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# COMPARATIVE ASSESSMENT OF REGULATORY AND PROVISIONING ECOSYSTEM SERVICES IN FOREST AND OPEN LANDSCAPES OF SOON VALLEY, PAKISTAN

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## Abstract

*Ecosystem services are crucial for sustaining environmental stability and supporting human well-being, especially in semiarid settings. This study assessed major provisioning (fodder biomass, soil organic matter) and regulating (soil temperature, soil moisture) ecosystem services in both vegetated and open land systems in the Soon Valley, Punjab. A comparative field-based approach was used, with soil samples collected from 0 to 15 cm depth and analysed using conventional procedures such as the Walkley-Black method for soil organic matter and gravimetric analysis for moisture content. The results found considerable disparities between land use categories. The mean soil temperature was much lower under vegetation (36.08°C) than on open ground (39.17 °C), with a very significant change ($F = 66.86$, $p = 0.001$). The soil moisture content was consistently greater beneath vegetation, ranging from 24.5 to 34.3%, whereas open land had lower values (17.0-25.9%). Soil organic matter (SOM) was significantly higher in vegetated regions (0.65-0.92%) than in open sites (0.45-0.69%), as confirmed by ANOVA ($F = 62.23$, $p < 0.001$). Vegetated systems had higher fodder biomass (338-528 g $m^{-2}$) than open land (198-335 g $m^{-2}$), suggesting better provisioning capability. These data show that vegetation greatly improves soil microclimatic conditions, increases moisture retention and carbon storage, and promotes higher biomass production. The study emphasizes the importance of vegetation in supporting ecosystem services and the necessity for appropriate land management measures to reduce environmental degradation in semiarid ecosystems.*

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## Introduction

Ecosystem services are generally defined as the benefits provided by ecosystems to humans, i.e., they contribute to making human life both possible and worth living (IPBES, 2019; Díaz et al., 2018). The Millennium Ecosystem Assessment framework identified ecosystem services within four categories: provisioning services, such as food and water, and regulating services, such as flood and disease control. The advantages that humans receive from natural ecosystems that support the survival and well-being of species on Earth are commonly referred to as ecosystem services. These services encompass the ecological conditions and processes that allow ecosystems to sustain and meet human needs, from social and economic advancement to fundamental survival. Ecosystem services are divided into four main categories by the global framework created by the Millennium Ecosystem Assessment: provisioning services (such as food, water, and raw materials), regulating services (such as flood control, disease mitigation, and climate regulation), supporting services, and cultural services. In semiarid areas, where natural resources are scarce and environmental stress is high, supplying and regulating services are especially important (IPBES, 2019; Foley et al., 2018).

Numerous ecosystem services can be measured directly, particularly provisioning services such as crop production, water availability, and fodder biomass. However, because they preserve ecosystem stability and production, managing services such as soil temperature moderation, moisture retention, and nutrient cycling are equally crucial (Kandziora et al., 2013; Wang et al., 2024). By affecting the soil microclimate, decreasing erosion, and improving water infiltration, vegetation plays a crucial role in controlling these processes. According to recent research, vegetation cover greatly lowers soil temperature and protects against environmental extremes, which promotes microbial activity and nutrient cycling (Zhang et al., 2024; Zhao et al., 2022).

Another important ecosystem function that is impacted by vegetation is water regulation. By minimizing nutrient runoff, lowering soil disturbance, and regulating sediment movement, vegetative and forested systems enhance water quality. However, by increasing evapotranspiration, they may also change hydrological dynamics and, under some circumstances, lower surface runoff and groundwater recharge (Calder et al., 2008; Liu et al., 2025).

According to recent studies, plant–soil interactions have a significant impact on greenhouse gas dynamics and carbon cycling, which helps regulate the global climate (Sun, 2025; Du et al., 2024).

The integration of ecological processes with human activities forms complex socioecological systems, where sustainable management is required to maintain ecosystem services. Recent advances in ecosystem science emphasize adaptive management approaches that consider the dynamic interactions between ecological and human systems (IPBES, 2019; Wang et al., 2024).

The current study intends to assess the primary provisioning (soil organic matter, fodder biomass) and regulating (soil temperature, soil moisture) ecosystem services across vegetated and open land. This study will highlight the significance of sustainable land management techniques in semiarid regions and offer up-to-date scientific insights into vegetation–soil interactions.

## Materials and Methods

The study was carried out in Punjab, Pakistan's Soon Valley, which is part of the Salt Range. The region has a semiarid climate with significant seasonal temperature variations. There are a variety of landforms in the valley, such as open spaces and wooded areas. Woody flora predominates in forest zones, whereas grasses and scant plant cover predominate in open areas. The region is appropriate for a comparative evaluation of ecosystem services because of these disparate biological circumstances.

