Volume 14 Issue 47
Originally issued as D10

Global Journal of Science Frontier Research: D
Agriculture and Veterinary
Volume 14 Issue 10 Version 1.0 Year 2014
Type : Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

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Keywords: annual crop field; biomass carbon; coffee based agroforestry; land use change; native forest; soil organic carbon.

GJSFR-D Classification : FOR Code: 050301

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I. Introduction

Forest conversion and land-use change in the tropics are major factors leading to losses in carbon stocks and increasing concentration of greenhouse gases in the atmosphere. The effect of land use changes on soil properties may vary for different soils, vegetation types and ecological zones (Lal 1999; Palm *et al.*, 2000; Bekele 2006; Fantaw *et al.,* 2008). Agricultural practices lead to a reduction in carbon stocks mainly due to removal of above ground biomass as harvest with subsequent burning and/or decomposition and losses of soil carbon by erosion (Lal 1999; Balesdent and Balbane 1996; Fahnestock *et al.,* 1996). Thus, there is a need for developing sustainable agricultural systems to maintain and improve biomass and soil organic compound (SOC) content while mitigating the land degradation and greenhouse gas emissions (Patrick et al., 2005; Takahashi et al., 2010). In tropics especially south and south-western highlands of Ethiopia, the deforestation of native forest has been significantly increased during the past 100 or more years (Pohjonen and Pukkala 1990; sited in Bekele 2006), which might be due to human habitation (Bekele 2006). Carbon in the soil is an important factor when studying global carbon budgets (Wilding et al., 2001; Berg and McClaugherty 2003; Lehtonen et al., 2004). Estimating the carbon stock in reliable values is necessary for understanding the global Carbon cycle, as well as for developing national inventories of greenhouse gases (Lehtonen et al., 2004); while estimating its spatial variability is important when developing carbon budgets, explaining climate change and characterizing ecosystems (Davis et al., 2004). Soil carbon can act as a source or as a sink for CO_2 in the atmosphere (Fisher and Binkley 2000; Högberg et al., 2002; Fröberg 2004) and can be considered as the biogeochemical linkage between the other major Carbon reservoirs: biosphere, atmosphere and hydrosphere (Wilding et al., 2001).

Forests sequester and store more carbon than any other terrestrial ecosystem and are an important natural brake on climate change (Lal 2005; IPCC 1997; Milne and Brown 1997). Tropical forests account for 40% of carbon stored globally in terrestrial biomass (Alves et al., 1997; Brown 1997) and contribute as much as 36% of the net exchange between atmosphere and terrestrial vegetation (Melillo et al., 1993). Thus, small changes in net carbon stock of tropical forests could result in significant storage or release of carbon to the atmosphere. The high productivity of these forests may make them particularly responsive to the growth enhancement from rising atmospheric CO_2 concentrations (Nabuurs et al., 1997; Prentice and Lloyd 1998; Tian et al., 1998). In order to reduce carbon in the atmosphere, it is important to investigate which type of land use is suitable for long-term carbon sequestration. When native forest is converted to agroforestry and/or, agricultural land, carbon stock may decline to some extent (Price and Willis 1993). Several researchers also revealed that the promising management practices to sequester biomass, and SOC and to reduce soil degradation are adopting agroforestry system (Cannell et al., 1995; Brown et al., 1996; Batjes and Sombroek 1997; Takahashi et al., 2010).

However, little is known of how coffee based agro-forestry practices in the vicinity of Gera Native forest, south western Ethiopia affect the storage of carbon in the biomass and soil matrix. Hence, the

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present investigation was undertaken estimate the difference in carbon stock (biomass and soil) between coffee based Agroforestry land use and other land uses namely annual crop field and native forestland use systems. Research hypothesis raised here is does coffee based agroforestry land use system has higher C Stocks and sequestration potential than annual crop field and native forestlands.

