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Alternatives To Improve Major Properties Of The Irrigated Soils In The Melkassa Agricultural Research Centre (MARC), Ethiopia, With Special Emphasis On Organic Matter And Water Holding Capacity

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Abstract: Poor soil physical conditions were identified to be the main cause for crop failures in the irrigated soils of Melkassa Agricultural Research Centre (MARC). From the major soil physical properties, low water holding capacity as a result of poor soil management practices has proven to be the key reason of lower agricultural production. As a consequence, lack of sufficient soil moisture is found to be the main cause of crop failures in MARC, the later occurred, in due course of insufficient precipitation and non-uniform distribution of rainfall. As organic matter plays a significant role in soil physical properties the low organic matter content of MARC soils is found to be the major cause of poor physical soil conditions. In a response to this problem the feasibility of organic matter application as an alternative solution for the problem of irrigated soils of Melkassa Agricultural Research Centre (MARC) was assessed. By improving the aggregate stability of the soil, organic matter application is found to improve this problem The possibility of having sustainable solution for the existing problem, the presence of sufficient amount of organic resources and suitable climate for the decomposition are some of the potentials observed to consider this option.

Key words: Irrigated soils, Organic matter, water holding capacity

1. Introduction

In irrigated agriculture soil degradation due to loss of the major soil properties as a result of improper management is one of the foremost problems. Although, irrigated agriculture provides some benefits such as yield increase and maximum utilization of the land and soil resource, its mismanagement ends with problems. The most central of the problems are variations in the infiltration and drainage rates, and degradation of soil structure (Çullu, M. A., et al. 1999). According to the survey made recently agricultural production in the irrigated soils of Melkassa Agricultural Research Centre (MARC) is experiencing unsustainable outcomes. Even though chemical fertilizers are used, lower productivity and crop failure continues to be problems in the research process. There are clearly observed signs of soil degradation characterized by surface crusting hard pan formation, low organic mater content and deficient in both essential and trace elements across the farm lands. Most of the research activities and seed multiplications both during the rainy season and off season are conducted using irrigation for the past three decades, with furrow and basin as the dominant irrigation types. However according to sources from the Farm Management section of MARC (the one responsible in managing the irrigation practice in the centre) there is no well developed irrigation scheduling for most of the crops grown. The amount of Irrigation water applied is determined from an experience and some crop physical indicators. Experience has shown that when ever there is no well planned irrigation schedule, irrigators are forced to apply excess or minimum amount of water depending on water availability, which both have a negative impact on the soil and crops grown. In addition in the irrigation system of MARC there is no well developed drainage system and measure as well to cope up the adverse effects of irrigation agriculture. Several soil fertility researches have been conducted in the centre to fix the rate of fertilizer for optimum production of major crops. Yet there is no any documented work done which indicates the extent of degradation and the possible strategies for the soil problems pointed out in the centre. The soils of MARC are from volcanic origin in situ or deposits of transported ranging from neutral to very alkaline with a general characteristics of low organic mater, deficient in both essential and trace elements adverse physico-chemical properties such as surface crusting and hard pan formation and is the most drought prone, with chronic and frequent crop failures resulting from the combined effect of poor soil and the erratic and inadequate rainfall (Melkassa annual report 2004). Improving this situation to have a sustainable utilization of the limited resource so as to have a successful research and seed multiplication practice is therefore a demanding action. And hence Alternative methods of improving the major soil properties of the irrigated soils of MARC are assessed with a special emphasis on organic matter and water holding capacity.

