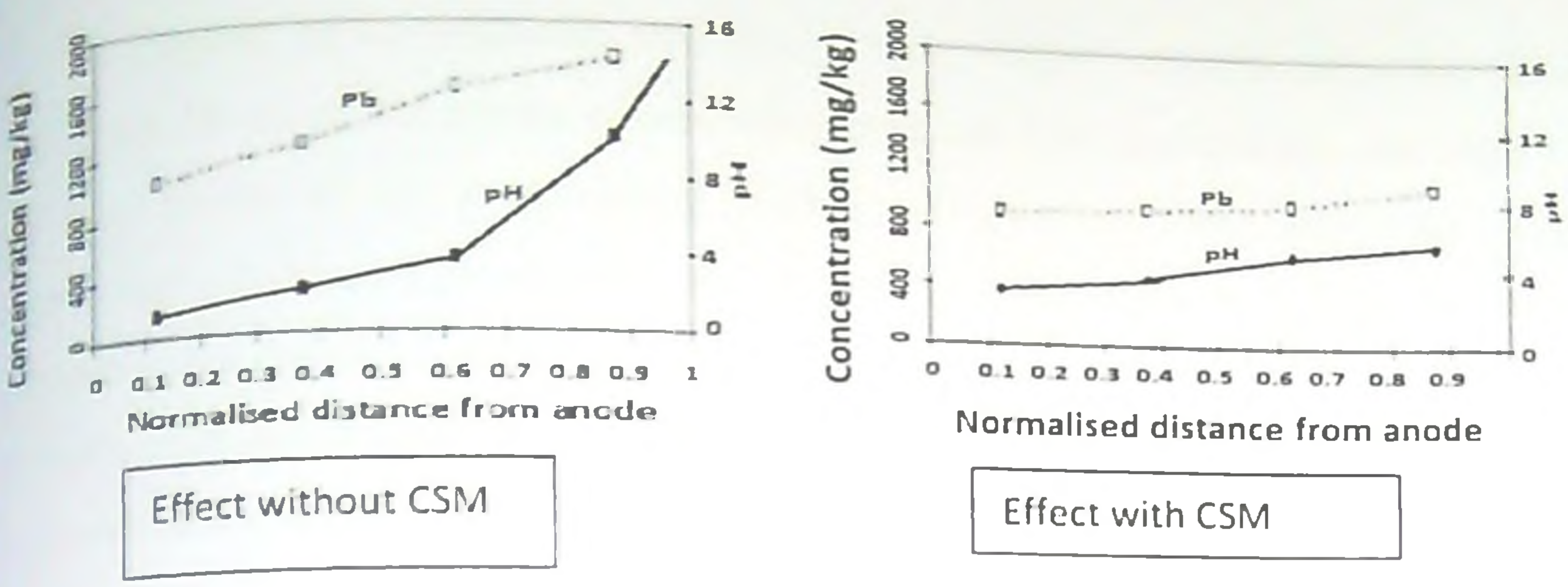
Figure 5. Effect of treatment duration in removal efficiency of Nickel (Utchimuthu *et al.*, 2012)



10.2 Using selective membranes

Cation selective membrane (CSM) was used to increase the efficiency by decreasing pH near cathode. In order to restrict the migration of OH^- ions due to electrolysis of water at the cation electrode, a CSM was inserted. The presence of the CSM decreased the pH of the solid phase throughout the clay column with pH deviation (Figure 6). An even distribution of Pb was observed throughout the clay column indicating that the CSM was effective in suppressing the movement of OH^- ions from the cathode chamber. The CSM decreases the pH and thus prevent the precipitation of Pb near cathode

Figure 6. **Effect of CSM on efficiency of electrokinetic remediatiom**



10.3 Using electrolyte enhancement solutions

Electrolyte enhancement solutions improves complexation and mobility of both metals and organic contaminants such as citrate for Pb and Cu (Chang *et al.*, 2010), acetate for Cu (Chen *et al.*, 2010), EDTA for heavy metals in general.

Table 1. The removal efficiency of enhancing agents

Enhancing agents	Removal efficiency (%)
Ethylene Triamine Tetra Acetic acid (EDTA)	45
Acetic acid	57
Sulphuric acid	73
Sodium chloride	79
Citric acid	82

10.4 Circulating fresh electrolyte

10.5 Applying electric potential in different modes (continuous, periodic, AC/DC combinations)

10.6 Oxidation may be enhanced by introducing oxidants such as hydrogen peroxide.

11. Advantages

Compared to conventional remediation technologies, electrokinetics has several advantages. Based on the results of laboratory tests and field applications, electrokinetics has been shown to be a promising method of covering ionic and water-soluble contaminants. It is easy to operate and requires simple equipment.There is minimal exposure to the operating personnel and the surrounding environment. It can be used as an *in-situ* or *ex-situ* remediation system, as a delivery system, as a containment system, or as a combination of these systems. It is applicable for a wide range of media: It may be used for soils, sludges, sediments, and/or groundwater. Electrokinetics is ideal for subsurface conditions that possess low permeability soils or soil deposits with stratified layers or lenses of variable permeability. Here the conventional remedial methods are commonly deficient. It is also applicable for a variety of contaminants: It may be used for metals, volatile or semi-volatile organic compounds, and radionuclides. There are currently no other viable *in-situ* methods for treating inorganic and organic compounds in porous media simultaneously. Ionic contaminants are absorbed to sediment particles and are often not available for removal by the simple flushing action of water. The pH shift produced by the electrolysis of the water effectively desorbs contaminating ions. In clayey sediments, hydraulic flow through pores can be extremely limited. Electrokinetic remediation is an effective method of inducing movement of water, ions, and colloids through fine-grained sediment. The process is competitive in cost and remediation effectiveness to other methods currently in use.

12. Disadvantages

The electrokinetic process is limited by the solubility of the contaminant and the desorption of contaminants from the soil matrix. Heavy metals in their metallic state have not been successfully dissolved and separated from soil samples. The process is also not efficient when the target ion concentration is low and non target ion concentration is high. Acidic conditions and electrolytic decay can corrode some anode materials. Conventional electrokinetic remediation requires contaminants to migrate from their initial location to an electrode. In some cases, the migration path could be long or there could be stagnant zones between wells where the rate of migration is particularly slow, both of which result in incomplete remediation of the contaminated zone. Moreover, sharply convergent electrical fields can result in heating and potential losses in the vicinities of electrodes. A pH-related deposition can cause contaminants to be removed from solution prior to arrival at the ground surface of point of removal (Murdoch, 1995). Electrolysis reactions in the vicinity of the electrodes may cause changes in ambient pH that may change the solubility and speciation of the contaminants. Heterogeneities or subsurface anomalies at sites, such as building foundations, rubble, large quantities of iron or iron oxides, large rocks or gravel, or submerged cover materials such as seashells, can reduce removal efficiencies. The presence of buried metallic conductors or insulators in the soil and reduction/oxidation and pH changes induced by the process electrode reactions can reduce the effectiveness of the process. Precipitation of species close to the cathode has been an impediment to the process. Heavy metals can prematurely precipitate close to the cathode at their hydroxide solubility value if the chemistry of the electrolyte at the electrodes is not altered or controlled.

13. Conclusion

The success of electrokinetics in soil restoration and decontamination in terms of inorganic contaminants (heavy metals) has demonstrated its ability to be one of the most cost effective and viable *in-situ* remediation processes compared to the conventional remediation technologies such as soil washing, ligand extraction, and vacuum extraction, thermal desorption, hydraulic fracturing, bio treatment, immobilization by encapsulation, and placement of barrier systems. Based on the literature review and researches, it is obvious that the field application of electrokinetic technology to remediate heavy metal contaminated soils /sediments is very limited and site specific. Additional laboratory studies and more pilot- and full-scale information from field applications are needed for better understanding of the technology and to customize the process in different field conditions.

14. Research gaps and future needs

Electrokinetics is fast emerging as a cost effective *in-situ* and *ex-situ* soil remediation technology for the removal of organic and inorganic contaminants. Numerous field scale tests have proven the commercial viability and technical effectiveness of the process when compared to other commercially available methods. The ability of EK to enhance the removal process by various mechanisms has been hown to demonstrate its effectiveness in ground remediation technology. In addition, hese mechanisms and their effects can be tailored or altered in order to: (1) Speed up emoval with the use of reagents, chemical surfactants etc; (2) lock in non-critical ontaminants in the soil by immobilization; (3) enhance removal of target contaminants while retarding some; (4) most field technologies use expensive nonreactive metals as lectrodes such as titanium or titanium coated metals. The consideration for the use of arbon forms (graphite, activated carbon or carbon fibers) needs to be further exploited, s these are relatively inexpensive and easier to produce. In addition, carbon in its various orms is available and indigenous to almost all countries. Particularly in the third world, where environmental controls in the past have been absent or sadly lacking, use of locally vailable and cheap electrodes could render the technology available to the poorest of ations; (4) study of various electrode geometries to enhance electroconductivity or allow ncreased surface area exposure. Use of hollowed out electrodes to allow pumping in and ut of absorption media and chemicals to enhance the EK Process; (5) Electricity usage of the process although still reasonable can be further reduced to increase the cost ffectiveness of the process. This can be addressed with the use of more lectroconductive electrodes, enhancing the soil's electroconductivity by addition of hemicals, etc; (6) research into other reagents and chemical processes that can decompose the soluble organic contaminants or absorb contaminants for immobilization.

15. Discussion

1. What is the effect of electrokinetic remediation on microorganisms?

It was found that most of the bacteria were transported by electro-osmosis. After 25 days of remediation the cell number and microbial diversity reduces especially in culturable bacteria like *Bacillus*, on the other hand dehydrogenase activity and several microbial populations were increased. So we should have better understanding about the native microbes and the contamination process.

2. Whether the remediated site is amenable to sustain growth?

There are some concerns about the condition of site once it was remediated. Soil may not be able to sustain growth.This is mainly due to physical, chemical and biological changes. The technology may be more applicable at industrial site where the concerns may not be an issue.

3. What are the electrodes used the electrokinetic remediation?

Commonly used electrodes are carbon, titanium etc. Usually inert electrodes are used because it doesn't cause any contamination to the system.

4. What is point of zero charge?

It is the pH at which the net charge on soil is zero.

5. What is normalised distance from anode?

It is the ratio of distance from anode to a specific point to the anode to cathode.

6. Whether we can use alternating current instead of direct current?

If we use AC the technique is called as electrical resistive heating remediation. It is used for the remediation of unsaturated soil which contain volatile organic compound as impurity. The technique depends on heating of soil.

7. Is this technique applicable for sandy soils?

Yes, it can be used for decontamination of sandy soil along with water flushing.

8. What is the cost of this technique?

It depends on energy consumption. If the energy consumption is $500 kWhr^{-1}$, It costs around \$ $25/m^2$

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17. Abstract

Electrokinetic remediation is an environmentally safe technique especially developed for the removal of contaminants in soil, sediments and sludge, although it can be applied to any solid porous material (Reddy *et al.*, 2006). It is based on the application of a direct electric current of low intensity to the porous matrix to be decontaminated. The effect of the electric field induces the mobilization and transportation of contaminants through the porous matrix towards the electrodes. Electrodes are inserted inside a chamber which is filled with water or appropriate solution to enhance the removal of contaminants.

Contaminants are transported out of the soil by several transportation mechanisms such as electromigration electro-osmosis, and electrophoresis (Kim *et al.*, 2002). Electromigration is defined as the transportation of ions towards the electrode of the opposite charge (Yeung and Gu, 2011). Electro-osmosis is the bulk transport of water, which flows through the soil as a result of the applied electrical field (Lynch *et al.*, 2007). Electrophoresis is the transport of charged particles of colloidal size and bound contaminants.

The main processes involved in electrokinetic remediation are electrolysis of water, diffusion, oxidation, reduction, adsorption, desorption, precipitation and dissolution. Electrolysis of water creates an acid front at the anode and a base front at the cathode. This generation of acidic condition may help to mobilize sorbed metal contaminants for transport to the collection system at the cathode.

Electrokinetic remediation offers several advantages over the other remediation methods that are in widespread use today. It is 50-90 per cent less expensive than the currently available metal remediation technologies. It is also extremely effective in low permeable soils.

Electrokinetic remediation is emerging as a viable, cost effective *in-situ* technique for cleaning heavy metal contaminated soils (Niroumand *et al.*, 2012). The field application of electrokinetic technology to remediate heavy metal contaminated soils/sediments is very limited and site specific. Additional laboratory studies and more field applications are necessary for the further understanding of the technology. The main thrust of future research appears to lie in the development of hybrid technologies which combine electrokinetic remediation with processes like bioremediation.

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The dimensions of soil security

By

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(2014-11-145)

MSc. Soil Science and Agricultural Chemistry

Seminar report submitted in partial fulfilment of requirement of the course

Soils. 591 Seminar (0+1)

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Aditya Mohan (2014-11-145), hereby declare that the seminar report entitled 'The ...s of soil security' has been completed by me independently after going through the ... cited herein and I have not copied from any of the fellow students or previous seminar

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2014-11-145

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...11/2015

CERTIFICATE

This is to certify that the seminar report entitled **'The dimensions of soil security'** has en solely prepared by Aditya Mohan (2014-11-145), under my guidance and has not been pied from seminar reports of seniors, juniors or fellow students.

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1. Introduction

A number of large existential environmental challenges have been recognized for the sustainable development of humanity and planet earth. These are Food Security, Water Security, Energy Security, Climate Change Abatement, Biodiversity Protection and Ecosystem Service Delivery (Bouma and McBratney, 2013). It is estimated that, by 2015 our earth will be having over nine billion inhabitants. This could result in an increase of 70% and 40% in world food and water demand respectively. The International Energy Agency is expecting a 40% increase in the demand for energy globally. Other environmental challenges such as climate change, biodiversity loss and overuse of natural resources are critically linked to the sustainability of ecosystem. The major ecosystem services are under great pressure globally. This will have grave impact on the capacity of ecosystem to ensure continued food, water and energy security.

For all these issues, we need action at all the levels, i.e. from local to global. We require comprehensive solutions and concrete results. These major environmental issues are studied by various disciplines that often operate somewhat independently. More interaction between these disciplines can result in more comprehensive characterizations of system earth, which, in turn, can help to develop more effective scenarios for the issues concerned. For the effective cooperation of disciplines, a connecting keystone became necessary. This led to the introduction of a new concept 'Soil Security'. The Soil Carbon Initiative (2011) suggested the introduction of the broad term 'soil security' rather than the more passive, common term 'soil protection'.

2. Soil science as a connecting keystone

When one analyses these environmental challenges, we can recognize that soil has a part to play in all of these (Herrick, 2000). Soils need to be re-framed, realizing that most issues are land-related. Soil degradation such as erosion, fertility loss, salinity, acidification, soil carbon decline, and compaction has long been reported and are recognized as threats by the European Union (CEC, 2006). These have detrimental consequences for agricultural productivity, provision of water, increased greenhouse gases and loss of biodiversity (Koch *et al.*, 2013). Without secure soil we cannot be sure of secure supplies of food and fibre, of clean freshwater, or of diversity in the landscape. We also reduce the potential of soil to act as a

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Soil security can be defined as the maintenance and improvement of the world's soil resource to produce food, fibre and freshwater, contribute to energy and climate sustainability, and maintain the biodiversity and the overall protection of the ecosystem (McBratney *et al.*, 2012). In this definition, security is used in the same sense that it is used for food, water and energy.

3. How soil and environmental challenges are connected?

The European Union has made a major contribution to societal and political awareness of soil science by approving a Soil Protection Strategy in 2006 that defines threats to soil and soil functions (CEC, 2006). Soil functions have universal relevance and are defined as:

(1) Biomass production

(2) Storing, filtering and transformation of nutrients, substances and water

(3) Biodiversity pool

(4) Physical and cultural environment

(5) Source of raw material

(6) Acting as carbon pool

(7) Archive of geological and archeological heritage

Soil security is anchored to the six global societal challenges through these seven soil functions. The quantity, quality and accessibility of food are affected by having a functioning soil available to produce food and avoid contamination. Soil acts for the provision of clean water and its storage as well as a filter minimizing the contamination of water ways and maintaining its ability to produce food and protect biodiversity. The use of plants for energy production (e.g. ethanol) is not always synergistic with food production and sustainable water resource use but still is essential. Carbon and nutrients are sequestered in soil and in plants that the soil supports, reducing the release of greenhouse gases. The use of soil for raw materials is also a major concern. Soil is the habitat for the largest gene pool and diversity of species, which enables the recycling of waste and provision of nutrients affecting food and water security. Soil provides a wide set of ecosystem services that contribute to 'soil as natural capital', which is also formulated by natural stocks and ecosystem goods.

4. Dimensions of soil security

To frame the concept of soil security, a set of dimensions need to be established and defined. As with other concepts such as food and water security, these dimensions should account for the quantity, quality and accessibility of the soil. It is also essential to recognize that this concept is not being developed in vacuo and those similar concepts of soil quality, soil health and soil protection have also been proposed to address the need to maintain and manage the condition of the soil (Doran and Ziess, 2000; Karlen *et al.*, 2001; Bouma and Droogers, 2007). The dimensions of soil security should address biophysical attributes as well as the economic, social and policy aspects. This would require a multi-dimensional, multi disciplinary approach recognizing all stakeholders, and therefore, a framework is required with dimensions that explicitly distinguish the assessment of the optimal state and the current state of the soil and, how the soil is effectively utilized. Such a distinction will enable a clearer comparison of the current condition of the system relative to its capability and an account of the values and context affecting how the soil system is being utilized in order to reconcile the measures using scientific principles and relativism. The concept acknowledges five dimensions such as

1. Capability
2. Condition,
3. Connectivity
4. Capital
5. Codification.

These are the five 'Cs' that need to be assessed in order to secure a soil.

4.1 Dimension 1: Capability

The capability of any given soil refers to its potential functionality. The question that capability can answer is, 'what functions can this soil be expected to perform, and in doing so what can it produce?' To answer this question, it is equally important to understand the soil's capability in the context of its own reference state. Reference state defines an optimal capacity of the soil to which the current condition of the soil can be compared.

Droogers and Bouma (1997) recognized management changes to soil and proposed that soil should be classified according to its genoform and phenoform. The genoform would be a soil in its natural state and recognizes that we know about soil and its genesis. Implicitly they recognized this as a reference state. The phenoform would be an account of how a soil has been altered. In particular, the phenoform recognizes the long-term or short-term effects of management changing a soil. Examples include, management resulting in erosion means a soil loss that cannot be returned; or decades of organic farming that increased the organic matter content of soil in the Netherlands (Bouma, 2002).

4.2 Dimension 2: Condition

The condition of the soil is concerned with the current state of the soil and refers to the shift in capability compared to the reference state. The concept of soil condition strengthened in the 1990's and the current vernacular would refer to soil condition as 'soil health' (Karlen *et al.*, 1997). However there is little value in talking about the health of any given soil, unless there is an understanding of how 'healthy' it can actually be. Regulatory bodies and land managers recognize the growing need for information on soil condition so they are informed about the impact of changes in management practices and justification for investment to maintain or improve the soil resource (Schipper and Sparling, 2000;Wilson *et al.*, 2008).

As with capability, the soil condition will vary in accordance to how it is managed and the nature of the intended use. If the soil is being managed in a way that is consistent with its capability, its condition will be 'fit for purpose'. For example, in agriculture a soil with high capability can have poor yields resulting from poor management, while a low capability soil through excellent management can produce high yields (Bouma, 2002; Tugel *et al.*, 2005).

Soil condition can be defined as the capacity of a soil to function, within land use and ecosystem boundaries, to sustain biological productivity, maintain environmental health, and promote plant, animal, and human health (Doran and Zeiss, 2000).

Similarly, the key to a sustainable use of the soil is to match its intended use with its capability, i.e. soil should not only be viewed through a lens focusing on its ability to produce (Robinson *et al.*, 2012). Therefore, the performance, productivity or functionality of a soil is the sum of its capability and condition'.

As with soil quality and soil health, the soil condition can be assessed using a set of usually more quickly varying indicators which are commonly grouped as physical, chemical and biological and are linked to a soil function (Doran and Parkin, 1996) and there is a call to adopt standardized methods to evaluate these (Nortcliff, 2002). Recently, the soil science community's deeper understanding of, and ability to assess, the soil biology has resulted in a suggestion that soil biota in the future may be a significant and broad indicator of the soil's condition (Zak *et al.*, 2003; Barrios, 2007).

4.2.1 Influence of management practices on soil

In one soil series in the Netherlands (the *genoform*) three different *phenoforms* were formed as a result of different management practices. Locations were identified using a soil map and interviews with farmers. Organic matter, bulk densities, and porosities were significantly different for the three phenoforms: biodynamic management (Bio), conventional management (Conv), and permanent grassland (Perm). The first management type, abbreviated as Bio, has been managed for 70 yr according to biodynamic principles (Reganold, 1995), which implies that no chemical fertilizer or chemical crop protection was utilized, but that soil quality was maintained by a favorable crop rotation and by use of organic fertilizer. The second type is the conventional (Conv) with a crop rotation of potato (*Solanum tuberosum* L.), grassland, sugarbeet (*Beta vulgaris* L.), and grains and use of agrochemicals. Soil tillage activities were comparable for Bio and Conv, and consisted of ploughing in autumn to a depth of 25 to 30 cm as the main tillage activity. For Bio as well as for Conv, a 2-year-old temporary grassland was selected that was part of the crop rotation used. The third management type is an old meadow (Perm), representing a soil structure with a more or less natural character.

Table 1: Basic properties of the top soil for the phenoforms

Field	Management	Bulk density (Mg m^{-3})	Organic matter (g kg^{-1})	Porosity (m^3 m^{-3})
Bio	Biodynamic temporary grassland	1.47	33.00	0.42
Conv	Conventional temporary grassland	1.68	17.00	0.36
Perm	Permanent grassland	1.38	50.00	0.46

Temporary grassland has highest bulk density among the three. The organic matter content is more for permanent grassland and least for the temporary grassland and it is similar in the case for porosity (Droogers and Bouma, 1997).

Even though the three phenoforms belong to a single genoform, they exhibit entirely different soil properties due to the adoption of different management practices.

4.3 Dimension 3: Capital

By placing a capital or monetary value on an asset serves to value or secure that asset. The concept of capital can be distinguished between five principal forms being, financial, manufactured, human, social and natural capitals. Of these natural capital is the stock of physical and biological resources and is comprised of renewable (e.g. living species), non-renewable (e.g. subsoil assets, such as petroleum and coal), replenishable (e.g. potable water, fertile soils) and cultivated (e.g. crops and forest plantations) natural capitals (Aronson *et al.*, 2007).

According to Robinson et al. (2009) placing a value on 'things' that contribute to human well-being avoids the neglect or omission of a resource or its contribution to the system in any decision-making process. They developed a definition for soils' natural capital by focusing on mass, structure and energy and found that soil moisture, temperature and structure are valuable stocks, along with inorganic and organic materials (Table 2).

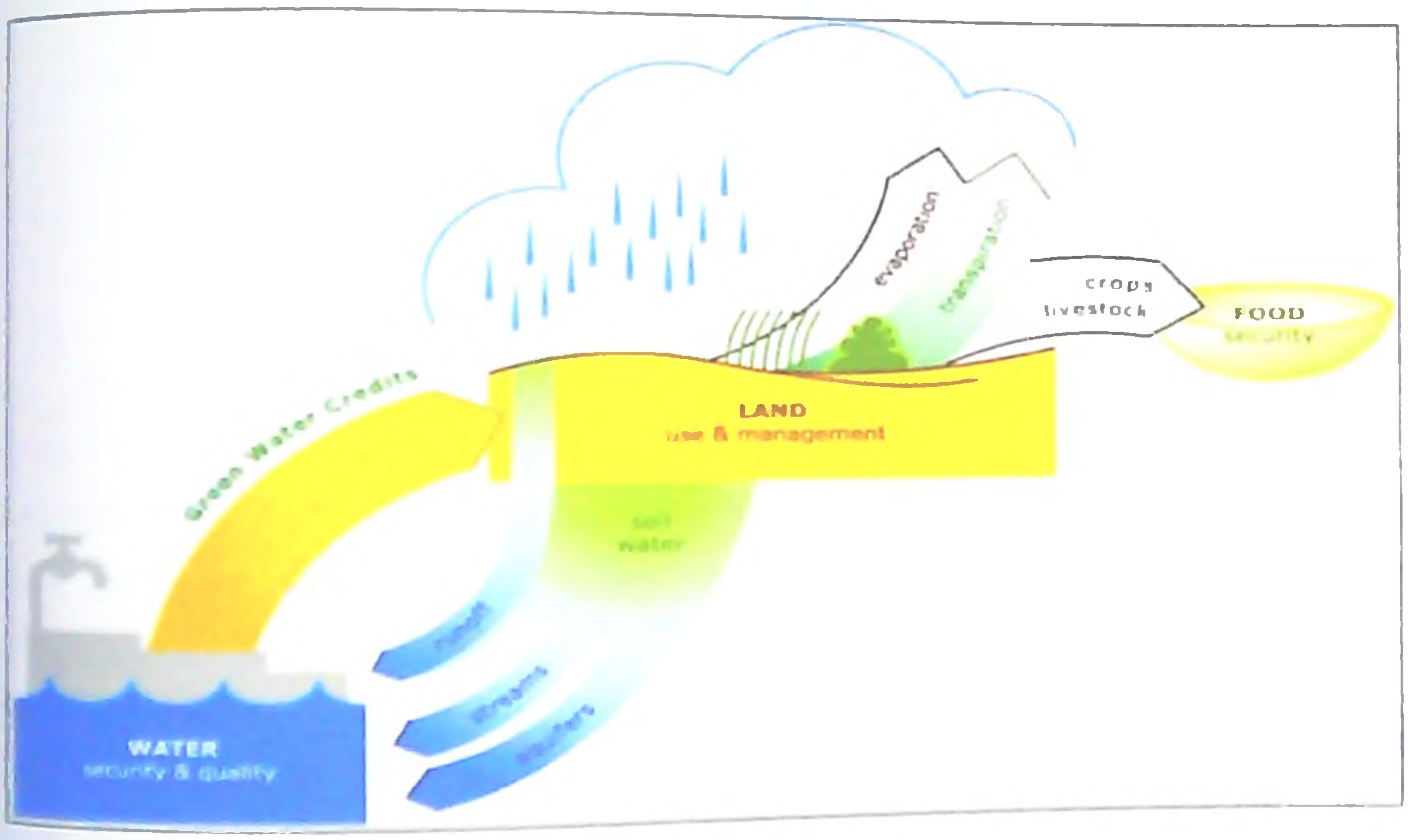
Table 2. Natural stocks of soil and its economic value (based on Robinson *et al.*, 2009)

Type of service	Indicator	Economic value
Mass		
Solid	**Inorganic material**	
	Material stock	Cost of building material
	Nutrient stock	Replacement cost of fertilizers
	Organic material	
	Carbon stocks	Carbon offsets
	Organisms	Medicines
Liquid	Soil water content	Irrigation and fresh water supplies
Gas	Soil air	Not reported
Energy		
Thermal energy	Soil temperature	Not reported
Biomass energy	Soil biomass	Relative for carbon with a premium for diversity
Organization		
Physico-chemical structure	Soil physico-chemical organization	Value of increased water holding capacity
Biotic structure	Biodiversity and food web	Diversity premium - a multiplier for carbon
Spatio-temporal structure	Connectivity, patches and gradients	Not reported

4.3.1 Green Water Credit (GWC)

Green Water Credit (GWC) is a mechanism for payments to land users in return for specified land and soil management activities that determine the supply of fresh water at source. Direct payment enables better management. A pilot study in Tana river basin, of Kenya, serve to illustrate the scheme. Together with the Kenyan research institute KARI, ISRIC started testing the concept of Green Water Credits in the Tana River Basin in 2007 (Droogers *et al.*, 2014)

Figure 1. Principle of GWC



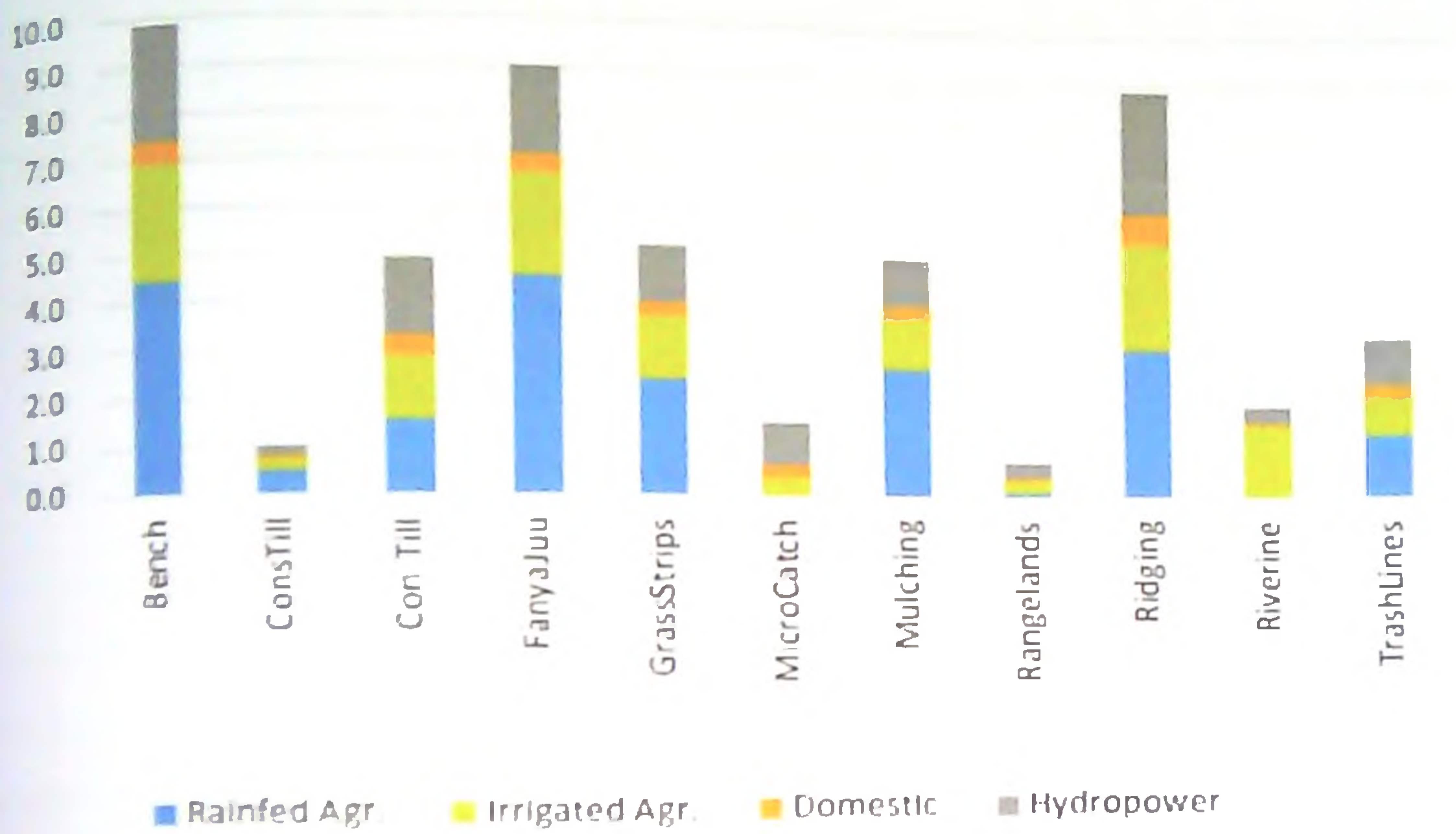
The Upper Tana Basin in Kenya faces severe challenges to meet increasing water demands due to poverty and population growth (Githui *et al.* 2009). The basin is of strategic importance for the water and energy supply of the country. Water downstream is used for hydropower, irrigation, industrial and domestic use in the capital Nairobi, creating a high downstream dependency on the quality of upstream soil and water management. There are important downstream water users who are in a position to pay for water management services for long term: hydro electric power, Nairobi city water supply and irrigators. Upstream farmers themselves may also benefit by higher crop yields resulting from higher available water and lower losses of fertile topsoil by erosion. Eleven conservation measures were considered for the study. They are:

- Bench terraces
- Conservation tillage
- Contour tillage
- Fanya juu terraces
- Grass strips
- Micro- catchments
- Mulching
- Rangelands
- Ridging
- Riverine protection
- Trash lines

The figure 2 extends the analysis by expressing financial benefits of each of the 11 measures for all partners involved in the GWC discussions. The conservation measures such as bench terraces, fanya juu terraces, ridging and mulching provide maximum revenue for the water sectors considered. The scenario studies have shown that the benefits of Green Water Management far outstrip the costs and that a fund and programme for rain-fed farmers is feasible. Potentially, according to these analyses, implementation of the GWC scenarios would have benefits that could go up to almost 10 million US$ annually.