### Design for Sampling

To study differences in the open and forest environments, sampling methods were employed using a comparative approach. To ensure that the

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samples were unbiased, samples were randomly selected from the two land use types. Multiple sampling points were established for every type of landscape. All observations and sample collection were performed under similar conditions in the environment.

**Vegetation Analysis**

To obtain an understanding of the total plant cover and characteristics of the landscapes, qualitative observation of the vegetation was undertaken at every sampling point. Vegetation was considered one of the supporting components in analysing environmental aspects and services without quantifying the vegetation through phytosociological characteristics. Fieldwork indicated differences in the vegetation cover among the open and forest environments.

**Evaluation of Provisioning Services**

Through observations from fieldwork, the evaluation of provisioning services was conducted indirectly. In view of the many types of herbaceous plants present, open landscapes were seen to provide animal grazing possibilities, while forest landscapes did not provide any direct provisioning services. Quantitative analysis was not conducted for this particular process since the study focused on overall resource availability.

**Measurement of Soil Organic Matter**

To measure the soil organic matter, the Walkley-Black procedure was employed. Samples of soil collected from each quadrat (to a depth of 0-15 cm) were air dried, powdered and sieved to remove impurities. Following the application of potassium dichromate and sulfuric acid to a known quantity of soil sample, the organic carbon content was estimated by means of titration. The measurement of organic carbon was carried out using the titration method after adding potassium dichromate and sulfuric acid to a fixed volume of soil. The percentage of organic matter was calculated based on the results obtained for organic carbon. The fertility and nutritional status of the soils from both land use categories were determined using this technique.

**Fodder Biomass Estimation**

To measure the biomass of the feed, aboveground vegetation was collected from each quadrant. A digital scale was used to weigh the gathered foliage to calculate the fresh biomass in grams per square meter. Grams per square meter were used to calculate the biomass.

**Assessment of Regulatory Services**

Regulatory ecosystem services were evaluated using environmental features that were measured during the study.

**Soil Temperature Measurement**

A digital thermometer was used to measure the temperature of the soil in each quadrat. To guarantee consistency across all sampling locations, readings were obtained at a consistent soil depth. To prevent the impacts of diurnal variation, measurements were taken at comparable periods of the day.

The temperature of the soil was measured in nearby open spaces as well as beneath vegetative land. The impact of vegetation on microclimatic conditions was assessed using the gathered data.

**Moisture Content**

Standard gravimetric techniques were used to determine the moisture content of the soil. At a depth of 0 to 15 cm, soil samples were taken from each quadrat. As soon as the samples were collected, their fresh weight was noted. After that, the samples were oven-dried at 105°C until they reached a consistent weight. The difference between fresh and dry weight in relation to dry weight was used to calculate the moisture content (%). Both vegetation and open land samples were measured.

**RESULTS AND DISCUSSION**

The results of floristic data and soil analysis are given in this chapter. The following points have been emphasized.

- Estimation of Regulatory ecosystem services (Temperature)
- Estimation of provisional ecosystem services (soil organic matter)

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**Estimation of regulatory ecosystem services (temperature)**

**Table 1: Table showing the soil temperature at Jabba site**

| Quadrat | Soil Temperature beneath the plant(°C) | Soil Temperature at open area(°C) |
|---|---|---|
| 1 | 36.2 °C | 38.9 °C |
| 2 | 37.4 °C | 39.7 °C |
| 3 | 35.3 °C | 39.9 °C |
| 4 | 34.6 °C | 40.1 °C |
| 5 | 36.8 °C | 40.3 °C |

**Table 2: Table showing the soil temperature at Khabikki site**

| Quadrat | Soil Temperature beneath the plant(°C) | Soil Temperature at open area(°C) |
|---|---|---|
| 1 | 35.1 °C | 38.4 °C |
| 2 | 36.2 °C | 39.7 °C |
| 3 | 37.3 °C | 40.1 °C |
| 4 | 36.8 °C | 39.3 °C |
| 5 | 33.4 °C | 37.9 °C |

**Table 3: Soil temperature at the Kanhati site**

| Quadrat | Soil Temperature beneath the plant(°C) | Soil Temperature at open area(°C) |
|---|---|---|
| 1 | 35.3 °C | 39.9 °C |
| 2 | 36.2 °C | 38.5 °C |
| 3 | 34.3 °C | 36.4 °C |
| 4 | 37.2 °C | 38.8 °C |
| 5 | 35.1 °C | 39.7 °C |