2. Back ground, justification and objectives

The soils of MARC are now experiencing a clear sign of inability to support sustainable agricultural production even with the help of chemical fertilizer. According to field observations and an interview made with the farm management section, soil degradation is evident in the centre with a characteristic sign of adverse physico-chemical properties such as surface crust formation, lower water holding capacity and hard pan formation. According to documents in the centre even though there are signs of observed soil degradation little has been done so far to know the extent of degradation so as to improve the situation. And it has already been seen that no solution was yet proposed to avert the observed problems. However in

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order to utilize the existing resource without causing a permanent harm to the natural process and have a sustainable agricultural production the existing soil condition of MARC soil has to be improved. An option of using a low cost and environmental friendly alternative is considered in this study. The use of organic matter as an alternative to improve the major soil properties in this area could be taken as an option, taking in to consideration the positive influence of organic matter in major soil properties, the availability of substantial organic resources in the centre and the presence of ideal tropical environment for the decomposition of organic materials to provide a sustainable solution for the problem. Many soil properties impact soil quality, but organic matter deserves special attention. It affects several critical soil functions, can be manipulated by land management practices, and is important in most agricultural settings (USDA technical notes). Insofar as organic matter contributes to improved soil physical properties (e.g., tilth, aggregation, moisture holding capacity and resistance to erosion) increasing soil organic matter will generally result in increased soil productivity. It is now widely recognized that soil organic carbon (SOC) plays an important role in soil biological (provision of substrate and nutrients for microbes), chemical (buffering and pH changes) and physical (stabilisation of soil structure) properties. In fact, these properties, along with SOC, N and P, are considered critical indicators for the health and quality of the soil. Hillel (1998, pg. 156) noted that it is obvious that the shape and range of the soil-moisture characteristic curve depends strongly on soil texture. He further noted that the low, wet range (< 100 kpa) of the matric suction curve depends mainly on the capillary effect and the pore-size distribution, hence is strongly affected by soil structure. At the higher and drier suctions, water retention is increasingly influenced less by structure and more by texture. This suggests that the increase of soil aggregation resulting from increased organic matter would change the field capacity more than the wilting point. Chemical properties are other components which are influenced by soil organic matter. SOM generally accounts for 50-90% of the cation adsorbing power of mineral surface soils. Like clay, humus colloids hold nutrient cations (P, CA, Mg; etc.) in easily exchangeable form wherein they can be used by plants but not too readily leached out of the profile by percolating water. Through its cation exchange capacity and acid and base functional groups, organic matter also provides much of the pH buffering capacity in soils. In addition N, P, S and micronutrients are stored as constituents of soil organic matter, from which they are released by mineralization (Brady 2002). Soil organic matter greatly influences the biology of the soil, because it provides most of the food for the community of heterotrophic soil organisms. Organic matter serves as a source of energy for both macro- and micro-faunal organisms (Brady 2002). Numbers of bacteria, actinomycetes and fungi in the soil are related in a general way to humus content. Earthworms and other faunal organisms are strongly affected by the quantity of plant residue material returned to the soil (Brady 2002). Organic substances in soil can have a direct physiological effect on plant growth. Some compounds, such as certain phenolic acids, have phytotoxic properties; others, such as the auxins, enhance plant growth. It is widely known that many of the factors influencing the incidence of pathogenic organisms in soil are directly or indirectly influenced by organic matter. For example, a plentiful supply of organic matter may favour the growth of saprophytic organisms relative to parasitic ones and thereby reduce populations of the latter. Biologically active compounds in soil, such as antibiotics and certain phenolic acids, may enhance the ability of certain plants to resist attack by pathogens. Having these all scientific background this alternative is selected with the following objectives.

- To asses sustainable and low cost alternatives for improving the soil problems of irrigated soils of Melkassa Agricultural Research Centre (MARC) soils, with special emphasis on water holding capacity.
- To show how organic matter improves poor quality soils especially water holding capacity.
- And to propose some possible organic matter improvement options for soil fertility enhancement for the study area.
- To have an in depth look at the major causes of low productivity in the irrigated soils of MARC.

3. Materials and methods

In order to investigate the feasibility of organic matter application as an alternative for the problems of irrigated soils of MARC the following materials and methods were employed.

3.1 Materials

Materials used during the study were: Topographic Map of the area, GPS, Digital camera, socio-economic data annual report and unpublished technical reports of the centre were referred, Metrological data and Field equipments like shovel, pickaxe, augurs, plastic bags soil sampling cans

3.2 Methods

Different methodologies were employed to explain how organic matter can be taken as an alternative to improve major problems of irrigated soil of the area. To mention them

- Literature review
- Primary and secondary data collection
- Computer soft-wares

4. Results and discussion

4.1 Major prolems of Agricultural production

According to the information collected during the study the following are the major problems blamed to hamper the progress of agricultural production in the centre in the order of magnitude

4.1.1 Lack of sufficient soil moisture

Observations reveal that because of limited water reserve store potential of the soils, uneven distribution of rainfall in the area and the occurrence of surface crust most of the water is lost to agricultural use.

