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GHG Emissions and Carbon Footprint in Two Integrated Farming System Models in Telangana State, India

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ABSTRACT

Reducing greenhouse gas (GHG) emissions and carbon footprint has become an important objective in farming, besides profitability and sustainability.A study was carried out to compare two different integrated farming system(IFS) modelsin Telangana state, India for their GHG emissions and carbon footprint. Both the IFS models, i.e.,IFS1 with crop+horticulture+2dairy buffaloes+6 goats+50 backyard poultry birds, and IFS2 with crop+horti-pasture+2 indigenous cows+12 goats+160 backyard poultry birds on a 1 ha area were carbon negative and environmentally safe. A total of 2.792 and 2.148 kg nitrous oxide was emitted from the cropping unit of IFS1 and IFS2 respectively. Increasing the area under legumes in the cropping unit of IFS 2 reduced the GHG emissions by 12.9%. Increasing commercial and irrigated dry (ID) crops not only helped increase profitability but also kept the GHG emissions at low levels. Horti-pasture system contributed to the negative carbon footprint by reducing the emission of GHGs, and by increasing the carbon sink. From the livestock unit, due to enteric fermentation, 94 kg of methane emissions were recorded with the improved breed of buffaloes (IFS 1) and 56 kg with indigenous cows (IFS 2). Improvement in soil organic carbon was observed under all cropping systems with the application of 10 Mg ha^{-1} organic manures each year. Due to manure production, 23.7 and 19.07 kg of methane emissions along with 15.27 and 9.38 kg nitrous oxide emissions were observed over these two years in IFS1 and IFS2 respectively.

Keywords: *Cropping Systems, Livestock, Integrated Farming Systems, Carbon footprint, Greenhouse gas emissions, Sources, Sinks, Sustainability,*

1. Introduction

Lowering the GHG emissions and carbon footprint from farming are important for mitigating climate change in agriculture (1).The contribution of farming to greenhouse gas (GHG)emissions is around 10-12% for the world (2) and 18% for India, where it is placed at third position after energy and industry sectors (3). Global GHG emissions from agriculture have increased by 17% between 1990and 2011(4). GHG emissions from agriculture arise mainly because of the three gases i.e., N_2O (nitrous oxide), CH_4 (methane) and CO_2 (carbon dioxide). Fertilizer (12%)and manure application (26%) are the two main agricultural practices contributing to N_2O emissions. The main sources for CH_4 emissions are submergedrice, enteric fermentation of livestock, and manure. CO_2 emissions are from manure application and the combustion of fuel used for farming activity. Researchers (5, 6) have recommended including crop rotations, recycling through manure management, improving livestock productivity, fodder management, etc., to reduce GHG emissions from the agriculture. Integrated crop-livestock system can have relatively low GHG emissions compared with separated systems (7).

Integrated farming systems approach is considered as one of the adaptation strategies to climate change. On the farm, different management practices along with agro-climatic conditions influence the quantity of GHGs emitted, like crop and soil management practices, summer fallow, crop rotations, application of fertilizers, type of tillage, and methodof irrigation, residue and manure management, etc.(8). To evaluate management practices that are effective in storing carbon in specific agroclimatic zones, measurements are essential at long term experimental sites to quantify the amount of carbon sequestered.The addition of organic matter and nutrients through straw, manure, green manure, fertilizers, etc., result in carbon sequestration over time if additions exceed aerobic decomposition of easily decomposable carbon. Similarly, depending on the treatment, manure applied to land could lead to either influx or efflux of GHGs. A moderate application rate of manure did not increase N_2O emissions enough to offset the gain in soil organic carbon, resulting in a net decrease in GHG emissions (9). Further, N_2O emission peaks may occur after rainfall during the growing season and after the application of nitrogen fertilizer. Fine-textured soils also have higher N_2O emissions than coarse-textured soils. Specific land use and management practices further determine whether the soil act as a net source or sink of GHGs.

Studies considering carbon footprint and GHG emissions from integrated farming system are scarce.Mostof theearlier studies on emissions focused on single components rather than the integrated systems.

