International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2018; 6(1): 1934-1938

Received: 14-11-2017
Accepted: 15-12-2017

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Biomass production and carbon sequestration potential of Apple based agri-horti-Pastoral systems under temperate conditions of Kashmir valley

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Abstract
Carbon sequestration potential of agri-horti-pastoral systems under temperate conditions of Kashmir valley was evaluated with five treatments viz:Apple +Lucerne (T_1), Apple +Beans-Pea (T_2), Apple +White clover (T_3), Apple +Orchard grass (T_4) and Apple + natural sward (T_5). The experiment was laid in an established apple orchard of about 20 years of age at Sher-e-Kashmir University of Agricultural Sciences and Technology at its Shalimar campus. A single row of six (6) trees per plot (net-cropped area of 81 m^2) was replicated thrice for each treatment with tree to tree spacings of 4.5 m. The highest fruit yield was recorded in Apple +White clover (24.2 kg/tree or 14.76 t/ha and 6.41 kg/tree) followed by Apple +Beans-Pea (22.16 kg/tree or 13.51 t/ha.). The control (Apple + natural sward) yielded lowest fruit yield 3.5 kg/tree or 2.13 t/ha. The maximum green fodder yield was observed in Apple + Lucerne (13.09 t/ha). Maximum biomass allocation (on dry weight basis) was recorded in stem portion of apple trees followed by tertiary, primary and secondary branches. The treatment Apple +Orchard grass gained maximum tree biomass (27.66 kg/tree).Total biomass and carbon stock of the system (tree+crop+fruit) was estimated and Apple + Lucerne (T_1) gained maximum total biomass 31.54 t/ha and carbon stock 14.19 t C/ha. The control treatment (Apple +natural sward) recorded minimum total biomass 22.77 t/ha and carbon stock of 10.24 t C/ha. The values of control remained at par with Apple +white clover. The total biomass removed from the system included fruit yield, fruit drop, fuelwood (pruning) and crop biomass of perennial fodders (above ground) except for Beans-Pea where the entire plants were removed along with roots at harvest and were assessed. Maximum biomass 10.31 t/ha and carbon 4.63 t C/ha was removed from treatment (T_1) Apple +Lucerne closely followed by Apple + Beans-Pea (9.77 t/ha and 4.39 t C/ha). The control (Apple + natural sward) recorded minimum biomass (5.07 t/ha) and carbon stock (2.28 t C/ha) that was removed. Consequently, the Apple +Lucerne (T_1) registered highest amount of carbon sequestered i.e., 9.56 t C/ha and Co_2 equivalent of 35.08 t/ha. Our study revealed that treatment (Apple +Lucerne) would conserve 1.02 million tons of carbon and 3.76 million tons of Co_2 equivalent.

Keywords: Biomass Production, carbon sequestration, agri-horti-pastoral systems, Kashmir valley

Introduction
Over the past two decades climate change has evolved from a debate about whether the planet is really warming to an increased focus on how to mitigate and adapt to its impacts, due mainly from the growing acceptance among scientists, policy makers and even the general public that climate change is real and happening. This acceptance is based on the overwhelming evidence presented by the scientific communities through intensive monitoring of global climatic systems, extensive observations on changes in terrestrial and aquatic systems and predictive modeling (IPCC, 2007 and Stern, 2007) [9, 23]. From the instrumental record of global temperature since 1850, the Fourth Assessment Report of the IPCC estimated that the current global mean surface temperature was about 0.42 to 0.54^o c above the 1961-90 annual average (IPCC, 2007) [9]. It also ranks eleven of the last twelve years (1995-2006) among the 12 warmest years. Further evidence of global warming comes from the observations made on the most vulnerable natural systems like glaciers, Coral reefs and atolls and alpine ecosystems (Ackley *et al*, 2003) [2] and observed increase in the frequency of occurrence of extreme events (Tebaldi *et al*, 2006) [24]. The rapid increase in concentration of Co_2 and other green house gasses (methane, ozone, carbon monoxide, nitrous oxides) is the leading factor considered for global warming and climate change.

Vegetation and soil are two major sink to sequester the atmospheric carbon dioxide, which contributes nearly 60% of the green house gasses. Kyoto protocol recognized that drawing Co_2 from air into biomass is the only practical way for mitigating the Co_2 from the atmosphere. Green Plants extract Co_2 from the air through photosynthesis, separating the carbon and oxygen atoms, returning oxygen to the atmosphere and using the carbon to make biomass in the form of roots, stems and foliage. Every year on a global scale a very large amount of Co_2 (in order of 100 billion metric tons) is sequestered (Kerchoffs and Reid, 2007) [11]. At the same time, carbon is released to the atmosphere from vegetative respiration, combustion of wood as fuel, consumption of biomass for food and natural decay. The net flux between carbon sequestration and release can be viewed as measure of the relative contribution to biomass to the carbon cycle. World flux is thought to provide a net sink of about 0.7 billion metric tons of Co_2 /year (IPCC, 1995).