II. Materials and Methods

a) General description of the study area

Gera is found in Jimma Zone of Oromiya Region, South-west Ethiopia. It is located within the longitudinal range 35° 57′ and 37° 37′ East and latitudinal range of 7° 13′ and 8° 56′ North.

The altitude of the area falls in the range between 1500–2900masl. The mean annual maximum and minimum temperature is 24.2°C and 14.2°C, respectively and mean annual rainfall is between 1800 and 2000mm. The major soil types are: *Arcisol, Nitisol* and *Leptosol*. The remnant forest vegetation at Gera area can be categorized as tropical Afromontane moist forests which have been further classified into: natural forest (virgin and disturbed) and plantation forests. The vegetation cover of the area was estimated to be 56% of the total area.

b) Research Methods

i. *Site Selection*

For this study, coffee based agroforestry, annual crop field and native forest types of land uses were considered. For selection of study site, informal survey was conducted to collect important information about the ages under particular land uses. Farmers were asked the time when they started converting the forest into coffee based agroforestry and annual crop fields. The site was selected along two altitudes: 1890 and 2100 m.a.s.l., where the three treatments were assigned. The selected annual crop fields and coffee based agroforestry are about 20 years old since converted from native forests. The native forest was also sampled adjacent to the selected land uses as control.

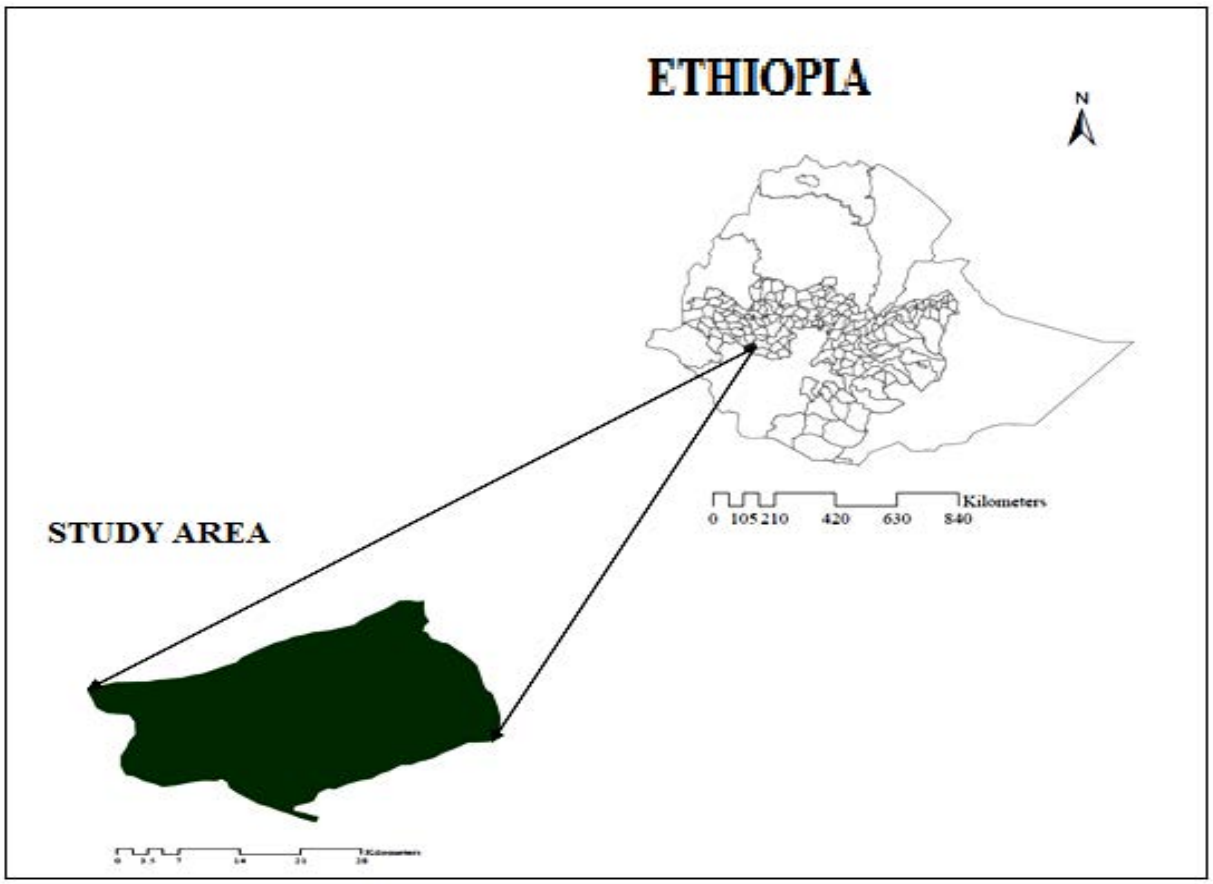

Figure 1 : Map of the study area

ii. *Plot Allocation and Measurement*

Stratified random sampling was used to collect data for the study. At each land uses, parameters were measured and their GPS coordinates were taken. Most coffee based agroforestry were rectangular in shape and large in size. A 100 m x 100 m sized plots were divided into 25 m x 25 m subplots. To choose the sample plot, each plot was numbered and lottery

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method was used for randomization. The centre points of each division were located and four subplots with 15 m x 15 m were laid out perpendicular to the borders. There were four sample plots for each land uses at each elevation and a total of twenty four sample plots were collected from the site at both elevation.