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Crop sequences should be considered rather than single crops when evaluating the impacts of farming systems on the environment (10). In an attempt to address some of the gaps discussed above and to improve the knowledge about integratedfarming systems and their impact on the environment, the present study was carried out to evaluate twoeconomically viableintegratedfarming system models developed under irrigated dry conditions for small and marginal farmers of Telangana State, India for their GHG emissions and carbon footprint.

2. Material and Methods

2.1 Experimental site

The study was conducted on a long-term (2010-18) fixed plot under All India Coordinated Research Project on Integrated Farming Systems (AICRP-IFS) that was initiated in the year 2010-11 at the research farm of Professor JayashankarTelangana State Agricultural University, Hyderabad, Telangana, India. The study siteis located at 17°19'0"N, 78°24'39"E in the semi-arid eco region of the Deccan plateau withmean annual precipitation of 745 mm, mean annual maximum and minimum temperatures of 34.7 and 17.5°C respectively and is characterized by hot summer and cold winters. The soilof the experimental site is a *TypicUstochrept*with sandy loam texture andbulk density of 1.60 Mg m^{-3}. The soil is slightly alkaline in reactionwith a pH of 7.86, nonsaline with electrical conductivity of 0.35 dSm^{-1} and low in organic carbon (0.36%), nitrogen (124 $kgha^{-1}$), available phosphorus (14.8 kg ha^{-1}) and available potassium (170 kg ha^{-1}).

2.2 Field plot treatment and management

Assessment of carbon footprint and greenhouse gas emissions (GHGs) was carried out fortwo integrated farming system models (IFS1and IFS2)developed under AICRP-IFS, PJTSAU for small and marginal farmers of Telangana State under irrigated dry situations in an area of 1 ha. IFS1was developed during 2011-12 to 2016-17by integrating field crops,fodder crops, horticulture and animal components in the 1 ha area. The crop component in 0.70 ha included arable cropping systems viz., rice-maize, rice-sunflower, maize-castor, maize + pigeonpea-bajra and pigeonpea + sweet corn-sunhempandfodder block with hybrid bajra-napier. The horticulture component (0.20 ha) included fruit crop guava and under-story vegetable intercrops,tomato andokra during rainy season, and beetroot and cluster bean in post rainy season. Intensified sequential and inter cropping systems with cropping intensity of 144% raised the net cropped area of 0.90 ha under field and horticultural units to 1.30 hawith46.15% area under cereals and millets,15.38% under oilseeds, 11.54% under pulses, 3.85% under commercial crops and 23.07% under fodder crops. The livestock component was initiated during 2011-12 with 2 dairy buffaloes (crossbred Murrah breed), 6 goats (Osmanabadi) and a supplementary unit of 50 backyard poultry birds (Vanaraja),housed in 0.10 ha along with vermicomposting units and manure pits for recycling farm waste and crop residues generated in the system. In 2016-17, there were 2 adults +3 calves in the cattle unit, and the size of the goat unit increased to 32 numbers. Organic manures were applied every year to cropland @10 Mg ha^{-1}. For the purpose of evaluation, the IFS model present at the end of 2016-17 is taken as IFS 1.

With a view to make the system more climate smart, during 2017-18, modifications were made to IFS 1.

The cropping system module was refined by adding climate resilient crops/varieties and redesigning it to meet the requirements of typical farmer household for food, nutrition, fodder, fuel, etc. Accordingly, rice-maize and rice–castor cropping systems in 2000 sq.m area were replaced with rice-groundnut cropping system. The horticulture unit was modified into horti-pasture unit by replacing the under-storey vegetable components with hedge lucernceand *Stylosantheshamata*as under storey intercrops in guava orchard. The household vegetable requirement was taken care duly by introducing a kitchen garden of 250m^2. With these changes in cropping systems, 31.25% area was under cereals and millets,18.75% under oilseeds, 18.75% under pulses, 6.25% under commercial crops and 25.0% under fodder crops. The gross cropped area was 1.60 ha with a cropping intensity of 178%. The crossbred buffaloes (Murrah) of the unit were replaced by2 indigenous cows (Gir) which produced 2 calves by the end of 2017-18. The size of the small ruminants unit was also reduced from 32 to 12 goats but7 kids were added during 2017-18, taking the total to 19 goats. Backyard poultry birds were changed from 50 Vanaraja breed birds to 160Aseel breed birds. Thus, the 1 ha IFS unit was modified to crop+ livestock (Gircows, 2 adults + 2 calves;Osmanabadigoats, 10 females + 2 males; 160Aseelpoultry birds)+ Hortipasture. Complementary units of vermicomposting and manure pits were continued for residue recycling in the system. Organic manures were applied to cropland @10 Mg ha^{-1}.This modified model of IFS 1 as at the end of 2017-18 is taken as IFS 2 for comparative evaluation.