In 2011, partly due to the outcomes of these scenario studies, international and Kenyan parties agreed to assist 100,000 smallholder farmers in the Tana River basin, using a new fund of US$ 40 million created by IFAD and Kenyan water and electricity companies. The goal of the GWC team now is to assist these Kenyan stakeholders, and also stakeholders in other catchments in the world that want to use the principles of Green Water Credits for improved land and water (Droogers *et al.*, 2006).

Figure 2. Total revenues (benefits minus costs) of implementation of the GWC scenarios for the four dominant water sectors



4.4 Dimension 4: Connectivity

Connectivity brings in a social dimension around soil. In part it is concerned with whether the person who is responsible for the soil in any given piece of land has the right knowledge and resources to manage the soil according to its capability. It could be argued that if there is no connection to the soil then the soil itself may not be valued and is prone to not being managed to its best condition. Transfer of soil science knowledge and skills has to do more than just provide acceptable solutions to complex problems; those with soil science knowledge also have to be able to identify what the needs are and follow this with effective communication of the solutions.

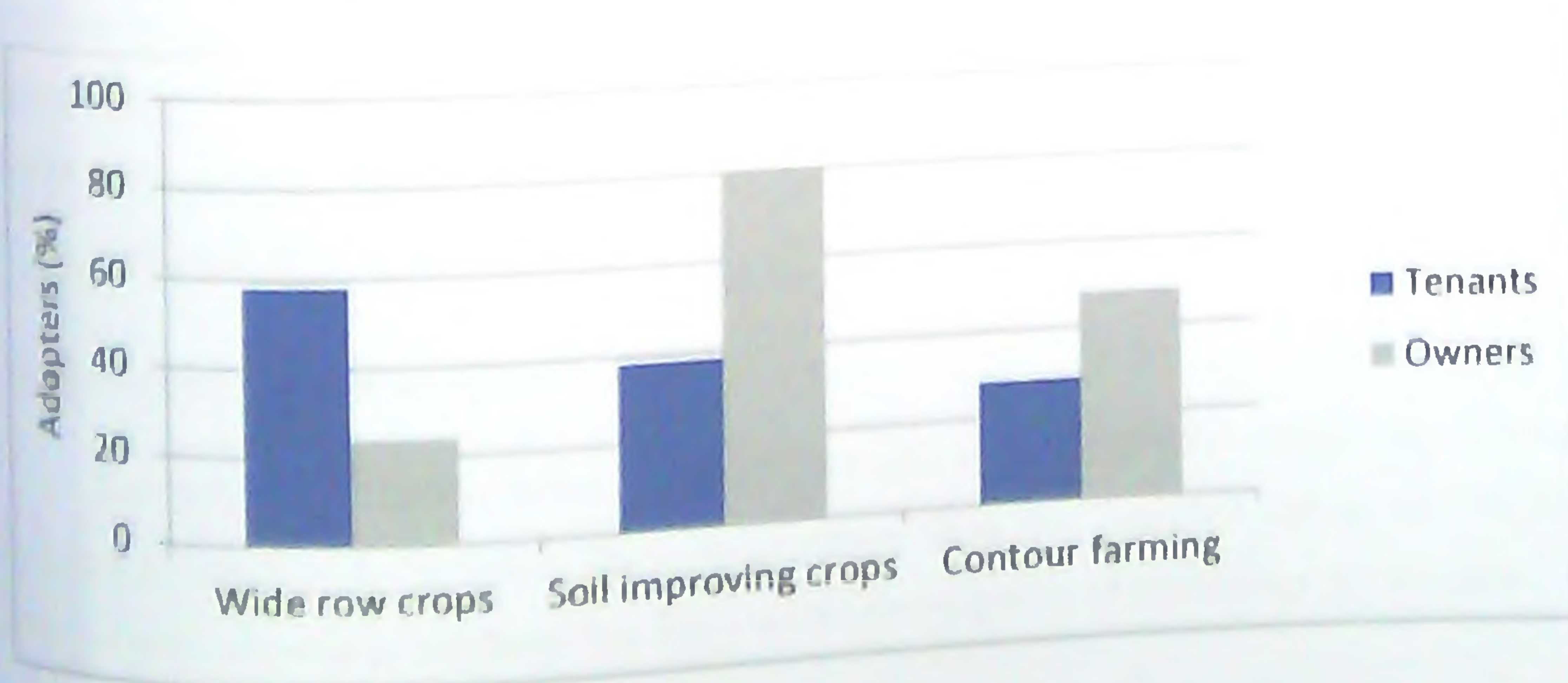
The sharing of knowledge involves knowledge brokers who in this case are those with 'hard knowledge and social intelligence' who can provide relevant soil science advice (Bouma et al., 2011). The continued engagement of these knowledge brokers would facilitate collaboration between research and education communities and those who require this knowledge so that change can be collaboratively addressed (Stockmann *et al.*, 2013).

The demand for those with good soil knowledge is high (Havlin *et al.*, 2010), and the teaching of the discipline is mainly housed in geology, geography, environmental science and agriculture programmes (Brevik, 2009) contributing successfully to these areas (Hopmans, 2007). Smiles *et al.* (2000) noted that the future challenge for soil science education is to stimulate curiosity and innovation as well as a good grounding in existing knowledge (Field *et al.*, 2010).

4.4.1 Soil conservation on rented and owned fields

Land tenure security is widely considered to be a fundamental factor in motivating farmers to adopt sustainable land management practices. The study conducted by Frazer (2004) aims to establish whether it is true that owner-operators adopt more effective soil conservation measures than tenant-operators. An analysis of the level of adoption of three types of erosion control measures such as wide row crops, soil improving crops and contour farming, on 263 blocks of arable land endangered by water erosion in the Czech Republic has proved that all measures were adopted by owners significantly more frequently than by tenants. From the figure 2, it is clear that, in all 3 cases, owner-operators appear to adopt conservation measures significantly more responsibly.

Figure 3. Adoption of control measures by tenants and owners



4.5 Dimension 5: Codification

No matter how secure soil may be through proper management of condition, valuing the capital and connectivity to society there still remains the need for public policy and regulation, at least as a safety net, and at best to synergize and positively feed back into the other aspects of soil security (dimensions). Good policy and policy decisions are dependent on including the appropriate stakeholders who will be able to articulate these challenges, and which are framed so that they can translate the codified knowledge, in this case, soil science knowledge into improved and more effective ways to provide practical solutions (Grímsson, 2007). This relies on the willingness for the community of scientists to collaborate with government authorities and the private sector.

Even though there is a general agreement about the principle of soil protection, the manner in which national rules and regulations are to be defined is still unclear. But, there have been a number of initiatives to give soil a stronger policy focus. The World Soils Policy leading to the World Soil Charter was developed in the early 1980s focusing on a set of principles on management of the land resource to improve their productivity and conservation for future generations (FAO, 1982). This resulted in United Nation's Environmental Programme (UNEP) assessing global and regional soil degradation which was published as the World Atlas of Desertification (UNEP, 1997). Doran and Jones (1996) noted that protecting soil quality should be as fundamental a goal as protecting air and water quality. The International Union of Soil Sciences developed the World Soils Agenda focusing on three tasks, being: science, policy and implementation. The science was focused on monitoring degradation, developing appropriate indicators and proposing technologies and approaches to enable frameworks for sustainable land management. The policy task produced an agenda of identifying an international multi-disciplinary network, along with an inter-government panel on soils, and to provide advice, develop and implement national soil policies.

4.5.1 Land and soil conservation in India

Soil and water conservation measures are one of the essential inputs for increasing agricultural output in the country. These programmes were first launched during the first plan. From the very beginning, emphasis has been on the development of technology for problem identification, enactment of appropriate legislation and constitution of policy coordination bodies. The centrally-sponsored scheme of soil conservation in the catchments of River Valley Project (RVP) was started in the third five-year plan. Subsequently, a centrally-sponsored scheme of reclamation of alkali soil was taken up in Punjab, Haryana and Uttar Pradesh during the Seventh Five Year Plan. During the ninth plan, extension of the scheme to all other States of India was approved where alkali soil problems exist as per scientific parameters. The scheme aims at improving physical conditions and productivity status of alkali soils for restoring optimum crop production. The scheme of watershed development project in shifting cultivation areas was launched in seven north-eastern states during the eighth plan from 1994-95 with 100 per cent central assistance to the state plan. The scheme aims at overall development of jhum areas on watershed basis. National Bureau of Soil Survey and Land Use Planning takes care of soil surveys, conservation programmes etc.

4.5.2 Policies and programmes in Kerala

Our state Kerala has environment policy as well as organic farming policy. The former one focuses on soil only as a part of the agricultural lands. But, the latter aims at soil health improvement.

Department of soil survey and soil conservation has been involved in various soil and water conservation programmes since the first five year plan. It includes:

1. Soil and water conservation on watershed basis with a view to sustain agricultural production and rejuvenate the ecosystem. It is assisted by NABARD. The major works proposed are graded bunds, moisture conservation pits, terracing, agro forestry etc.

2. Stabilization of landslide areas was implemented for the reclamation of land slide prone areas landslide affected areas and restore degraded ecosystem. The major works proposed are graded bunding, vetiver planting, stubble mulches, coir geo textiles etc.

They also give thrust to protect the catchment of reservoirs for drinking water schemes in Aruvikkara and Sasthamkotta with a view to prevent soil erosion and protect the reservoir from siltation. The works proposed would help in the eco regeneration of the catchment. Various location specific conservation interventions like stone pitched contour/graded bunds, moisture conservation pits, terracing, stream bank stabilization structures, retaining walls etc are carried out for the protection of the catchments.

5. Threats to soil security

The European Commission has identified five threats to soil security, classified as erosion, compaction, contamination, organic matter decline, salinization, landslides, and surface sealing. Many of these would relate largely to soil condition, capability and capital. A non-exhaustive wider list of threats to soil security is given in the following table and clearly, in any given situation, an evaluation of the intensity of these threats needs to be made for the proper security of soil (McBratney *et al.*, 2014)

Table 3. Threats of soil security

Dimension	Threats
Capability	Erosion, landslides, sealing by infrastructure, source of raw materials
Condition	Contamination, loss of organic matter, physical soil degradation, salinization, floods
Capital	Inadequate assessment of soil stock value, indiscriminate treatment of soil
Connectivity	Inadequate soil knowledge of land managers, lack of recognition of soil services by society
Codification	Incomplete policy framework, poorly designed legislation

6. Summary

Soil has an integral part to play in the global environmental sustainability, challenges of food security, water security, energy security, climate stability, biodiversity, and ecosystem services. Indeed, soil has the same existential status as these issues and should be highlighted and treated similarly. There is an imperative for a concept of soil that is similar to food, water and energy security. The concept of soil security is multi-dimensional. It recognizes capability, condition, capital, connectivity and codification of soil entities and encompasses the social, economic and biophysical sciences.

The capability of soil can be thought in terms of a reference state that defines an optimal capacity of the soil to which the current condition can be compared. To determine if a soil is 'good' or 'bad' for a particular purpose or if its use enhances or degrades its condition will depend on what value society places on this soil, who influences how it is used, and how this use may be regulated. To account for this value-laden relative criteria we suggest that three dimensions identified as capital, connectivity, and codification be defined.

Placing a value on 'things' that contribute to human well-being, avoids the neglect or omission of a resource or its contribution to the system in any decision-making process. That's the importance of the dimension capital.Connectivity is concerned with whether the person who is responsible for the soil in any given piece of land has the right knowledge and resources to manage the soil according to its capability. No matter how secure soil may be through proper management of condition, valuing the capital and connectivity to society there still remains the need for public policy and regulation, at least as a safety net, and at best to synergize and positively feed back into the other aspects of soil security.

These five dimensions should be accounted for the proper security of soil. The European Commission has identified five threats classified as erosion, compaction, contamination, organic matter decline, salinization, landslides, and surface sealing. These threats should be identified and evaluated to ensure soil security.

7. Conclusion

Soil security is a wider, more integrative, concept than 'soil quality', 'soil health' or 'soil protection', because it is strengthened by the proposal of the soil capability, capital, connectivity and codification dimensions, which are not explicitly identified in the other concepts. There is a persuasive need for developing a thorough risk-based framework for assessing soil security locally, regionally, nationally and globally using the dimensions. A lot of work is needed to develop this concept into a fully developed risk-based soil security assessment and policy framework. The assessment framework for soil security should be risk based in the sense that it should recognize and utilize the uncertainties in the assessment of each of the dimensions and their combination.

8. Discussion

1. What is the difference between the concepts, soil security, soil quality and soil health?

The concepts soil quality and soil health focus only on the condition of soil. But the soil security concept is strengthened by the proposal of the soil capability, capital, connectivity and codification dimensions, which are not explicitly identified in the other concepts being compared.

2. Can you explain about soil carbon initiative?

Soil carbon initiative, a summit lead by Andrea Koch, was conducted on February 2011 to re-vitalize the role of soils on food security and climate change mitigation.

3. What you mean by sealing by infrastructure?

Loss of soil resources due to covering of the soil surface with impervious materials for housing, roads, construction works etc.

4. Are there any mechanisms to support the persons who conserve soil and water conservation?

The answer is subsidies. Various State Plan schemes have been implemented by Department of soil survey and soil conservation in Kerala such as soil and water conservation on watershed basis, stabilization of landslide areas, protection of catchments of reservoirs of water supply scheme etc. Almost 100% subsidy is provided in the case of stabilization of landslide areas.

5. What is the status of soil security in Kerala?

Kerala State Planning board has conducted a soil survey and it revealed a critical deficiency of boron, exceedingly high levels of phosphorous and high acidity are eroding soil fertility in farms.

The analysis of 1. 17.251 soil samples collected from panchayats across the State showed the serious nature of soil acidity. The interim result of the study revealed that 59 per cent of the samples were deficient in boron, while 76 per cent were low in magnesium, and 40 per cent low in calcium. Boron deficiency can lead to stunted growth and deformities in plants while low magnesium levels result in yellow leaves and fruit rot. Calcium deficiency is responsible for impaired root growth and fruit rot. Fifty per cent of the soil samples were found to be high in phosphorous and 18 per cent high in potassium while 23 per cent of the samples were low in nitrogen, 26 per cent low in sulphur, and 12 per cent deficient in zinc.

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COLLEGE OF HORTICULTURE, VELLANIKKARA

Department of Soil Science & Agricultural Chemistry

SOILS 591: MASTER'S SEMINAR

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Admission number: 2014-11-145

Major advisor: Dr. Sreelatha A. K.

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Date: 21.11.2015

Time: 11.30 a.m.

The dimensions of soil security

Abstract

Soil security is an overarching concept of soil, motivated by sustainable development. It is concerned with the maintenance and improvement of the global soil resource to produce food, fibre and freshwater, contribute to energy and climate sustainability, and to maintain the biodiversity and the overall protection of the ecosystem (McBratney *et al.*, 2012). The word 'Security' is used here for soil in the same sense as that it is widely used for food and water. The soil has an integral part to play in the global environmental sustainability challenges of food security, water security, energy sustainability, climate stability, biodiversity, and ecosystem service delivery (Herrick, 2000). Indeed, soil has the same existential status as these issues and should be recognized and highlighted similarly.

The concept of soil security is multidimensional. It acknowledges the five dimensions *viz.*, capability, condition, capital, connectivity, and codification, of soil entities which encompass the social, economic and biophysical sciences and recognize policy and legal frameworks.

The capability of any given soil refers to its potential functionality in the context of its own reference state. Droogers and Bouma (1997) recognized the management changes to soil

ad proposed that soil should be classified according to its genoform and phenoform. The ondition of the soil refers to the shift in capability compared to the reference state. The erformance or functionality of a soil is the sum of its capability and condition. By placing a apital or monetary value on an asset, that asset seems to be secure. Defining natural capital by mbracing mass, energy, and organization, Robinson *et al.* (2009) found that the soil moisture nd structure are valuable stocks, along with inorganic and organic materials. Connectivity rings in a social dimension around the soil. If there is no connection to the soil then the soil tself may not be valued and is prone to not being managed to its best condition.

Transfer of soil science knowledge and skills has to do more than just provide acceptable olutions to complex problems. Good policy and policy decisions are dependent on including the ppropriate stakeholders and which are framed so that they can translate the codified knowledge, nto improved and more effective ways to provide practical solutions (Grimsson, 2007). There is persuasive need for developing a thorough risk-based framework for assessing soil security ocally, regionally, nationally, and globally using its dimensions.

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Societal value of soil organic carbon

By

Rincy Rose T. John

(2014-11-146)

M. Sc. Soil Science and Agricultural Chemistry

Seminar report

Submitted in partial fulfilment for the requirement of the course

SOILS. 591 Master's Seminar (0+1)

DEPT. OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

COLLEGE OF HORTICULTURE

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DECLARATION

I, Rincy Rose T.John (2014-11-146), hereby declare that the seminar report 'Societal value of soil organic carbon', has been completed by me independently after going through the reference cited herein and I have not copied from any of the fellow students or previous seminar reports.

Rincy Rose T. John

2014-11-146

Vellanikkara

Date: 08/12/2015

CERTIFICATE

This is to certify that the seminar report entitled **'Societal value of soil organic carbon'** has been solely prepared by Rincy Rose T. John (2014-11-146), under my guidance and has not been copied from seminar reports of seniors, juniors or fellow students.

Vellanikkara

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Societal value of soil organic carbon

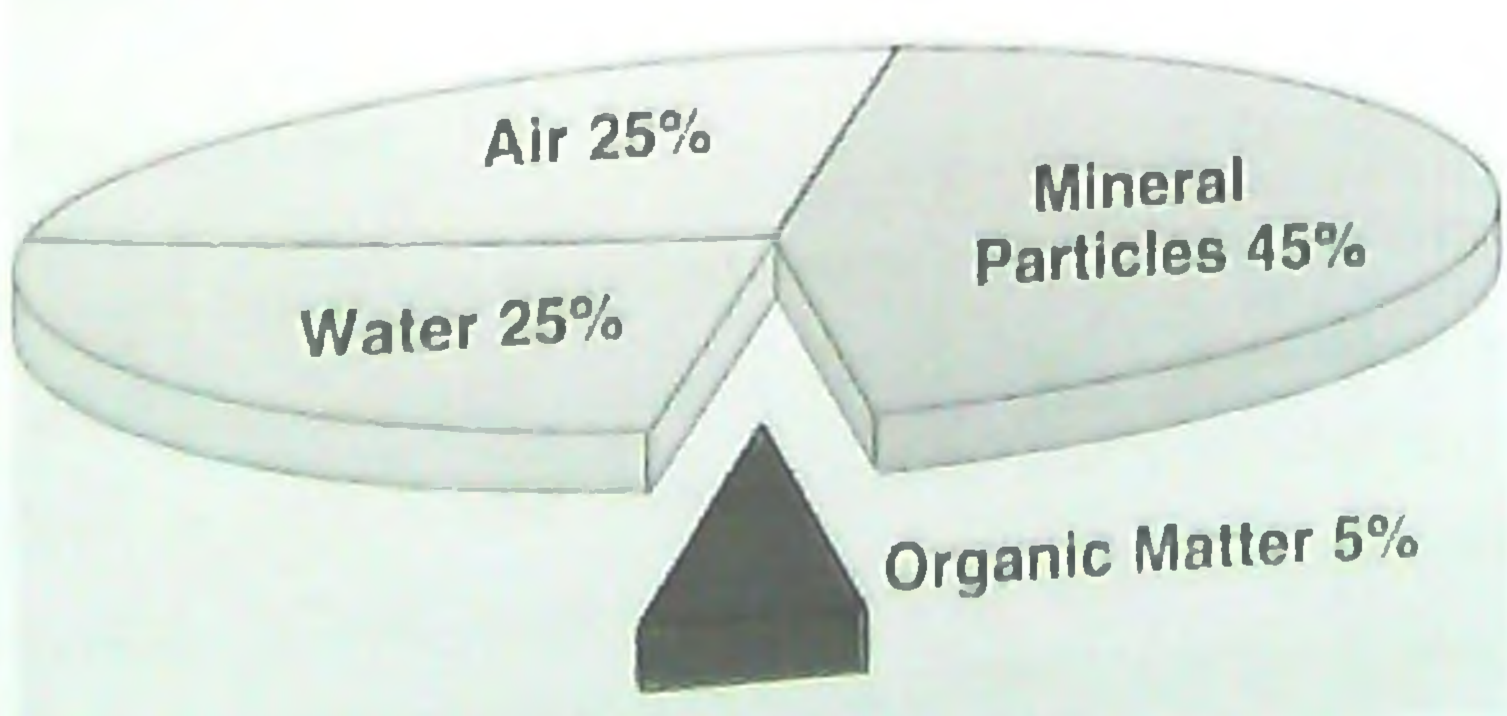
1. Introduction

Carbon is the 15th most abundant element in the Earth's crust and the fourth most abundant element in the universe by mass after hydrogen, helium, and oxygen. Soil carbon is the largest terrestrial pool of carbon: it is more than three times the amount of carbon present in atmosphere. Soil carbon plays a key role in the carbon cycle, and thus it is important in global climate models. Soil contains carbon (C) in both organic and inorganic forms. In most soils the C is held as soil organic carbon (SOC).

2. Volume composition of mineral soils

The average composition of soil consists of 25 per cent water, 25 per cent air, 45 per cent mineral particles and five per cent organic matter. This five per cent organic matter governs the whole properties of soil. The term soil organic matter (SOM) is used to describe the organic constituents in the soil (tissues from dead plants and animals, products produced as these decompose and the soil microbial biomass). The term 'soil organic carbon' refers to the C occurring in SOM in soil. SOM contains about 50 – 58 per cent of SOC by weight. So if a soil contains 1% organic C from a soil test, it can estimate that about 1.7% of the soil by weight is organic matter. Carbon content in the soil is the major factor in its overall health, hence SOC is known as universal keystone indicator for soil health.

Figure: 1 Volume composition of mineral soils



3. Classification of soil carbon

Soil carbon is the largest terrestrial pool of carbon containing about 2,200 billion tonnes of carbon. This is more than three times the amount of carbon held in the atmosphere (Batjes, 1996). Carbon stored in soils worldwide represents the third largest sink in existence, after oceans and geologic sinks. There is two-four times as much C stored in soils as there is in the atmosphere and approximately four times the C stored in vegetative material (i.e. plants). Soil carbon is found as either inorganic (i.e. mineral) or organic materials. Soil inorganic carbon pool consists of 700 billion tonnes and SOC pool is about 1,500 billion tonnes (Lal, 2015).

Inorganic soil C is generally found as carbonates of calcium ($CaCO_3$, or limestone) and magnesium ($MgCO_3$). Excluding concentrated deposits of these materials that arose from deposition of the shells of aquatic invertebrates, the majority of these inorganic forms of C are found in alkaline soils.

The organic forms of C in soil are a very diverse group of materials that can be defined as "everything in or on the soil that is of biological origin, whether it's alive or dead". The SOC pool comprises of relatively undecomposed biomass (remains of plants and animals) undergoing rapid changes in its composition over time or the labile pool, and highly decomposed recalcitrant material called humus. Both labile and recalcitrant fractions of the SOC pool are strongly related to soil quality, soil fertility, especially nutrient recycling and availability, is influenced by the magnitude of the labile fraction. Soil structure, water retention and transmission properties, susceptibility to erosion and crusting/compaction are strongly impacted by the concentration of the humus fraction (Lal, 2015).

4. Value of soil organic carbon

SOC is a finite but essential natural capital. SOC has an economic value when we consider as an asset that provides benefits for human. Commodification (transformation of goods and services, as well as ideas or other entities that normally may not be considered goods, into a commodity) of SOC is the process of bringing it into market sphere by converting into commodity that has an exchange value. It is not possible to assess its true worth in monetary terms. Just as the monetary value of an animal (human) cannot be computed by summing up the market values of nutrients in blood, bones, and tissues, so also the value of soil or SOC cannot be assessed by adding the monetary equivalent of its constituents (C, N, P, S, etc.). Indeed, life is more than the sum of its innate constituents. While treating SOC as a mixture of compounds, the monetary cost of these inputs must be adjusted for any benefits to human beings (Lal, 2014).

As a natural capital SOC has an economic value. According to Lal (2014) there are two types of value assigned to SOC.

a) Value to the farmers: for soil quality enhancement
b) Value to the society: for ecosystem services

The increase in soil carbon will increase the profitability of the farm by increasing soil fertility, increasing beneficial species, suppress the diseases, increasing water retention, improving drainage and aeration and increasing crop yields. This will reduce the cost of cultivation and enhance efficiency of field. Then the farmers get benefits from the better yield.

But the intensification of agriculture degrades the soil quality with depletion of SOC. So farmers should be encouraged to improve soil quality through maintaining high SOC content by considering the carbon as a commodity. Moreover government can provide adequate incentives for their efforts taken in enhancing SOC status of soil.

5. Societal value of SOC

Ecosystem services are the services provided by natural capital to support human well being. According to Millennium Ecosystem Assessment (MEA) (2005), there are four types of ecosystem services *ie.*, supporting, regulating, provisioning and cultural services.

a) Supporting services: they are necessary for the production of ecosystem services like nutrient cycling, water retention, biodiversity, exchange of gases with atmosphere.
b) Regulating services: these are the benefits obtained by regulation of ecosystem services such as carbon sequestration, greenhouse gas (GHGs) emissions, erosion control.
c) Provisioning services: they make the ecosystem to provide goods and services like food, fibre, fuel and water.
d) Cultural services: they are the non-material benefits obtained from the ecosystem through spiritual enrichment and aesthetic experiences eg. Outdoor recreational pursuits, landscapes, supporting habitats.

All these ecosystem services are inter-related and the range of ecosystem services provided by SOC includes increasing net primary productivity and agronomic yield in the context of food and nutritional security, improving plant available water capacity in the root zone, reducing water runoff and soil erosion, minimizing sedimentation and nonpoint source pollution, offsetting anthropogenic emissions and mitigating/adapting to climate change, denaturing pollutants and purifying water, and enhancing biodiversity.

'The societal value of SOC refers to the monetary equivalent of ecosystem services provisioned by a unit amount of SOC' (Lal, 2014).

As per Banwart *et al.*, (2015), the major ecosystem services can be categorized as five different dimensions such as provision of food, water and energy, regulation of climate and maintaining biodiversity.

5.1 Ecosystem services: provision of food

According to FAO (2009), the world population is expected to reach 9.6 billion by 2050. Then there will be an additional global food demand of one billion tonnes per year. But the global soil resources are showing signs of serious degradation. Carbon loss is one of the major reasons to this degradation. So the real goal is to increase and sustain food production to meet the demand of growing population with increased SOC.

From the plate 1, it is clear that by adding organic matter as a source of carbon to the field it will increase the SOC status; the SOC enhances the physical, chemical and biological properties and which leads to improve the soil quality which results in more crop yield (Bai *et al.*, 2008). The physical characters such as soil structure, aggregate stability, water holding capacity, bulk density and soil color. SOC increases the surface area of mineral particles which enhances cation exchange capacity and nutrient availability. It also has buffering action in soil. Biological activity also improves due to high amount of SOC as a source of energy for microorganisms.

