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Biological carbon sequestration, 'C' footprints and CO_2 offsets *via* organically *vs* inorganically grown fennel (*Foeniculum vulgare*)

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ABSTRACT

A field experiment carried out with organic manures and mineral fertilizers along with absolute control. There were 12 treatments comprising 10t ha^{-1} sheep manure, 4t ha^{-1} vermi-compost, recommended doses of fertilizers (90:40:30 kg ha^{-1} of N:P:K) alone or in combination with *Azotobacter* and PSB inoculants. Results revealed that biological sequestration of carbon (C) of fennel was higher with 10 t ha^{-1} sheep manure and seeds inoculated with PSB over the other treatments and was least in control. However, C accumulation in various parts of crop was more in stover (990.7 kg ha^{-1}) followed by seed (699.6 kg ha^{-1}) and roots (507.1 kg ha^{-1}). Similarly, highest CO_2 offset can be achieved by using 10 t ha^{-1} sheep manure along with PSB in a season (10.03 t ha^{-1}) or per day (62.7 kg ha^{-1} day^{-1}) basis. Among the manures, C foot print was also higher with 10 t sheep manure along with PSB inoculants thereby net balance of CO_2 offsets was higher with vermi-compost (4t ha^{-1}) than sheep manure. The net balance of CO_2 offset was second highest with PSB and least with control. The pool of soil organic carbon in rhizospheric soil was higher with vermi-compost followed by recommended doses of fertilizers and sheep manure. Therefore, it can be assumed that highest CO_2 offset can be credited by fennel with vermi-compost. However, highest growth, yield and 'C' sequestration can be achieved by sheep manure along with bio-fertilizers.

Keywords: Biological carbon sequestration, C Footprints, CO_2 offsets, *Foeniculum vulgare,* Inorganics, Organics.

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INTRODUCTION

Global warming is a worldwide problem and a challenge of 21st century for the human to sustain on earth planet. Our progress in all sphere of life with over exploitation of natural resources leads to loss of resilience power of the nature. Non judicious use of energy and resources emitted huge amount of green house gasses and raised the temperature of troposphere. This has led to reduced rainfall in parts of the world, melting icecaps, receding glaciers, advancing deserts, a change in weather patterns and associated phenomena. Global warming is a natural phenomenon that has been ongoing since the last ice age but has accelerated in recent years. A significant part of the greenhouse gases (carbon dioxide, methane,

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nitrous oxide and other gases) have been generated in recent times and as a result several organizations have started to call for the control, restriction and measurement of the carbon emissions by various industries and sectors, and subsequent labeling of their respective carbon footprints. The Kyoto Protocol that has been ratified by most nations requires a mandatory reduction in greenhouse gas emissions worldwide. Therefore, we have to reduce the carbon foot print in all the sectors to stabilize the global warming for mitigate this effect by limiting emissions and sequestering carbon through precision agriculture, cropping system, minimal use of agrochemicals, N inputs (75%) afforestation/reforestation etc. The agriculture sector contributes significantly to global carbon emissions from diverse sources such as product and machinery manufacture, transport of materials and direct and indirect soil greenhouse gas emissions (Hillier *et al.*,10). The latest UK Greenhouse Gas Inventory estimates the proportion of the nation's overall carbon footprint due to agriculture to be around 8% to 75% of which is directly related to fertilizer use (Choudrie *et al.*, 4). However, detailed studies into the contribution of specific farming activities during crop production to the overall footprint are only recently being conducted by Adler *et al.* (2) and St Clair *et al.* (23). It is also possible that, to some extent, reduction in the carbon footprint is correlated with other environmental benefits. For example, reduced agrochemical inputs [a goal of organic and integrated farm management (IFM) systems] is likely to decrease the carbon footprint and may also have a beneficial effect on the biodiversity within and around arable fields (Squire *et al.*, 22, Robinson and Sutherland, 20, Marshall *et al.*, 16). It is therefore important to be able to identify the environmental impact of different management approaches. Although there is an implicit association between organic and environment friendly in the context of farming, this assumption does not necessarily hold true for all measures of environmental impact. Keeping in view, CO_2 offset credit and carbon foot print of fennel crop was worked out with its production by organic and inorgan means.