**Soil Temperature at the Jabba Site**

Soil temperature variations for the Jabba site with open and vegetated areas are provided in Table 1. The soil temperature for vegetated land showed slight variation among quadrants, fluctuating between 34.6 °C and 37.4 °C. Quadrants 2 and 4 recorded the highest and lowest values of 37.4 °C and 34.6 °C, respectively. The other quadrants, such as 36.2 °C, 35.3 °C, and 36.8°C, exhibited average values. On the other hand, the soil temperature for open land was found to be considerably higher, fluctuating between 38.9 °C and 40.3 °C. Open spaces showed an increase in heating, as indicated by the maximum value of 40.3 °C in quadrant 5 and minimum value of 38.9 °C in quadrant 1.

**Khabikki Site Soil Temperature**

Table 2 shows the fluctuations in the soil temperature for vegetated and nonvegetated lands at the Khabikki site. The soil temperature for vegetative lands fluctuated between 33.4°C and 37.3°C. Quadrat 3 was found to have the highest temperature of 37.3°C, while quadrat 5 had the lowest temperature of 33.4°C. All other quadrats had little variation in their soil temperatures, which ranged between 35.1°C and 36.8°C. The temperatures for open land ranged between 37.9°C and 40.1°C, with quadrats 3 and 5 recording the highest temperatures of 40.1°C and 37.9°C, respectively. Unlike in vegetative cover, there is a clear increase in temperature for open land.

**Soil Temperature of the Kanhati Site**

The soil temperature variations at the Kanhati site are presented in Table 3. Vegetated land had temperatures varying from 34.3°C to 37.2°C, where quadrat 4 was the hottest and quadrat 3 was the coldest. Others included 35.3°C, 36.2°C, and 35.1°C, with moderate temperatures. Open land had temperatures higher than those in vegetated land, varying from 36.4°C to 39.9°C. Quadrat 1 was the hottest, with a temperature of

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39.9°C, while quadrat 3 was the coldest, with a temperature of 36.4°C.

**Table 4: Comparison of Temperature between the Study Sites**

The comparison of temperature between the study sites shows a highly significant value of 0.001.

| | N | Mean | Std. Deviation | Std. Error | 95% Confidence Interval for Mean | | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound | | |
| **Vegetative Land** | 3 | 36.08 | .330 | .191 | 35.26 | 36.90 | 36 | 36 |
| **Open Land** | 3 | 39.17 | .566 | .327 | 37.77 | 40.58 | 39 | 40 |
| **Total** | 6 | 37.63 | 1.744 | .712 | 35.80 | 39.46 | 36 | 40 |

**Table 5: ANOVA**

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| **Between Groups** | 14.353 | 1 | 14.353 | 66.862 | .001 |
| **Within Groups** | .859 | 4 | .215 | | |
| **Total** | 15.212 | 5 | | | |

**Temperature Comparisons of the Soils at Different Research Locations**

Temperature comparisons between open and vegetated lands in general at different research locations are presented in Table 4. While open land had a higher average temperature of 39.17°C, vegetated land had an average temperature of 36.08°C. The standard deviations of both groups suggest relatively small variances. In addition, the confidence interval for vegetative land lies between 35.26 and 36.90°C, while that of open land is between 37.77 and 40.58°C. This clearly illustrates that various forms of land use have distinct temperatures. Vegetated land typically has lower temperatures than open ground.

**Soil Temperature ANOVA**

The soil temperature ANOVA results are presented in Table 5. As revealed from the study, vegetative and open lands were significantly different (p = 0.001). There was a great variance between the two land forms, considering that the between-group sum of squares was 14.353. This was even made stronger by the high value of F (66.862). There is evidence of very little variability within the groups because of the mean square of 0.215. From these results, it is evident