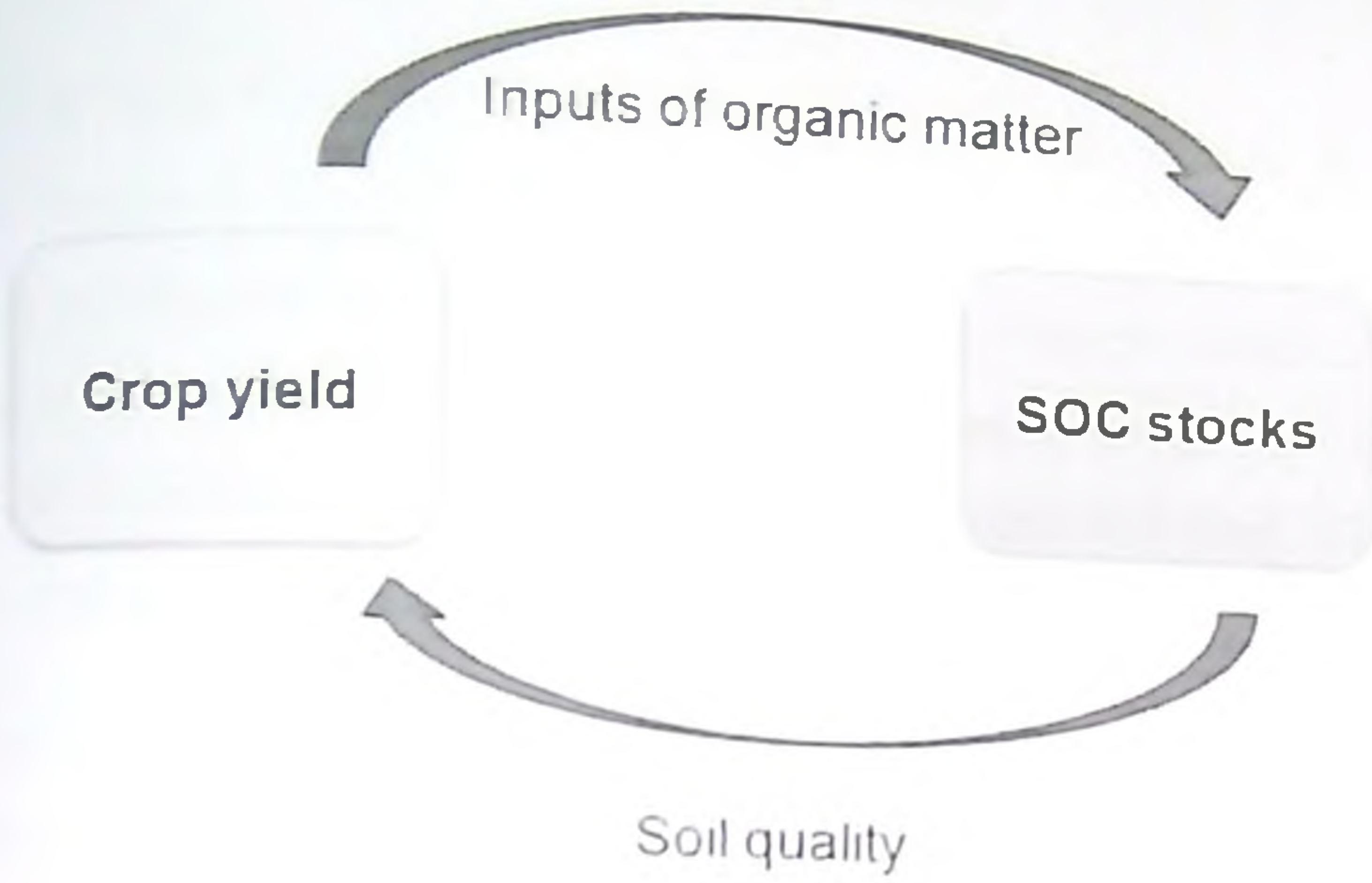


Plate 1: Mechanism of high food production

Table 1: Effect of SOC on agronomic yield of crops

Crop	Increase in productivity (kg t^{-1} SOC ha^{-1})
Rice	160
Wheat	15-30
Sorghum	90
Soybean	145
Safflower	59
Pearl millet	170

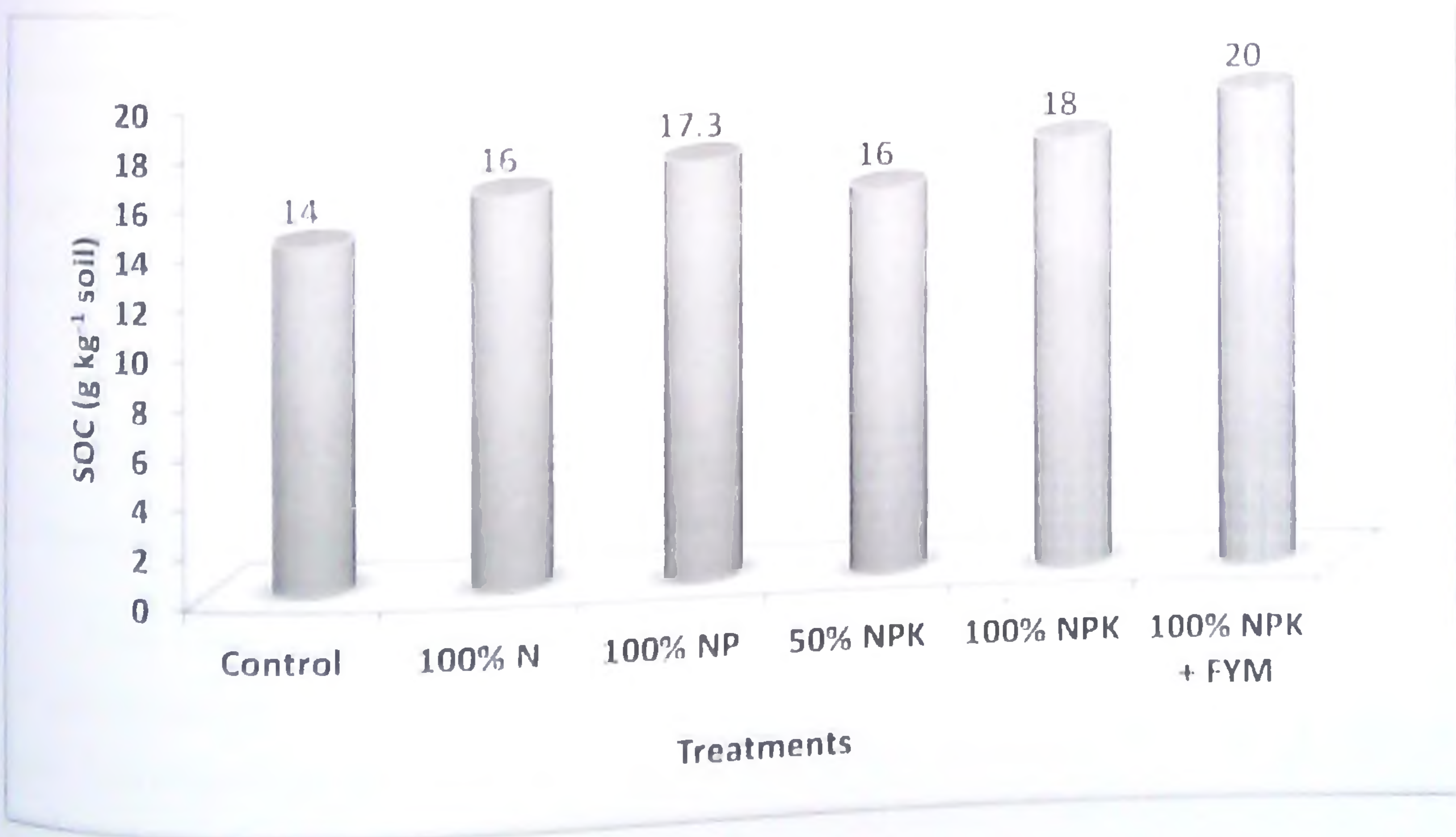
(Srinivasarao *et al*., 2009)

5.1 a. Long-Term Fertilizer Experiment (LTFE)

Long-Term Fertilizer Experiments in India was started in 1970 under All India Co-ordinated Research Project (AICRP). The purpose is to evaluate the effect of long-term application of organic and inorganic manures on crop production and soil health. Now it is conducted in 17 centers in different soil types around the country. LTFEs are more useful for studying the changes in soil properties and processes over time. Change in SOC is one of the properties that can be estimated clearly using LTFE.

The result of LTFE in Pattambi showed that the application of organic manure along with mineral fertilizers improves the SOC status (figure 2) which ultimately leads to the increase in yield of the paddy (figure 3). LTFE mainly proved the conjunctive use of chemical fertilizers with manures maintained relatively large amount of SOC leads to more yield (IISS. AICRP-LTFE Report, 2013).

Figure: 2 Treatment effect on SOC in a LTFE at Pattambi



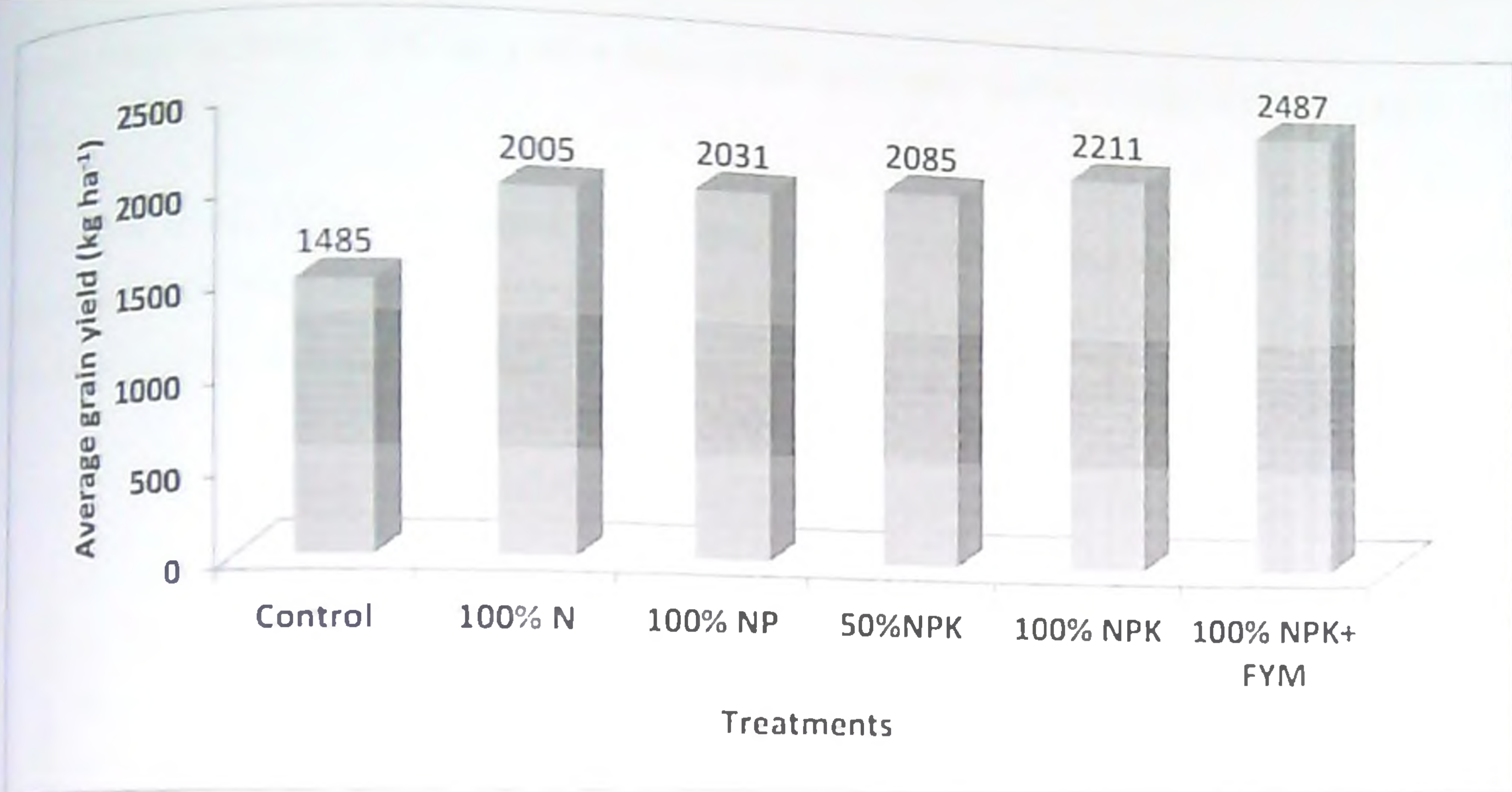


Figure 3: Rice yield in LTFE at Pattambi

The permanent maurial trials conducted at Regional Agricultural Research Station (RARS), Pattambi indicated that the grain yield and straw yield were the highest for the cattle manure and mineral fertilizers combinations. The available nutrients in the soil also get reduced due to continuous application of inorganic fertilizer alone. The organic carbon build up was the highest in cattle manure applied fields. It is an ongoing project with dwarf indica type of rice has completed 41 years and 50 years for tall indica type (KAU research report, 2015).

Enhancing the SOC status in soil is one of the options to increase the yield and soil health. So it can be used as a tool for improving the mankind.

5.2 Ecosystem services: provision of water

Two- thirds of the earth's surface is covered by water and human body consists about 70 per cent of water. So it is clear that the water is one of the prime elements responsible for life on earth. Today clean and safe water is scarce; nearly one billion people in the world do not have access to it. The goal is to ensure the provision of sufficient quality of safe water.

SOC determines the soil properties that regulate the quality and quantity of water. SOC increases the aggregate stability of soil which improves the infiltration rate of water and decreases the susceptibility of soil to water erosion and runoff. This will ultimately increase the ground water recharge. SOC acts as a filter to the pollutants hence it improves the quality of water.

Brar *et al.*, (2015) estimated the infiltration rate (figure 4) and aggregate stability with respect to SOC. They selected treatments with different dose of fertilizers and manures. They found the positive correlation of SOC with infiltration rate and aggregate stability of soil.

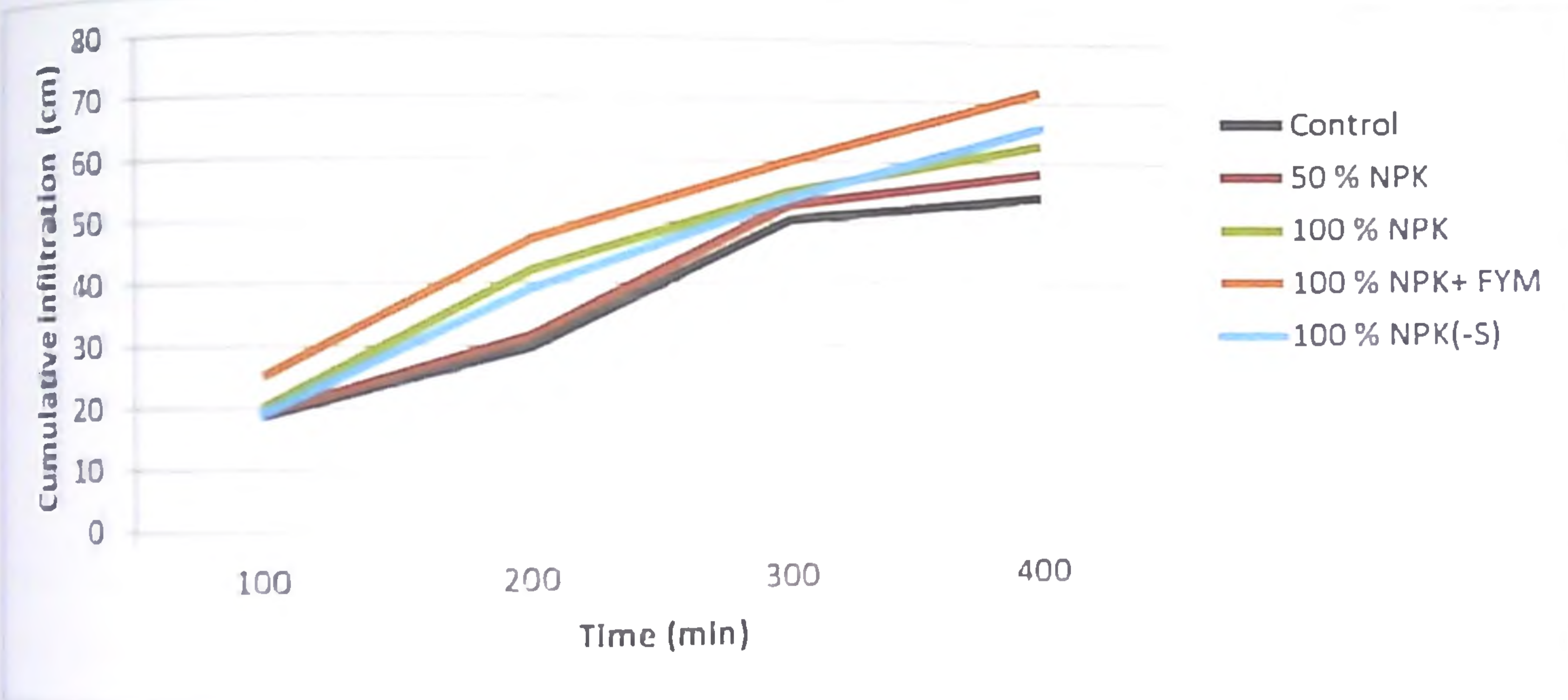


Figure: 4 Effect of SOC on infiltration rate of water

5.3 Ecosystem services: provision of energy

Major energy sources in the world are fossil fuels and gasoline. Fossil fuels are the accumulated remains of living organisms that were buried millions of years ago. Actually they are the forms of carbon and non-renewable resources. They will produce carbon dioxide during burning. So it's the time to think about an alternative to fossil fuels.

Nowadays plants are being grown to produce bio-energy to reduce the use of fossil fuels. The goal is to increase bio-fuel production to meet the demand for energy while increasing the SOC status. The use of biomass for energy production is considered a promising way to reduce net carbon emissions and mitigate climate change (Don *et al.*, 2012). Maintaining or increasing biomass fuel production per unit area will require the careful management of soil carbon stocks over vast areas of the global landscape. Soil carbon management must be considered explicitly in carbon accounting efforts associated with biomass fuel production.

Sustainable energy crops like jatropha, poplar, pongamia etc. can be grown in wastelands and other degraded lands improves the carbon status along with bio-fuel production. Soil carbon is one of primary energy sources of microorganisms. They are producing high energy during decomposition. By decomposing 20 t of farmyard manures, they produce about 105 million kilo joules (M kJ) which is almost equivalent to the energy produced from three tonnes of anthracite coal. The potential energy of a hectare furrow slice is of a soil with 2.5 per cent organic carbon is about 1675 M kJ, equivalent to the heat value of 50 t anthracite coal. If this entire potential energy equivalent were changed to heat, it would be enough to raise the temperature of soil up to 600°c (Brady, 2001). But actually there is no such heat production because the energy produced during decomposition is utilized by microbes for their metabolic activity.

5.4 Ecosystem services: regulation of climate

During the last four decades, the concentration of CO_2 is increased from 270 ppm to 400 ppm. This increase in concentration of CO_2 leads to the global warming and climate change. The real goal is to mitigate the climate change through reducing the GHGs by biological carbon sequestration.

Carbon sequestration is the process of removing carbon from the atmosphere and depositing it in a reservoir. it entails the transfer of atmospheric CO_2, and its secure storage in long-lived pools (UNFCCC, 2007). The biological sequestration is done by plants through the process of photosynthesis and stored the carbon as biomass. It is estimated that the increase in every tonne of SOC represents the decrease in 3.67 tonnes of CO_2 from the atmosphere sequestered in the soil. There are different techniques for biological sequestration such as afforestation, conservation tillage, agro forestry and reduction of desertification. Through the different techniques of biological sequestration increase the SOC status, this will reduce the concentration of CO_2 in atmosphere, one of the potential GHGs. This will help in mitigation of climate change.

Datta *et al.*, (2015) studied Carbon sequestration capacity of different land use types in sodic soils of Karnal (figure 5). They found that the guava and eucalyptus have more capacity to sequester the organic carbon. It was due the high leaf and bark fall along with more biomass production of those crops.

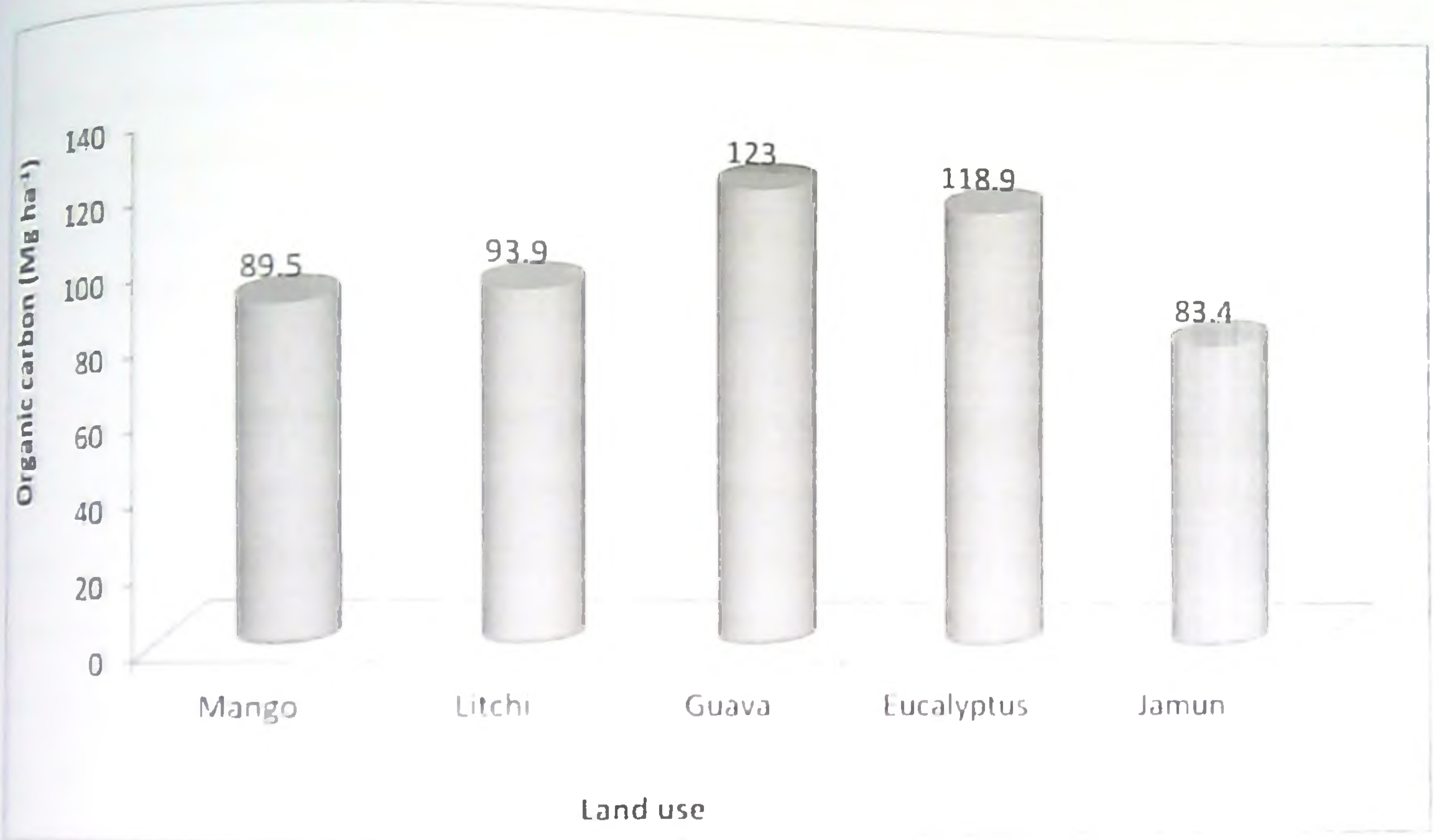


Figure: 5 Carbon sequestration capacity of different land use types

The planting of perennial trees on the problematic and wastelands may decrease the soil degradation through carbon sequestration and enhances the SOC status.

5.4 a. Carbon trading and policies

There are some policies related to biological carbon sequestration like BioCarbon fund and Forest Carbon Partnership Facility (FCPF)-carbon fund. BioCarbon fund is a financial assistance given by World Bank for developing countries to conserve soil carbon in agroecosystems. Whereas FCPF-carbon fund is intended to provide incentives to the developing countries, stakeholders and indigenous people for conserving soil carbon. In USA, there is an institution for studying carbon namely Carbon Management and Sequestration Centre (CMASC) at Ohio State University.

Carbon markets and carbon trading are components of national and international attempts to mitigate green house gas emission, where all the GHG are converted to CO_2 equivalent and are traded in carbon markets. The currency used in these markets is carbon credit (one tonne of CO_2).

Carbon emissions trading is a form of emissions trading that specifically targets carbon dioxide (calculated in tonnes of carbon dioxide equivalent or tCO_2e) and it currently constitutes the bulk of emissions trading. This form of permit trading is a common method countries utilize in order to meet their obligations specified by the Kyoto Protocol; namely the reduction of carbon emissions in an attempt to reduce (mitigate) future climate change (Birla *et al*., 2012).

Under Carbon trading, a country having more emissions of carbon is able to purchase the right to emit more and the country having less emission trades the right to emit carbon to other countries. More carbon emitting countries, by this way try to keep the limit of carbon emission specified to them. Carbon farming is rapidly becoming the new agriculture where C sequestered in soil/trees/wetlands could be traded just as any other farm produce (Lal., 2014).

5.5 Ecosystem services: maintaining biodiversity

Convention on Biological Diversity (CBD) stated that human activity is causing species extinction at a rate of 100-1000 times than the natural rate. Biodiversity is variability among the living organisms. Loss of biodiversity not only leads to fundamental changes in ecosystem but also negatively affect their overall performance of ecosystem services (Pascual *et al*., 2015). Soil is considered as the largest reserve of biodiversity and variability among the belowground flora and fauna are known as belowground biodiversity. There is close association between the belowground and above ground diversity. By increasing the SOC status, the biodiversity will be improved and ultimately leads to improvement in ecosystem services and goods.

Soil microorganisms play an important role in transformation of nutrients from unavailable form to available forms. Table 2 shows the effect of SOC on microbial population in a LTFE at Palampur (IISS, AICRP-LTFE Report, 2013). It showed that the microbial population such as bacteria, actinomycetes and azotobacter was highest for the treatment of fertilizer with farmyard manure. It was due to high amount of carbon as a source of energy for microorganisms.

Table 2: Effect of SOC on microbial population

Treatments	No. of Bacteria (cfu x 10^5 g^{-1} soil)	No. of Actinomycetes (cfu x 10^3 g^{-1} soil)	No. of Azotobacter (cfu x 10^3 g^{-1} soil)
Control	9.53	19.76	127.83
50 % NPK	24.56	52.4	55.16
100 % N	4.55	46.33	11.86
100 % NP	7.96	24.33	45.5
100 % NPK	11.49	20.30	17.5
150 % NPK	6.94	5.75	14.61
100 % NPK + FYM	28.08	73.23	226.16

Saha *et al.*, (2009) conducted an experiment in the homegardens (HG) of the Madakkathara panchayath of Thrissur. They found that the high amount of SOC accumulation in the surface layers of soil with high plant density (figure 6). From high density to low plant density the accumulation of SOC found decreased with soil depth across all the treatments.

It is found that the forest has maximum capacity to contribute organic carbon to soil. Small homegardens (< 1 acre) and rubber plantation have more SOC accumulation than the large homegardes (> 1 acre) (figure 7). The SOC accumulation within one meter depth were in the decreasing order of forest> small HG> rubber plantations> large HG> coconut gardens> paddy (Saha *et al.*, 2010), which proves the relationship between the biodiversity and SOC status.

Figure 6: Depth wise SOC in homegardens with different plant densities

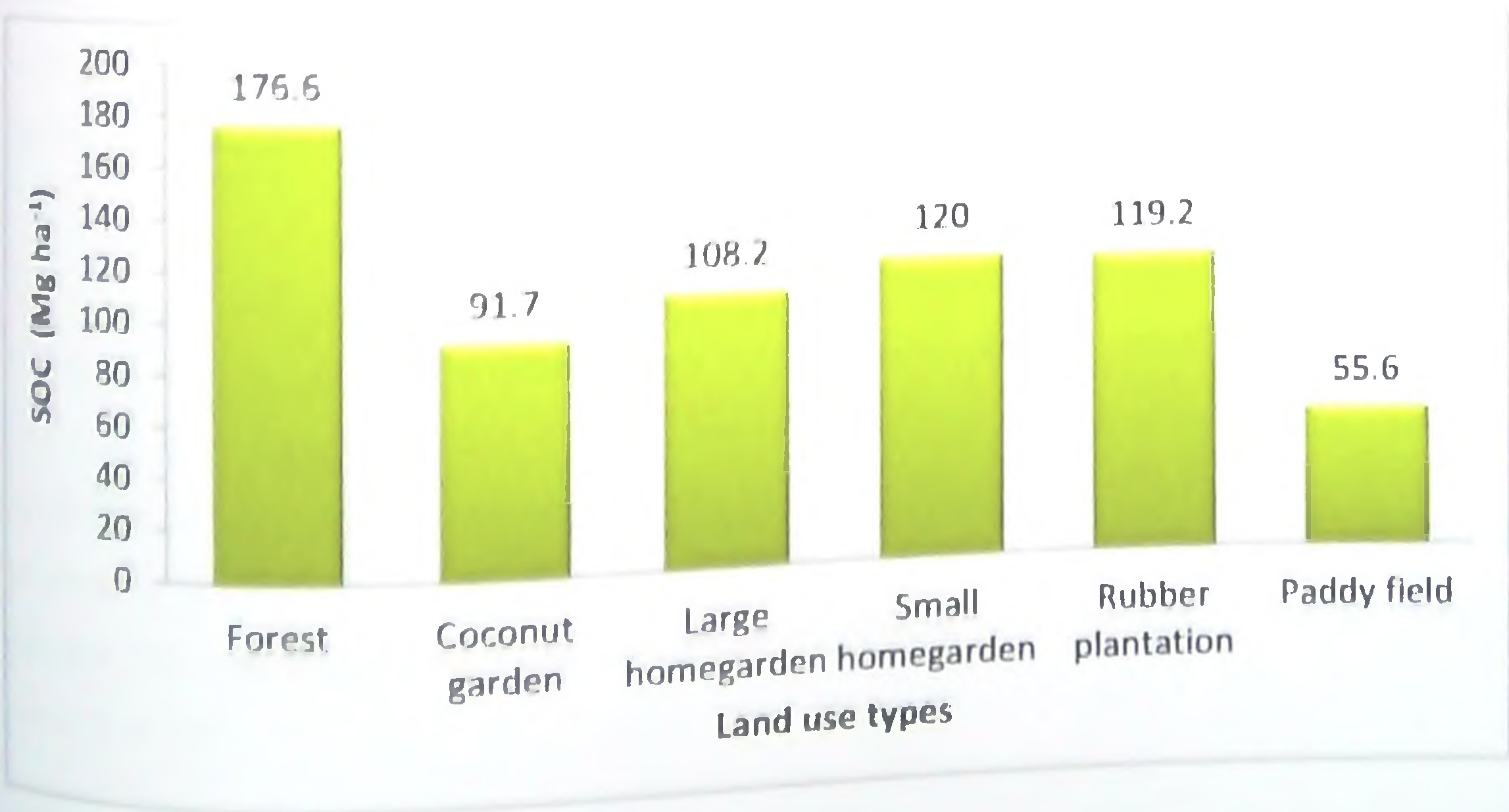


Figure 7: SOC content in different land use types

6. Interactions and trade-offs between services

Soil organic carbon is central to the essential services and could be an important determinant of maintenance, buffering and enhancement of the supply of many ecosystem goods and other services under changing socio-economic and environmental conditions. A focus on SOC enables us to set out the interactions between individual services and to assess appropriate synergies associated with actions to enhance SOC from local to global scales.