MATERAIL AND METHODS

Location and climate:

The present investigation was carried out at National Research Centre on Seed Spices, Tabiji-farm, Ajmer, Rajasthan located between 74° 35'39" to 74° 36' 01"E longitude and 26° 22'12" to 26° 22' 31" N latitude during 2007-08 and 2008-09. Climate of the Ajmer area characterized as semi-arid. The average annual rainfall of the area is 536 mm and most of it (85-90%) received between June to September. July and August are most rainy months contributing 60.0% of the average rainfall. The moisture control section remains dry for more than 90 cumulative days and hence moisture regime classified as Ustic. The mean annual temperature is 24.5 to 25.0°C. January is the coolest month of the season and temperature remain around 7.0°C. Currently frost is also occurring in this month with changing climatic pattern. The potential evapotranspiration, which is measure of evaporative demand of the climate, it always shows higher than the moisture received resultant annual loss though PET is 1566 mm. However, July and august are the months when rainfall exceeds more than the potential evapotranspiration (Singh and Shyampura, 21).

Experimental soil:

The soil of experimental area comprises a member of fine loamy, mixed calcareous, hyperthermic family of Typic Heplustepts. The soil was more than 100 cm deep, brown to dark brown in colour, slightly to moderately alkaline, slightly calcareous having approximately 5.0% calcium carbonates. The texture of experimental soil was sandy loam and with subsurface sandy clay loam, which was analyzed by International Pipette method (Piper, 19). Soil was lower to medium fertile in respect of nitrogen and phosphorus availability and medium fertile with respect to availability of potassium. Soil samples were analyzed for available nitrogen (Subbiah and Asija, 24), 0.5M $NaHCO_3$ extractable phosphorus (Olsen *et al.*, 18), and 1N NH_4OAc extractable potassium (Jackson, 12). Average water retention at field capacity was 8.0% and 11.0% in surface and subsurface soil, respectively. Soil organic carbon (SOC) was estimated by wet digestion method as described by Walkley and Black (25).

Treatments and observations:

The treatments comprises, absolute control(T_1) seed inoculation with *Azotobacter* (T_2) and Phosphate Solublizing Bacteria (PSB) (T_3), Sheep Manure (SM)-10 t ha^{-1} (T_4), SM-10 t ha^{-1} + *Azotobacter* (T_5), SM-10 t ha^{-1} + PSB (T_6), Vermicompost (VC) 4 t ha^{-1} (T_7), VC 4 t ha^{-1} + *Azotobacter* (T_8), VC 4 t ha^{-1} +PSB (T_9), Recommended Dose of Fertiliser (RDF 90:40:30 kg ha^{-1} of N:P:K) (T_{10}), RDF+ *Azotobacter* (T_{11}) and RDF+PSB (T_{12}). These 12 treatments were replicated thrice in Randomized Blok Design. Growth and yield parameters were recorded and soil and plant samples were analyzed for 'C' using CHNS Analyzer.

General calculations and Statistical analysis:

Chemically analyzed data for carbon in plant multiply with plant biomass for the calculation of its accumulation in various plant parts and finally biological carbon sequestration. Carbon foot print for the production of fertilizers and manures was calculated based on the emission during manufacture and preparation of compost and vermicompost (IPCC, 11, Hao *et al*., 9, Kongshaug, 14 and Brentrup and Pallière, 3). Rest of the other factors (cultural activities) are common for the carbon footprint for organic or inorganic production of fennel therefore they were not considered. Carbon foot print was substracted from the biological carbon sequestration (t ha^{-1}) to get the net balance of 'C' for calculation of tradable CO_2 offsets (per season and per day basis). Soil organic carbon pool was calculated by the bulk volume of soil and soil organic carbon content in rhizospheric soil. The balance of carbon and net creditable CO_2 offset was calculated by substracting input (C equivalent) from output (C equivalence) and adding SOC built up by the crop inputs. The experimental data were analyzed statistically for variance (ANOVA) using Randomized Block Design for interpretation of the results (Cocharn and Cox, 5).

RESULTS AND DISCUSSION:

Yields

Yield of the fennel was significantly influenced by application of organic manures, biofertilizers and mineral fertilizers alone or in combinations. However, highest seed yield obtained with 10.0 t sheep manure + *Azotobacter* and highest accumulation of stover with 4.0 t vermicompost along with *Azotobacter*. This might be attributed by the balance supplement of nutrients with these inputs (Fig 1.). Aishwath *et al.* (1) also reported positive impact of organic manure along with biofertilizers (*Azotobacter*) on yield and nutrient use efficiency of wheat. Besides the taping of N from the atmosphere, these biofertilizers also fasten the mineralization of organic manure and leads to release of nutrients and utilization by the crop for the growth and development.