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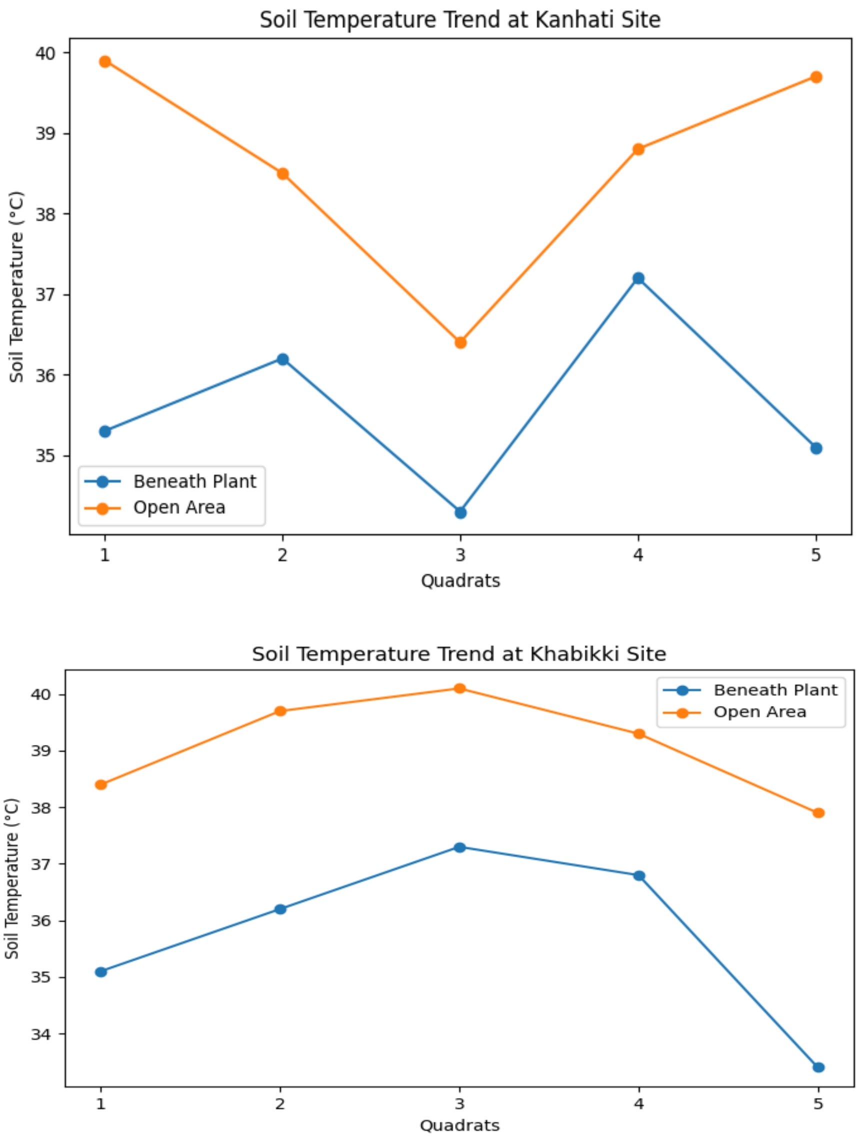


**Figure 1 (1a-1b) a) Soil temperature trend at Jabba site b) Soil temperature trend at Khabikki site**

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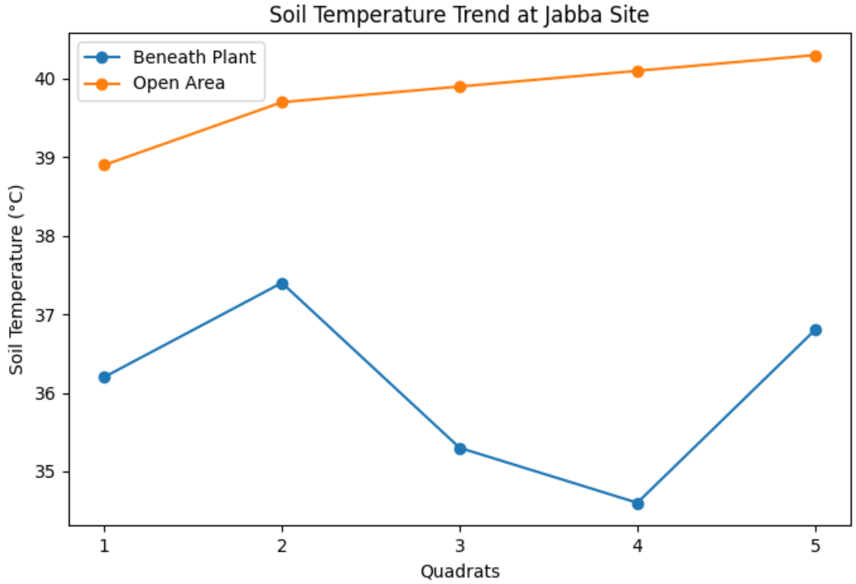


**Figure 2: Soil temperature trend at the Kanhati site**

Table 6: Moisture content at the Jabba site

| Quadrat | Beneath Plant (%) | Open Area (%) |
|---|---|---|
| 1 | 33.8 | 24.5 |
| 2 | 34.1 | 25.9 |
| 3 | 32 | 23.7 |
| 4 | 33 | 24.4 |
| 5 | 34.3 | 25.3 |