Actions affecting SOC long-term goals will inevitably have interactions and feedbacks. For example, as previously discussed, one interaction is between SOC and climate. In this case, management that induces SOC losses contributes to increasing greenhouse gas concentrations in the atmosphere, which will increase air temperature and create a feedback by accelerating SOC decomposition and further losses. Actions focusing on increasing the provision of one ecosystem service individually often impact various other ecosystems services negatively. Typical examples are the focus on agriculture intensification for food production, which has led to water pollution and losses of biodiversity due to excess nutrients and pesticides and the clearance of native vegetation or drainage of peat lands for biomass fuel production, which also led to losses of biodiversity, water quality and quantity and contributed to climate changes through significant release of CO_2 to the atmosphere (Banwart *et al.*, 2015).

One view of interactions is that each essential service has an optimal operational range of SOC (plate 2). For example, while food production can, and continues to, operate at relatively low levels of SOC, there is a general hierarchy with other services requiring higher levels of SOC to be maintained effectively and for people to reap the benefits. The window for sustainable livelihoods is defined as the optimum range of C stocks that are adequate to supply all essential services. It is necessary to identify and overcome barriers to the adoption of practices that enhance SOC. Actions should focus on multiple ecosystem services to optimize efforts and the benefits of SOC.

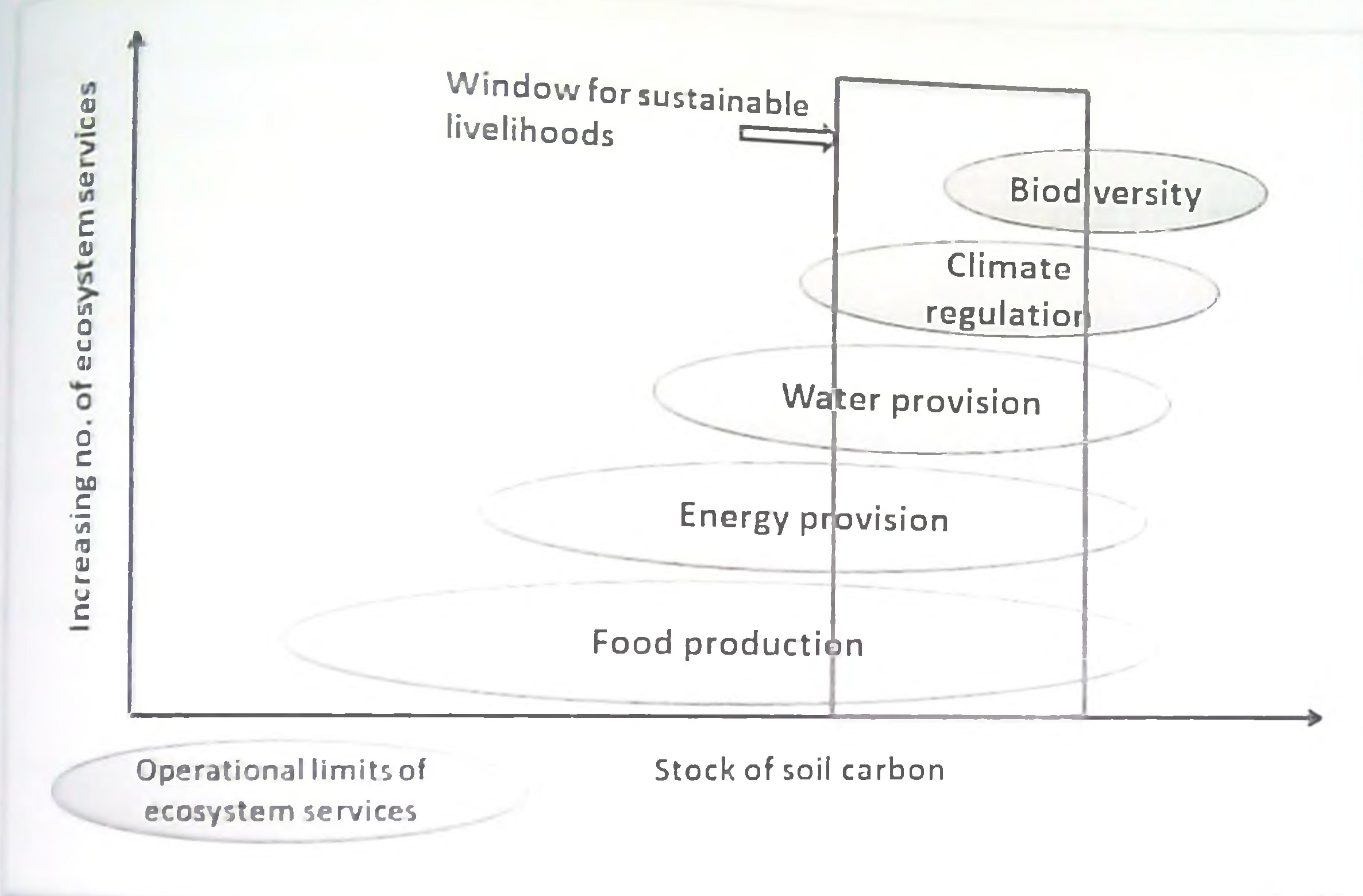


Plate 2: Optimal operational range of SOC

The boundaries to these operational limits will vary at the local scale but ultimately are tied by the global potential to store SOC. As the current stock of SOC is below the optimal stock from a societal perspective, managing soils for multiple services implies working towards levels of SOC that will allow all services to be delivered adequately.

7. Measurement of SOC content

A simple way to determine the SOM content of a soil is to burn off the organic matter in a furnace and determine the mass lost. To determine SOC an assumption can then be made that SOM is, on average, 58% C. This method is called 'Loss on Ignition'. It is a very approximate method which varies in accuracy depending on the clay content of the soil.

Another method is to use chemical means to oxidize the C in SOM to carbon dioxide (CO_2) and organic acids. The amount of the oxidizing agent used gives a measure of the mass of

C oxidized. This method is called 'The dichromate method' as it involves oxidation by boiling the soil sample with an acid dichromate solution. It is also referred to as the Walkley Black method, after the scientists who first documented its use.

SOC stocks are estimated from the SOC content, estimated bulk density and the corresponding soil depth by using the following equation (Choudhury *et al.*, 2013)

SOC density (kg ha^{-1}) = SOC x BD x soil depth

SOC stock = (SOC content of the soil x BD x area x depth)/10

Where SOC stock is given in Pg (10^{15} g), SOC content is in' g C g^{-1}', BD is in 'Mg m^{-3}', area is in 'M ha' and depth is in ' m'.

8. Factors affecting soil organic carbon

Soil carbon levels are determined by factors such as rainfall, temperature, vegetation, management practices and soil type. Then it reaches equilibrium values associated with individual systems and locations. However, these equilibriums are disturbed when areas are cleared and used for agricultural production. The primary control on the global distribution of soil carbon is rainfall, which leads to greater accumulation of soil organic carbon in humid regions. Temperature plays a secondary role with greater accumulation of organic carbon in colder regions (Batjes, 2011).

Globally, clearing natural vegetation for agriculture results in large reductions in SOC levels and further declines may occur due to management practices. Most of the reduction in SOC occurs in the surface soil layer, 0–10 cm. Therefore, soil carbon levels of agricultural soils are lower than corresponding soils under natural vegetation. This difference in SOC indicates the potential for soil carbon storage. Rapid decline in SOC occurs when land under natural vegetation is cleared and converted to agriculture but restoration of SOC level (e.g. under reduced tillage) occurs at a much slower rate. In agricultural systems, soil carbon levels tend to be variable and dependent on management practices. The change in SOC is determined by the balance of carbon inputs over losses

9. Management of soil organic carbon

There are a wide range of management options and farming practices that can increase SOC levels by either increasing inputs or decreasing losses, e.g. stubble retention, Conservation tillage, cover crops and Integrated Nutrient Management (INM). Inputs can also be increased by direct additions of organic materials, composts, manure and other recycled organic materials. Practices leading to increased productivity of crops and pastures – In theory, any management practice that can increase production from an area of land should lead to increased SOC storage because of the increase in carbon inputs. Farmers are familiar with practices such as fertilizer application, improved rotations, improved cultivars and irrigation which can lead to large yield increases. Productivity increases can also be achieved by crop intensification practices such as multiple and double cropping, however, it should be noted that some of the yield increasing practices involve the use of fertilizers and irrigation water which require large energy consumption and therefore increase carbon dioxide emission (Lal., 2010).

Conservation farming is rapidly gaining worldwide acceptance as a farming practice to improve soil and water conservation. In cropping, cultivation is either reduced (reduced tillage) or completely eliminated (no-tillage) and stubble (crop residue) is retained. Reduced tillage reduces carbon losses (from both reduced cultivation and reduced fossil fuel usage) and stubble retention increases carbon inputs to the soil; both of these lead to SOC increases. Maintaining SOC concentration above the threshold level of ~2% in the root zone is essential (Lal., 2015).

10. Conclusion

SOC is a key parameter for maintaining soil physical, chemical, and biological quality. Thus, maintaining SOC concentration above the threshold level of ~2% in the root zone is essential. It is widely known that increase in SOC concentration in depleted soils increases crop yield and use efficiency of input, and has numerous global benefits. The magnitude of yield increase depends on soil type, crop, management, antecedent SOC concentration, and the weather during the growing season. Carbon farming is rapidly becoming the new agriculture where C sequestered in soil/trees/wetlands could be traded just as any other farm produce. Therefore, assigning appropriate societal value to SOC and implementing policies for its judicious management are critical to ecological restoration of our once and future planet so that soils will always save us.

SOC is a finite but essential natural capital, and it must be used, enhanced, and restored by land use and management systems that create a positive soil/ecosystem C budget, by decreasing losses (e.g., erosion and decomposition) and increasing input (e.g., crop residues, cover cropping, and manuring) and recommended management practices (e.g., conservation agriculture).

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12. Discussion

1. What do you mean by anthropogenic emission?

It is process of emission of GHGs due to human activities. They are mainly from the burning of fossil fuels, power generation process, mining process and even from the desertification.

2. What do you mean by natural capital?

It is the existing stock of natural resources like living species, fertile soils, crops, nutrients and soil organic carbon

3. Whether SOC is sufficient in Kerala condition?

No, Kerala is under tropical-humid climate; due to this the organic matter decomposition rate is high which leads to minimum status of SOC. Generally Kerala soils are having 1-2% organic carbon level. So we should apply organic matter as a source of carbon source and do good management practices for maintaining enough SOC status.

13. Abstract

KERALA AGRICULTURAL UNIVERSITY

COLLEGE OF HORTICULTURE, VELLANIKKARA

Department of Soil Science & Agricultural Chemistry

SOILS 591: Master's Seminar

Name: Rincy Rose T. John

Admission number: 2014-11-146

Major advisor: Dr. Jayasree Sankar S.

Venue: Seminar Hall

Date: 21-11-2015

Time: 10.45a.m.

Societal value of soil organic carbon

The top metre of the world's soil stores approximately 2,200 billion tonnes of carbon, two thirds of which is in the form of organic matter. This is more than three times the amount of carbon held in the atmosphere (Batjes, 1996). In soil, carbon exists in both organic and inorganic forms, the former being predominant. Soil Organic Carbon (SOC) constitutes 58 per cent of the organic matter and reflects the soil fertility and productivity by maintaining physical, chemical and biological properties of soil (Lal, 2015).

The main use and value of soil is commonly associated with agriculture. But they are of basic importance to the provision of many ecosystem services. The amount and dynamics of soil carbon are major determinants of the quantity and quality of these services which are divided into four categories, *viz*., supporting, regulating, provisioning and cultural (Banwart *et al.*, 2015). These services underpin many of the functions that can lead to social, economic and environmental benefit to mankind. The societal value of soil organic carbon refers to the monetary equivalent of ecosystem services provisioned by a unit amount of SOC (Lal, 2014). The range of ecosystem services includes increasing net primary productivity and agronomic yield in the context of food and nutritional security, improving plant available water, reducing water runoff, off-setting anthropogenic emissions, mitigating climate change and enhancing biodiversity.

Each of the ecosystem services has an optimal operational range of SOC. Certain services require SOC at lower levels while others may operate at higher levels. The optimum range of carbon stocks that are adequate to supply all essential services is the window for sustainable livelihood (Banwart *et al.*, 2015).

The amount of SOC depends on soil texture, climate, vegetation and land use management. The primary control on the global distribution of soil carbon is rainfall, which leads to greater accumulation of soil organic carbon in humid regions. Temperature plays a secondary role with greater accumulation of organic carbon in colder regions (Batjes, 2011).

One-quarter of global land area has suffered a decline in productivity and the ability to provide ecosystem services because of SOC loss in the past 25 years (Bai *et al.*, 2008). Such degraded land would release greenhouse gases to the atmosphere as a result of accelerated decomposition either due to land use change or unsustainable land management practices (Lal, 2010). Management practices determine the actual storage of organic carbon in soil by increasing inputs and decreasing losses. Multiple ecosystem services can be enhanced by soil management that favours SOC stabilization which ultimately leads to human well-being.

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Biosolids: as soil amendment

By

Aneesa Beegum M.M

(2014-11-223)

MSc. Soil Science and Agricultural Chemistry

Seminar report submitted in partial fulfilment of requirement of the course

Soils. 591 Seminar (0+1)

DEPT. OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

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DECLARATION

I, Aneesa Beegum M. M (2014-11-223), hereby declare that the seminar report entitled 'Biosolids: As soil amendment' has been completed by me independently after going through the reference cited herein and I have not copied from any of the fellow students or previous seminar reports.

Vellanikkara

Date:27/11/2015

Aneesa Beegum M. M

2014-11-223

CERTIFICATE

This is to certify that the seminar report entitled '**Biosolids; as soil amendment**' has been solely prepared by Aneesa Beegum M. M (2014-11-223), under my guidance and has not been copied from seminar reports of seniors, juniors or fellow students.

Vellanikkara

Date: 27/11/2015

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CERTIFICATE

Certified that the seminar report entitled 'Biosolids: As soil amendment' is a record of seminar presented by Aneesa Beegum M. M (2014-11-223) on 19th November, 2015 and is submitted for partial requirement of the course Soils.591.

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1.Introduction

India's population has increased from 342 million in 1947 to around 1.12 billion at present. As a result of increasing population, industrialization, urbanisation wastewater generation increased in recent years (Usman *et al.*, 2012). An estimated quantity of 38,354 MLD (million litre per day) of sewage is generated in major cities of India. Discharge of untreated sewage into water bodies has resulted in contamination of 75% of all surface water bodies across India.

Central Pollution Control Board studied that there are 269 sewage treatment plants in India. This water purification produce large amount of sludge and its disposal is a great issue. Land application of biosolids achieves a complete reuse of its nutrients and organic carbon at a relatively low cost. Recycling is the most technically, economically, and environmentally appropriate method (Matthews, 1998).

2. Biosolids

Biosolids are the nutrient rich organic materials resulting from the treatment of sewage sludge (US EPA, 1999). The term biosolids created in 1991 by the Name Change Task Force at Water Environment Federation (WEF), the water and wastewater industry's main trade and lobby organization in the USA, to distinguish treated sewage sludge from raw sewage sludge and facilitate land application of processed sewage sludge that would be more acceptable to the public.

3. Production process of biosolids

Wastewater usually undergoes three treatment processes in treatment factories. The primary step is a physical screening or settling process to remove sediment but with all the dissolved minerals still in the effluent. The secondary step is a biological process where dissolved biological matter is progressively converted into a solid mass using a cultivated culture of indigenous, water-borne bacteria, thereby large amount of biological oxygen demand (BOD) is removed from the wastewater. A tertiary step, which is a chemical process employed to remove nutrients especially N and P, which are the main concern of eutrophication of waters. After the tertiary step, the effluent may be suitable for discharge into a stream, river, lagoon, or wetland or used for irrigation.

The wastewater treatment residuals (sewage sludge) obtained after the primary process have to undergo additional treatments to reduce pathogens and attractiveness to vectors and this treated sewage sludge is used as a soil amendment.

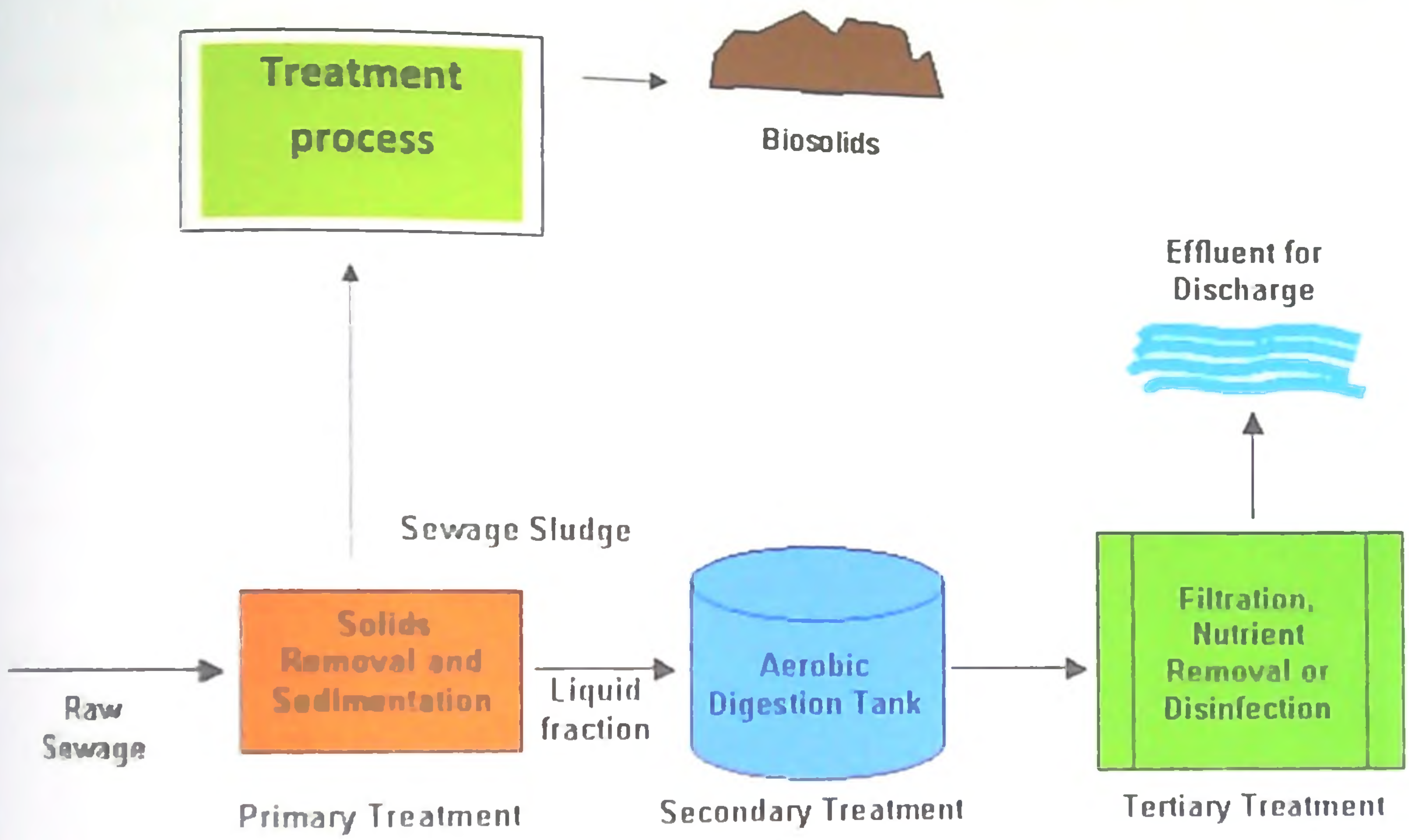


Plate 1. Production process of biosolids

4. Treatment process

To meet the regulatory requirements for land application the wastewater residuals have to undergo additional treatments to minimize the potential for odor generation, destroys pathogens (disease causing organisms), and reduces the material's vector attraction potential. Treatments include aerobic digestion, anaerobic digestion, composting, alkaline stabilization, heat drying and dewatering. They may be also used to control odor and inactivate heavy metals.

4.1 Alkaline stabilization

Alkaline stabilization is the process of treating sludge with alkaline materials to raise the pH level and to make conditions unfavorable for the growth of organisms (such as pathogens). The most common alkali is lime; however, kiln dust, Portland cement, and fly ash also have been used. Where lime or another alkaline additive (for example, recycled kiln dust), is relatively inexpensive, alkaline stabilization is often the most cost-effective process for wastewater solids stabilization. So this stabilization process helps to destroy pathogen and minimise the potential for odour generation and reduce vector attraction.

Alkaline stabilized biosolids help to create soil pH conditions in which metals are insoluble, minimizing plant uptake and movement of metals to groundwater. Soils which have a low pH will benefit greatly from the alkaline material and will be more fertile. Lime is usually low in metals and, when blended with wastewater solids can improve the quality of the product with respect to metals.

Alkaline stabilized biosolids are excellent for land reclamation in degraded areas, including acid mine spoils or mine tailings. Soil conditions at such sites are very unfavorable for vegetative growth often due to acid content, lack of nutrients, elevated levels of heavy metals, and poor soil texture. Alkaline stabilized biosolids help to remedy these problems making conditions more favorable for plant growth and reducing erosion potential.

Plate 2. Alkaline stabilized biosolids

4.2 Anaerobic digestion

Anaerobic digestion is a process that microbially degrades organic matter without the use of oxygen. Biodegradable organic matters, both soluble and particulate are converted to carbon dioxide, methane and water. The anaerobic process also reduces and inactivates pathogens (Grady *et al.*, 1999).

Organic matter + $H_2O \rightarrow CH_2 + CO_2 + H_2O$

A wide range of microorganisms primarily prokaryotic, mainly bacteria and methanogens are involved in anaerobic digestion. The characteristic of the microbial community depends on the substrate with which the digester is fed. The conversions of complex organic materials into simple matter are carried out by four types of microorganism, hydrolytic bacteria, fermentative acidogenic bacteria, acetogenic bacteria and methanogens.

4.2.1 Hydrolysis

Hydrolytic bacteria break down large organic molecules (e.g. polysaccharides, proteins) into smaller soluble molecules (e.g. sugars, amino acids). The hydrolysis reactions are catalyzed by extracellular enzymes (cellulases, proteases) produced by the bacteria. Hydrolysis rate depends on temperature, biodegradable organic matter, biomass nature, particles size and pH.

4.2.2 Acidogenesis

Fermentative acidogenic bacteria transform sugars, amino acids and fatty acids to organic acids, alcohols, ketones, CO_2 and H_2. In an anaerobic digester, the acidogenic bacterial population is the largest covering 90% of the total.

4.2.3 Acetogenesis

Fatty acids and alcohols are converted to acetate, hydrogen, and carbon dioxide by acetate and H_2 producing bacteria called acetogenic bacteria. These groups of bacteria require low H_2 partial pressure for fatty acid conversions. Substrate is converted to propionic acid, butyric acid and ethanol and so acetate formation is reduced under relatively high H_2 tensions. Methanogens help in achieving low H_2 tensions by continually removing H_2 to produce methane. Thus, the H_2 producing bacteria have a symbiotic relationship with the methanogens that use the H_2 (Grady *et al.*, 1999).

4.2.4 Methanogenesis

Acetate, CO_2 and H_2 formed from the acidogenesis process are used by the methanogens to produce methane gas. Methanogens are split into: Aceticlastic methanogens which convert acetate into methane and CO_2, and, H_2-oxidizing which convert hydrogen and carbodioxide into methane. In an anaerobic digestion process among these substrates the methanogens use about two-thirds of the methane produced which is derived from acetic acid while only one third is from H_2 and CO_2.

4.3 Aerobic Digestion

Aerobic digestion involves the oxidation of biodegradable and microbial cellular matter by aerobic microorganisms resulting in the overall reduction in the mass of sludge and generation of finite amount of stabilized cell mass.

In an aerobic digestion, biodegradable particulate organic matter is hydrolyzed converting it into biodegradable soluble organic matter releasing ammonia-N and phosphate. The biodegradable soluble organic matter thus produced is then converted into water, carbon dioxide and active biomass through the action of heterotrophic bacteria. The factors affecting the performance of aerobic digestion are retention time, temperature, pH, mixing, solids type and biosolids configuration (Grady *et al.*, 1999).

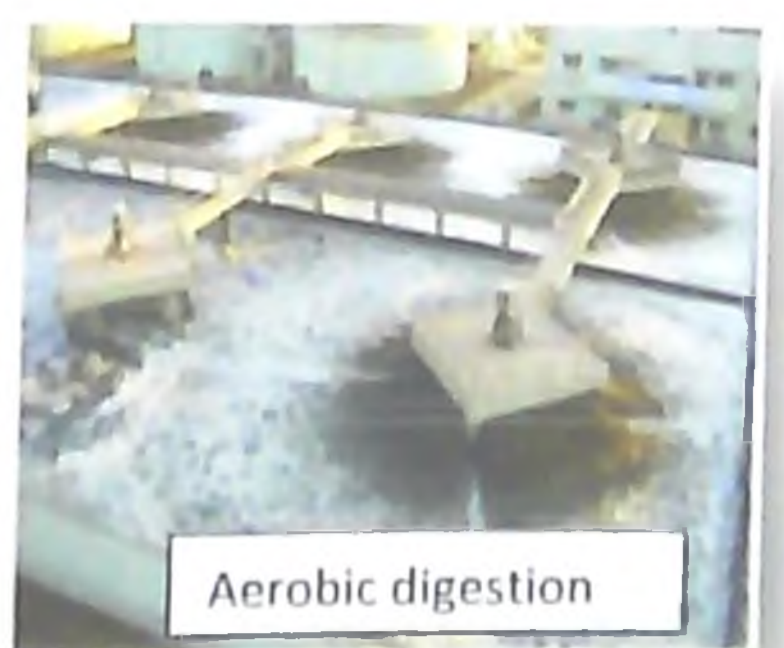


Plate 3. Anaerobic and aerobic digestion

4.4 Composting

Composting is aerobic process of mixing sludge with agricultural by-product sources of carbon such as sawdust straw or wood chips. In the presence of oxygen,bacteria digesting both the sewage sludge and plant material generate heat to kill disease causing microorganisms and parasites. Composting is one of the methods for treating biosolids to create a marketable end product that is easy to handle, store and use. Several studies reported that composting results in significant decrease in pathogenic bacteria, fungi and helminth egg. If not aerated and stored properly, unstable compost can emit nuisance odours. Sewage sludge composts in recent decades have received great attention (Senesi *et al.*, 2007).

The three most commonly used methods for composting wastewater residuals into biosolids are aerated static pile, windrow and in- vessel composting.

4.4.1 Aerated Static Pile

Dewatered biosolids are mechanically mixed with a bulking agent and stacked into long piles over a bed of pipes through which air is transferred to the composting material. As the pile is starting to cool down, the material is moved into a curing pile (Hickman, 1999).

4.4.2 Windrow

Dewatered wastewater solids are mixed with bulking agent and piled in long rows. Since there is no piping to supply air to the piles, the material is aerated mechanically by devices such as drums and belts powered by agricultural equipment. This periodic mixing is essential to move outer surfaces of material inward so they are exposed to the higher temperatures deeper in the pile. After this process, the material is moved into curing piles.

4.4.3 In-Vessel

A mixture of dewatered wastewater solids and bulking agent is fed into a silo, tunnel, channel, or vessel. Augers, conveyors, rams, or other devices are used to aerate, mix, and move the product through the vessel to the discharge point.