Biological C sequestration and CO_2 offsets

Irrespective of treatments, carbon reserve in various parts of crop was more in stover (990.7 kg ha^{-1}) followed by seed (699.6 kg ha^{-1}) and roots (507.1 kg ha^{-1}). However, carbon accumulation in seed stover and root was highest with 10.0 t sheep manure and seeds inoculated with PSB followed by 4.0t vermicompost + PSB (Fig. 2). The increment of biological carbon sequestration was in order of 20.0, 30.3, 52.9, 54.8, 76.8, 45.8, 46.5, 66.5, 32.3, 44.5 and 32.3 per cent with the corresponding inputs of *Azotobacter*, PSB, SM-10 t ha^{-1}, SM-10 t ha^{-1} + *Azotobacter*, Sheep Manure-10 t ha^{-1} + PSB, VC 4 t ha^{-1}, VC 4 t ha^{-1} + *Azotobacter*, VC 4 t ha^{-1} + PSB, RDF, RDF + *Azotobacter*, RDF+PSB, respectively. All the treatments was statistically differed form each other with respect to carbon accumulation in various plant parts of fennel. It is obvious that the biomass in stover was more than any other part of the fennel resulting higher uptake of C in stover. Similarly, root, stover and seed produced more with sheep manure and PSB, hence biological sequestration of carbon of fennel was highest with 10 t $ha^{-1}$of sheep manure and seeds inoculated with PSB over the other treatments and was least in control (Fig 3). This might be due to total biomass accumulation which was highest with this treatment. The corresponding CO_2 offset t $ha^{-1}season^{-1}$ and per day influx was also highest with sheep manure and PSB, accounted approximately double than the control (Fig. 4). Photosynthetic assimilation of atmospheric carbon dioxide by land plants offers the underpinnings for terrestrial carbon C sequestration. A proportion of the C captured in plant biomass is partitioned to roots, where it enters the pools of soil organic C and soil inorganic C which can be sequestered for millennia. Plants can play two fundamentally different roles as C sinks, first capturing atmospheric CO_2 through photosynthesis and second plants store large amounts of organic C in above and belowground biomass. Storing C in living biomass represents a rather short-term (decades to centuries) sequestration; when the plants decay, C is returned to the atmosphere. However, if plants are well maintained or undisturbed, they in an ecosystem can continue to act as a C sink for several centuries (Jansson *et al*., 13).

Mineralizable soil C pool, net balance of C and creditable CO_2 offsets

Soil organic carbon pool was highest with 4t vermicompost and was at par with vermicompost applied with biofertilizers followed by sheep manure alone or in combination with biofertilizers (Fig. 5). Rest of the treatments remained at par. This might be due to higher proliferation of seminal roots contributing to higher SOC pool after decay. Through the process of photosynthesis, all plants absorb carbon dioxide from the atmosphere; release oxygen molecules; and store carbon in plant tissues, especially roots. As plants die, carbon molecules remain underground unless disturbed by tillage or any operation allowing carbon atoms to combine with oxygen and escape into the atmosphere as carbon dioxide. This carbon could be hold temporarily by the crops and or could sequester in soil by residue management. As pointed out by Feng *et al*. (8), the non-permanent nature of carbon stocks in soils makes abatements achieved in this way essentially different from those obtained by avoiding CO_2 emissions. From an economic perspective, the issue is thus to assess how the value of one additional unit of carbon sequestered in agricultural soils compares with what can be obtained from one unit of CO_2 avoided (Feng, 7 and Mc Carl *et al.*, 17).

Net balance of carbon or in terms of carbon foot print obtained was positive. This positive balance was highest with the application of vermicompost with PSB followed by vermicompost alone, which was more than double as compared to control (Fig 6). The net carbon input output balance calculated in Punjab, which was 1.0 Tg year^{-1} (input) and ˜ 12 Tg year^{-1} (output) under various cropping systems (Dubey and Lal, 6). In comparison to RDF, net balance of carbon was 54.7 % higher under vermicompost. Moreover, the net balance of carbon was least in control. Likewise, the creditable CO_2 offset was highest with vermicompost applied with PSB (13.0 t ha^{-1}season^{-1}) and least under control (6.2 t ha^{-1}season^{-1}) as depicted in Fig. 7. With the application of RDF, the creditable CO_2 offset (7.9 t ha^{-1}season^{-1}) was lower than the vermicompost (12.2 t ha^{-1}season^{-1}), whereas it was 27.4% higher than the control. This is because of carbon foot print of fertilizers production was much higher than the organic manure and not only that organic manures also contribute towards the soil organic carbon to creates positive balance. It also attributes that organic manures are not alone to create positive balance over control but also by application of fertilizers. Many companies, multinational corporations, utility and power generation companies and others have been buying carbon credits for a number of reasons in developed countries. Some companies have subsidiaries based in foreign countries that have signed on to the Kyoto Treaty and are required to either reduce emissions or buy offsetting credits. Some companies are buying credits as part of a good corporate citizen, public relations campaign and many are genuinely concerned about reducing greenhouse gas emissions. For others, buying credits is strictly a business investment in the event that carbon prices increase. Credits can be bought and sold easily by brokers much as other commodities are traded in other exchanges. Farming carbon and trading C credits, for generating another income stream for farmers and land managers, are needed to promote conversion to a restorative land use and adoption of recommended management practices. To make terrestrial C a tradable commodity requires development of appropriate protocol(s) to predict, measure, verify, and certify C pool and flux at landscape, farm, watershed at regional scales (Lal, 15).

