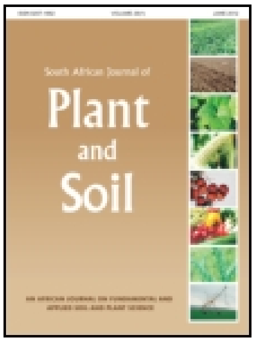


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*Short Communication*

# Carbon stocks in fynbos, pastures and vineyards on the Agulhas Plain, South Africa: a preliminary assessment

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**Large tracts of fynbos on the Agulhas Plain are being converted to agriculture. Carbon (C) stocks in fynbos, pastures and vineyards were measured in this preliminary study to determine whether conservation of fynbos results in greater C storage relative to agricultural land uses. Fynbos had greater aboveground C than pastures (12.7 ± 1.7 vs 0.8 ± 0.3 t C ha$^{-1}$), greater root C than pastures and vineyards (13.0 ± 11.7, 4.9 ± 1.4 and 0.2 ± 0.2 t C ha$^{-1}$, respectively), less soil organic C than pastures (1.26 ± 0.14 vs 2.06 ± 0.22%) and less total soil C than pastures (66.7 ± 7.2 vs 99.2 ± 10.9 t C ha$^{-1}$). The results indicate that conversion of fynbos into pastures is unlikely to result in a net loss of C stocks because reductions in aboveground biomass, litter and root C are recovered through gains in soil C. Conversion of fynbos into vineyards is likely to result in a net loss of approximately 23 t C ha$^{-1}$ in aboveground and root biomass.**

**Keywords:** aboveground biomass, agriculture, carbon sequestration, land conversion, land use, soil carbon

Expansion of agriculture is a threat to the biodiversity in fynbos vegetation of the Agulhas Plain, South Africa (Pence et al. 2003), particularly given that only 4% of this area is formally protected (Cole et al. 2000). In this preliminary investigation, the carbon (C) storage value gained from conserving fynbos was assessed compared with the establishment of new pastures or vineyards. If fynbos C stocks are greater than that of alternative land uses, C storage could be deemed to be an added benefit of fynbos conservation analogous to REDD+ (Reducing Emissions from Forest Degradation and Deforestation) (Rawat 2010). Three fynbos types representative of Agulhas Plain vegetation, namely Elim Asteraceous Fynbos (EAF), Overberg Sandstone Fynbos (OSF) and Agulhas Limestone Fynbos (ALF) (Mucina and Rutherford 2006, Euston-Brown 2007), were sampled for biomass and soil C in intact fynbos sites and converted pastures and vineyards (vegetation types are described further in Table 1). Site selection was constrained by the limited land area of certain land uses within each fynbos type. Consequently, equal replications of all land uses could not be obtained in each vegetation type. Sample sites are presented in Figure I.

Soil samples were taken with an auger (5 cm diameter) to a depth of 30 cm and analysed for root and stone content (extracted by wet sieving, <2 mm), organic C (Walkley-Black method; Walkley 1947) and particle size distribution (hydrometer method on a subset of samples; USDA 1982). Total soil C (0–30 cm) for each site was calculated using organic C, bulk density and stone volume data. Aboveground biomass in fynbos and pastures was measured through destructive harvesting of a 2 m × 2 m plot. In fynbos, litter was separated from stems and leaves. Aboveground biomass of vineyards was not measured as destructive harvesting was impractical. The effect of fynbos age on aboveground biomass was not considered in this preliminary study. Oven-dried biomass and litter was assumed to be 50% C by mass (Birdsey 1996). Significant differences ($p < 0.05$) in root and soil C were compared (1) within and between each vegetation type using one-way analysis of variance (ANOVA) and (2) between land uses with *post hoc* Tukey tests. Differences between land uses in aboveground biomass were determined using a Student's *t*-test. All statistics were conducted using STATISTICA version 10 (StatSoft, Tulsa, USA, 2010).