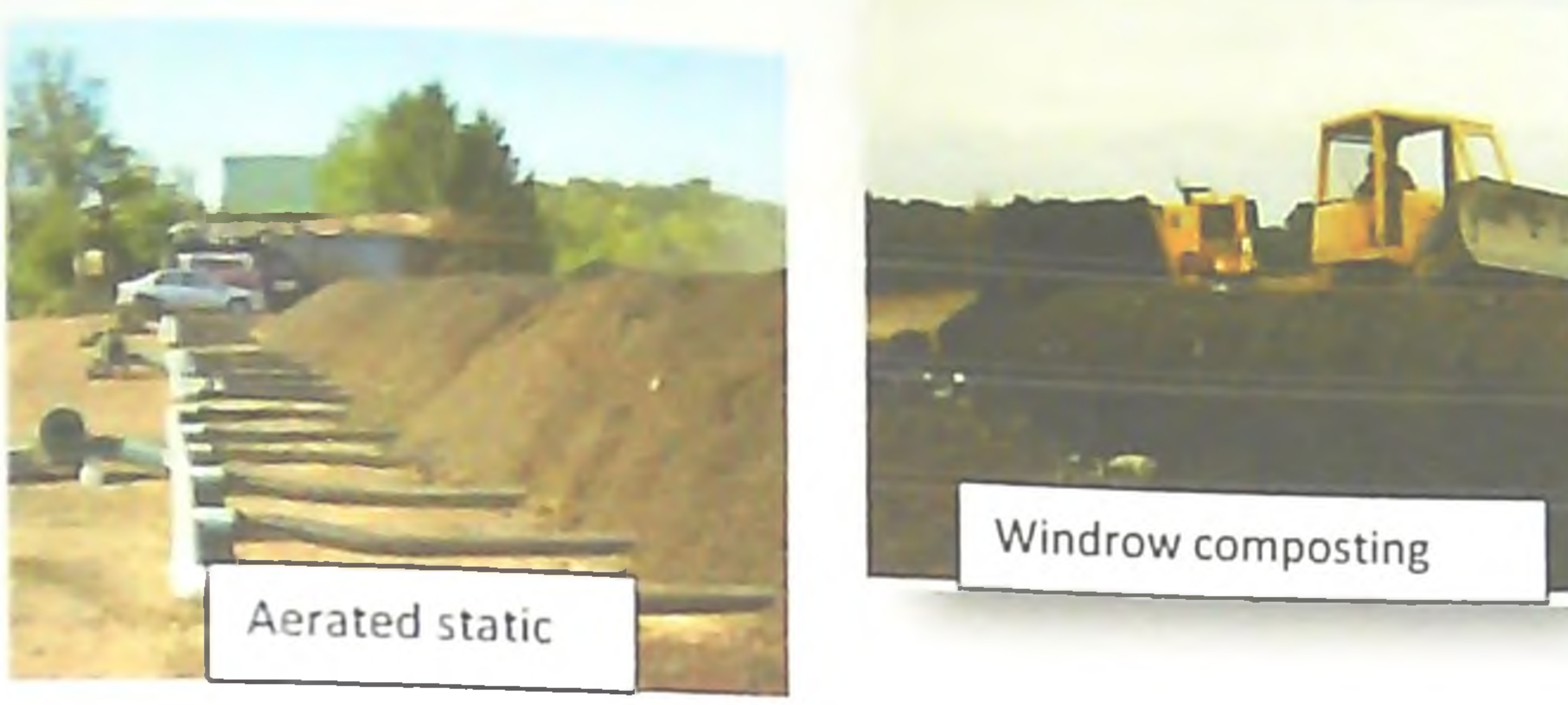


Plate 4. Aerated static and windrow composting

4.5 Heat drying

This process uses the application of heat to kill pathogens and eliminate water content. Solar drying is used in some locations, however direct and indirect dryers are more common. In direct dryers the wastewater soilds come into contact with hot gas, which cause evaporation. Rotary dryer is the most commonly used direct dryer. In indirect dryers solids remain separated from heating media by metal walls and solids never come in contact with heating medium moisture is evaporated when wastewater soilds contact with metal surface heated by hot medium. Heat drying slightly lowers potential for odor but greatly reduces volume.

4.6 Dewatering

High force separation of water from solids that decrease the volume of solids. Most common dewatering methods are vacuum filters, centrifugers and drying beds.

5. Forms of biosolids

There are a large number of forms of biosolids products including liquid, cake, and pellet form (Lu *et al.*,2012). Liquid biosolids may come directly from the digester without going through any dewatering/drying process, thus usually having high water content (94–97%) and a low dry solid content (3–6%). Cake biosolids with the texture of a wet sponge can be created with digested liquid sludge or undigested liquid sludge, alkali-stabilized with quicklime (calcium oxide) or hydrated lime (calcium hydroxide). Cake biosolids usually have a solids content of 11–40%. Pellet biosolids are produced by heating and drying to a solid content of more than 90%.

From liquid to cake to pellet form both volume and weight of biosolids are subsequently reduced increasing economic value by reducing transportation or storage costs. Pellet biosolids can be easily handled and spread with conventional agricultural equipments.

6. Composition of biosolids

Parameters	Range
pH	4.2 - 8.0
EC (dS m^{-1})	1.02 – 6.0
N (%)	3.0 – 6.0
P (%)	0.9 – 1.6
K (%)	0.2 – 0.8
Ca (mg kg^{-1})	1.0 – 2.0
Mg (mg kg^{-1})	1.1 – 3.2
S (mg kg^{-1})	0.2 – 1.2

7. Uses of biosolids

Uses of biosolids are categorised into two energy production and land application. Because of very high heating value of dried biosolids it can be used as a substitute for coal and also biosolids are used for bio-fuel production. By the process of gasification (partial oxidation of biomass and it is converted to carbon monoxide, hydrogen and methane) syngas is produced, this syngas is used for production of bio-fuels like methanol and ethanol.

Biosolids are used on agricultural land, forests, rangelands, or on disturbed land in need of reclamation. They are added to soil to supply nutrients and replenish the soil organic matter. It improves soil structure and tilth, enhance moisture retention, and reduce soil erosion, which make conditions more favorable for root growth and increases the drought tolerance of vegetation. Application of biosolids increase the yield of barly (Gardiner *et al.*, 1995). Biosolids supply nutrients that are important to plant growth. For example, nitrogen and phosphorus, as well as some essential micronutrients such as nickel, zinc and copper.

8. Biosolids as soil amendment

In agriculture, intensive cultivation practices often lead to a gradual decrease in the organic matter content of the soil and result in decrease in soil fertility. Biosolids are rich in organic matter that contain sufficient nitrogen and phosphorus. Heathwaite *et al.* (2006) reported significant increase in organic matter, nitrogen and phosphorus when biosolids were added to soil. So it can be used as a soil amendment. The use of organic amendments such as sewage sludge is a common practice to improve physical, chemical and biological properties of depleted soils by supplying organic matter (Carbonell *et al.*, 2011).

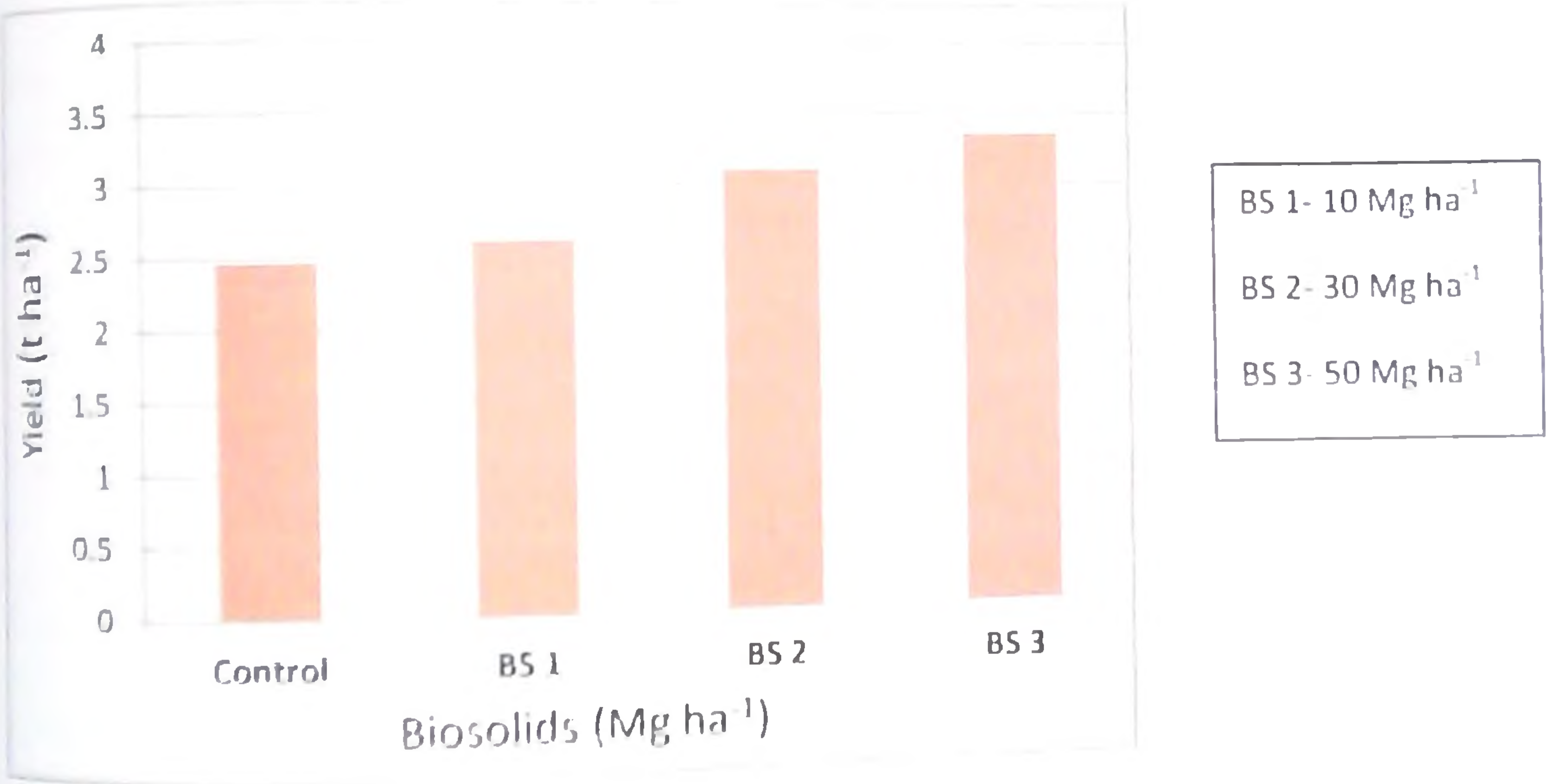
As a source of organic matter and nutrients it improves soil physical properties such as bulk density, porosity, aggregate stability, water holding capacity and infiltration rate, chemical properties such as organic matter content, pH, cation exchange capacity and nutrients, biological properties such as microbial activities and microbial biomass, all of which may be reflected in an increase in crop yield(Barbarick *et al.*, 2004).

Table 1. Effect of biosolids on soil physical properties

Levels of biosoilds ($Mg\ ha^{-1}$)	Bulk density ($g\ cm^{-3}$)	Field capacity (%)	Wilting Point (%)
Control	1.41	27.46	14.23
10	1.32	29.46	16.01
30	1.3	30	16.51
50	1.27	33.85	18.39

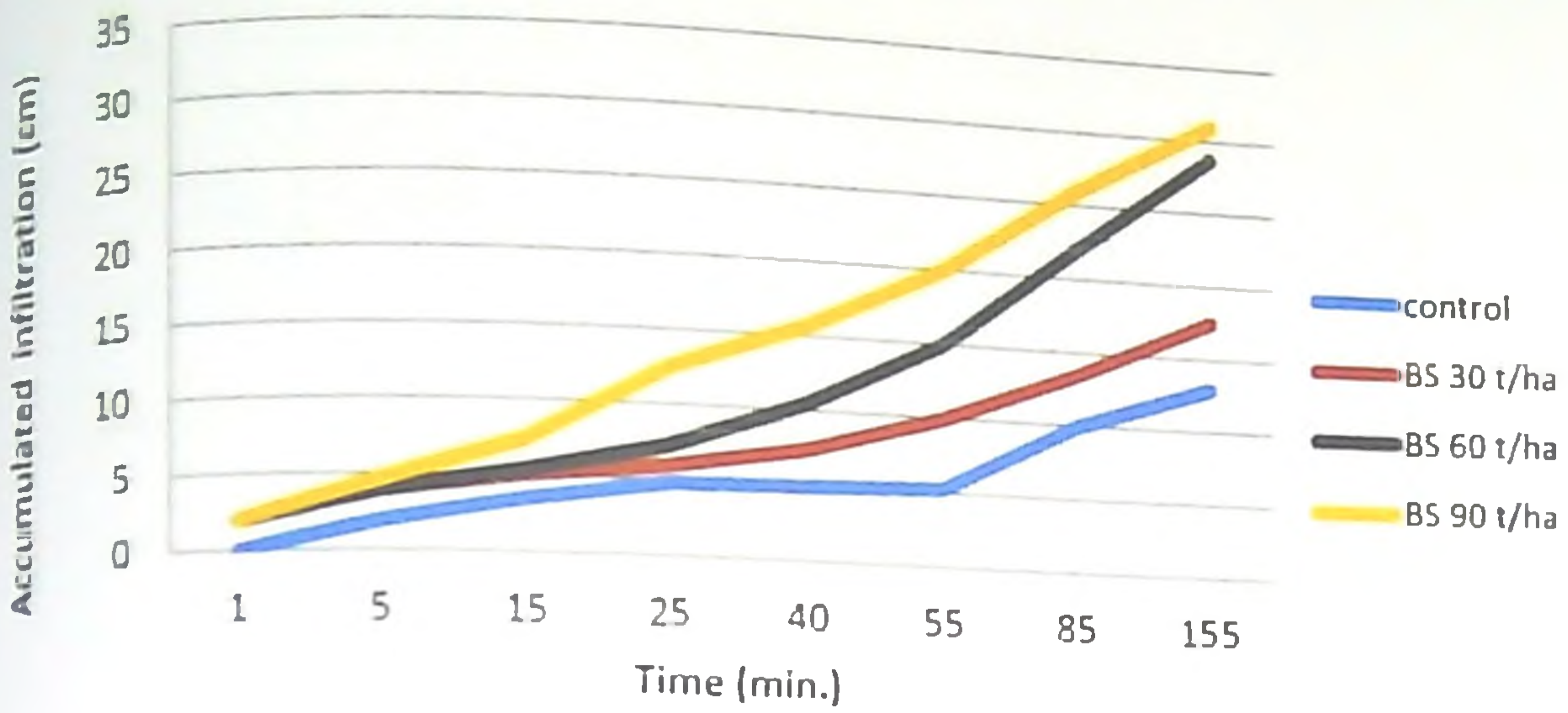
Table 1 shows effect of biosolids on soil physical properties like bulk density, field capacity and wilting point (Tsadilas *et al.*, 2005). Bulk density is minimum for the soil receiving higher dose of biosolids. Biosolids application significantly reduces the bulk density from 1.41g cm^{-3} to 1.27gcm^{-3}. The decrease in bulk density is most likely attributed to the increase in organic matter content. Other physical properties like field capacity and wilting point were significantly increased because of biosolids application. Field capacity was increased from 27.5% in the control to 33.8% in treatment 50 Mg ha^{-1}. Similarly wilting point was increased from 14.23% to 18.39%. They concluded that the influence of biosoilds is a consequence of increasing soil organic matter, which is closely related to all these properties.

Figure 1. Effect of biosolids on cotton yield



Biosolids application significantly increased cotton yield from 2.47 ton ha^{-1} in the control treatment up to 3.35 ton ha^{-1} in the BS3 treatment. This may be partially attributed to the beneficial effect of biosolids organic matter addition because of positive relationship recorded between organic matter content and cotton yield. Tsadilas *et al* (2005) reported that biosolids application significantly increased total soil N and plant-available P, Fe, Zn, Mn, and B, and concentrations of all these elements were significantly correlated with cotton yield.

Figure 2. Effect of biosolids on accumulated soil infiltration



Salazar *et al.* (2012) observed that accumulated infiltration increased at the higher dose of application of biosolids on degraded soils. Organic matter content of biosolids increase soil aggregate stability and it may protect soils against crust formation and increase infiltration rates by enhancing the macro porosity and reduce the risk of soil erosion.

Table 2. Effect of biosolids on soil chemical properties

Treatments	Total organic carbon (g kg^{-1})	Bases (mg kg^{-1})	Phosphorus (mg kg^{-1})
Control	9.3	3.7	5.3
Fertilized	9.3	4.3	7.3
BS 30	10.3	11.8	21.3
BS 60	11.2	17.2	28
BS 90	11.4	23.5	49.1

Salazar *et al.* (2012) studied the effect of biosolids on some chemical parameters like total organic carbon, concentration of bases and phosphorus. Total organic carbon and bases increase proportionally with the dose of biosolids from 30 to 90 ton ha^{-1}. This contrasts with the fertilized soil, which shows no change except for an increase in the base phosphorus level. All the chemical parameters were increasing with increasing the doses of biosolids.

Figure 3. Effect of biosolids on soil pH

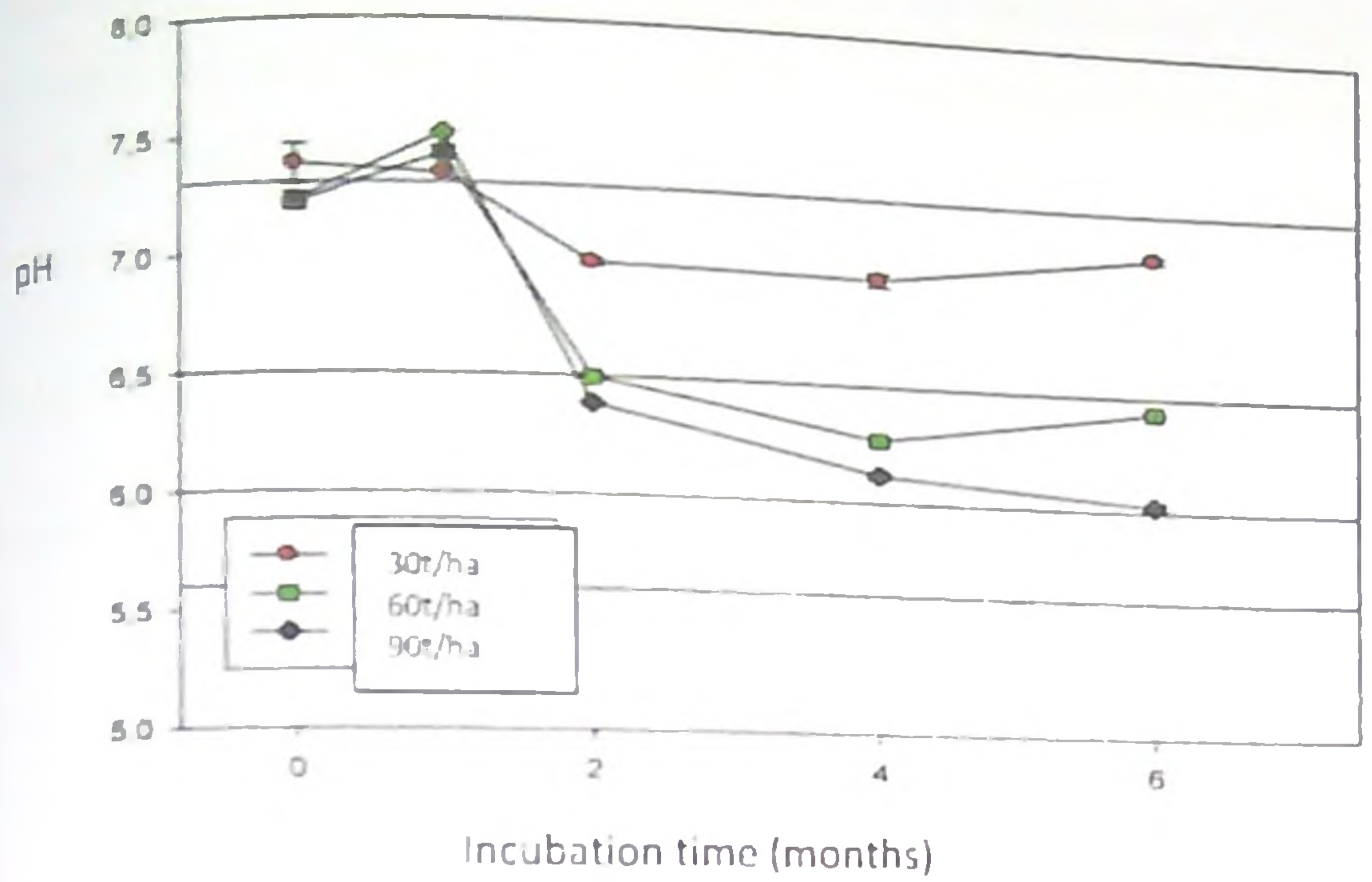


Figure 3 shows pH evolution over incubation time. A slight acidification is seen for the highest dose of incorporated biosolid. This acidification process could be directly related to dissolution of soluble bases (Ca^{2+}, Mg^{2+}), with its subsequent leaching, comparatively similar to what occurs in the presence of a high rainfall situation. At lower biosolid doses, the pH remains close to neutrality. Simultaneously, it is important to consider the decomposition of organic matter that entails the biosolid system, producing CO_2 acidifying the soil at the end of the experiment (Antilen *et al.*, 2014).

Figure 4. Effect of biosolids on soil CEC

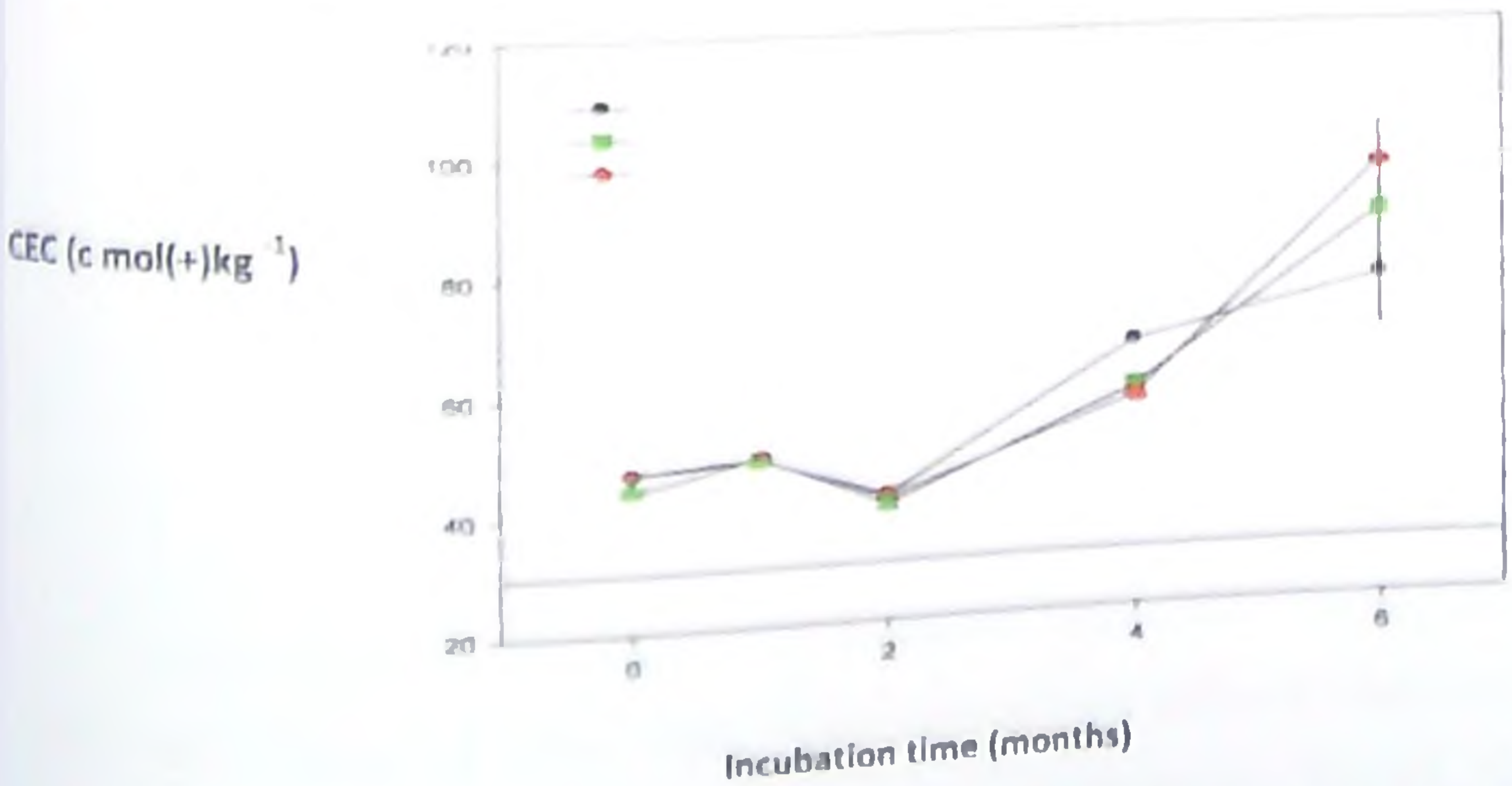


Figure 4 displays the effect of biosolid application on the content of ammonium acetate extractable cations, in which a moderate increase is observed. Since the presence of both inorganic components and OM are responsible for the CEC value, the increase is related to the organic component of the waste, as a result of the high number of acidic functional groups that are capable of interacting with soil cations. From an agricultural standpoint, soils with high CEC tend to be more fertile, because the probability for nutrient losses by leaching is low. A larger storage and supply capacity of the cultures is thus obtained.

Table 3. Characteristics of biosolids compost

Parameters	Characteristics
pH	7.8
Total organic matter(g kg^{-1})	45.4
Nitrogen(g kg^{-1})	16.6
Phosphorus(g kg^{-1})	9.6
Calcium(g kg^{-1})	119.5
Magnesium(g kg^{-1})	4.6

Figure 5. Effect of biosolids on maize yield

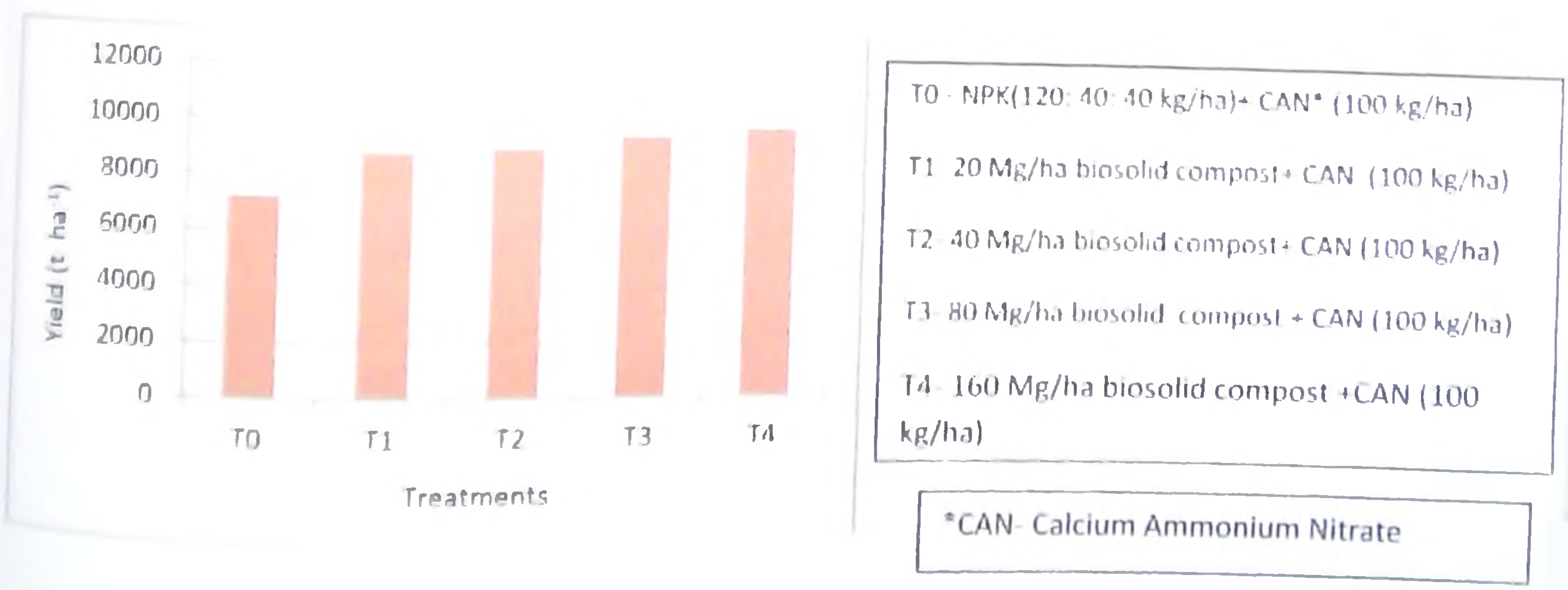


Figure 5 shows the influence of biosolids compost on maize yield. Compost used for this study was biosolids obtained from Vidyaranyapuram effluent treatment plant at Mysore. Here sludge was mixed with sawdust and lime and composted for 30 days. Figure 5 shows that grain yield of maize was significantly influenced by different treatments. Among the treatments T_1 and

T_1 recorded higher grain yield (9500 and 9800 kg ha^{-1}) than other treatments. They concluded that the use of biosolids compost in appropriate rates provides a good quantity and quality corn yield (Begum, 2011).

Figure 6. Impact of biosolids on carbon sequestration in soil

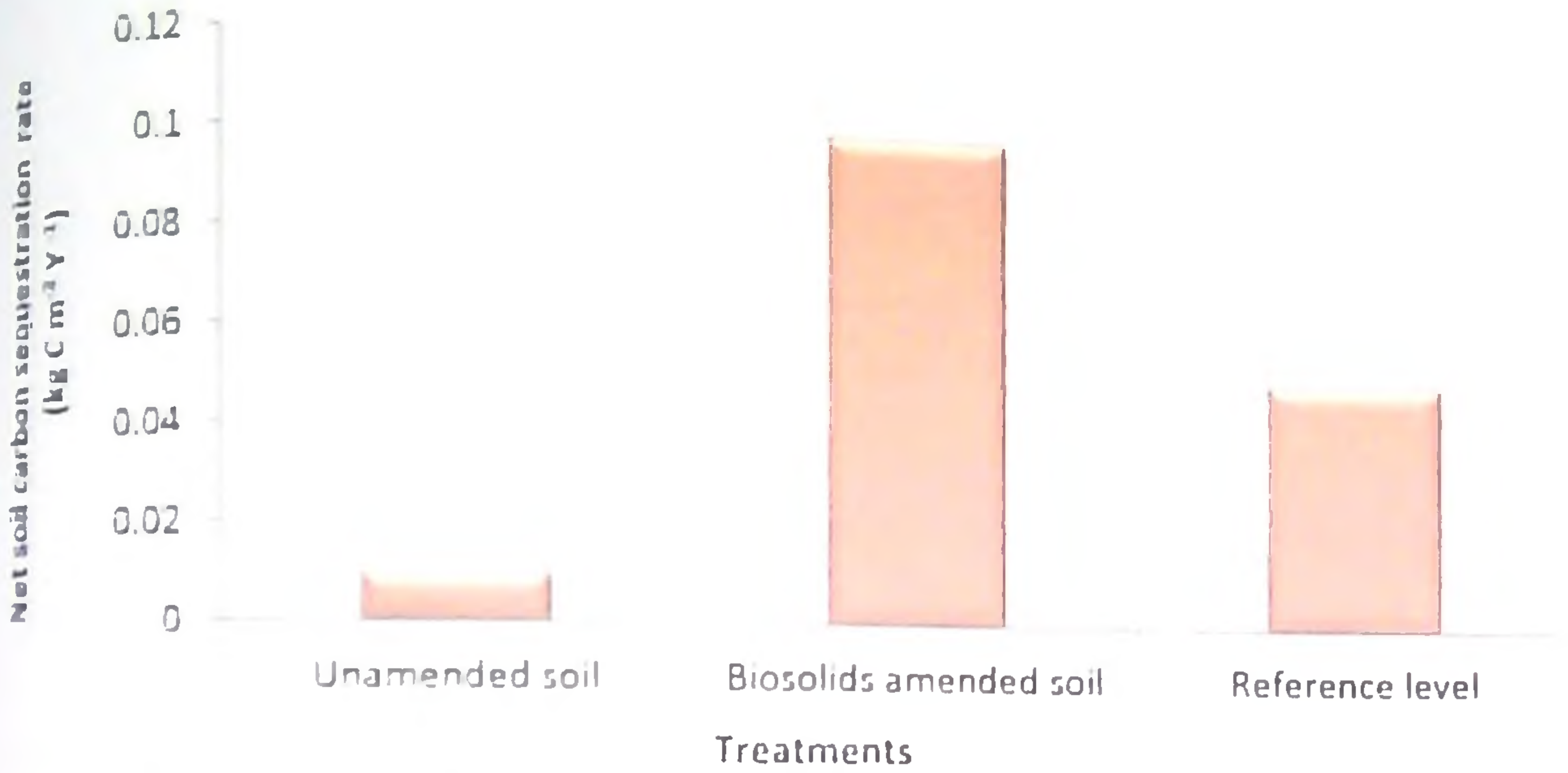


Figure 6 shows the annual rate of net soil carbon sequestration was near zero without amendment, but significantly positive with biosolids amendment. Biosolids can improve the carbon metabolism of microorganism in agriculture soils and it leads to high carbon sequestration. They concluded that no other soil amendment like biosolids have displayed such high effectiveness in restoring lost organic carbon (Tian *et al.*, 2014).