CONCLUSIONS

It can be concluded that fennel grown with vermicompost has more C balance (C foot print) among the other organic and inorganic crop inputs. This indicates that growing fennel with organic input is not only economic but also has more C offsets, and can contribute to combat against rising global environment problems and C cycle. In all the three plant parts (root, shoot and seed), C reserve was found highest where 10 t sheep manure applied with PSB and least was in control plots. The pool of soil organic carbon in rhizospheric soil was higher with vermicompost followed by recommended doses of fertilizers and sheep manure. However such study must be conducted under various conditions for the precise assessment of C footprint and CO_2 offsets of growing crops in the region.

Fig 1. Seed and straw yield (q ha^{-1}) of fennel.

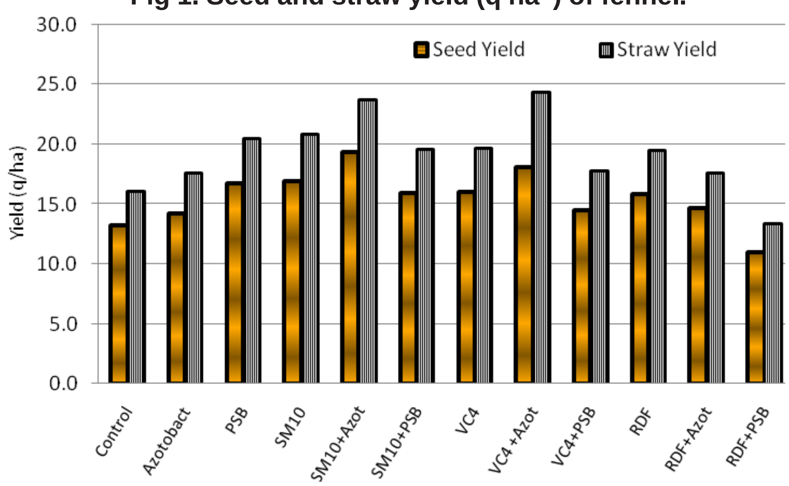


Fig 2. Carbon accumulation (kg ha^{-1}) in various parts of fennel.

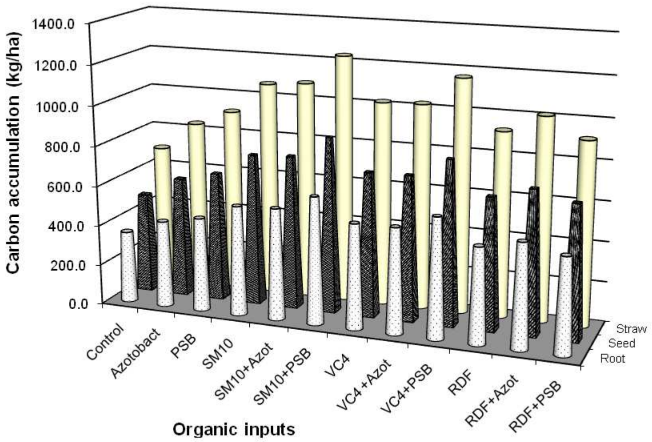


Fig 3. Total Biological C sequestration (t ha^{-1}) in fennel.

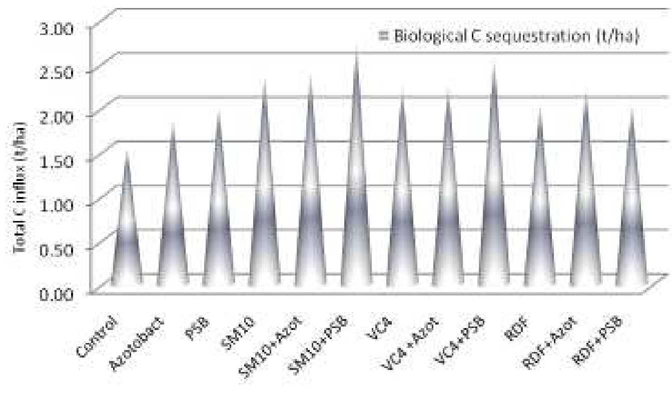


Fig 4. Seasonal and daily CO_2 off sets by fennel.