4.1.1.1 Low water holding capacity

According to the laboratory analysis results of the surface soil samples taken from all the farm lands the range of the two water available extremes indicate the presence of low

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water holding capacity for optimum crop production. The highest value of field capacity observed in the rain fed loamy soil is 31.2 % and the minimum value is 27.4 % with an average of 28.1% and the highest permanent wilting point value is observed in the clayey soil of the newly cultivated soil and is 22.5% and the minimum value is observed in the loamy soil of the rain fed field of the centre and is 14.3% with an average value of 17.9%. And hence the total available water (TAW) is 10.2% which according to FAO standards is considered as minimum for optimum crop production in irrigation agriculture. Study results in this area indicated that one of the reasons for lower water holding capacity is the presence of poor soil physical condition characterized by poor soil aggregation, poor structural make up and the formation of surface crusts. One of the major causes of poor soil physical condition according to Koopmans, Chris and Walter Goldstein 2001 is Lower organic matter content. The surface soils of MARC have an organic matter content ranging from 0.84 % in a newly cultivated land and rain cultivated land to 0.44 % in an area where there is an intensive irrigation practices with an average soil organic matter content of about 0.65% as indicated in the following table.

Table 1 Average values of some of the major soil properties of MARC (Survey data)

Parameter	Unit	Value
OM	(%)	**0.65**
CEC	(%)	**29,5**
FC	(%)	**28,1**
PWP	(%)	**17,9**
Bulk density	**g/cc**	**1,2**

4.1.1.2 Insufficient and erratic rainfall

Poor distribution and amount of rainfall is the other major causes of crop failure in the study area. The rainfall pattern of the area is abnormal for the production of crops suitable in the agro-ecologies (MARC annual report). The rainfall records taken from the meterological station in the centre indicates the presence of unsuitable rainfall pattern for crops suitable for the agro-ecology. According to recent reports from Ministry of Agriculture (MoA) the frequency of drought occurrence in the country is reduced to every two years in comparison to every 10 years before 1984. According to a report in the centre in recent time, especially 2002 cropping season, there was a complete crop failure because of drought. Even if there is sufficient rainfall the distribution is also not uniform to suit the crop water demand for optimum crop production. The distribution is such that there is always moisture deficit towards the end of each cropping season. Especially during the critical stages of grain filling and maturing there is no or minimum rainfall (see graph below). Occurrence of surface crust is also another reason of moisture loss observed in the study. In the soil of MARC formation of surface seal is a common phenomenon. Surface seal results in the decline of the infiltration of water in to soil with a final consequence of water and soil loss due to runoff (Brady 2002). In addition to these all because of the high temperature in the area through out the year there is high evaporation, which is also another challenge for the availability of the limited moisture in the area.

4.1.2 Soil degradation

Soil degradation is one of the major sources of crop failure in this area. Improvement of soil resources thus in many cases represents an important avenue for improving the research outcomes of the centre. According to the survey conducted in the area the causes of soil degradation (the main cause of physical, chemical and biological degradation of cultivated land) is poor and inappropriate soil management practices. The centre runs research activities for the past three decades with out having a well developed irrigation scheduling for all of the crops grown. The amount of Irrigation water applied is determined from an experience and some crop physical indicators. From literatures although, irrigated agriculture provides some benefits such as yield increase and maximum utilization of the land and soil resource, its mismanagement ends with problems. Soil degradation is expressed in this area in different forms. According to the survey conducted the major signs of soil degradation responsible to hamper crop production in MARC are explained below:

4.1.2.1 Decline of soil fertility

Continuous cultivation is one of the causes of soil fertility decline observed in the study area. Before this area is taken by the present organization, it was one of the big privately owned farms in the area. Even if it was difficult to find information on the soil management practices during those days, for the past three decades since the farm is in the hand of MARC no effort has been made to maintain a proper nutrient recycling to maintain the fertility of the soil resources. The study area is found in one of the most agriculturally exploited part of the country. In this area lower performance and complete failure of crops is common even if inputs like chemical fertilizers are used. Absence of efficient nutrient recycling is one of the reasons for such crop failure as clearly observed from the production record and soil survey laboratory results. There is a common fertilizer application rate of 100kg/ha DAP and 50kg/ha Urea for all crops except leguminous crops where there is no Urea application. According to the results from the laboratory analysis of the surface soil samples, the soil is deficient in both macro and micro nutrients (table below)

Table 2 Macro and micro nutrients (survey result)

	T.N(%)	**K^+**	**Ca^{++}**	**Mg^{++}**	**Na^+**	**P**	**CEC**	**pH**
	%	**Meq/**	**Meq/100g**	**Meq/100g**	**Meq/100g**	**ppm**	**Meq/100g**	
MARC soil	**0,11**	**3,08**	**15,65**	**2,94**	**0,33**	**11,23**	**29,29**	**7,44**
description	**Minimum**	**Minimum**	**Sufficient**	**Sufficient**	**Ok**	**V. minimum**	**Sufficient**	**Not suitable**

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In spit of the fact that there is an application of fertilizer, low productivity and failure of crops continues to be events in the agricultural production process of MARC. According to sources from the farm management section the productivity of crops in the centre is fluctuating year after year. As it is indicated in the following tables and subsequent graphs in addition to the complete failure of crops in the year 2002, the productivity of major crops in the study area is not sustainably constant even in relatively good rainy seasons.

4.1.2.2 Decline in soil organic matter content

Continuous cultivation is one of the causes of soil fertility decline observed in the study area. As experience indicates continuous cultivation exposes the inside of a soil for a varied temperature. This situation accelerates the decomposition and subsequent loss of soil organic matter. In addition to the absence of efficient nutrient recycling in the area the organic matter content of the soil is becoming very low according to the standards set for similar soils in the tropics. The soil organic matter content is below the optimum value in comparison to similar soils in the tropics that is on average 0.65%.

4.1.2.3 Accelerated erosion

According to field observation and laboratory analysis, the soil aggregates of the study area are weakly developed and unstable. The loss of pore continuity at the soil surface by sealing and crusting or at the adjacent soil layers by eluviation of fine topsoil particles causes the reduction of water infiltration. As a result, runoff and soil loss can significantly increase with a final consequence of erosion of the surface soil. According to the observation made in the study area water and wind are the main sources of accelerated soil erosion. Absence of forest cover and the presence of heavy rains are also the other reasons which cause soil erosion in the study area.

4.1.3 Others

4.1.3.1 Backward cultivation practices

Agricultural activities in MARC are mechanized. Tractors are used to till the farm lands and chemical fertilizers are also used. However the ways these implements are used are not well designed and coordinated. As a result of this situation a hard pan formation is observed in the soil survey which is situated at a depth of 27cm to a max depth of 48 cm. Therefore the method of cultivation is still another drawback for the performance of agricultural activities in the area.