Figure 7. Effect of biosolids on biological properties after 15 days of biosolids application

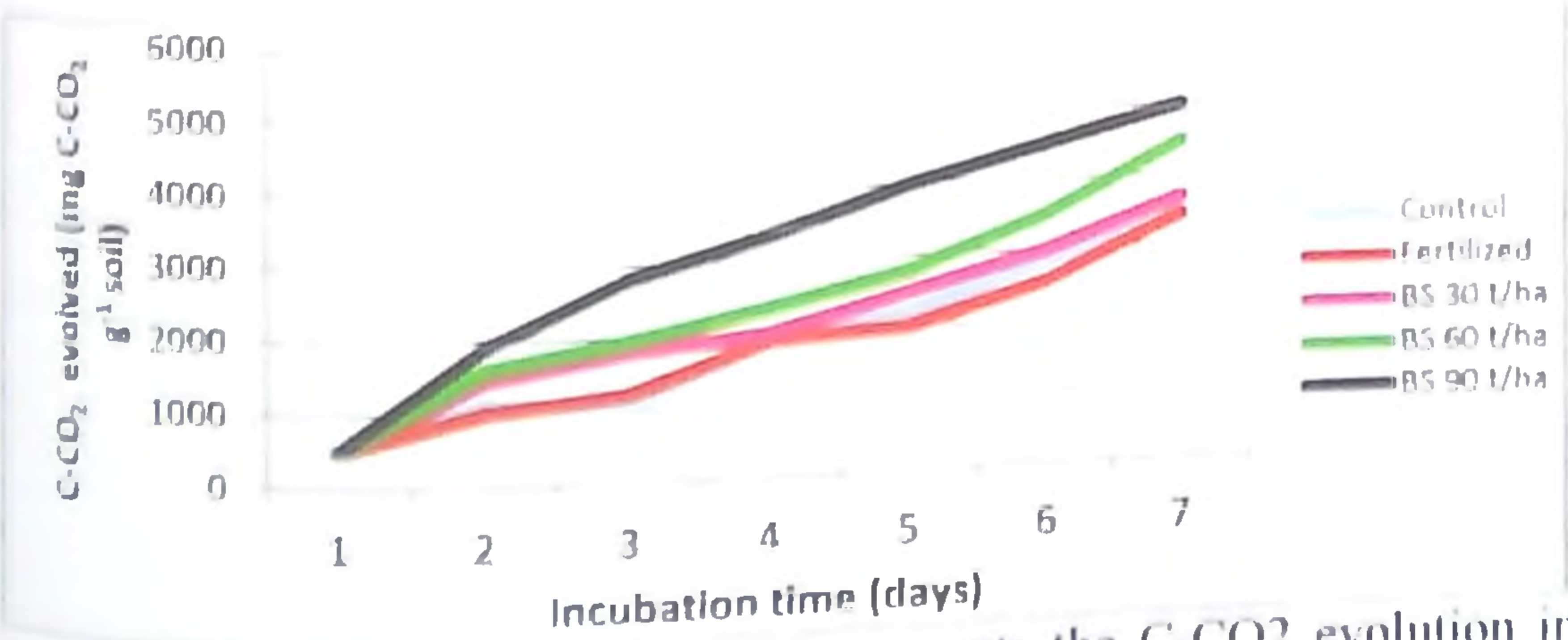


Figure 7(Salazar *et al.*, 2012) presents the C-CO2 evolution in soil fertilized with the three treatments: BS30, BS60 and BS90. After 15 days of incorporation of biosolids, the soil samples were collected and analysed. They observed that there were no great differences compared to the control, indicating that the incorporation of the biosolids into the soil requires more time. In systems with added biosolids where there was additional organic matter available as a source of energy for microorganisms, microbial respiration was increased.

Figure 8. Effect of biosolids on biological properties after 4 months of biosolids application

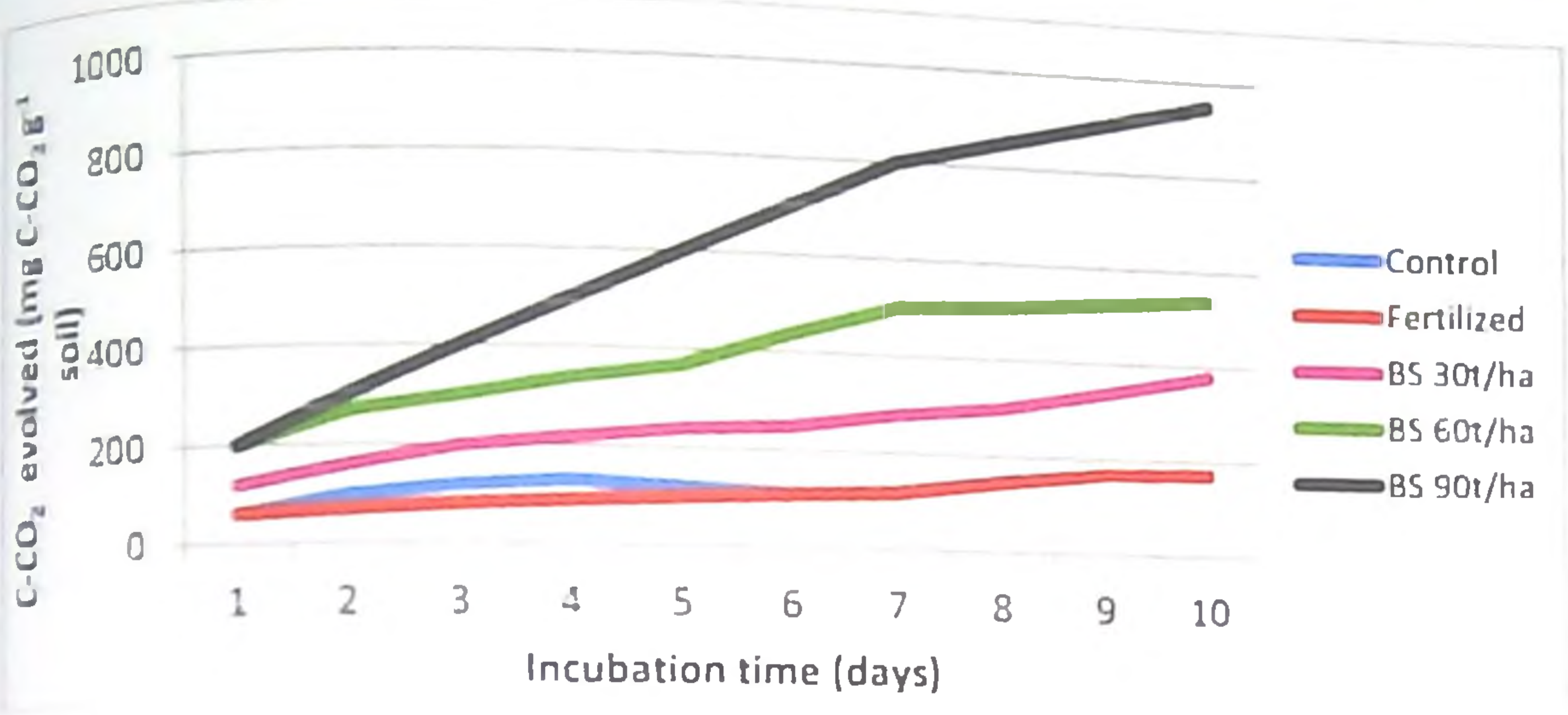


Figure 8 shows that four months after the incorporation of biosolids into the soil and before harvesting, BS 90 in particular presented the highest level of microbial activity. They concluded that after proper incorporation of biosolids microbial activity was increased.

Table 4. Long term effects of biosolids on microbial activity

Year of application	MBC (mg kg^{-1})	MBN (mg kg^{-1})	MBP (mg kg^{-1})
Soil depth : 0-15 cm			
0	134	16	9
2	156	21	10
5	257	30	16
25	496	52	30
Soil depth :15-30 cm			
0	84	11	8
2	117	13	8
5	152	14	11
25	257	27	16

Table 4 (Yucel *et al.*, 2015) showed that soil microbial biomass and associated biological properties were significantly influenced by the temporal effects of biosolid application. The MBC(microbial biomass carbon) content at 0 to 15 cm depth was higher by 1.9 and 3.7 folds in

5 and 25 years of biosolid applied fields respectively than in the control. Similar responses of MBC to biosolid application at 15 to 30 cm depth were also observed. While MBN (microbial biomass nitrogen)and MBP(microbial biomass phosphorus) contents were higher in the 25 years of biosolid applied fields, they did not vary among the control and short-term biosolid-applied fields.

9. Impact of biosolids on water quality

The U.S. Environmental Protection Agency and a panel of scientists with biosolids expertise examined all aspects of biosolids in the environment, including potential effects on ground water quality, and food quality. Research showed that land application of biosolids at calculated rates poses little or no risk to groundwater. The organic forms of nutrients in biosolids are less able to dissolve in water than chemical fertilizers and less likely to leach into groundwater or run off into surface water.

Guidelines control how, where, how much, and how often biosolids can be spread to ensure that ground and surface water is not contaminated. Biosolids are applied at a rate that allows the crops to use most of the nutrients as they become available. This keeps the nutrients from ending up in ground and surface waters. Metals in biosolids are in a form that is hard to dissolve in water and tend not to move from where they were applied. Potential impacts to water sources are minimized by proper management practices, including:

- Not over applying biosolids.
- Maintaining buffer zones between application areas, surface water bodies and groundwater.
- Following soil conservation practices.

The organic nitrogen and phosphorus found in biosolids are used efficiently by crops because these plant nutrients are released slowly throughout the growing season. This enables the crop to absorb these nutrients as the crop grows. This efficiency lessens the likelihood of groundwater pollution by nitrogen and phosphorous that can occur after chemical fertilizer applications.

10. Impact of biosolids on food quality

Biosolids can be safely used to grow food crops. This issue has been studied by agricultural scientists for decades. The safety of food crops was a major consideration in setting the standards for biosolids that could be used in agriculture. Research and field experience confirms that crops were not negatively affected when the regulations are followed. Scientists from Washington State University have repeatedly tested crops fertilized with biosolids and found no differences in quality from those treated with chemical fertilizers. Decades of research and actual application of biosolids have resulted in scientific agreement among qualified researchers that the use of biosolids in accordance with existing federal and state guidelines and regulations presents negligible risk to the consumer, to crop production, and to the environment. In fact, the science-based approach used in developing the biosolids standards could serve as a model for policy and regulation in other areas of agricultural production and food safety.

11. Quality criteria of biosolids

The Standards for the Use or Disposal of Sewage Sludge were developed and published by the US EPA(United States Environmental Protection Agency, 1999) on February 19,1993. They established biosolids quality requirements for its land application. These requirements address pathogen and vector attractiveness reduction, metal loading and concentration limits, and nutrient limits.

11.1 Pathogen reduction

Pathogens (e.g.bacteria, viruses, protozoa, helminths) can cause disease. According to US EPA regulations pathogens in biosolids are to be reduced prior to land application to minimize potential for diseases. There are two classes of pathogen reduction: Class A and Class B. Class A pathogen reduction is necessary if biosolids are to be applied to lawns, home gardens, or other types of land, or bagged for sale, or land application and requires pathogen densities be reduced to below detection limits (dry weight basis) for density. For example *Salmonella* sp. less than 3 CFU per 4 g biosolids, enteric viruses less than 1 PFU per 4 g biosolids and less than 1 viable helminth ova per 4 g biosolids.

Class B pathogen reduction is necessary for any other application and requires a fecal coliform density in the treated sewage sludge (biosolids) less then 2 million CFU per gram biosolids. Public access is not restricted for biosolids that meet Class A requirements. Since Class B biosolids still contains considerable pathogens, site restrictions that limit crop harvesting, animal grazing, and public access for a certain period of time is required.

11.2 Vector attractiveness reduction

As vectors (e.g. rodents, birds, insects) can spread diseases by harboring and transferring pathogens, reducing the attractiveness of biosolids to vectors reduces the potential for transmitting diseases from pathogens in biosolids. Treatments like anaerobic and aerobic digestion, alkaline stabilization will changes the characteristics of biosolids and reduce attractiveness to vectors.

11.3 Nutrient limits

Nutrients	Range (%)
Nitrogen	3- 8
Phosphorous	1.5-3.5
Sulphur	0.6-1.3
Calcium	1- 4
Magnesium	0.4- 0.8
Potassium	0.1- 0.6

Although maximum nutrient application rates in federal biosolids regulations are not well defined,the standards stipulates that agronomic rates cannot be exceeded. To protect groundwater or surface water quality, nitrogen is regulated through an agronomic rate approach, requiring an estimate of crop N need and biosolids N availability.

11.4 Trace element limits

Trace metal	Concentration (mg kg^{-1})
Arsenic	42
Cadmium	39
Copper	1503
Lead	301
Mercury	17
Nickel	421
Selenium	100
Zinc	2805

Land application of biosolids must meet the limiting concentrations for these trace elements set in the US EPA regulation. If the concentration limit of any one of these elements is exceeded, the biosolids cannot be land applied. Biosolids that meet Class A pathogen reduction requirements, metals limits (pollutant concentrations), and vector control requirements are considered to be "Exceptional Quality" (EQ) biosolids. Exceptional quality biosolids can be used with few site restrictions.

12. Advantages

Biosolids are nutrient-rich organic materials with an organic matter content of upto 50%. Therefore, biosolids can be utilized as a soil conditioner to improve physical, chemical, and biological properties of soils, especially those degraded or disturbed soils. Biosolids addition not only improves soil properties but also helps to solve serious environmental problems concerning disposal of large quantities of wastes (Weber *et al.*, 2007). Besides acting as a food source for microorganisms, organic materials are the major binding agents for aggregate formation and stabilization. Optimum soil structure, in turn, improves many other important soil physical and chemical properties such as bulk density, porosity, water retension, cation exchange capacity, aeration, drainage, microbial communities and soil fauna thus contributing to disease suppression and reduced soil erosion. Application of biosolids can reduce bulk density and improve water holding capacity in short-term may be mainly due to biosolids direct dilution effect, its high organic matter content, and partly due to its effect on aggregate formation and stabilization. Improved pore size distribution by long term application of biosolids in soil may be linked to the increased volume of macropores or micropores, depending on the texture of the soil. Biosolids treated soil was less sensitive to compaction than untreated soil due to the improved pore volume. Biosolids have the advantage of high organic matter content and have been used to remediate sites previously contaminated with trace metals by binding and converting the metals to less soluble fractions.

Besides improving soil quality, biosolids application can supplement or replace commercial fertilizer. An advantage of using biosolids to supplement or replace fertilizer is its ability to slow-release nutrients. Biosolids release N and other nutrients over several growing seasons. Alkali-stabilized biosolids can be used as liming material to alleviate soil acidity and Al toxicity. pH was increased from 5.7 to 6.9 for an acid clay sandy loam and from 4.5 to 6.0 for a strongly acid sandy loam.

13. Disadvantages

Odour

odor is one of the reasons for lack of public acceptance. Management techniques such as incorporating biosolids into the soil, vegetation buffers, timing of the application etc. can be used to reduce odour problems.

Excess loading of nutrients

Biosolids are generally applied at a rate to meet the crop's nitrogen need. Since the phosphorus content of biosolids can be relatively high, more phosphorus can be applied than the plants need. Over time, phosphorus can build up in the soil. With continued application, excess phosphorus can move into surface water, creating pollution problems.

Heavy metals

Many of the metals, such as zinc and copper, are essential for plant growth, but some metals in large quantities can create problems with plant growth or animal health. US EPA (United States Environmental Protection Agency) set limits on the maximum amount of a metal that can be applied to a site. These limits were based on the lowest amount of a particular metal that would create a health problem for people, animals or plants. Most metals do not move easily into plants or water when the soil pH is near neutral. Soils should not be over-limed because a few metals like molybdenum, arsenic, selenium become more available and move more easily into plants (Sciubba *et al.*, 2014).

Pathogen

In biosolids, the primary source of pathogens is human wastes. Class A biosolids are extensively treated so there are very few or no pathogens. Class B biosolids are also treated to reduce the levels of pathogens, though some are still present. According to regulations, Class B biosolids are to be incorporated into the soil or restrict site access to surface-applied biosolids to minimize potential exposure. Composting, if conducted properly, is a very effective method for disinfection and destruction of pathogens primarily by exposing pathogens to high temperatures for a prolonged period of time.

14. Conclusion

Biosolids is a very important soil amendment for sustainable agriculture. It improves organic matter status of the soil. It also adds macro and micronutrients to the soil. Improvement in organic matter content in soil helps in improving soil physical conditions, rejuvenating soil health and stimulating biological activity. Organic matter in biosolids reduces the negative environmental effects of heavy metals and other pollutants by binding contaminants. Higher level of soil organic matter can sequester carbon and mitigate greenhouse gas emissions. Regarding the pathogen in sewage sludge, their number can be significantly reduced before application to soil by appropriate sludge treatments. An enhanced microbial activity due to addition of biosolids reduces the survival of the pathogens in soil. Therefore, use of biosolids in agriculture will be appropriate and beneficial, if applied according to appropriate guidelines to minimize environmental and ecological damage and maximize potential benefits for sustained agricultural productivity. In the future, long term monitoring is still needed to evaluate the potential impacts of biosolids land application on soil quality and the environment.

15. Discussion

1. What is syngas?

Syngas is a composition of carbon monoxide, hydrogen and methane.This syngas is produced by the process of gasification.In gasification biomass undergoes partial oxidation and it is converted to syngas.This syngas is further used for the production of bio-fuels

2.Which method of treatment is more efficient?

Composting is a more efficient method. It is a proven method for pathogen reduction and results in a product that is easy to handle, store, and use. The end product is usually a Class A, humus-like material without detectable levels of pathogens that can be applied as a soil amendment and fertilizer to gardens, food and feed crops. This compost provides large quantities of organic matter and nutrients (such as nitrogen and phosphorus) to the soil and it improves soil texture, soil exchange capacity and it have all characteristics of a good organic fertilizer.

3.What is the actual cost for heat drying process?

Exact costs of heat-drying wastewater solids are difficult to estimate and are dependent on the specific type of dryer, fuel source, and moisture content of the feed solids. Costs for heat-drying equipment typically ranged between $127,000 and $208,000.

4.How bulk density affect yield?

Bulk density reflects the soil's ability to function for structural support, water, solute movement, and soil aeration. Biosolid contain around 45% of organic matter, this will reduce bulk density of soil, so pore size distribution is increased. Plants can easily penetrate roots into the soil and absorb sufficient water and nutrients.

5.Is there any regulation in india?

India has no legislative measures to control continued application of sludge as a manure. So in Indian condition long term experiment should undertaken to develop the protocol for economic utilization of biosolids in agriculture field.

6. Is this biosolids can commercialise in india?

Yes. india has a good potential for the production and use of sewage sludge generates in various metros and municipalities. So after proper treatments this sewage sludge can be used as a soil amendment.

16. Reference:

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17. Abstract

Water purification produces large amount of waste or sludge, the disposal of which is important because some of its components may be converted into pollutants that can have a negative impact on the environment (Celis *et al.*, 2006). Land application of this sludge after proper treatment is a beneficial way of recycling organic matter and nutrients to soil.

Biosolids are nutrient rich organic materials resulting from the treatment of sewage sludge (US EPA, 1999). In wastewater treatment factories wastewater usually undergoes physical screening or settling process to remove sediments. To meet the regulatory requirements for land application, the sludge obtained after settling process have to undergo further treatments such as aerobic and anaerobic digestion, alkaline stabilization, composting and heat drying to reduce pathogen and vector attraction. Composting is one of the important methods for treating sludge to create a marketable end product that is easy to handle, store and use.

Liquid, cake and pellets are the three forms of biosolid products. Liquid biosolids have high water content (94-97%) and low solid content (3-6%). Cake biosolids usually have a solid content of 11-40% and pellets have more than 90% solid content (Lu *et al.*, 2012).

Biosolids are rich in both organic matter (45-70%) and essential plant nutrients which can be utilized as a soil amendment or fertilizer. Soil amendment is a material that can improve soil physically or chemically, making it more suitable for plant growth. Biosolids will improve physical, chemical and biological properties of soil (Salazar *et al.*, 2012). The higher organic matter content of biosolids will help to sequestrate carbon in soil and mitigate greenhouse gas emission (Tian *et al.*, 2014). Nutrient value of biosolids varies with the source of wastewater and wastewater treatment process.

According to US Environmental Protection Agency (US EPA), land application of biosolids should meet the quality criteria like pathogen reduction, vector attraction reduction, nutrients and trace elements limits (US EPA, 1999). Odour is one of the main problems for lack of public acceptance for biosolids. Organic and inorganic forms of sulphur, ammonia, amines and organic fatty acids are identified as the most offensive odour causing compounds. Proper digestion process will reduce odour of biosolids.

Biosolids as soil amendment in agriculture will not only provide plant nutrients and humus but also results in hygienic disposal of sewage sludge which otherwise cause pollution. In future, long term experiments should be conducted to develop a protocol for economic utilization of biosolids.

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Soil processes in relation to climate change

By

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(2014-11-217)

MSc. Soil Science and Agricultural Chemistry

Seminar report submitted in partial fulfilment of requirement of the course

Soils. 591 Seminar (0+1)

DEPT. OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

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DECLARATION

I, Shridhar N. (2014-11-217), hereby declare that the seminar report entitled 'Soil processes in relation to climate change' has been completed by me independently after going through the reference cited herein and I have not copied from any of the fellow students or previous seminar reports.

Vellanikkara

Date:20/04/2016

Shridhar N

2014-11-217

CERTIFICATE

This is to certify that the seminar report entitled '**Soil processes in relation to climate change**' has been solely prepared by Shridhar N. (2014-11-217), under my guidance and has not been copied from seminar reports of seniors, juniors or fellow students.

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1. Introduction

The most recent report of the Intergovernmental Panel on Climate Change (IPCC) indicates that the average global temperature will probably rise between 1.1 and 6.4 °C by 2090–2099 as compared to 1980–1999 temperatures, with the most likely rise being between 1.8 and 4.0°C (Rounsvell *et al.*, 1994). Climate change will also influence global precipitation patterns, altering both the amount of precipitation received and the distribution of precipitation over the course of an average year in many locations. With this change in climate there will be effects on the environment, including the soil. Soils are also important to climate change and food security has the potential to threaten food security through its effects on soil properties and processes. Understanding these effects and what we may do to adapt to them, requires an understanding of how climate and soils interact and how changes in climate will lead to corresponding changes in soil. Therefore, here we focus on what we know about soil-climate interactions with a particular focus on the Carbon and Nitrogen cycles, how climate change may alter soil properties and processes, and what that might mean for soil erosion and food security in the future.

2. What are soil Processes?

Soil processes are the processes which occur in soil at two different stages which are before the soil development and after the well developed soil is formed. Before the soil development there are 11 processes are leads to the development of soil under the influence of five soil forming factors like climate, organisms, parent material, relief and time they are as follows.

2.1 Soil processes before the soil formation

2.1.1 Structure development : The arrangement of individual particles like silt, clay and sand with humus into aggregates.

2.1.2 Humification : The transformation of raw organic matter into humus by biochemical decomposition.

2.1.3 Leaching : The process of removal of soluble salts from the soil.

2.1.4 Salinization : The process of accumulation of salts in the soil.

2.1.4 Lessivage : The process of removal of clay from upper to lower part of soil.

2.1.5 Ferruginization : The release of iron from primary minerals which disperses as coatings on soil particles which impart red colour to the soil.

2.1.6 Laterization : Removal of silica soil and accumulation of sesquioxides.

2.1.7 Podzolization : Removal of iron and aluminium complexes with humus from upper part to lower part of the soil.

2.1.8 Calcification : Process of accumulation of calcium carbonate in lower part of the soil.

2.1.9 Gypsification : The process of accumulation of calcium sulphate in lower region of the soil.

2.1.10 Gleization : The reduction of iron under anaerobic conditions with production of bluish to greenish grey colour with or without mottles.

(Brady, 1984)

2.2 Soil processes after the soil formation

After the well developed soil different processes are taking place in soil which are categorized into physical, chemical and biological or biochemical processes.

3. Soil physical processes :

Under physical processes there is changes in physical composition of the compounds and its properties. There are many processes are taking place they are as follows.

3.1 Aggregate formation : Aggregate formation requires a cementation of flocculated particles and here organic matter is the major binding agent of different soil particles. In arid climate where precipitation is less and high temperature cause less accumulation of organic matter leads to less aggregate formation and vice versa in humid condition.

3.2 Soil erosion : The rate of soil erosion depends on combined effect of climate variables. At higher precipitation the rate of erosion will increase through surface runoff and at lower precipitation the erosion decreases due to less vegetation.

3.3 Soil acidification : The rainfall influences the leaching of bases from upper to lower part of soil due to increase in its intensity and distribution.

3.4 Infiltration : At lower rainfall areas the rate of infiltration decreases due to dry condition and high temperature but in humid condition it is increases through downward entry of water to lower profile.

3.5 Leaching : The downward movement of salts, soil particles into lower horizons high at high precipitation and in case of arid climate it is decreased.

4. Soil chemical processes

These are the processes where chemical composition of substances vary with the various climatic factors mainly rainfall, temperature and different organisms. Chemical processes are taking place at the surface with the alteration or disappearance of some compounds and formation of new compounds. The rate of chemical reaction increases with increase in the amount of dissolved CO_2 and other compounds in water and with temperature. It is minimal in desert areas due to scarcity of water and in cold regions due to low temperature and vice versa in humid tropical climate. The presence of organic and inorganic acids which are formed as a result of microbial breakdown of plant residues also accelerates chemical weathering and for clear understanding individual processes are described below they are as follows.

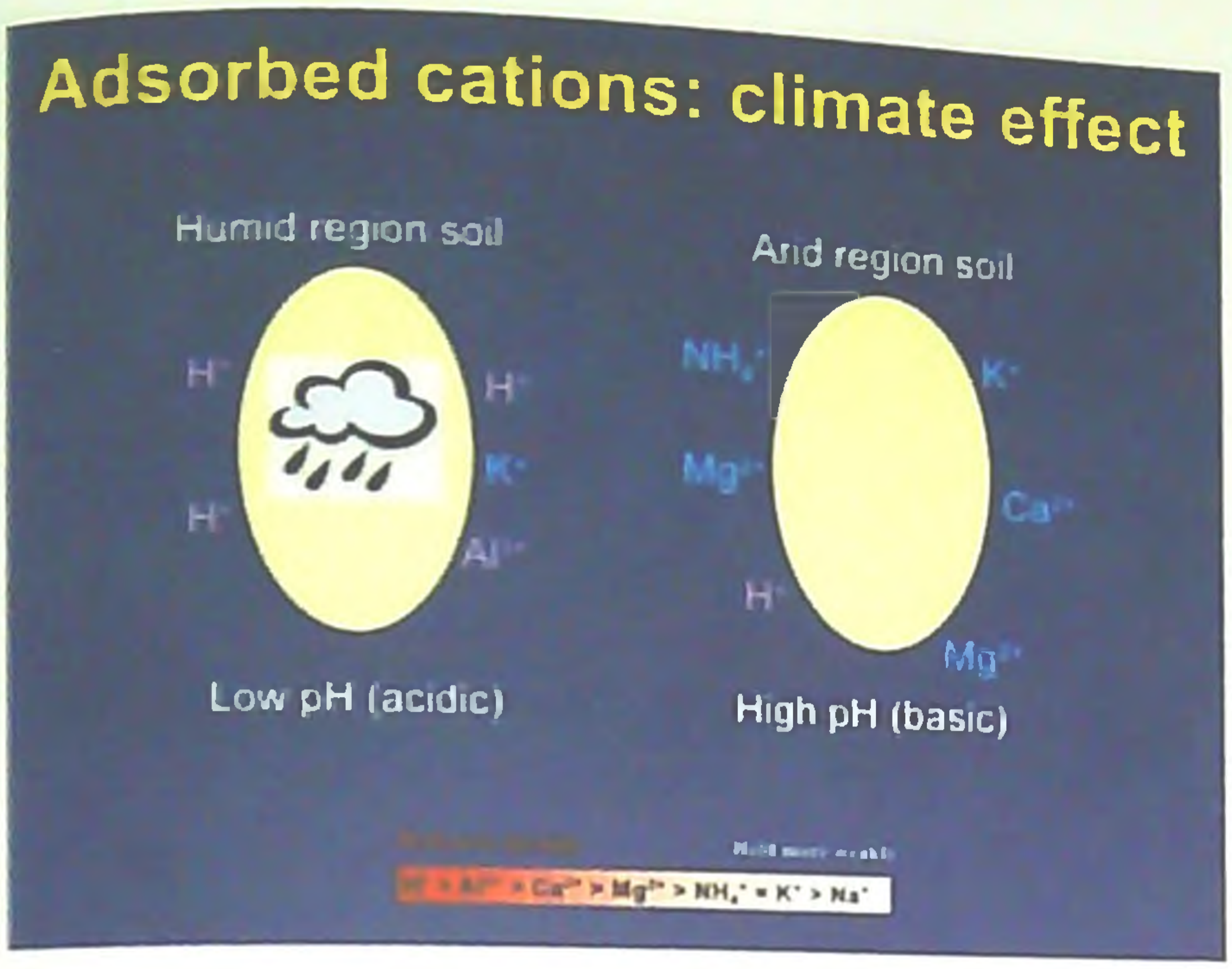
4.1 Ion exchange :

The exchange of equal amount of ions between solid and solution phase. In arid climate where precipitation is less the ion exchange will also less due to accumulation of organic matter is less because organic matter is the main source of different ions in soil. The Plate 1. shows that in humid region soil the exchange of hydrogen ions will more so the soil become acidic but in arid region exchange of ammonium ions will cause soil become alkaline.