Forest ecosystems are considered to be major sinks of carbon (C) and can help to mitigate climate change (Pan *et al*. 2011) [13], but the potential of agroforestry for global C sequestration has only recently been acknowledged (Smith *et al*. 2007; Jose and Bardhan 2012) [21, 10].

The greatest role of agroforestry in relation to climate change is perhaps in mitigating the emission of Co_2 by productively sequestering carbon from the atmosphere. A number of studies have estimated the potential of agroforestry systems to act as effective carbon sinks (Winjum *et al*, 1992; IPCC, 2000; Albrecht and Kanji, 2003 and Montaginini and Nair, 2004) [26, 8, 1, 12].

The carbon sequestration is influenced by factors such as climate, soil characteristics, topography, species, density and age of the biomass. Different trees behave differently under different soil and climate in terms of carbon assimilation.

Through regional studies, potentiality of different land use systems should be evaluated to estimate the quantum of carbon each can sequester and agroforestry is one of the important land use system of Kashmir. Agroforestry may provide a viable combination of carbon storage with minimal effect on the food products as the carbon sequestration is a secondary product.

Materials and methods

The present study on carbon assimilation was carried out in an established apple orchard during the year 2007-2008 and 2008-2009. The Orchard was planted in 1988 at Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar campus, Srinagar at an elevation of 1578 m asl. The treatment combinations included: T_1- Apple + Lucerne, T_2- Apple + Beans-Pea, T_3- Apple + White Clover, T_4- Apple + Orchard grass and T_5- Apple + natural sward.

The average plot size was 87.5 m^2 (net cropped area 81 m^2) with single row of six (6) apple trees at density of 610 trees/ha. The apple trees were spaced at 4.5 m x 4.5 m. The perennial grass component was seeded during autumn, 2006. Kharif-Rabi rotation of Beans-Pea was followed as per the season. Recommended packages and practices were adopted. The tree biomass was estimated by adopting non-destructive method (dry weight basis) for different tree parts-stem, branch, leaf and roots. The stem biomass was estimated by formula given by Pressler (1865) [14] and Bitterlich (1984) [6].

f (form factor)=$2h_1/3h$

Where h_1= height at which diameter is half of dbh h = total tree height

Volume=f x h x g

Where f=form factor, h= total height and g= basal area = ∏ $(dbh/2)^2$ dbh is the diameter at breast height

The specific gravity of wood samples was determined by water displacement method.

Specific gravity= weight/volume

Weight of stem biomass= Specific gravity of stem wood x Volume

Total number of branches were categorized into different classes as primary, secondary and tertiary. Volume of each representative branch was determined by Quarter girth formula= $\Pi (g/4)^2$ and then multiplied with sp. gravity and the resulted biomass was estimated further by multiplying the number of each category of branches. The leaf litter was collected periodically from leaf litter bags tied around the apple trees. The total biomass (above ground) was the sum of stem, branches and leaf litter. The tree biomass converted into carbon by the factor of 0.45 (Ajtay *et al*, 1979) [3]. Similarly the crop biomass was estimated using quadrat method. All the crop plant occurring within the quadrat was cut and oven dried at 65±5°c to a constant weight. The crop biomass was converted to carbon by a factor of 0.45 (Woomer, 1999) [27]. The above ground biomass of deciduous trees was converted into below ground biomass with a factor of 0.25 and for crop plants it was 0.50 (Schulre, 1983) [19].

The total carbon stock in the agroforestry components (woody+non-woody) was estimated and the carbon sequestered was calculated as;

Total carbon stock in the AF system-Carbon removed from the system

The biomass removed from the agroforestry system included fruit, crop, fodder, and fuelwood (pruning), which was converted into carbon by a factor of 0.45. The equivalent Carbon dioxide (eCO2) was obtained by a factor of 3.67 (Kerckhoffs and Reid, 2007) [11].

Results and discussion

Five different treatments were compared in terms of carbon sequestration in agri-horti-pasture system. The treatments varied significantly when compared on the basis of yield parameters viz: fresh fruit yield, fruit drop and crop yields. Apple + white clover (T2) recorded highest fresh fruit yield (24.2 and 6.41 kg/tree) followed by Apple +Beans-Pea (22.16 kg/tree) which was at par in terms of fruit yield. The control treatment (Apple + natural sward) yielded lowest fresh fruit of apple (3.5 kg/tree).The fodder yield was observed maximum with Apple + Lucerne (T_1) 13.09 t/ha of green fodder. Apple +white clover gave minimum yield of green fodder (4.39 t/ha) which remained at par with Apple + natural sward and Apple + Orchard grass (Table 1).