Table 7: Moisture content at the Khabikki site

| Quadrat | Beneath Plant (%) | Open Area (%) |
|---|---|---|
| 1 | 29.9 | 21.5 |
| 2 | 30.5 | 22.7 |
| 3 | 28.3 | 20.6 |
| 4 | 31.2 | 22.4 |
| 5 | 29.6 | 21.2 |

Table 8: Moisture Content at the Kanhati site

| Quadrat | Beneath Plant (%) | Open Area (%) |
|---|---|---|
| 1 | 26.5 | 18.1 |
| 2 | 27.2 | 19.8 |
| 3 | 24.5 | 17 |

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| | | |
|---|---|---|
| 4 | 26.1 | 18.4 |
| 5 | 25.7 | 18.9 |

**Soil Moisture Composition**

**Moisture Content at Jabba Location**

The soil moisture composition for the Jabba location can be seen in Table 6 above. The moisture content for areas covered with vegetation was between 32.0% and 34.3%, which shows that moisture retention in such areas is relatively high. In quadrat 5, the maximum moisture content of 34.3% was recorded, while the minimum was recorded in quadrat 3, where it was 32.0%. In other quadrats, there were steady moisture contents at approximately 33%. For open lands, on the other hand, the moisture content was much lower, between 23.7% and 25.9%.

**Moisture Content at the Khabikki Site**

The moisture content of the Khabikki site is depicted in Table 7. In the case of vegetated land, the moisture percentage varied from 28.3% to 31.2%, with quadrat 4 registering the maximum moisture content while quadrat 3 recorded the minimum moisture content. Other quadrats had moderately different moisture percentages ranging from 29 to 30%. The moisture content of open land showed a significant difference, ranging from 20.6% to 22.7%, with quadrats 2 and 3 showing the maximum (22.7%) and minimum (20.6%), respectively.

**Moisture Content of the Kanhati Site**

The moisture content of the soil found at the Kanhati site is illustrated in Table 8. The percentage of moisture content for vegetated land ranged between 24.5% and 27.2%, with quadrat 2 containing the highest amount of moisture, while quadrat 3 contained the least. Stability was demonstrated by other figures that remained within a narrow range. The open land moisture content was relatively low, with values falling between 17.0% and 19.8%. Quadrats 2 and 3 had the highest (19.8%) and lowest (17.0%), respectively.

**Table 9: Comparison of Moisture content between the Study Sites**

| Group | N | Mean | Std. Deviation | Std. Error | 95% CI Lower | 95% CI Upper | Min | Max |
|---|---|---|---|---|---|---|---|---|
| Vegetative Land (Beneath Plant) | 3 | 428 | 78.01 | 45.04 | 233.83 | 622.17 | 355 | 510 |
| Open Land | 3 | 262.67 | 50.5 | 29.15 | 136.99 | 388.35 | 198 | 335 |
| Total | 6 | 345.33 | 98.41 | 40.17 | 242.16 | 448.51 | 198 | 510 |

**Comparison of Moisture Content in Various Research Locations**

The table below shows the moisture content comparison in different research locations. The mean moisture level of vegetative land was higher (428) than that of open land (262.67). This can be seen from the standard deviation levels. Open land has a confidence interval range of 136.99 and 388.35, while that of vegetative land is 233.83 and 622.17. This can also be seen from the lowest and highest moisture levels. Vegetation increases soil moisture levels significantly.