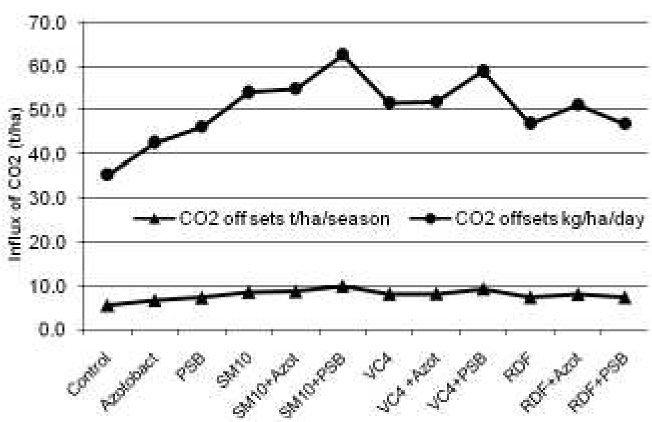


Fig 5. Soil organic carbon pool (t ha^{-1}) after fennel.

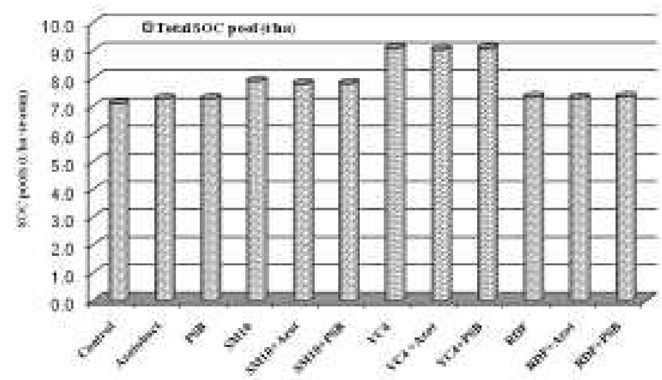


Fig 6. Net balance of c/foot print (t ha^{-1} season^{-1}) with fennel.

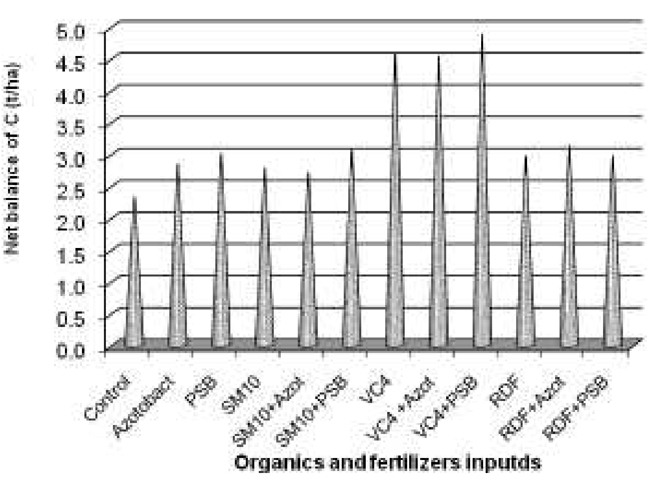
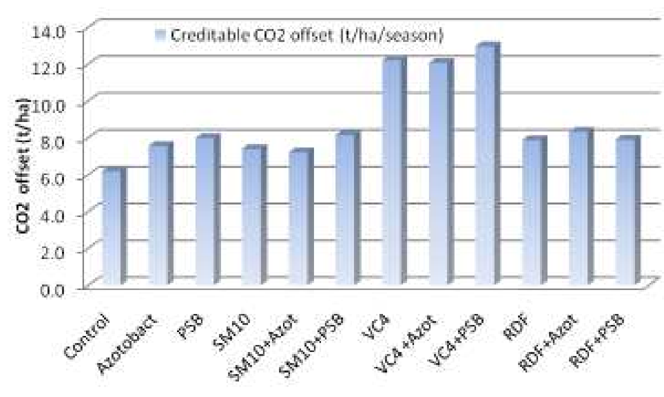


Fig 7. Creditable CO_2 offset (t ha^{-1} season^{-1}) *via* fennel production.



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