iii. *Estimating above-ground biomass*

The diameter of all trees in each plot greater than or equal to 5cm at breast height were measured by using calliper and/or tape meter. The species type was recorded and their heights were measured using hypsometers. The diameter for coffee shrub was measured at 15 cm above ground (Sugara et al., 2006), while it was at the ground level for Enset (*Ensete ventricosum*) and Banana (*Musa paradisiaca*) (Blomme et al., 2008). Based on average diameter, total height, above ground biomass and carbon stock were calculated by following appropriate allometric equations. The above ground biomass of individual tree was estimated by following Brown et al., (1989). This equation was used to estimate above ground biomass in several studies (Roshetko et al., 2002; Lascol et al., 2006).

$$Y = e^{x}\{-2.134 + 2.530 * ln\,(D)\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where D = diameter (cm) and Y = total above ground biomass in (Mgha-1).

The equation used for estimating aboveground biomass of banana, based on pseudo-stem diameter was developed in (Hairiah et al., 2001). Thus, the biomass of banana and Enset in this study were estimated following this general biomass allometric equation and then converted to C content.

$$Y = (0.0303\ D)^{2.1345} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where D is diameter (meters)

Above ground biomass of coffee plants was estimated by using the following regression formula as mentioned by Sugara et al., (2006) in shade tree coffee systems.

$$\log 10\,(B_T) = -1.113 + 1.578 * \log 10\,(d_{15}) + 0.581 * \log 10(h) \ldots\ldots\ldots 3$$

Where d15 = diameter at 15cm, h= height and BT= is total aboveground biomass.

The above-ground biomasses of all individual trees, Banana, Enset and coffee in a plot were summed to calculate total biomass for each plot, and the plot-level values of estimated above-ground biomass were then converted to biomass per hectare (Mg ha^{-1}) for each land use. Aboveground biomass was converted into C by multiplying by 0.5 (Mac Dicken 1997):

$$AGBC = Y \times 0.5 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

Where Y is total of above ground biomass in (Mg ha^{-1}), and AGBC is above ground biomass Carbon in (Mgha^{-1}).