4.2 Organic matter application as an alternative

4.2.1 Availability of organic material in MARC and its suitability for soil improvement

According to the survey done in the centre there is sufficient amount of organic matter source and potential. This can be classified in to two different categories the one available in the centre presently and the potential to produce further. As a centre of improved seed multiplication there is ample source of crop residue which is not actually utilized in the centre. According to the yield records and FAO conversion factor on average 481.4 tons of crop residue is produced annually in the research centre (table below). Out of this 73.6 ton is from leguminous source, and the rest from maize and sorghum. Presently this crop residue is actually not utilized. After harvest it is piled in some part of the centre and finally removed. This can be a valuable source of organic matter as a soil improvement. According to Canada Department of Agriculture, Fisheries and Aquaculture recommendation for an effective nutrient recycling and erosion protection a mulching rate of plant products 6 ton/ha is found to be effective. Therefore the present resource if used as a mulch material can mulch 81 ha farm. This coverage can be increased by producing mulch material in the free area and by using this product as a composting component. There is also a potential to produce organic resources suitable for the preparation of soil improving materials. In between each farm fields there is a space which is provided for vehicle and free movement. This free space is estimated to be 4.86 ha. Only 40% is used as road for the transportation of agricultural products for access of vehicles. Therefore there will be 3 ha net area for the production of organic substances. The dry matter yield of trees which can be used for such purposes ranged from 4 to 12 t dry matter/ha/year depending upon location (ARNAB 1989). For tropical environment an average of 8 ton/ha is usually taken. Thus it is possible to produce 18.4 ton of green organic matter. This is the minimum that can be achieved there is a potential to increase this output. The other potential source of organic matter in MARC is from the cattle production in the center. There are 15 dairy cows and 15 fattening oxen and 8 calves. In an observation made during the survey the manure produced by these livestock is piled near the barn without any purpose and is becoming a source of pollution. Utilizing this resource will have a double impact, one it can be a valuable source of soil improving material and two can reduce the danger of environmental pollution According to the manure production rate of cattle recommended by Pennsylvania University Agronomy guide of 2005 – 2006 these animals can produce 555 tons of solid and 577 m^3 of liquid manure per year. If this quantity is directly spread as a soil improving material according to the recommended rate by Cooperband, Leslie 2005 it can serve an organic matter source for more than 30 ha area. This coverage can be improved to suite the demand by using manure as a composting component

4.2.2 Major characteristics and suitability of available materials as organic mater source

4.2.2.1 C: N ratio

Organic matter is broken down by microbes which use carbon for energy. They also have a high requirement for nitrogen. Microbes have a requirement of about one nitrogen atom for each 25 carbon atoms. This is a carbon-to-nitrogen ratio (C:N) of 25:1 or 25. If the organic matter has a higher C:N, microbes will need more nitrogen than is in the organic matter and will take it from the soil. Microbes are more efficient than crops in obtaining nitrogen from the soil. If there is no enough nitrogen for both the microbes and the crop, the crop will not obtain what it needs. Eventually there will be a net gain in nitrogen, but crops can suffer in the short term. If organic matter with a high C:N is applied to soil shortly before planting a crop, additional nitrogen may be needed to assure that the needs of both the microbe and the crop are met. Organic matter with a

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C:N of less than 25:1 (25) should not be a problem and in some cases can contribute nitrogen for crop use (Foley, BJ and LR Cooperband. 2002).

Table 7 Organic amendment C:N (Adapted from various sources, including Rynk, 1992,to illustrate representative values.)

High in carbon	C:N ratio
Corn stalks	60-70
Straw	40-150
Corn silage	40
Fall leaves	30-80
High in Nitrogen	
Hay	15-30
Dairy manure	5-25
Hog manure	10-20
Vegetable wastes	10-20

Green materials usually have lower C:N ratios than woody materials or dead leaves. Animal wastes are more N rich than plant wastes (Cooperband, Leslie.2002). Therefore the presence of much materials with high C:N ratio can be counteracted by the presence of green materials (10 -15) (http://www.attra.org/attra-pub/covercrop.html), legume hays (15 -19)(http://www.umass.edu/fruitadvisor/nesfpmg/008.pdf) and farmyard manure (table above) in the study area.

4.2.2.2 Nutrient makeup of the available OM resources

The estimated contribution of the existing resource is summarized in the following table. These values are estimated by considering a direct application method of organic matter, mulching. Mulching is considered for estimation because the other feasible methods like composting requires a closer and onsite verification as its product depends on many factors as climate and the type of ingredients used.