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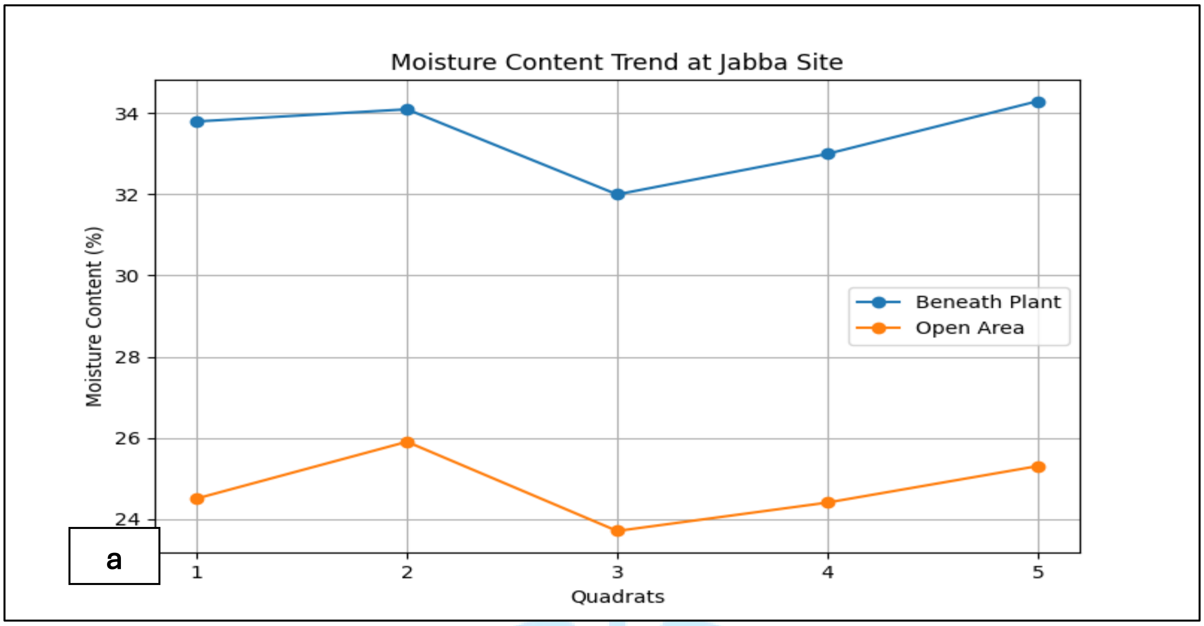


**Figure 3 (3a-3b): a) Moisture content trend at Jabba site b) Moisture content trend at Khabikki site**

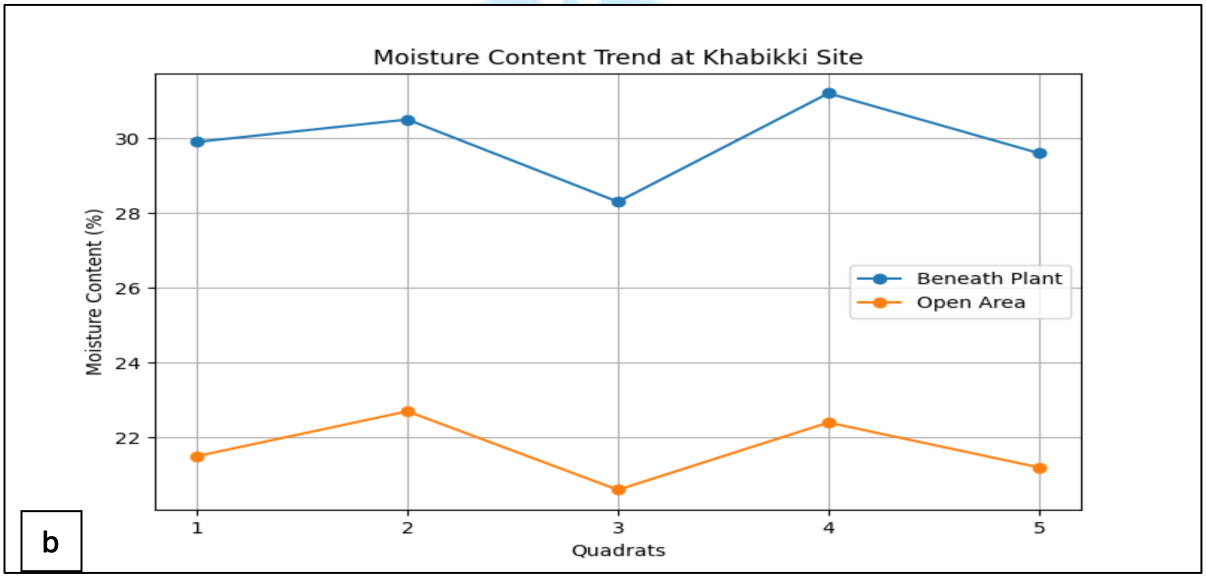


**Figure 4: Moisture content at the Kanhati site**

**Estimation of provisional ecosystem services (soil organic matter)**

**Determination of soil organic matter at the Jabba site**

In forest area quadrats, soil organic matter ranged from 0.65 to 0.89% with a mean value of 0.76%. The maximum soil organic matter recorded in quadrat five was 0.89%, and the minimum organic matter recorded in quadrat two was 0.65% at the forest site. In open land, the soil organic matter ranged from 0.47 to 0.69% with a mean value of 0.58%. The soil organic matter at the open site was a maximum in quadrat one

(0.47%), and a minimum was recorded in quadrat five (0.69%).