In the cropping unit of both the farming systems, well-decomposed FYM was uniformly applied one month before sowing of rainy season crops at the rate of 1 kg per m^2 in every cropping system once in every year. The amount of NPK fertilizers required were different for different crops and recommended N, P, K were applied through inorganic fertilizers (urea, single super phosphate, muriate of potash)for all the crops as per the recommendations of the state. All the agronomic practices, *viz*, sowing, irrigation, fertilizer application, weed management and crop protection, were followed according to package of practices of the region. Crop stubbles left over in the field after harvest of the crop were incorporated into the field before sowing of next crop. The carbon footprint from the two farming systems was computed by estimating the sources and sinks from various sources.

2.3 Estimation of sources of carbon

Greenhouse gas (GHG) emissions *viz.,* CO_2, N_2O and CH_4 from various components like crops, trees, manure and livestock were considered as sources from the farming systems. GHG emissions in cropped area were estimated using gas chambers. IPCC coefficients (11 and 3) were employed for estimating the GHGs from energy use, manure management, livestock and other components.

2.4 Measurement of GHGs using chambers

The GHG emissions from crop lands were measured over the annual cycles (a cycle means complete year) from June to May, using a static opaque chamber method. Samples were collected once in every 7 days during the crop cycle. The chamber covered a field area of 0.36m^2 and was placed on a fixed PVC frame on each plot. The chamber was 0.5m high and each top box was equipped with a circulating fan to ensure complete gas mixing. For every measurement of flux, four gas samples were drawn from the chamber using a 50 ml syringe at 0, 10, 20 and 30 min after the chambers were placed on the fixed frames.

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Samples were collected between 8:00 and 10:00 am on the sampling daysas the soil temperature at that time was close to the daily average soil temperature and minimized the influenceof diurnal variation in GHG's during the sampling period (12). The gas samples were analyzed in laboratory using a gas chromatograph.

2.5 Estimation of carbonsinks

2.5.1 Plant biomass carbon

Shoot and root biomass carbon from various production systems like crops, trees and pastures were the major sinks, in addition to carbon added to soil through manure application. Shoot biomass was recorded for the field and horticultural crops at the time of harvest. Root biomass was estimated as 14.1, 30.9, 12.2, 19.2, 26.1, 16.4, 9.0, 8.3, 12.9, 5.9 % of harvestable total above-ground biomass (including economical part and non-economical part) in rice, groundnut, pigeonpea, maize, bajra, sunhemp, cotton, green gram, fodder sorghum andnapier crops, respectively duly collecting root samples immediately after harvesting the crop following the core-sampling procedure (13).

Carbon inshoots and roots of crops was estimated using wet combustion method. Root rhizo-deposited C was calculated as 65% of C root biomass C(14, 15). Stubble biomass of crops was taken as 2.5% of total above ground biomass. Per cent C content in the roots of crops was 41.2, 40.9, 36.38, 48.1, 44.8, 40.9, 32.14, 35.33, 46.40, 44.8% in rice, groundnut, pigeonpea, maize, bajra, sunhemp, cotton, greengram, fodder sorghum andnapier respectively. Percent C content in stubbles was 31.8, 48.2, 46.4, 46.0, 45.5, 41.17, 42.96, 48.0, 45.1 in rice, pigeonpea, maize, bajra, sunhemp, cotton, green gram, fodder sorghum andnapier respectively. Carbon concentrations of FYM and vermin-compost, determined by wet combustion method were 26.4% and 19.6**%** respectively.

Biomass of the tree component in the farming systems (Guava trees in horticulture component) was estimated by a non-destructive method by measuring the height and diameter at breast height (DBH),i.e., at 1.37 m from the ground level.