Maximum biomass allocation (on dry weight) was recorded in tree stem followed by tertiary, primary and secondary branches. The stem, primary and secondary branch biomass observed non significant variation among the treatments, however the biomass of tertiary branches differed significantly and recorded maximum biomass in Apple + Orchard grass (6.39 kg/tree.) closely followed by Apple +Lucerne (6.03 kg/tree). Consequently the Apple + Orchard grass gained maximum tree biomass (27.66 kg/tree) followed by Apple +Lucerne (25.89 t/ha) which were at par (Table-2).

The total biomass (above ground and below ground) on dry matter basis and carbon stock of system components differed significantly between treatments (Table-3). The treatment Apple +Orchard grass gained maximum tree biomass 21.08 t/ha (16.87 t/ha above and 4.21 t/ha. below ground). Apple

+White clover recorded minimum tree biomass 16.41 t/ha (13.13 t/ha above and 3.28 t/ha below ground). The carbon content of Apple +Orchard grass resultantly observed maximum 9.98 t C/ha. Apple +Lucerne recorded maximum total crop biomass 10.14 t/ha (6.76 t/ha above and 3.38 t/ha below ground) and consequently the maximum carbon stock 4.56 t C/ha. The fruit yield +drop was significantly highest in Apple +White clover 3.53 t/ha and carbon content of 1.58 t/ha.

Apple+Lucerne gained maximum total biomass (tree+crop+fruit) of 31.54 t/ha. and carbon 14.19 t/ha. Whereas Apple +natural sward observed minimum total biomass and carbon stock 22.77 and 10.24 t/ha respectively, which remained at par with Apple + white clover (Table 3). The total biomass removed from the system included fruit yield & drop, fuelwood (pruning) and biomass of perennial grasses (above ground only) except for beans-pea where the entire plant was removed with roots at harvest. Maximum fruit yield and drop was recorded in Apple + white clover (3.53 t/ha). Whereas Apple +Orchard grass observed maximum yield of fuel wood (2.15 t/ha.) in terms of pruning, which is due to maximum biomass of tertiary branches. Maximum biomass of crop was registered in Apple +Lucerne 6.76 t/ha followed by Apple + beans-Pea 5.61 t/ha, which was at par. Apple+Lucerne recorded maximum biomass (10.50 t/ha) and carbon stock (4.63 t C/ha) that was removed from the system followed by Apple +beans-Pea. The Apple +natural sward registered minimum value of biomass 5.07 t/ha and carbon 2.28 t C/ha. The values of biomass which was removed in Apple + White clover, and Apple +Orchard grass were at par. The variability in the carbon stock of different agri-horti-pastoral systems depends primarily on its age, structure, functional components, their number and intensity of management. The variability in the productivity of agroforestry systems as recorded in our case is in conformity with the observations of (Albrecht and Kandji 2003) [1]. Average sequestration potential in agroforestry has been estimated to be 25 t C/ha over 96 million ha of land in India (Sathaye and Ravindranath, 1998) [17]. Singh (1995) [20] reported that rye and orchard grass were found to be the best grass species and clovers and lucerne the best perennial legumes for introduction in apple orchards.

The carbon sequestration was maximum with the Apple +Lucerne 9.56 t C/ha closely followed by Apple +Orchard grass 9.31 t C/ha. However Apple +White clover registered the lowest carbon reservoir 7.41 t C/ha. The equivalent Co_2 was also observed maximum with Apple +Lucerne 35.08 t/ha followed by Apple +Orchard grass (34.16 t/ha). Minimum value of equivalent Co_2 was recorded with Apple + White clover (27.19 t Co_2/ha) that was at par with Apple+natural sward (29.21 t/ha).

Under different environmental conditions, average carbon storage by agroforestry practices has been estimated to be 9, 21, 50 and 63 t C/ha in semi-arid, subhumid, humid and temperate regions respectively (Schroeder, 1994). Several studies have shown that inclusion of woody component in agricultural landscape often improves the productivity of systems while providing opportunities to create carbon sinks (Verma, 2006) [25]. Rajput *et al*., (2015) [15] reported that rate of CO_2 mitigation potential was maximum (7.81 Mg ha^{-1} year^{-1}) in the orchard + cereal–cereal based land use system and maximum carbon density (90.88 Mg ha^{-1}) of both soil and plant was also observed in orchard + cereal–cereal based land use system at 1,300–1,600 m above mean sea level. They further concluded that fruit based agroforestry systems exhibit significantly higher values of above, below and total biomass than the pure orchard and annual based cropping systems.

The apple based agroforestry systems in which forage combination is integrated is a useful strategy for mitigating the atmospheric CO_2. Jammu and Kashmir has emerged as the largest apple producing region in the country with a substantial area of 107177 ha under apple orchards (Anon., 2008) [5]. This quantum of land area holds promise for carbon mitigation by adopting apple based agroforestry systems. Our study revealed that Apple+Lucerne would provide 1.02 million tons of sequestered carbon (under biomass) and 3.76 million tons of equivalent Co_2.