**Table 10: Table showing the soil organic matter at Jabba site**

| Quadrat | Soil organic matter in Forest area(%) | Soil organic matter in open area (%) |
|---|---|---|
| 1 | 0.68 | 0.47 |
| 2 | 0.65 | 0.51 |
| 3 | 0.78 | 0.63 |
| 4 | 0.83 | 0.62 |
| 5 | 0.89 | 0.69 |

**Table 11: Table showing the soil organic matter at Khabikki site**

| Quadrat | Soil organic matter in forest area(%) | Soil organic matter in open area(%) |
|---|---|---|
| 1 | 0.89 | 0.61 |
| 2 | 0.87 | 0.63 |
| 3 | 0.81 | 0.49 |
| 4 | 0.91 | 0.53 |
| 5 | 0.85 | 0.57 |

**Table 12: Soil organic matter at the Kanhati site**

| Quadrat | Soil organic matter in forest area (%) | Soil organic matter in open area (%) |
|---|---|---|
| 1 | 0.92 | 0.61 |
| 2 | 0.87 | 0.57 |
| 3 | 0.75 | 0.48 |
| 4 | 0.69 | 0.45 |
| 5 | 0.80 | 0.60 |

## Ecosystem Service Provision

### Organic Matter in the Soil

### Organic Matter in the Soil at the Jabba Site

The organic matter in the soil of the Jabba site is presented in Table 10. The SOM of vegetative land ranged between 0.65% and 0.89%, while the highest SOM content was noted for quadrat 5 and the lowest for quadrat 2. The remaining quadrats yielded moderate values between 0.68% and 0.83%. The SOM of open land was relatively low in comparison to vegetative land, ranging between 0.47% and 0.69%, and for quadrats 5 and 1, the highest and lowest values were registered, respectively.

### Organic matter at the Khabikki site

The data on soil organic matter (SOM) at the Khabikki site are presented in Table 11 below. The range of soil organic matter in the vegetated land is between 0.81% and 0.91%, whereby quadrat 4 has the maximum value, while quadrat 3 has the minimum value. The rest of the quadrats retained a value of approximately 0.85%. In the open land, the soil organic matter is relatively low, varying from 0.49% to 0.63%.

### Soil Organic Matter of the Kanhati Site

The data on soil organic matter content at the Kanhati site are presented in Table 12. The percentage of vegetative land was between 0.69% and 0.92%, where the largest value was found for quadrat 1 and the smallest for quadrat 4. All other percentages were within the 0.75%–0.87% range. Open land exhibited low amounts of organic matter, ranging from 0.45% to 0.61%.

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Quadrat 1 showed the largest number, while quadrat 4 had the smallest.

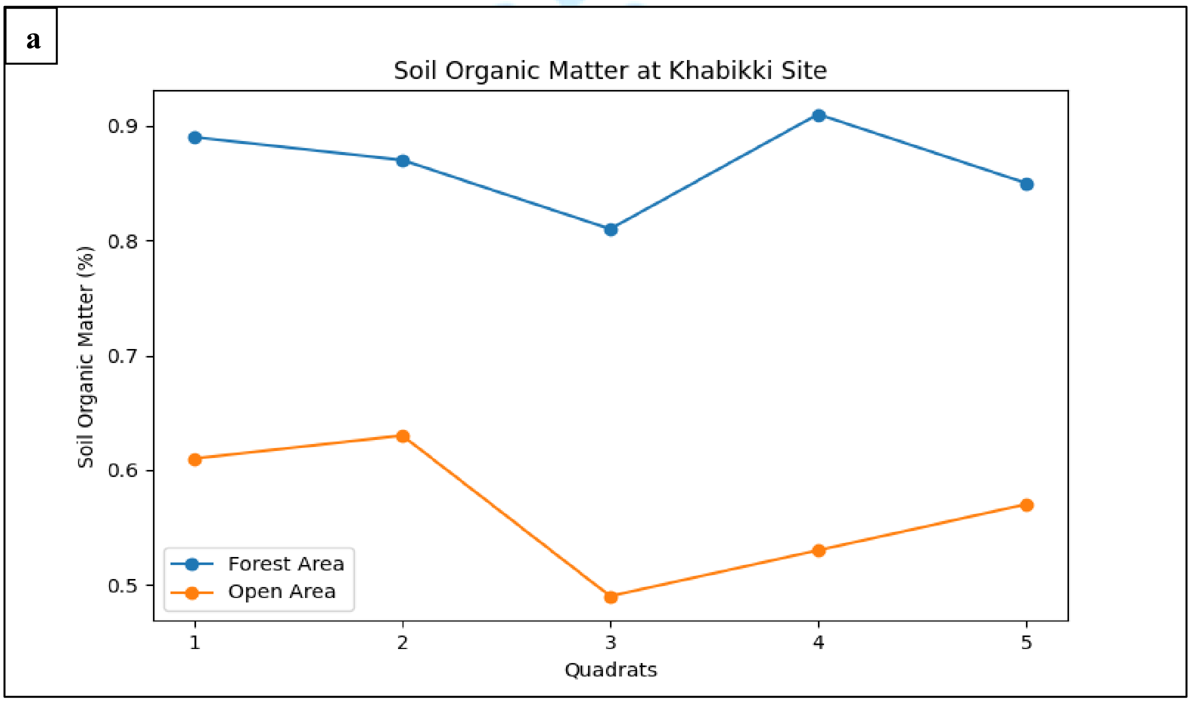
**Table 13: Comparison of soil organic matter between the sites**