The standing volume (m^3) of the trees was calculated by employing the formula (16)

$$Volume = \pi r^2 \mathrm{H}$$

Where π = 3.14, r is radius, which is half of the DBH (m) and H is the height of the tree (m).

Aboveground biomass of tree was calculated using tree volume and wood density. Wood density of guava trees was taken from literature as760 kg m^{-3} (17).

Above-ground biomass (AGB; kg $tree^{-1}$) = Volume (m^3) × wood density (kg m^{-3})

Below-ground biomass (BGB) of the tree includes live root biomass, excluding fine roots and was calculated using 0.26 factor of root: shoot ratio(18)

BGB (kg $tree^{-1}$) = AGB (kg $tree^{-1}$) × 0.26

Sum of AGB and BGB gives total biomass (TB) of the tree

TB (kg $tree^{-1}$) = AGB (kg $tree^{-1}$) + BGB (kg $tree^{-1}$)

In general, 50% of the biomass is considered as carbon for plant species (19), So Carbon Storage = 0.5 × Biomass. The total carbon so estimated was multiplied with a factor of 3.6663 to calculate CO_2 equivalent taking the basis of atomic weight ratio of CO_2 to C.

2.5.2 Soil oxidisable carbon

Composite soil samples from 0 to 0.15 m were collected after the harvest of crop cycle with the aid of soil auger.

The collected soil samples were shade dried and passed through 0.5mm sieve for analysis of soil oxidisable carbon byWalkley and Blackmethod (20).Soil bulk density was estimated by core method and the quantity of carbon stock per hectare was calculated using the following formula.

C stock (Mg ha^{-1}) = C content (g kg^{-1}) × Bulk density (Mg m^{-3}) × Depth (m)

All the carbon measurements made in various components were expressed in CO_2equivalents(CO_2-e).

3. Results and Discussion

3.1 Emissions from cropping

Estimation of emissions from cropland under various cropping systems in IFS1during *kharif* and *rabi* seasons indicated that a total of 1546 kg CO_2-e GHGs were emitted from the cropping unit in 9000 m^2 area (Table 1),the maximum being in rice-maize system (487.2 kg CO_2-e). Higher GHG's emission in ricemight be due to flood water oxygen, which acts as the electron acceptor is related to higher emission (21 and 22). Among the ID crop sequences,*Bt* cotton + greengram-fodder sorghum recorded maximum GHGs (107.5 kg CO_2-e).Tongwane et al. also reported similar findings(23).

Emissions of greenhouse gases from cropland under various cropping systems in IFS2 model during *kharif* and *rabi* seasons (Table 2) indicated that a total of 2.148 kg nitrous oxide/ year was emitted from the cropping unit. Maximum emissions of nitrous oxide per annum were recorded in rice-groundnut cropping system (0.455 kg N_2O). Due to submergence, anaerobic rice paddies are a key source of GHG emissions, and are ranked as the fourth largest agricultural source of GHG emissions (26). The lowest quantities of emissions were observed in the pigeonpea + sweet corn-bajra system (0.237 kg N_2O or 78.4 kg CO_2-e).In terms of CO_2 equivalence a total emission of 1346 kg CO_2 was recorded from 9000 m^2 area. Mohammadi et al. also reported a wide variationin GHG emissions in different crops under cultivation(25).

3.2 Emissions fromlivestock

From the livestock unit (Crossbed Murrah buffaloes, goats and vanaraja poultry) of IFS1, due to enteric fermentation, 274 kg of methane emissions per annum were recorded (Table 3) and maximum enteric emissions were observed in goatery unit with 32 goats (128 kg).Due to manure production viz., 16.5 t of farm yard manure and 2.24 t of vermin compost, 23.7 kg of methane emissions and 15.3 kg nitrous oxide emissions were observed. A total of 11018.6 kg CO_2e was recorded from the livestock unit and52.5% of these emissions were from enteric fermentation (5785.5 kg CO_2-e).Vetter et al. also reported that rice and livestock contribute the most to total GHG emissions(26). Harish et al. reported that crops and livestock had wide annual variation in the GHG emissions(27).