Fynbos vegetation had greater aboveground C than pastures (12.7 ± 1.7 vs 0.8 ± 0.3 t C ha$^{-1}$; $p = 0.001$), greater root C than pastures ($p = 0.03$) and vineyards ($p = 0.002$) (13.0 ± 11.7, 4.9 ± 1.4, and 0.2 ± 0.2 t C ha$^{-1}$, respectively), less soil organic C than pastures (1.3 ± 0.1 vs 2.1 ± 0.2%; $p = 0.013$) and less soil C stocks than pastures (66.7 ± 7.2 vs 99.2 ± 10.9 t C ha$^{-1}$; $p = 0.03$) (see Table 1). Litter comprised, on average, approximately 27% of aboveground C in fynbos. A subset of soils analysed for particle size distribution showed that fynbos soils had greater sand and lower silt content than vineyards (Table 2). Bulk densities for soils from each land use, estimated from particle size distribution data (Saxton et al. 1986), were 1.8 g cm$^{-3}$ in fynbos, 1.7 g cm$^{-3}$ in pastures and 1.4 g cm$^{-3}$ in vineyards. Fynbos soil C stocks at a depth of 30 cm were 51.6 ± 4.6, 57 ± 15.3 and 75.8 ± 9.5 t C ha$^{-1}$ in EAF, ALF and OSF, respectively.

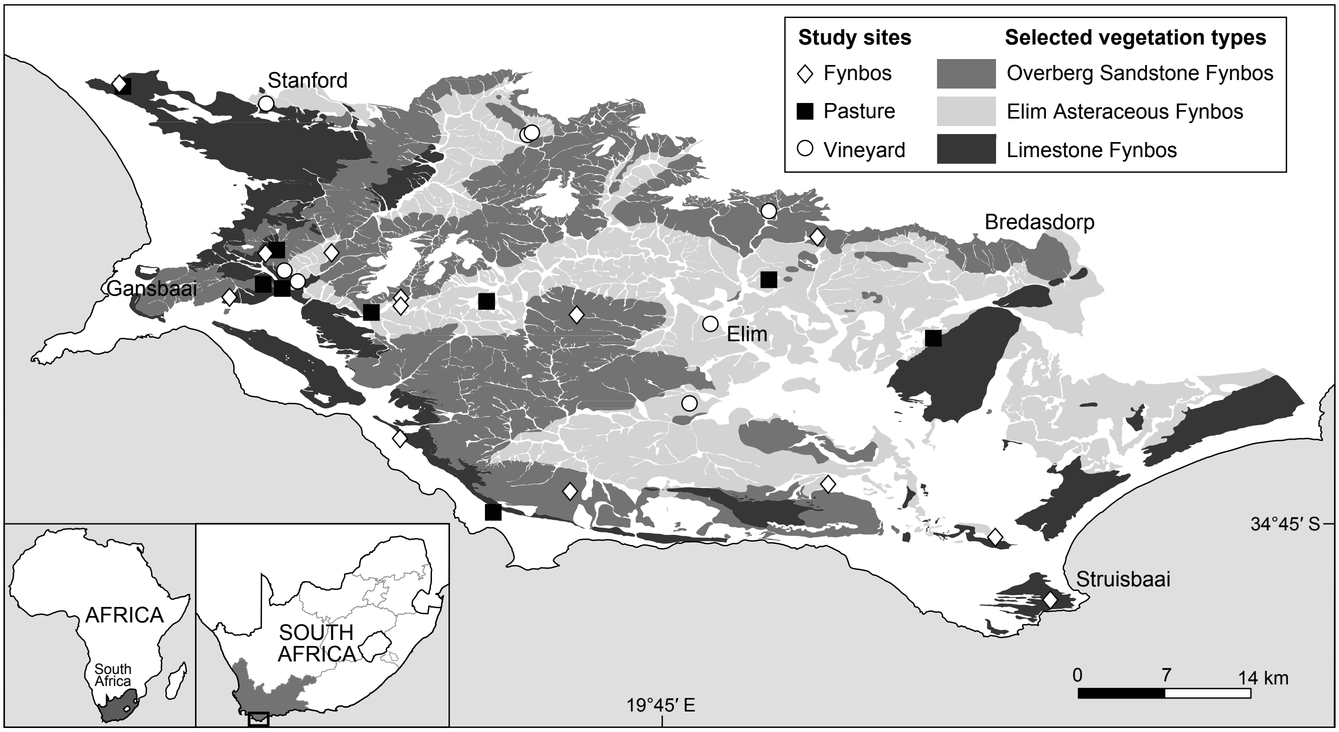


**Figure 1:** Location of the sampling sites on the Agulhas Plain, South Africa. Vegetation types are from Euston-Brown (2007) and Mucina and Rutherford (2006)