According to Cairns et al., (1997), root biomass of tropical trees in moist area is about 22% of above ground biomass. Depending on this, root biomass of individual tree was estimated by taking 22% of the above ground biomass (root biomass = 0.22 x Y). Study by Blomme et al., (2008) indicates that, the below ground biomass for Enset and Banana (root + corm) is 35% and 31%, respectively, of their above ground biomass. In this study, below ground biomass was estimated by using these results and, then converted to biomass carbon according to equation 5. The shoot: root ratio (biomass) of coffee often assumed for tropical trees ranged between 4:1 and 2:1 (van Noordwijk et al., 2002). In this study, we have used the least ratio (4:1) for coffee below ground biomass in order to decrease overestimation and then converted it to biomass carbon following equation 5.

$$BGBC = RB \times 0.5 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

Where BGBC is below ground biomass carbon, RB is root biomass which is equal to 0.22Y.

$$TBC = AGBC + BGBC \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Where TBC is total biomass carbon.

iv. *Soil Analysis*

Soil samples were analyzed for bulk density, soil organic carbon, pH and textural fractions by removing undisturbed soil using core sampler from each land use categories. From each plot, five points were established in each direction (north, east, south and west) one meter inside the plot boundary, and one at the centre. At these five points, soil samples were collected from 0 to 30 cm depth by using soil auger. Soil samples were air dried at room temperature and were then sieved by 2 mm size mesh. The samples were

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mixed and homogenised and sub samples were taken for estimation of Carbon, pH and textural analysis. SOC was analysed according to Walkley and Black (1934), Bulk density was determined by drying the sample in an oven drier at 105°C for 24 hours. Total SOC stock per hectare ($Mgha^{-1}$) was calculated according to the following equation (Bekele, 2006):

$$SOC(Mgha^{-1}) = SOC(gKg^{-1}) \times d \times BD(g^{-3}) \times 10 \ldots\ldots\ldots\

Table 2 : Mean values of soil organic carbon (SOC) across the land use types at each elevation

Organic Carbon	Elevation (m.a.s.l)	Land uses types		
		Annual crop fields	Coffee based agroforestry	Native Forest
SOC ($Mgha^{-1}$)	1890	63.34±2.95a	90.65±8.89b	92.57±2.41bc
	2100	66.99±2.21a	94.30±5.14b	98.95±4.84bc

Note: Parameters with similar letter are not significant in each row at P <0.05

The stock of SOC results from the balance between litter input and decomposition over time (Liski et al., 2002), while stored in the soil as humus and related stable organic compounds, the C is not circulating through the atmosphere (Berg and McClaugherty 2003). As a part of the dynamic carbon cycle of forests, soil C is linked to the development of vegetation and also affected by the past events (Liski et al., 2002; Nabuurs et al., 1997). In the present study, about 31.95% of SOC was lost following conversion of native forest to annual crop field land, which was cultivated for 20 years. Consistently, conversion of native forests to annual crop field land resulted in 20-50% loss of SOC (Sampson and Scholes 2000). According to Bekele (2006), deforestation of native forest followed by 75 years of continuous cultivation depleted the SOC by 43% at Belete native forest. The loss of SOC in his study is higher than the present study, but the age of cultivation and larger soil depth might have contributed for the higher amount of loss.

The SOC was not in a linear relationship with the number of years of cultivation as indicated in a chrono-sequence study (Lemenih et al., 2004). In his study, Lemenih et al., (2004) indicated that; much of the SOC was lost in the first few decades. The lower SOC contents in crop field land sites was due to various factors such as the breakdown of aggregates because of cultivation, increase in aeration of the soil and increase in the rate of mineralization by soil micro-organisms (Balesdent et al., 1990; Lal 1999; Lemenih et al., 2004). The SOC depends on the balance between the annual input of dead plant material and the annual loss of SOC by decomposition (Nabuurs et al., 1997, McDonagh et al., 2001; Lemenih et al., 2004; Bangroo et al., 2011).