4.2 Solution : The process of dissolving solid in liquid it separates solid into soluble ions.

$$NaCl + H_2O \Longrightarrow Na^+ + Cl^- + H_2O$$

(Halyte)



(Bear, 1964)

Plate.1 Ion exchange in different climatic region

4.3 Hydration : Chemical combination of water molecules with a compound to form new compound.

$CaSO_4 + 2H_2O \Longrightarrow CaSO_4 2H_2O$

(anhydrite) (gypsum)

4.4 Hydrolysis : The process of breakdown of water molecules into hydrogen and oxygen ions.

Feldspar + water $\Longrightarrow$ Silicate clays

4.5 Oxidation : Occurs well in well aerated soil i.e in arid region.

$2Fe + 3O_2 \Longrightarrow 2Fe3O_3$

(limonite)

4.6 Reduction : Occurs in water logged condition i.e humid condition.

$Al_2O_3 + 3H_2O \Longrightarrow Al_2O_3$

4.7 Carbonation : Process of combination of Carbon dioxide with any base which produces carbonates and bicarbonates.

$H_2O + CO_2 \Longrightarrow H_2CO_3$

(Carbonic acid)

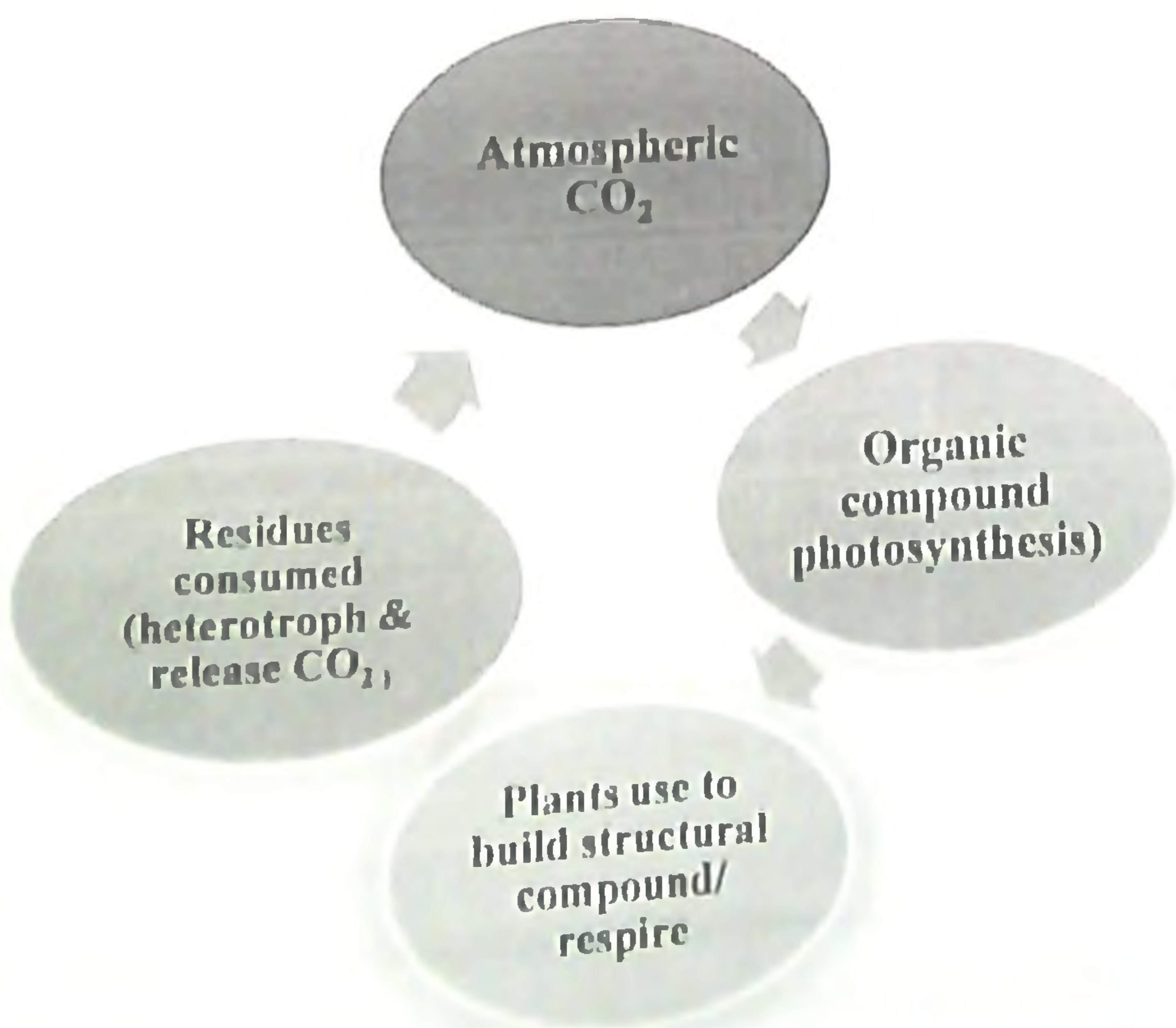
5. Biological/Biochemical processes

These are the processes where the involvement of both living organisms and chemical oxidation reduction reactions. Here the soil respiration is a major process which influence the Co_2 emission by breaking of organic compounds and it accounts 84% (Brevik, 2012) among all the green house gases and other processes are nutrient transformation and organic matter decomposition.

5.1 Soil respiration :

Soil respiration refers to the production of carbon dioxide when soil organisms respire. This includes respiration of plant roots, rhizosphere, microbes and soil fauna.

Figure 1 : Soil respiration process



(Atkin *et al.*,2000)

Soil respiration is a key ecosystem process that releases carbon dioxide from the soil in the form of CO_2. CO_2 is acquired from the atmosphere and converted into organic compounds in the process of photosynthesis. Plants use these organic compounds to build structural components or respire them to release energy. When plant respiration occurs below ground in the roots, it adds to soil respiration. Over time, plant structural components are consumed by heterotrophs. This heterotrophic consumption releases CO_2 and when this CO_2 is released by below ground organisms, it is considered soil respiration.

6. Types of soil respiration

6.1 Microbial respiration

Microbial respiration is another process in which cells gain energy from organic compounds. In this metabolic pathway energy is derived from the carbon compound without the use of oxygen. The products of this reaction are carbon dioxide and usually either ethyl alcohol or lactic acid. Due to the lack of oxygen, this pathway is described as anaerobic respiration. This is an important source of CO_2 in soil respiration in water logged ecosystems.

6.2 Root respiration

Plants respire some of the carbon compounds which were generated by photosynthesis. When this respiration occurs in roots, it adds to soil respiration. Root respiration usually accounts for approximately half of all soil respiration. Thus the amount of CO_2 produced through root respiration is determined by the root biomass and specific root respiration rates. Directly next to the root is the area known as rhizosphere which also plays an important role in soil respiration.

6.3 Rhizosphere respiration

The rhizosphere is a zone immediately next to the root surface with its neighbouring soil. In this zone there is a close interaction between the plant and microorganisms. Roots continuously release substances or exudates into the soil. These exudates include sugars, amino acids, vitamins, long chain carbohydrates, enzymes and lysates which are released when roots cells break. The amount of carbon lost as exudates varies considerably between plant species. It has been demonstrated that up to 20% (Atkin *et al.*,2000) of carbon acquired by photosynthesis is released into the soil as root exudates. These exudates are decomposed primarily by bacteria.

These bacteria will respire the carbon compounds through the TCA cycle; however, fermentation is also present. This is due to the lack of oxygen due to greater oxygen consumption by the root as compared to the bulk soil, when soil at a greater distance from the root.

Figure 2: Different types of soil respiration

6.4 Soil animals

Soil animals graze on populations of bacteria and fungi as well as ingest and break up litter to increase soil respiration. Micro fauna are made up of the smallest soil animals. These include nematodes and mites. This group specializes on soil bacteria and fungi and by ingesting these organisms, carbon dioxide that was initially in plant organic compounds and was incorporated into bacterial and fungal structures will now be respired by the soil animal. Meso fauna are soil animals from 0.1 to 2 millimeters (0.0039 to 0.0787 inch) (Atkin *et al.*,2000) in length and will ingest soil litter.

The faecal material will hold a greater amount of moisture and have a greater surface area. This will allow for new attack by microorganisms and a greater amount of soil respiration.

Macro fauna are organisms from 2 to 20 millimeters (0.079 to 0.787 inch) (Hutsch *et al.*,2002) such as earthworms and termites. Most macro fauna fragment litter, thereby exposing a greater amount of area to microbial attack. Other macro fauna burrow or ingest litter, reducing soil bulk density, breaking up soil aggregates and increasing soil aeration and the infiltration of water.

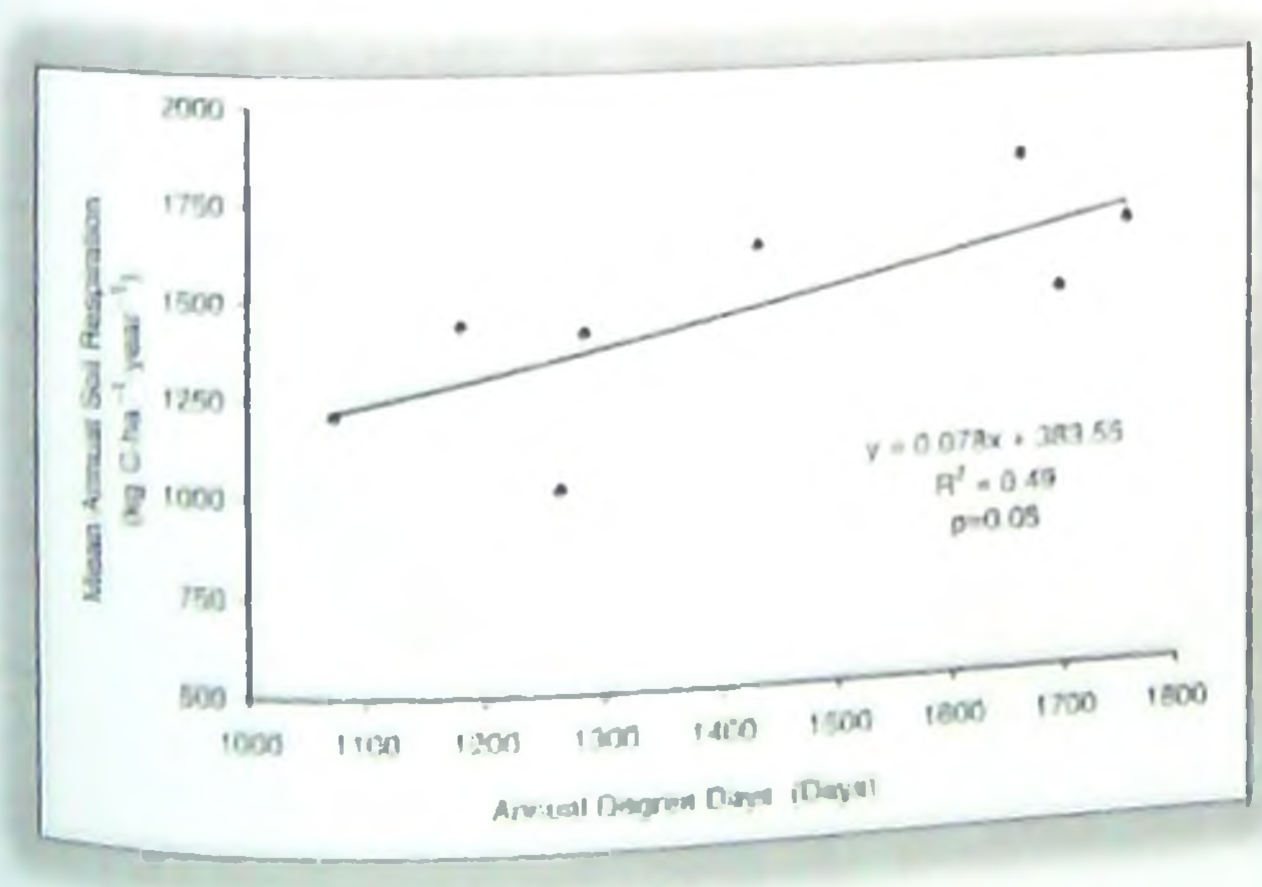
7. Soil factors regulating soil respiration

Regulation of CO_2 production in soil is due to various abiotic or non-living factors like Temperature, soil moisture and nitrogen all contribute to the rate of respiration in soil.

7.1 Temperature

Temperature affects almost all aspects of respiration processes. The Temperature will increase respiration exponentially to a maximum, at which point respiration will decrease to zero when enzymatic activity is interrupted. Root respiration increases exponentially with temperature in its low range when the respiration rate is limited mostly by the TCA cycle. At higher temperatures the transport of sugars and the products of metabolism become the limiting factor. At temperatures over 35°C root respiration begins to shut down completely. Microorganisms are divided into three temperature groups: cryophiles, mesophiles and thermophiles. Temperature increases lead to greater rates of soil respiration until high values retard microbial function, this is the same pattern that is seen with soil moisture levels.

Figure 3 :Relationship between mean annual respiration and soil heat index as expressed by annual degree days



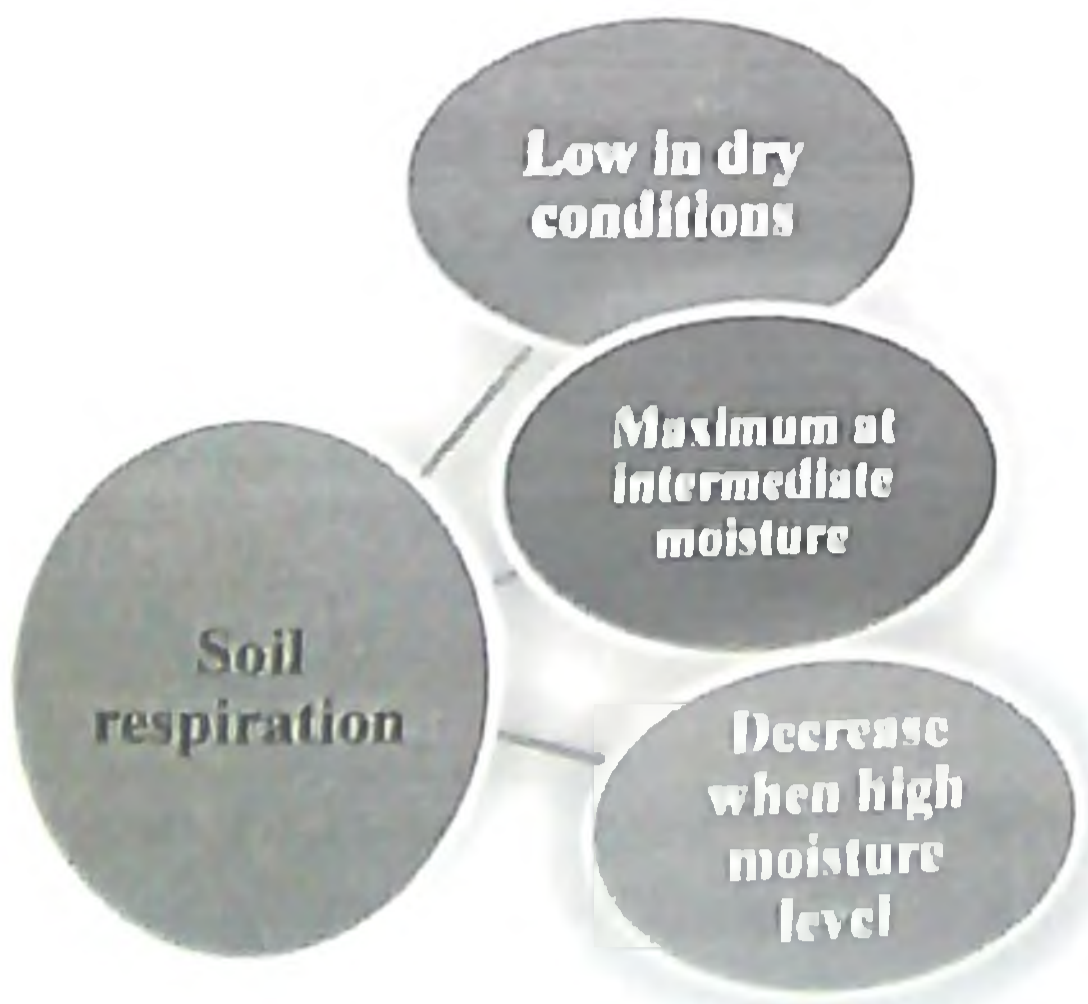
(Cheng *et al.*,2007)

Cheng *et al.*(2007) studied that relationship between mean annual respiration and annual degree days here the mean annual respiration increases with mean annual degree days exponentially to a maximum, at which point respiration will decrease to zero when enzymatic activity is interrupted and they are directly proportional to each other.

7.2 Soil moisture

Soil moisture is another important factor influencing soil respiration. Soil respiration is low in dry conditions and increases to a maximum at intermediate moisture levels until it begins to decrease when moisture content excludes oxygen. This allows anaerobic conditions to prevail and depress aerobic microbial activity. Studies have shown that soil moisture only limits respiration at the lowest and highest conditions with a large plateau existing at intermediate soil moisture levels for most ecosystems. This can decrease the rate of soil respiration temporarily, but the lysis of bacteria causes for a spike in resources for many other bacteria. Root respiration will increase with increasing soil moisture, especially in dry ecosystems. Upper levels of soil moisture will depress root respiration with the exception of wetland plants, which have developed specific mechanisms for root aeration.

Figure 4: Effect of soil respiration on different moisture level

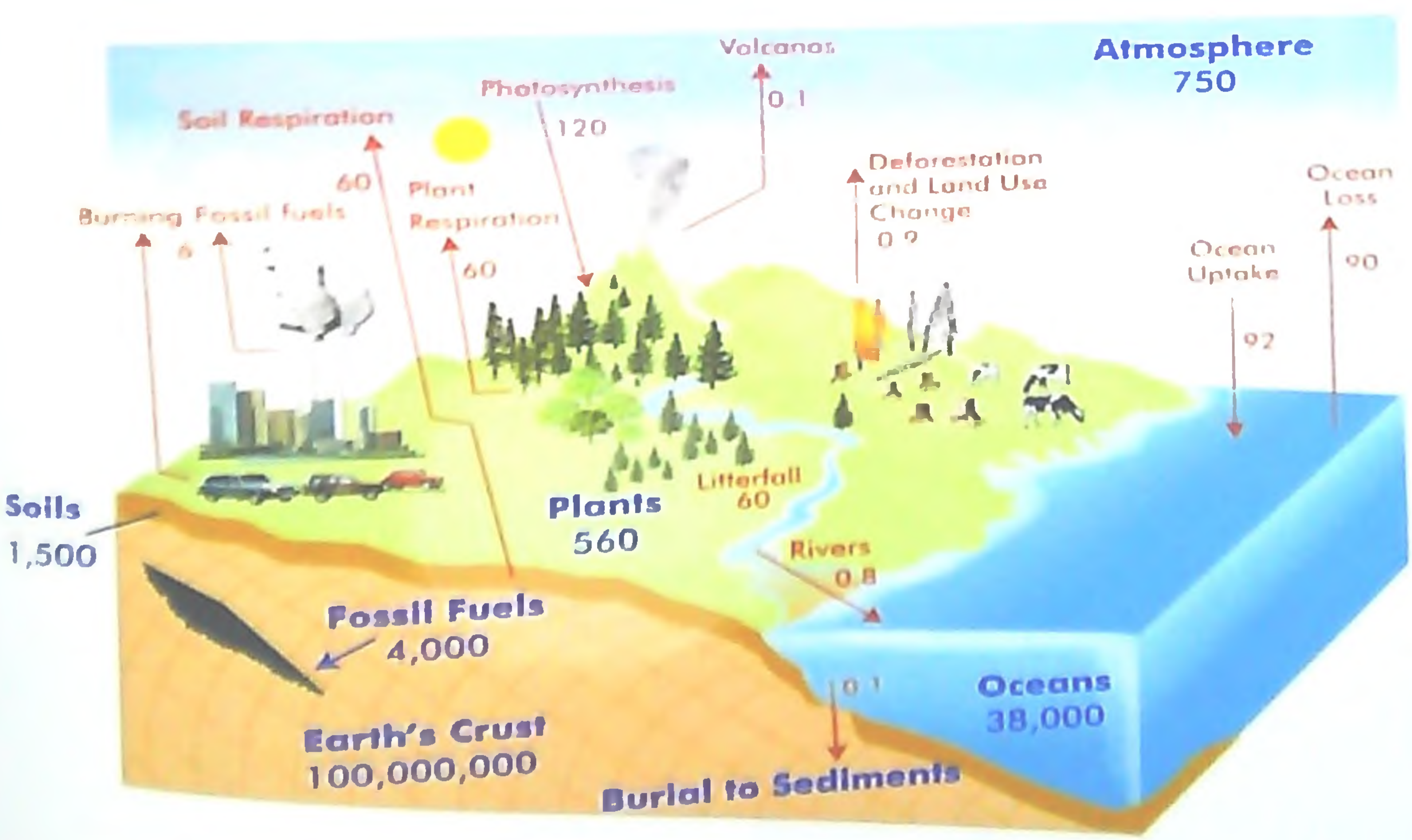


8. Nutrient transformation

Soils - part of global Carbon and Nitrogen cycles

Soils are integral parts of several global nutrient cycles. These are the most important from the perspective of soils and climate change interactions are the carbon and nitrogen cycles because C and N are important components of soil organic matter and because carbon dioxide (CO_2), methane(CH_4), and nitrous oxide(N_2O) are the most important of the long-lived greenhouse gases. The global C and N cycles were in balance with inputs approximately equalising outputs prior to the industrial revolution when low populations and levels of technology minimized the anthropogenic generation of greenhouse gases but the burning of fossil fuels, tilling of soil, and other human activities have altered the natural balance such that we are now releasing more C and N into the atmosphere each year than is taken up by global sinks. Human management of soils can have a profound impact on the balance of C and N gas emissions from those soils, and therefore influences global climate change.

Plate 2: Global carbon cycle (1 Pg = 10^{15} g)



(Brevik, 2012)

The largest active terrestrial C pool is in soil, which contains an estimated 2,500 Pg of C compared to 620 Pg of C in terrestrial biota and detritus and 780 Pg of C in the atmosphere. Carbon is readily exchanged between these pools therefore they are called active pools. In addition to the active pools, there are approximately 90,000,000 Pg of C in the geological formations of Earth's crust, 38,000 Pg of C in the ocean as dissolved carbonates, 10,000 Pg of C sequestered as gas hydrates, and 4,000 Pg of C in fossil fuels (Brevik, 2012) . However, most of the C in the pools is locked up over long periods of geologic time and not readily exchanged, leading to these pools being referred to as inactive pools.

When discussing agriculturally related aspects of climate change the active pools receive more attention due to the ability of C to move rapidly between them, but the release of C from the inactive pools, particularly though the combustion of fossil fuels is also an important anthropogenic source of greenhouse gases. Soils naturally sequester C through the soil-plant system as plants photosynthesize and then add dead tissues to the soil. Carbon is also naturally emitted from soils as CO_2 and CH_4 gases due to microbial respiration, with the form of the C gas depending on the oxygen status of the soil system. Well-aerated soils are dominated by CO_2 emissions, while anaerobic conditions are associated with CH_4 generation. The balance between C added to the soil and C emitted from the soil determines whether the overall C levels in a given soil increase or decrease. When C levels in a soil increase that C is taken from the atmosphere, decreasing atmospheric levels, and when C levels in a soil decrease that C is added to the atmosphere, increasing atmospheric levels.

Human actions strongly influence the C balance in managed soils. Soil management techniques such as no-till systems may result in lower CO_2 emissions from and greater C sequestration in the soil as compared to management systems based on intensive tillage although some recent studies have indicated that no-till systems may simply result in higher C accumulations in the upper 15–20 cm of the soil with no increase in C when the entire soil profile is considered. Other management changes such as using cover crops, crop rotations instead of monocropping and reducing or eliminating fallow periods can lead to C sequestration in soil as can returning land from agricultural use to native forest or grassland. Sequestration of C tends to be rapid initially with declining rates over time. Most agricultural soils will only sequester C for about 50–150 years following management changes before they reach C saturation.

Table1 :1 Soil organic carbon stocks in different soil orders in India

Soil order	SOC pool (Pg)	
	0 – 30 cm	0 – 150 cm
Entisols	1.36	4.17
Inceptisols	4.67	15.07
Vertisols	2.62	8.78
Aridisols	7.67	20.30
Mollisols	0.12	0.50
Alfisols	4.22	13.54
Ultisols	0.14	0.34
Oxisols	0.19	0.49

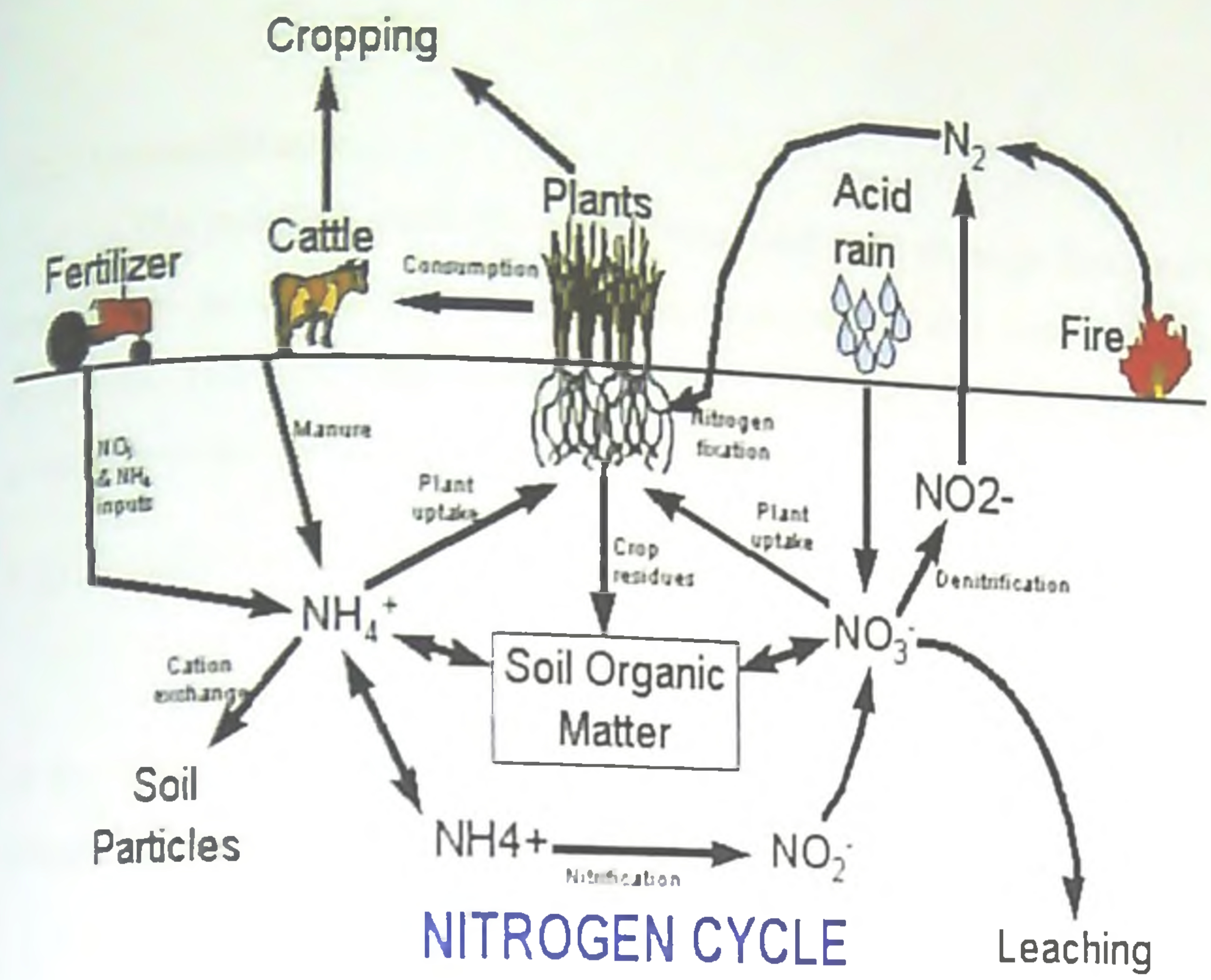
(Velayutham *et al.*, 2000)

Velayutham *et al.*(2000) observed that soil organic carbon stocks in different soil orders like entisol, inceptisol, vertisol, aridisol, mollisol, alfisol,ultisol and oxisol and he found highest organic carbon in aridisol i.e 7.67 and 20.30Pg at 30 &150cm respectively.

8.2 Global Nitrogen Cycle

Nitrogen is one of the primary nutrient component of many biomolecules including proteins, DNA, and chlorophyll and critical for the survival of all living organisms. Although nitrogen is very abundant in the atmosphere and it is largely inaccessible in this form to most organisms. Only when nitrogen is converted from dinitrogen gas into ammonia (NH_3) does it become available to primary producers such as plants.