**Table 1:** Carbon stocks in fynbos, pastures and vineyards in different fynbos types. Significant differences ($p < 0.05$) are indicated by letters. Soil C measured to a depth of 30 cm

| Vegetation/ land use | Aboveground C (t C ha$^{-1}$) | | | Litter C (t C ha$^{-1}$) | | | Root C (t C ha$^{-1}$) | | | Soil C (t C ha$^{-1}$) | | | Soil C (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SE | *n* | Mean | SE | *n* | Mean | SE | *n* | Mean | SE | *n* | Mean | SE | *n* |
| **Combined fynbos types** | | | | | | | | | | | | | | | |
| Fynbos | 9.3$^{a}$ | 1.0 | 6 | 3.4 | 0.7 | 6 | 13.0$^{a}$ | 2.7 | 16 | 66.7$^{a}$ | 7.2 | 16 | 1.26$^{a}$ | 0.14 | 16 |
| Pasture | 0.8*$^{b}$ | 0.3* | 3* | | | | 4.9$^{b}$ | 1.4 | 11 | 99.2$^{b}$ | 10.9 | 11 | 2.06$^{b}$ | 0.22 | 11 |
| Vineyard 1 | | | | | | | 0.2$^{c}$ | 0.2 | 8 | 68.9$^{ab}$ | 10.9 | 8 | 1.82$^{ab}$ | 0.30 | 8 |
| Vineyard 2** | (3.2)** | | | | | | (2.78)** | | | | | | | | |
| **Overberg Sandstone Fynbos*** ** | | | | | | | | | | | | | | | |
| Fynbos | 11.6 | 0.4 | 2 | 4.8 | 1.6 | 2 | 13.3$^{a}$ | 4.6 | 5 | 83.8 | 10.4 | 5 | 1.56 | 0.19 | 5 |
| Pasture | 1.4* | | 1* | | | | 2.0$^{b}$ | 0.4 | 3 | 88.7 | 23.4 | 3 | 1.77 | 0.46 | 3 |
| Vineyard | | | | | | | 0.9$^{b}$ | 0.9 | 2 | 81.6 | 38.6 | 2 | 2.21 | 1.08 | 2 |
| **Elim Asteraceous Fynbos*** ** | | | | | | | | | | | | | | | |
| Fynbos | 6.5 | 0.4 | 2 | 1.9 | 0.1 | 2 | 4.4$^{a}$ | 1.6 | 5 | 55.2 | 5.3 | 5 | 1.06$^{a}$ | 0.09 | 5 |
| Pasture | 0.4* | | 1* | | | | 2.8$^{ab}$ | 0.9 | 5 | 100.8 | 9.2 | 4 | 2.20$^{b}$ | 0.39 | 5 |
| Vineyard | | | | | | | 0.0$^{b}$ | 0.0 | 6 | 64.6 | 10.5 | 6 | 1.69$^{ab}$ | 0.27 | 6 |
| **Agulhas Limestone Fynbos*** ** | | | | | | | | | | | | | | | |
| Fynbos | 9.9 | 0.9 | 2 | 3.4 | 0.9 | 2 | 19.9 | 4.4 | 6 | 62.0 | 15.9 | 6 | 1.17 | 0.31 | 6 |
| Pasture | 0.6* | | 1* | | | | 11.4 | 2.3 | 3 | 107.1 | 17.4 | 3 | 2.14 | 0.36 | 3 |