Table 8 Estimated nutrient contribution of the available organic resources (NRCS and Ohio online web sites)

Type of Organic matter		Unit	Quantity	Available nutrients			Remarks (C/N)
				N (ton)	P_2O_5(ton)	K_2O(ton)	
Straw (hay)		ton	481.4	2	0.4	5	24 - 41
Farmyard manure	dry	ton	555	2.52	1.03	2	5 - 15
	liquid	m^3	577	10.7	4.3	8.3	5 - 15
Green manure (Lucenea and sesbanea)		ton	18.4	0.8	0.1	0.6	10 - 15
Total		ton	531.8	16.02	5.83	15.9	

According to the estimated values given in the table above, these organic resources will provide an estimated amount equal to 34.8 ton of urea fertilizer, 12.7 ton of DAP and 29.7 ton of KCl according to http://www.hort.cornell.edu/department/faculty/good/growon/macronut.html

4.2.3 Type and method of organic matter application suitable for the area

As an alternative to amend the observed problems of soil physical properties in the study area increasing the present status of soil organic matter is observed to be feasible. Improving the soil organic matter status of the soil can be achieved in different ways. Several organic matter application methods can be considered. For this study application methods are selected considering the following criteria:

- According to the existing condition of land utilization,
- ease of operation and
- the availability of organic materials observed in the study area

According to these criteria the following methods are selected

- Cover crops
- Manure application
  - Farm yard manure
  - .Green manuring
- Agro-forestry practices
  - Alley Cropping
- Composting

5. Conclusion and recommendation

According to the situations observed in MARC agricultural production, a decline in production and performance of crops below their actual potential is becoming a common phenomenon which calls for an immediate action. It is also surprising that this situation is happening in all the farms where the centre uses chemical fertilizers. As it was observed application of fertilizer has not changed the results of crop production that further solutions must be considered. The use of organic matter to improve the poor physical soil properties has proven to be feasible according to this study. Poor soil physical conditions such as low water holding capacity, surface crusting and hardpan formation are found to be the major causes of crop failure in MARC soils according o the survey made and the soil laboratory results. By improving the aggregate stability of the soil, organic matter application is found to improve this

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problem. Organic matter behaves somewhat like a sponge, with the ability to absorb and hold water up to 90 percent of its weight. A great advantage of the water-holding capacity of organic matter is that the matter will release most of the water that it absorbs to plants. In contrast, clay holds great quantities of water, but much of it is unavailable to plants. The low range of water available extremes (the difference between FC and PWP) that is identified in the study can be improved by organic matter application. Because humus has a Cation Exchange Capacity (CEC) of 2 to 30 times as great (per kg) as that of the various types of clay minerals, it generally accounts for 50 to 90 % of the cation-adsorbing power of mineral surface soils. Like clays, humus colloids hold nutrient cations (potassium, calcium, magnesium, etc) in easily exchangeable form, wherein they can be used by plants but are not too readily leached out of the profile by percolating waters. Soil laboratory results indicate that MARC soil is also characterised by its low content in the major and trace nutrients. Application of organic matter is found to contribute nutrients essential for plants performance. According o the available data and recommended conversion factors, the available and potentially estimated organic matter resource is found to contribute major and trace plant nutrients equal to 34.8 ton of urea fertilizer, 12.7 ton of DAP and 29.7 ton of KCl. Therefore as an alternative to improve the existing problems of irrigated soils of MARC, organic matter application can be can be considered. In this study application of organic matter as an alternative to improve the irrigated soil problems of MARC is proved to be feasible. In addition to having a sustainable solution for the existing problem, the presence of sufficient amount of organic resource and suitable climate for the decomposition are some of the potentials observed to consider this option. Several methods of organic matter application can be considered to improve the soil organic matter level of a soil. According to this study, Cover crop, Manuring (Green manuring and Farmyard manuring), Mulching, Alley cropping and composting are the alternative application methods found to be feasible, in consideration to the climate, availability of resources and culture of cultivation. However specific recommendations of the most successful organic matter application methods were not dealt in this study as it requires site specific study. Therefore In order to make this alternative more concrete, further study on the identification of the efficient organic application methods and specific rate of application is required. In order to make a specific recommendation of successful organic matter application methods a site specific research on the farms of MARC must be conducted by considering the most important parameters influencing the success of organic matter application methods.These parameters include,

- Appropriate method of OM application in terms of the time required to give the desired result,
- Method of decomposition employed,
- Appropriate time of application,
- Rate of application

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