From the livestock unit (indigenous Gir cows,goats and Aseel poultry) of IFS 2, due to enteric fermentation, 167.8 kg of methane emissions (Table 4) were recorded and maximum enteric emissions were observed in goatery unit with 19 goats (95 kg) in IFS 2. Recyclingresidues, dung and shed wastes generated 12.78 t of farmyard manure and 2.17 t of vermicompost per annum and due to manure production, 19.07 kg of methane emissions and 9.38 kg nitrous oxide emissions were observed. A total of 7565.0kg CO_2-ewas emitted from livestock unit. Life cycle assessments of various livestock systems showed that on-farm emissions represent the largest contribution to the C footprint of dairy (28).

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Thus, the ruminant animals and their gaseous emissions (enteric or from manure) should be the primary targets of a successful GHG mitigation programme. In the current study also, replacing the crossbred buffaloes with indigenous cows reduced the emissions from the livestock by 43.14%.Todde et al. (2017) reported that Precision livestock farming technologies could be applied to reduce the carbon footprint (29)and form an important tool to reduce the environmental impact of livestock farming.

3.3 Carbon budgeting

Carbon budgeting of IFS1(Table 5)indicated that the modelwas carbon negative and environmentally safe and acted as a net sink (-19262 kg CO_2-e)with absorption of 32074 kgCO_2-e through biomass productionof crops, treesand soil organic carbon sequestration and emission of12812 kg CO_2-efrom crops, livestock, manure management and energy use.Carbon crediting of IFS 2 also indicated that the model was more carbon negative, with a sink of 36250 kg CO_2-e through biomass production, trees and soil organic carbon sequestration and a source of 9214 kg CO_2-e from crops, livestock, manure management and energy use.

On comparison of IFS1 and IFS2, it is evident that the inclusion of more legumes and reducing the cereal component reduced nearly 200 kg CO_2 emissions per annum from the same piece of land. Inclusion of leguminous crops in the system resulted in 12.9% lower emissions.Gan et al. (2014) and Yoaet al. (2017) Earlier reports also indicated that rotations including legumes had lower N_2O emissions compared to the continuous wheat or cereal rotations 930 and 31). Similarly, maintaining a suitable breed of livestock along with optimum size of large and small ruminants in IFS2 resulted in 3453.6 kg lesser CO_2-eemissions than IFS1. Change in the livestock strain and feed system affects the GHG emissions and carbon footprint (32).

For small and marginal farmers, low carbon foot print or ecological safety is a secondary concern.

The primary aspects like profitability and productivity of both the integrated farming system models are superior to farmers' model with average annual productivity of 5 t ha^{-1} (rice grain equivalent yield-RGEY) and net income of Rs 54000/- of the region. IFS1 recorded a productivity of 41.4 t RGEY ha^{-1} and net profit of Rs 2,17,493 ha^{-1}. Similarly, IFS2 registered a productivity of 33.3 t RGEY $ha^{-1}$and net profit of Rs2,13,631 ha^{-1}.

Conclusion

Both the IFS models in the study were carbon negative, indicating that integrated farming systems with tree component and recycling of organic matter can reduce the carbon footprint of farming and contribute to climate change mitigation. Reducing the area under rice and allocating it to irrigated dry crops, preferably, legumes, can reduce the GHG emissions from cropland. Emissions from livestock can be lowered through choice of breeds and optimizing the number of animals. Efficient recycling of organic wastes and application of organics to the soil lead to the sequestration of carbon in soil, which in turn increases the soil fertility and consequently, crop productivity and farm profitability.

Further scope of study: A detailed life cycle assessment based studies pertaing to emissions of various components in location specific modules provides an opputunity for recommendation of climate smart, sustainable and profitable IFS models to clientele.

Conflict of intrest: No conflict of intrest exists among the authors.