* The aboveground biomass and litter in pastures are combined

** Default root and shoot estimates for vineyards are derived from Carlisle et al. (2010)

*** Three fynbos types representative of Agulhas Plain vegetation, namely Elim Asteraceous Fynbos (EAF), Overberg Sandstone Fynbos (OSF) and Agulhas Limestone Fynbos (ALF) (Euston-Brown 2007). Mucina and Rutherford (2006) described the vegetation categories as follows. OSF = Moderately tall, dense restioid, ericoid-leaved and proteoid shrublands. Acidic lithosol soils derived from Ordovician sandstones of the Table Mountain Group. ALF = Moderately dense, low shrublands contain tall emergent proteoids. Soils are alkaline grey regic sands on Bredasdorp Formation limestone. EAF = Also classified as 'Elim Ferricrete Fynbos'; open to closed dwarf shrubland with occasional scattered tall shrubs; extensive areas of asteraceous fynbos dominated by low proteoid elements. Soils are Glenrosa and Mispah and prismacutanic and pedocutanic soils derived from Bokkeveld Shale, Cape Granite, ferricrete and silcrete

**Table 2:** Sand, silt and clay content in fynbos, pastures and vineyards in different fynbos types. Significant differences ($p < 0.05$) in root and soil C were compared (1) within and between each vegetation type using one-way ANOVA and (2) between land uses with *post hoc* Tukey tests. Significant differences are indicated by letters

| Vegetation/ land use | Sand | | | Silt | | | Clay | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SE | *n* | Mean | SE | *n* | Mean | SE | *n* |
| Fynbos | 93.3$^{a}$ | 1.4 | 6 | 3.72$^{a}$ | 1.2 | 6 | 3.0 | 0.8 | 6 |
| Pasture | 75.2$^{ab}$ | 7.2 | 9 | 17.5$^{ab}$ | 5.7 | 9 | 7.3 | 2.4 | 9 |
| Vineyard | 52.5$^{b}$ | 9.4 | 6 | 35.6$^{b}$ | 7.7 | 6 | 12.0 | 4.1 | 6 |

Differences in soil C stocks between vegetation types were not significant.

In this preliminary study, conversion of fynbos to pastures and vineyards was shown to influence ecosystem C stocks. Fynbos conversion to pasture reduced aboveground C by approximately 12 t C ha$^{-1}$. The relatively small loss of C (compared to conversion of forest or thicket; Mills and Cowling 2010) is expected given that fynbos has relatively small quantities of aboveground biomass (van Wilgen 1982, Baritz et al. 2010). We estimated the loss of aboveground C from conversion of fynbos to vineyards to be approximately 10 t C ha$^{-1}$ assuming that aboveground C in vineyards is approximately 2–3.2 t C ha$^{-1}$ (Nendel and Kersebaum 2004, Carlisle et al. 2010). Root C decreased by approximately 8 t C ha$^{-1}$ with conversion of fynbos to pastures. In vineyards the small size and negligible quantity of roots sampled was unexpected and suggests that sampling was insufficient to reflect vineyard root distribution. Based on an average estimate of vineyard biomass and root:shoot ratios (Carlisle et al. 2010) we estimate that root C decreased by approximately 10–13 t C ha$^{-1}$ with conversion of fynbos to vineyards. Conversion of fynbos into pastures and vineyards consequently resulted in an estimated net biomass loss of approximately 20 and 23 t C ha$^{-1}$, respectively. We note that these estimates need to be refined to account for fire history of fynbos and further quantification of vineyard biomass.

Soil C stocks in pastures were approximately 32 t C ha$^{-1}$ greater than in fynbos. The increase in soil C stocks after conversion to pastures is likely to be a result of the dense root structure of grasses (see e.g. Post and Kwon 2000) and relatively fast growth rates of pasture as a result of fertiliser inputs (Mills and Fey 2003). The greater clay content and generally finer texture (Table 2) of pastures relative to fynbos soils is also likely to be a contributing factor to the greater sequestration of soil C (Percival et al. 2000). Further research is required to quantify the influence of both pasture grass structure and growth rates versus soil texture on soil C stocks.

The results of our study indicate that the net effect of fynbos conversion to pastures on total C stocks is likely to be minor relative to conversion to vineyards and that the wildflower industry could potentially generate a net C saving by reducing conversion of fynbos to vineyards on the Agulhas Plain. Quantifying the amount of C that is likely to be lost through this conversion will require further research into socioeconomic factors such as the likelihood of vineyard expansion into fynbos landscapes as well as more detailed studies on above- and below-ground C in existing vineyards.

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