The SOC loss from the conversion of native forest to coffee based agroforestry remained very low after 20 years of cultivation following deforestation. In most terrestrial ecosystems, the majority of net primary production is shed in the form of plant litter, which originates from above and below ground plant organs. Tree species differ in their allocation of C to above and below ground components and in their fine root mortality (Cairns et al., 1997). There is also a considerable site-specific variation in the quality and quantity of litter produced by different tree species (Aerts 1997). These factors may explain the similar amounts of SOC in coffee based agroforestry as in native forest while having lower biomass C than the native forest. In addition, it may suggest that the coffee based agroforestry system protects the loss of SOC and if the annual crop field reverts to coffee based agroforestry in the study area; it could lead to SOC sequestration.

c) Total carbon stock

Total C (BC + SOC) in native forest, coffee based agroforestry and annual crop field land were 230.09 ± 27.88, 150.73 ± 12.21 and 65.40 ± 2.64 Mgha-1respectively. There were significant differences in total C between the native forest, coffee based agroforestry and annual crop field land. Further, there was no significant difference in total C between the elevations for each land uses (Fig.2). Coffee based agroforestry land uses had the second largest total C stock and has significantly higher total C than the annual crop field. The difference between native forest and coffee based agroforestry was mainly from the difference in biomass C.

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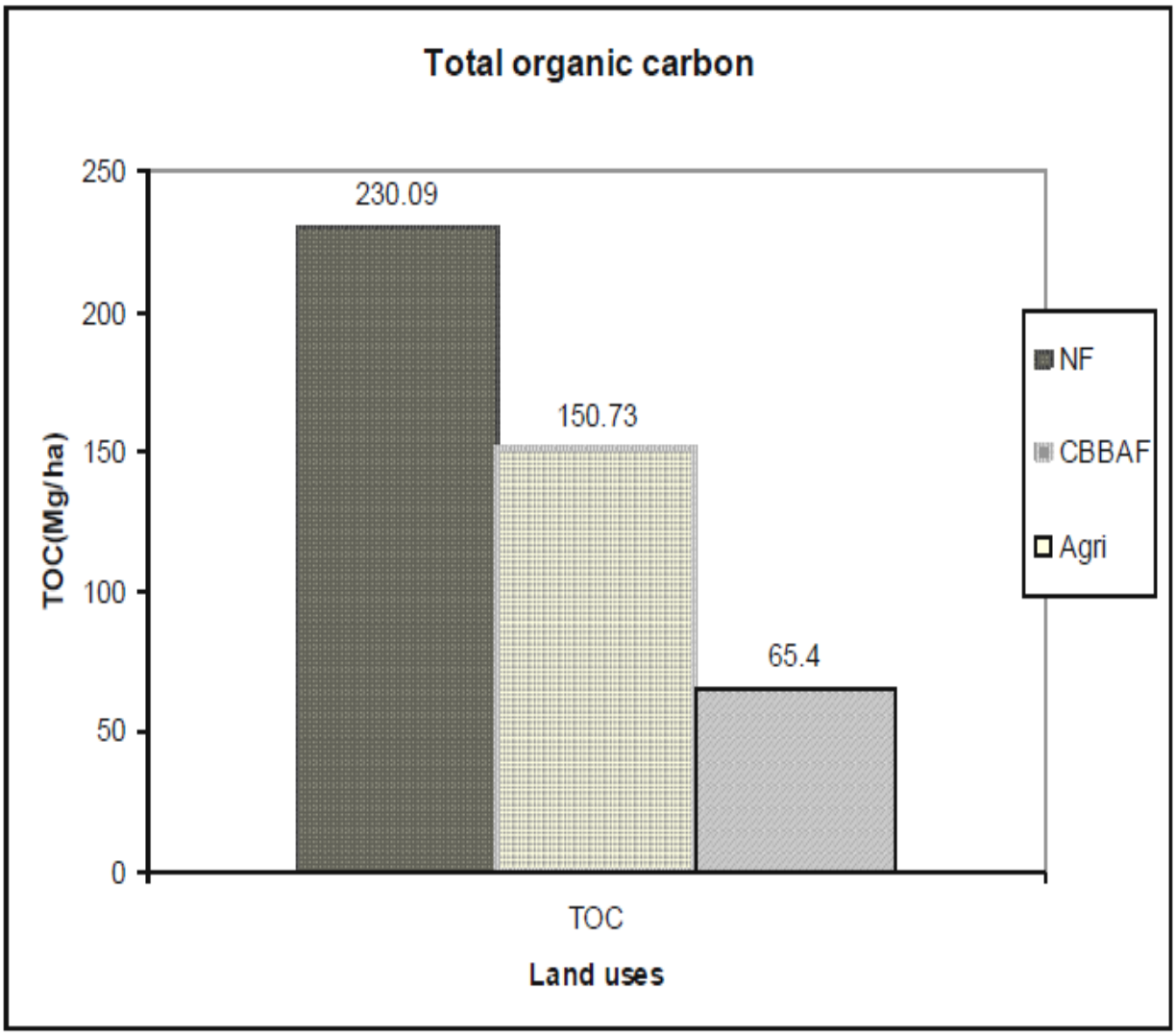