In addition to N_2 and NH_3, nitrogen exists in many different forms, including both inorganic (ammonia, nitrate) and organic (amino and nucleic acids) forms. Thus nitrogen undergoes many different transformations of applied nitrogen through external inputs like fertilizer, manure, plant dead tissues and acid rain in the ecosystem, changing from one form to another as organisms use it for growth and in some cases energy. The major transformations of



(Morford *et al.*,2011)

nitrogen are nitrogen fixation, nitrification, denitrification, and ammonification. The transformation of nitrogen into its many oxidation states by the activities different microorganisms such as bacteria and fungi. There are Four processes are involved in the nitrogen cycle through the biosphere like nitrogen fixation, ammonification, nitrification and denitrification.

8.2.1 Nitrogen Fixation :

The nitrogen molecule (N_2) is quite inert to break it apart so that its atoms can combine with other atoms requires the input of substantial amounts of energy. There are three processes are responsible for most of the nitrogen fixation in the biosphere are as follows.

- atmospheric fixation by lightning.
- biological fixation by certain microbes alone or in a symbiotic relationship with some plants and animals.
- industrial fixation by fertilizer manufacturing.

8.2.2 Ammonification :

The proteins made by plants enter and pass through food webs at each tropic level their metabolism produces organic nitrogen compounds that return to the environment, chiefly in excretions. The final beneficiaries of these materials are microbial decomposition of molecules in excretions and dead organisms into ammonia.

8.2.3 Nitrification :

Ammonia can be taken up directly by plants usually through their roots. However, most of the ammonia produced by decay is converted into nitrates. Until recently this was thought always to be accomplished in two steps :

- Bacteria of the Nitrosomonas oxidize NH_3 to nitrites(NO_2^-).
- Bacteria of the Nitrobacter oxidize the nitrites to nitrates(NO_3^-).

8.2.4 Denitrification :

Denitrification reduces nitrates and nitrites to nitrogen gas, thus replenishing the atmosphere. In the process several intermediates are formed like nitric oxide (NO), nitrous oxide (N_2O)(a greenhouse gas 300 times as potent as CO_2), nitrous acid (HNO_2) and some fire hazards also cause to emission of nitrous oxides.

9. Influence of Soil processes on climate change

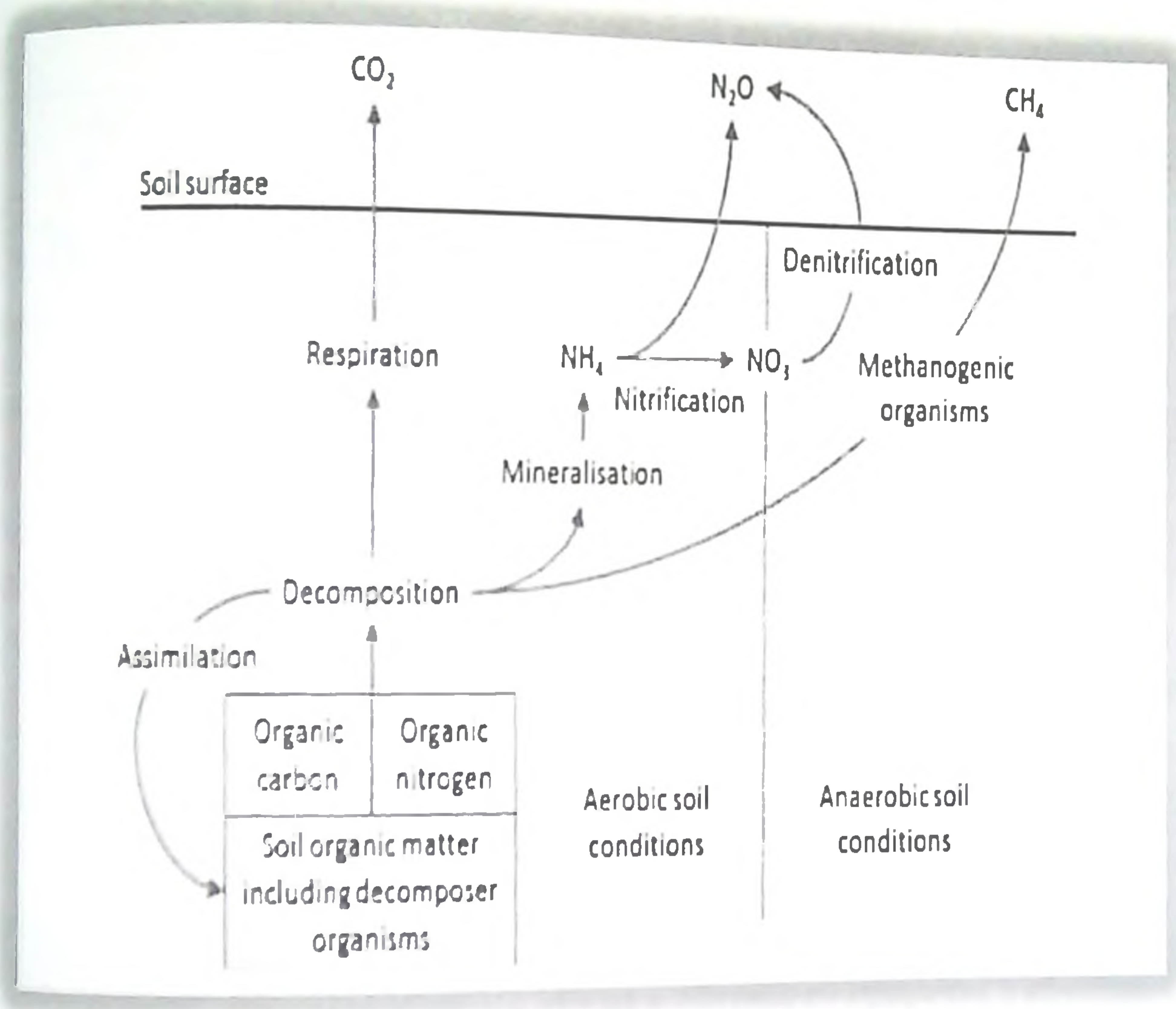
Soils contain large stores of organic carbon and nitrogen i.e 1500–2400 Pg C (Houghton ,2005) and 190 Pg N (Mackenzie *et al.*,1998) depending on the soil depth. These stores are continuously exposed to decomposition and a range of additional biologically mediated transformations that generate or consume all three major greenhouse gases (CO_2, N_2O, and CH_4). Globally, soils and their management therefore have the potential to either enhance or reduce atmospheric concentrations of greenhouse gases and the magnitude of any associated climate change. Using respective estimates of 1500 and 720 Pg for carbon contained in soil and the atmosphere and an atmospheric concentration of 390ppm for CO_2 (Mauna and Ryan,2010) a 1% change in the amount of carbon stored in soils would equate approximately to an 8ppm change in atmospheric CO_2 concentration, provided all other components of the carbon cycle remained constant.

However, given the potential mediating responses provided by photosynthesis and oceanic exchange, when this calculation is coupled with the observation that initiating agricultural production results in a 20–70% reduction in the amount of carbon stored in soils (Luo *et al.*, 2010) the way in which agricultural soils are managed has the potential to either enhance or reduce atmospheric concentrations of CO_2. Additionally, the impact of agricultural management practices on emissions of N_2O and CH_4 must be considered, given their high levels of radiative forcing relative to CO_2 (310 and 21 times that of CO_2 over a 100 year time frame, respectively) (Luo *et al.*,2010). Concern also exists over the potential positive feedbacks that a changing climate may have on rates of greenhouse gas emission from soil in view of the strong impact that climate can have on the biological processes leading to production and consumption or storage of CO_2, N_2O and CH_4.

9.1 Soil processes that influence emission of green house gases(GHG) to atmosphere from soil

Emission of greenhouse gases from soil fluctuate both temporally and spatially due to variations in environmental factors and soil properties and quantification of multiple processes is often required to define net fluxes. For example, net CO_2 emissions result from the balance between CO_2 uptake through photosynthesis and CO_2 release from respiration by plants, animals, and microbes. The soil organic matter is the main source of soil organic carbon and organic nitrogen which undergoes microbial decomposition in well aerobic soil through mineralization process the protein is converted into ammonia and this ammonia undergoes nitrification will converted into nitrate through nitrite in the presence of heterotrophic bacteria and this nitrate under anaerobic conditions converted into nitrous oxide through denitrification and by the action of methanogenic bacteria this ammonia is converted to methane and emitted to atmosphere and the organic compound used in microbial respiration leads to emission of carbon dioxide to the atmosphere and the plant roots and tissues get decomposed again transformed into dead organic matter in the soil.

Plate :4 Soil processes that influence emission of green house gases(GHG) to atmosphere from soil



(Baldock *et al.*,2012)

Pathak *et al.*,2010 studied that green house gas emission from different agriculture systems in that rice cultivation contributes highest methane production i.e 3.33Mt and agriculture soil have highest nitrous oxide production i.e 0.14Mt respectively due to different environmental conditions in agriculture.

Table 2: Green house gas emission from Indian agriculture

Source	CH_4 (Mt)	N_2O (Mt)
Rice cultivation	3.33	-
Agricultural soil	-	0.14
Crop residue burning	0.23	0.06
Total	3.56	0.14

(Pathak *et al.*, 2010)

10. Influence of climate change on soil processes

Changes in atmosphere CO_2 concentration, temperature & precipitation modify soil plant system like soil organic matter decomposition and increase or decrease in soil fertility and biological activity.

(Cheng *et al.*, 2007)

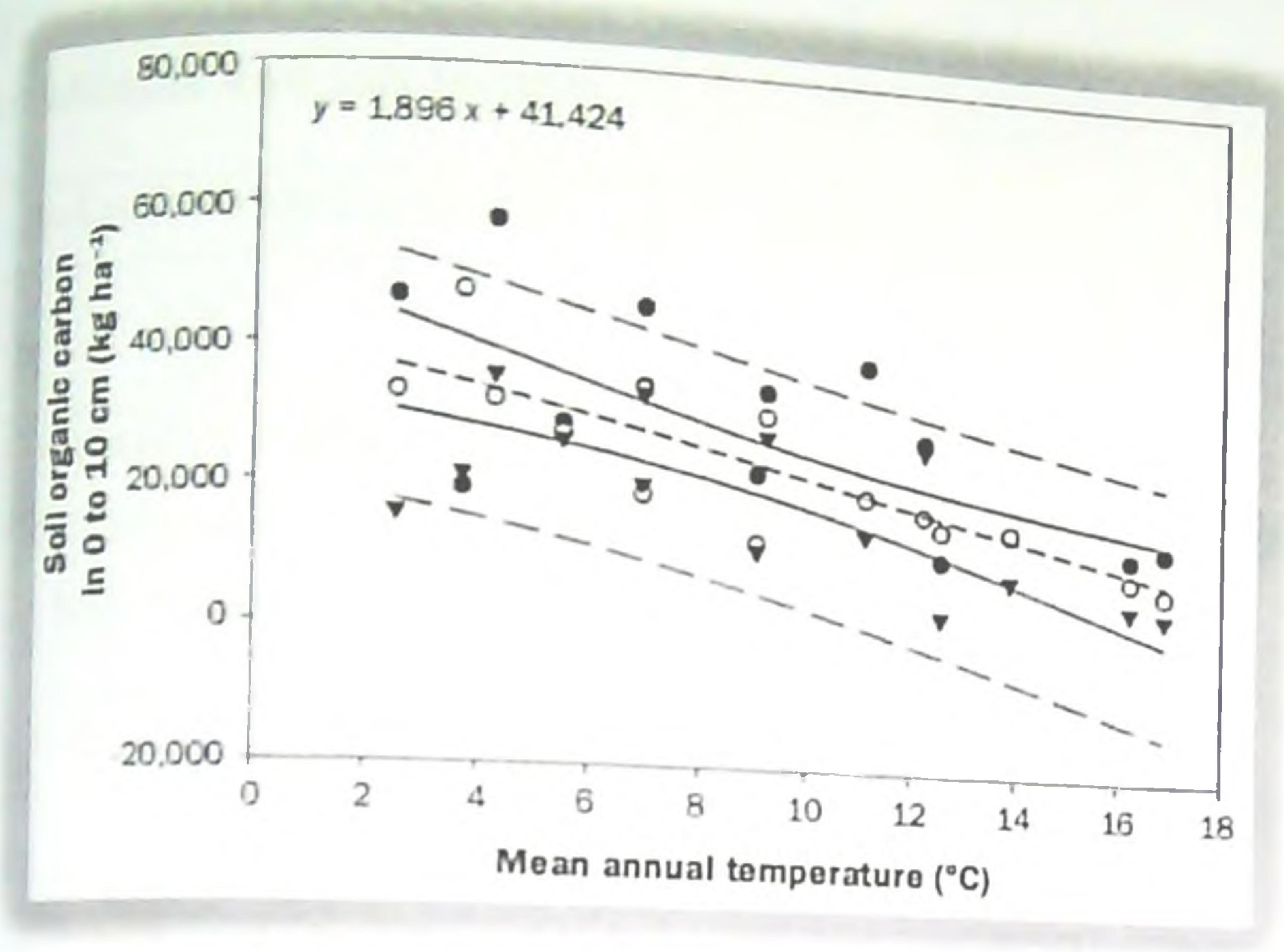
10.1 Organic matter dynamics

Soils act as both sink and source of carbon affects carbon storage, because of temperature, moisture and radiation. Soil warming and drying leads to 32% reduction in soil carbon (IPCC, 2007) predicts global average temperature to increase by 1.1–6.4 C during current century. Global warming is expected to profoundly impact ecosystem processes such as soil organic matter (SOM) dynamics. Carbon (C) in SOM accounts for 80% of terrestrial C pool and is regarded as an important potential C sink that may help off set the greenhouse effect (Maia *et al.*,2010). Small changes in SOM stock under global change can potentially effect atmospheric CO_2 concentrations. In addition, warming induced changes in SOM regulate the availability of nitrogen (N) for plant growth and ultimately influence the net primary productivity of terrestrial ecosystems. Hence, it is imperative to understand how global warming will effect SOM dynamics.

For example, climatic warming increases soil temperature and hence accelerates organic matter decomposition rates, leading to loss of soil C and N. Conversely, some studies have reported that warming leads to increases in soil C and N because of great increases in biomass and litter inputs in tundra ecosystems (Day *et al.*, 2008). These differences are not surprising given response of soils to warming depends on many factors, such as soil moisture and temperature and in particular on plant species that provide carbon inputs to soils.

Figure2: Soil organic carbon (SOC) as a function of mean annual temperature(MAT)

Follet *et al.*(2012) studied that a negative relationship between MAT and SOC stocks. Based upon geographic location and dominant vegetation, Homann *et al.*(2007) observed that SOC in the 20cm (7.9inch) depth was negatively correlated to MAT for all seven ecological regions. Temperature and SOC stocks were strongly negatively related in a database analysis including about 300 pedons representing cultivated soils and 500 pedons representing range land soils. Decreases in SOC stocks with increasing temperature can be linked to increasing soil respiration and SOM decomposition.



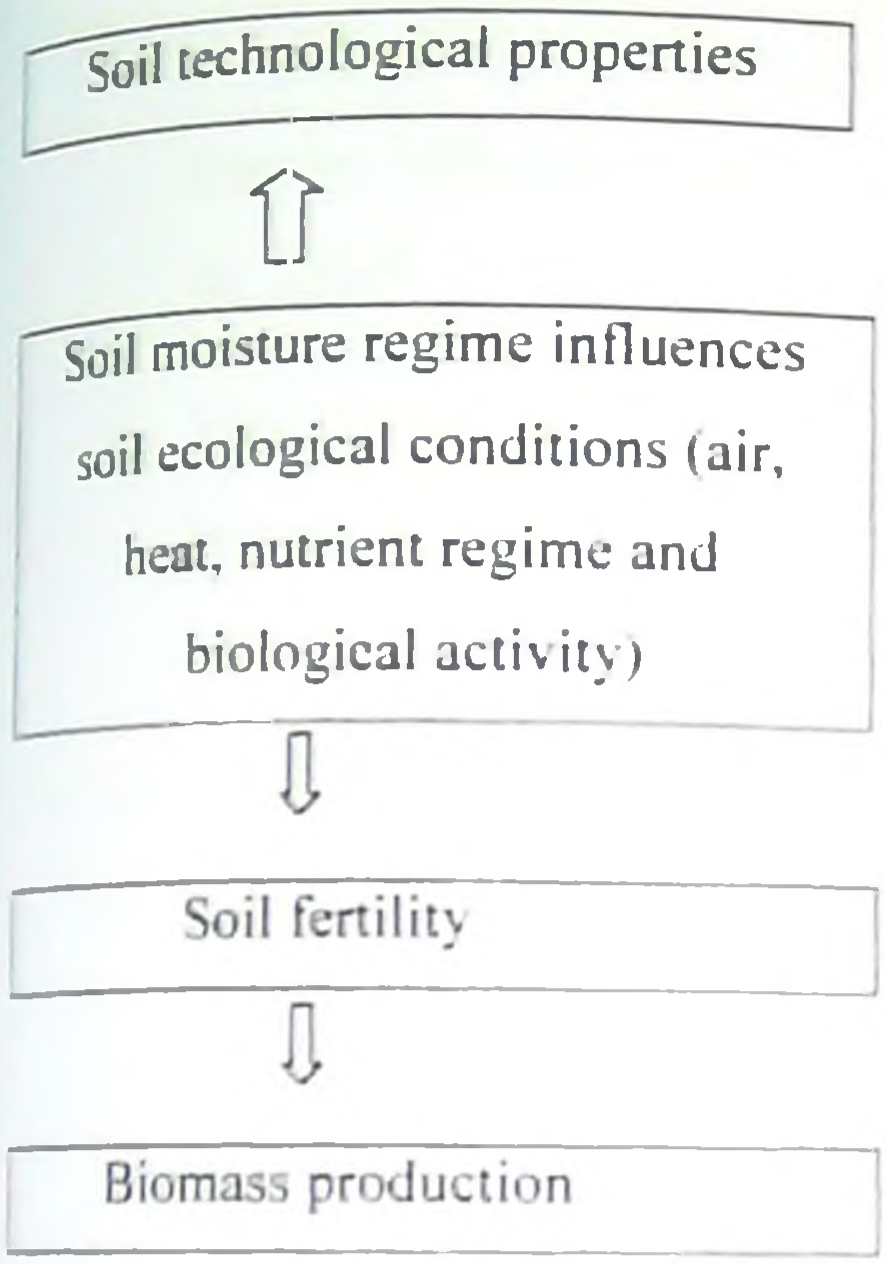
(Follet *et al.*,2012)

Figure5 : Soil organic carbon (SOC) as a function of mean annual temperature(MAT)

10.2 Impact of climate change on soil fertility and soil biological activity

Climate change may have stronger or weaker, permanent or periodical, favourable or unfavourable, harmful (sometimes catastrophic), primary (direct) or secondary (indirect) impact on soil processes. Among these processes soil moisture regime plays a distinguished role. It determines the water supply of plants, influences the air and heat regimes, biological activity and plant nutrient status of soil. In most cases it determines the agro-ecological potential, the biomass production of various natural and agro-ecosystems and the hazard of soil and or water pollution.

Figure 6. The relationships between soil moisture regime, other soil ecological conditions and soil fertility



MANAGEMENT ASPECTS

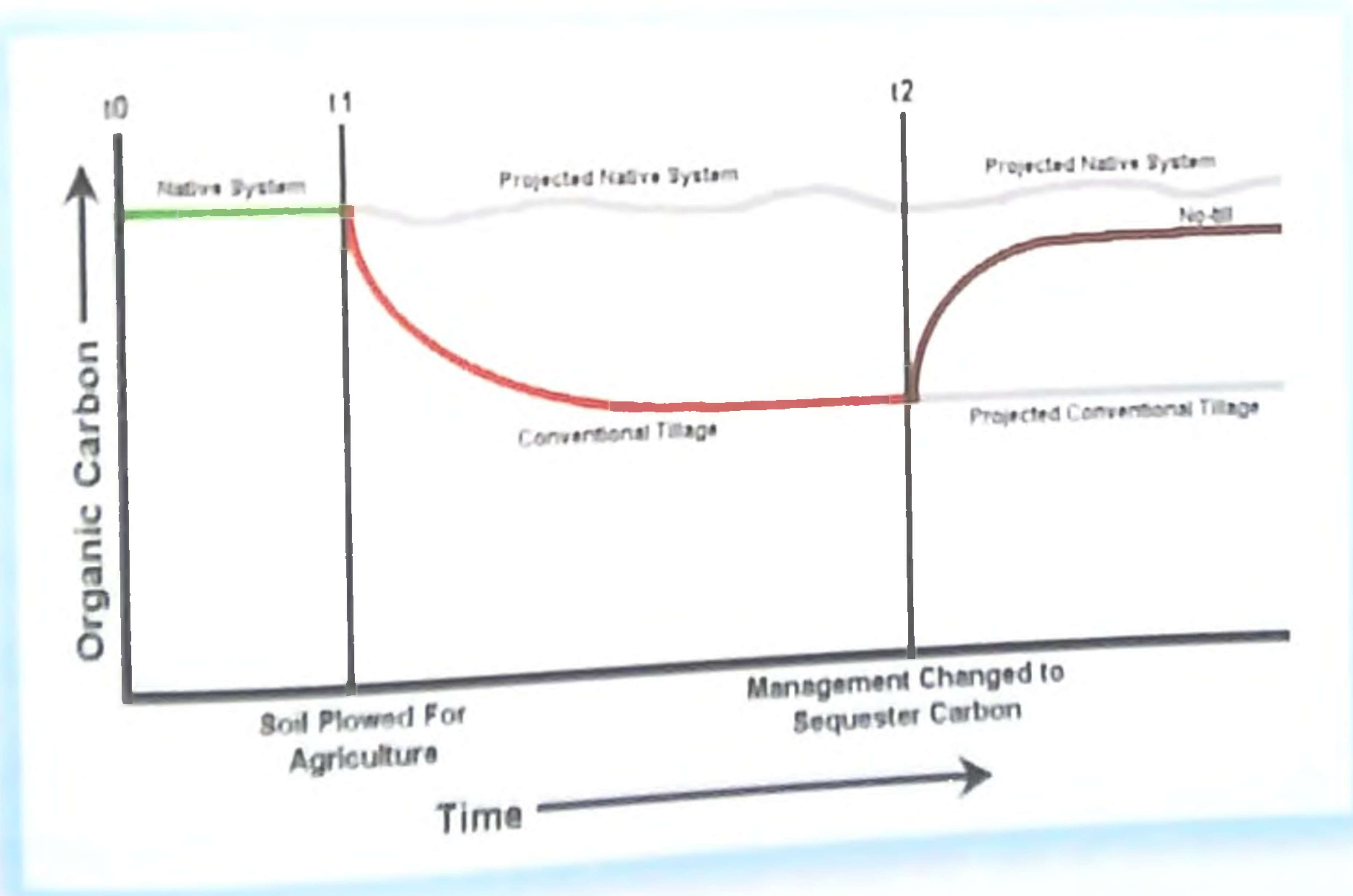
Greenhouse gas (GHG) management help to reduce harmful effects on soil processes and assess, monitor and manage their GHG emissions associated with their activities, products to help mitigate GHG emissions.

11.1 Mitigating CO_2 emissions

- Site energy audits and implementation of energy management technologies have reduced refinery emissions by 5% through careful attention to energy consumption and measurement.
- One business unit saved $265,000 per year and reduced emissions by 8,000(Allen *et al* .,2003) tonnes a year by challenging the practice of maintaining spare capacity in on-site electricity generators.
- Fired heater tubes can be fouled with certain crude oil components, thus reducing heat transfer efficiency increasing pressure drop, shortening run times, and increasing

operating and maintenance costs.

- Boiler and fired heater tubes develop scale on the fired side of the tube and Past procedures required furnace shutdown for cleaning on a regular basis.
- A petrochemical complex implemented improved divided wall column technology. Energy efficiency increased by 30%,CO_2 emissions were reduced by 30%(Cheng *et al.,2006)*
- New turbine technology that allows us to take advantage of the pressure drop as fluid is brought into a terminal is generating 3MW(e) (megawatts of electrical power) of extra electricity from previously wasted energy.
- Flaring (burning) of waste hydrocarbon streams has been routine practice from the earliest days of the oil and chemical industry because it is the safest disposal method.
- Replacement of conventional gas actuated valves to control flow from gas wells with no loss systems eliminated cold venting of methane from a large production operation.



(Brevik, 2012)

Figure 7. Effect of tillage on C sequestration

Brevik,(2012) showed that Tilling a native soil leads to reduced soil organic C levels, while management changes such as a conversion to no-till techniques may lead to increased soil organic C as compared to conventional tillage techniques.

Typical changes in soil organic carbon with time under different soil management. Time t0 to t1 represents the soils under a native ecosystem. At t1, the soil was broken for agricultural production using conventional tillage, leading to a decline in soil organic matter. The "Projected native system" is the expected soil organic matter content if the native ecosystem had not been disturbed. At t2, management was changed to sequester carbon in the soil. The "Projected conventional tillage" is the expected soil organic matter content if conventional tillage had been maintained. Note that changes in organic carbon content are rapid immediately following management changes but rates of change decrease and then stop as the soil reaches carbon equilibrium.

11.2 Mitigating methane emissions

- Alternate wetting & drying reduces 60-90% (Peer *et al.*, 1995) in paddy fields.

Appropriate water & nutrient management

- Incorporating ducks into rice systems.
- Reducing the water saturation in rice fields.
- Avoid application of organic matter to the rice fields.
- Excess phosphorous application leads to decrease in methane production.
- Reduce the coal extraction, refining and transportation

Mitigating N emissions

- The application of N fertilizers based on recommendation at proper time of the crop growing period.
- Use of nitrification inhibitors like N-serve reduce the rate of decomposition by the reducing activity of nitrifying bacteria.
- Avoid the use of ammonical based fertilizers due to heavy loss through voltalization and denitrification.

Figure 8: 11.3 Mitigating N emissions

(Campbell , 1990)

- Application of fertilizers at surface layer easily absorbed by the plants and deep placement cause leaching and wastage of nutrients takes place.
  - Practice of growing high nutrient use efficiency crops in the field will reduces the emission of nitrous oxide from the soil to atmosphere.

12. Conclusion :

The Earth climate system is changing due to changing levels of greenhouse gases in the atmosphere; the most important of these gases are C and N based. Because soils are part of the C and N cycles and C and N are both important components of soil organic matter, the organic matter content of soils will be influenced by climate change. Changes in average temperatures and in precipitation patterns will also influence soil organic matter. This in turn will affect important soil properties such as aggregate formation and stability, water holding capacity, cation exchange capacity and soil nutrient content. Exactly how soil organic matter will be influenced by climate change involves highly complex and interconnected systems that make it difficult to isolate a single variable, such as temperature or precipitation patterns.

and reach meaningful conclusions about how a change in that single variable affects the system being studied. However, we do know that there is the possibility that soils could contribute increasing amounts of greenhouse gases to the atmosphere and lose their ability to act as a sink for C as global temperatures increase. There is the chance we will see negative impacts on physical and chemical properties of our soils that are essential for the production of food and fibre products. However, we do know that there is the possibility that soils could contribute increasing amounts of greenhouse gases to the atmosphere and lose their ability to act as a sink for C as global temperatures increase.

However, the research done on soils and climate change to date has generated many questions with few firm answers. It is critical that we better understand how C sequestration in soil is influenced by limitations in nutrients like N and P. We also need to know more about the effects of climate change on the N cycle, an area of research that has received far less attention than the C cycle. At present, little is known about how climate change will impact soil organisms and those organisms are very important in driving the portions of the C and N cycles that take place in the soil. Changes in atmospheric CO_2 levels might alter metal uptake by plants, which could lead to food products with unsafe levels of those metals in their tissues, but research in this area has not provided consistent results. A better understanding of these areas is crucial to provide us with insight on how changes in soil processes and properties might influence soil erosion and food security.

"Think globally and act locally"

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KERALA AGRICULTURE UNIVERSITY

COLLEGE OF HORTICULTURE, VELLANIKKARA

Department of Soil Science & Agricultural Chemistry

SOILS 591: Master's seminar

Name: Shridhar N.

Admission no: 2014-11-217

Major advisor: Dr. Durga Devi K.M.

Venue: Library hall

Date: 05- 02-2016

Time: 11: 30 a.m.

Soil processes in relation to climate change

Abstract

According to the fourth assessment report of Intergovernmental Panel on Climate Change (IPCC), global temperature is expected to increase between 1.1 and 6.4 °C during the 21st century which will influence precipitation patterns, altering both the amount of precipitation and its distribution. With this change in climate there will be effects on soil environment which has potential to threaten food security through its effects on soil properties and processes. In order to make solutions to the problems of predicted global environmental changes, it is necessary to understand the interactive physical, chemical, and biological processes in soil that regulate the total earth system (Rounsevell and Loveland, 1994).

Soil processes can be categorized into two (i) soil formation processes and (ii) processes taking place in well developed soil system. The major soil formation processes (pedogenic processes) are structure development, humification, translocation of lime, leaching, salinization, clay migration or lessivage, ferruginisation, laterization, podsolization, regur formation, gleization. These processes are influenced by five different factors like climate, organisms, relief, parent material and time.

Climate change has different types of effects on soil processes. Among these, soil moisture regime plays very important role it determines the water supply of plants, influences the air and heat regimes, biological activity and plant nutrient status of soil. The influence of climate change on soil structure (type, spatial arrangement and stability of soil aggregate (Varallyay,

2010) is a complex process. The integral influence of climate - hydrology -vegetation - land use changes are reflected by the field water balance and soil moisture regime (Varallyay and Farkas, 2008).

Soils contain large stores of organic carbon and nitrogen. These stores are continuously exposed to decomposition and a range of additional biologically mediated transformations that generate or consume all three major green house gases (CO_2, N_2O, and CH_4). High precipitation increases leaching, filtration losses and reductive processes. Low precipitation may reduce the solubility, mobility and availability of available elements and compounds.

Methane and nitrous oxide emissions from Indian agricultural soils are responsible for only about 0.23 and 0.1% respectively of the global warming caused by the world's CO_2 emissions. Thus over all green house gas emission from Indian agriculture, especially from the soil is a small fraction of the total world green house gas emission (Bhatia *et al*, 2004).

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