Table 1: Yield components in Agri-Horti-Pasture system (pooled)

Treatment (610 trees/ha)	Fruit yield (FW) kg/tree	Fruit yield (DW) kg/tree	Fruit drop (FW) kg/tree	Fruit drop (DW) kg/tree	Fodder/Crop (FW) t/ha	Fodder/Crop (DW) t/ha
T_1-Apple+Lucerne	12.21	2.59	1.55	0.15	13.09	6.76
T_2 Apple+ Beans -Pea	22.16	4.70	2.02	0.181	7.35	1.68
T_3 Apple+White clover	24.20	5.15	6.41	0.64	4.39	2.72
T_4 Apple+Orchard Grass	7.83	1.66	3.87	0.34	7.03	3.51
T_5 Apple+natural sward (Control)	3.5	0.74	1.47	0.16	5.99	3.30
LSD	4.91	1.06	2.70	0.08	2.67	1.33
SED	2.13	0.46	1.17	0.03	1.16	0.57

Table 2: Apple tree biomass (Dry weight, kg/tree)

Treatment (610 trees/ha)	Stem	Primary branches (no.of branches)	Secondary branches (no.of branches)	Tertiary branches (no.of branches)	Leaf Litter	Total Tree
T_1 Apple+Lucerne	14.09	2.05 (3.5)	1.78 (7.33)	6.03 (520.66)	1.93	25.89
T_2 Apple+Beans-Pea	15.28	1.83 (3.5)	1.99 (7.66)	5.00 (450.66)	1.46	25.57
T_3 Apple+White clover	13.39	1.31 (3.0)	1.88 (6.33)	3.31 (351.3)	1.65	21.54
T_4 Apple+Orchard Grass	14.82	2.36 (3.01)	2.44 (6.66)	6.39 (540.66)	1.65	27.66
T_5 Apple +natural sward (control)	15.64	1.29 (2.66)	1.71 (7.16)	2.88 (274)	1.17	22.68
LSD	NS	NS	NS	1.52	NS	1.95
SED	1.00	0.52	0.28	0.66	0.66	0.84

Table 3: Biomass and carbon stock of Agri-Horti-Pasture system components (t/ha.)

Treatment (610 trees/ha)	Tree A/G	Tree B/G	Total (Tree)	Carbon (Tree)	Crop A/G	Crop B/G	Total (Crop)	Carbon (Crop)	Fruit yield+ drop	Carbon (Fruit)	Total Biomass	Total Carbon
T_1 Apple+Lucerne	15.79	3.94	19.73	8.87	6.76	3.38	10.14	4.56	1.67	0.75	31.54	14.19
T_2 Apple+Beans -Pea	15.59	3.89	19.48	8.76	5.09	0.52	5.61	2.52	2.97	1.33	28.06	12.79
T_3 Apple+White clover	13.13	3.28	16.41	7.38	2.35	1.17	3.52	1.58	3.53	1.58	23.46	10.55
T_4 Apple+Orchard Grass	16.87	4.21	21.08	9.48	3.51	1.75	5.27	2.37	1.22	0.54	27.57	12.40
T_5 Apple+natural sward	13.83	3.45	17.28	7.77	3.30	1.65	4.95	2.22	0.54	0.24	22.77	10.24
LSD	0.63	0.56	0.78	0.35	1.04	0.47	1.32	0.59	0.68	0.30	1.07	0.32
SED	0.27	0.24	0.34	0.15	0.45	0.20	0.57	0.25	0.29	0.13	0.46	0.14

Table 4: Total biomass, biomass removed and carbon sequestered in Agri-Horti-Pasture system components (t/ha)

Treatment (610 trees/ha.)	Total Biomass	Fruit yield+ drop	Pruning (fuelwood)	Crop (A/G)	Biomass Removed	Total Carbon removed	Carbon sequestered	Equivalent CO_2 sequestered
T_1 Apple+Lucerne	31.54	1.67	1.88	6.76	10.31	4.63	9.56	35.08
T_2 Apple+Beans-Pea	28.06	2.97	1.19	5.61	9.77	4.39	8.23	30.20
T_3 Apple+White Clover	23.46	3.53	1.10	2.35	6.98	3.14	7.41	27.19
T4 Apple+Orchard Grass	27.57	1.22	2.15	3.51	6.88	3.09	9.31	34.16
T_5 Apple+natural sward	22.77	0.54	1.23	3.30	5.07	2.28	7.96	29.21
LSD	1.07	0.68	0.62	1.48	1.66	0.74	0.71	2.63
SED	0.46	0.29	0.27	0.64	0.72	0.32	0.30	1.14

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