Figure 2 : TOC in each land uses

NF = native forest, CBAF= coffee-based agroforestry and, Agri= annual crop field

In agreement with this finding, Milne and Brown (1997) have shown that, forest land conversion to agroforestry would actually loose C, but to a much less extent than the conversion to annual crop field. The higher total C in coffee based agroforestry than annual crop field is because of the higher SOC as well as the higher biomass C in coffee based agroforestry as compared to that in annual crop field. The coffee based agroforestry has diverse plant communities and higher in number than that of annual crop field land. Any disturbance of vegetation or of the soil itself is likely to alter the balance between litter input to the soil and decomposition loss, and so cause a change in the reservoir of carbon (Milne and Brown 1997). Factors and processes that determine the rate of change in biomass and soil C stock influence the total C stocks.

This study did not consider C from coarse woody debris and associated necromass and this could lead to an underestimation of the total C stocks. According to Keller et al., (2000), coarse woody debris mass varied from 49.7 to 59.9 Mgha-1 in mature forest sites in Eastern Amazonia and it was about 16% of above ground biomass. Delaney and Powell (1998) also found that dead wood mass contributed 33.3 – 42.3 $Mgha^{-1}$ necromass in tropical moist and wet forest zones in Venezuela, which were 9.6 –12.4% of the total above ground biomass. However, the results of present findings indicated that, land use change mainly affects the organic carbon stock either in their biomass and soil matrices. It shows that native forest cleared for crop production and coffee based agroforestry in the study area lose high organic carbon in both biomass and soil within 20 years of subsequent cultivation after deforestation.

IV. Conclusion

The results of this finding indicated that, land use change mainly affects the organic carbon stock

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either in their biomass and soil matrices. It shows that native forest cleared for crop production and coffee based agroforestry in the study area lose high organic carbon in both biomass and soil within 20 years of subsequent cultivation after deforestation. Native forest and coffee based agroforestry have much higher biomass carbon as compared to annual crop field, and native forest has higher biomass carbon than coffee based agroforestry. On the other hand, Native forest has similar amount of SOC as that of coffee based agroforestry, and it has higher SOC than annual crop field. Major declines were observed for annual crop field, which mainly because of biomass removal which is the principal source of plant organic carbon. Despite the clear decline in SOC within 20 years, is resulted from reduced above and belowground litter inputs and increased microbial decomposition, and it may from aeration while land cultivation is undertaken. The higher total C in native forest as compared to annual crop field and coffee based agroforestry shows that; the conversion of native forest to coffee based agroforestry reduces emission of C as compared to annual crop field. In addition, the conversion of annual crop field to coffee based agroforestry can sequester large amount of C in the soil as well as in the biomass.

V. Acknowledgements

The authors would like to thank the Ethiopian ministry of education for giving support for this study and special thanks to Addis Ababa city Water works design and supervision for their technical guidance. Finally, the authors would like to thank the anonymous reviewers for their valuable feedback which helped to improve this publication.

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