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Table 1: GHG emissions from cropland of crop + livestock + horticulture in IFS1

Crop/ Cropping system	Area (m^2)	N_2O emissions (kg $area^{-1}$)			Methane (kg $area^{-1}$)	Total (kg CO_2-e)
		Kharif	Rabi	Total		
Rice-Maize	1000	0.192	0.282	0.474	16.2	487.2
Rice- Castor	1000	0.192	0.141	0.333	16.2	443.5
Bt cotton + Greengram- Fodder Sorghum	1000	0.244	0.103	0.347		107.5
Maize- groundnut	1000	0.278	0.031	0.305		94.7
Pigeon pea + Sweet corn-Sunhemp	1000	0.228	0.021	0.264		96.6
Pigeon pea + Maize -Bajra	1000	0.244	0.084	0.312		82.0
Orchard block- Guava	2000					
Tomato- Clusterbean -600 m^2		0.175	0.019	0.194		60.2
Bhendi-Beet root -600 m^2		0.078	0.031	0.110		34.0
Fodder block (Hybrid bajranapier var-APBN-1)	1000	0.452				140.3
Total	9000			2.792		1546.0

Table 2: GHG emissions from cropland of crop + livestock + horti-pasture in IFS2

Crop/ Cropping system	Area (sq.m)	N_2O emissions (kg $area^{-1}$)				Methane (kg $area^{-1}$)	Total (kg CO_2-e)
		Kharif	Rabi	Summer	Total	Kharif	
Rice- groundnut-sunhemp	2000	0.384	0.062	0.009	0.455	32.4	818.6
Bt cotton + greengram- fodder sorghum	1000	0.244	0.103		0.347	-	107.5
Maize- groundnut	1000	0.274	0.031		0.305	-	97.6
Pigeonpea + sweet corn-bajra	1000	0.228	0.009		0.237	-	78.4
Pigeon pea + maize-sunhemp	1000	0.244	0.083		0.327	-	96.3
Orchard block Guava + Hedge lucerne&stylo	1800	0.046 0.053			0.099	-	14.4 16.3
Fodder block (Hybrid bajranapier var-Co4 &Super napier)	1200	0.378			0.378	-	117.1
Total	9000				2.148	32.4	1346.0

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Table 3: GHG emissions from livestock unit of crop + livestock (crossbred buffaloes) + horticulture in IFS1

Livestock	Units	Enteric Methane Production (kg CH_4/yr)	Methane Production from manure (kg CH_4/yr)	N_2O emissions from manure (kg N_2O/yr)	Total (kg CO_2-e)
Crossbred buffaloes(Murrah)	2	94	8.4	2.94	3061.5
Calves < 1Year	1	8	1.1	0.16	241.7
Calves 1-2 Year	2	44	6.8	1.14	1421.1
Goatery	32	128	6.4	10.29	6012.3
Poultry	50	1.5	1.0	0.74	282.0
Total		274	23.7	15.27	11018.6

Table 4: GHG emissions from livestock unit of crop + livestock (indigenous cows) + horti-pasture in IFS2

Live stock	Units	Enteric Methane Production (kg CH_4/yr)	Methane Production from manure (kg CH_4/yr)	N_2O emissions from manure (kg N_2O/yr)	Total (kg CO_2-e)
Indigenouscows (Gir)	2	56	10.0	2.62	2069.9
Cow calves	2	18	1.69	0.65	616.0
Goatery	19	95	4.18	6.11	3976.8
Poultry	160	6	3.20	2.37	902.3
Total		167.8	19.07	9.38	7565.0

Table 5: Net GHG emissions (kg CO2-e) in crop + livestock (2 Murrah buffaloes +32 goats +poultry) + horticulture vs crop + livestock (2 indegenous cows + 12 goats + poultry)+horti-pasture in IFS2

S.No	Sources			Sinks			Net Credit GHG(Source- Sink)	
	Enterprises	CO_2-e (kg)		Enterprises	CO_2-e (kg)		kg CO_2-e	
		IFS-1	IFS-2		IFS-1	IFS-2	IFS-1	IFS-2
1	Agricultural/horticultural Crops	1546.0	1346.0	Trees-Horticulture/ Hortipasture	2135	2254.84		
2	Manure management	5233	3306.79	Total Biomass - Agricultural/horticultural Crops	29785	33839.92		
3	Livestock enteric fermentation	5786	3523.80	Soil Organic carbon stocks	154.0	154.33		
4	Energy	247.0	310.61					
	Total of Sources	12812	9214	Total Sinks	32074	36250	-19262	-27036

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