The comparison of soil organic matter shows a highly significant value of 0.001.

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| **Between Groups** | .091 | 1 | .091 | 62.227 | .001 |
| **Within Groups** | .006 | 4 | .001 | | |
| **Total** | .097 | 5 | | | |

**ANOVA for Soil Organic Matter**

The results from the ANOVA test for soil organic matter are provided in Table 13. It was observed that there was a high level of significance (p = 0.001) between vegetative and open lands in this particular study. High variation among groups is reflected in the value of F (62.227). Between-group variation was higher than within-group variation. This shows that the nature of land usage significantly influences soil organic matter. The SOM was higher in vegetative lands than in open lands.



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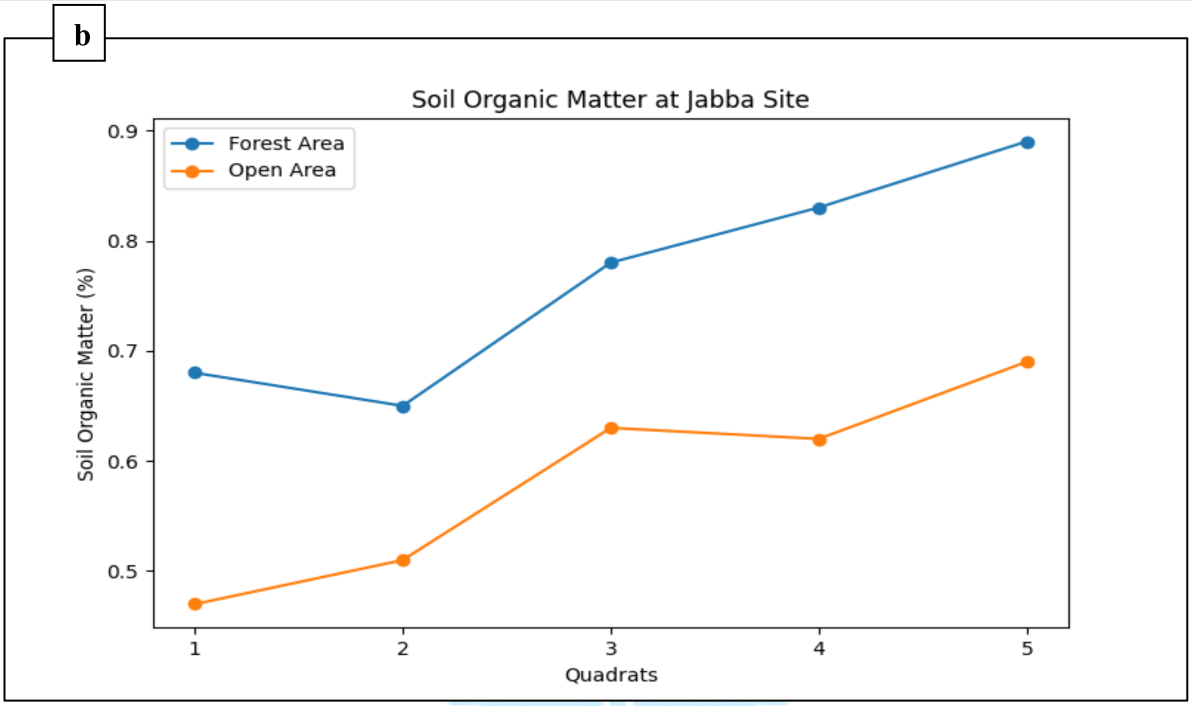


Figure 5 (5a-5b) a) Soil organic matter at Jabba site b) Soil organic matter at Khabikki site

Figure 6: Soil organic matter at the Kanhati site

Table 14: Fodder at the Jabba site

| Quadrat | Fodder in forest area | Open area (g/m²) |
|---|---|---|
| 1 | 505 | 318 |
| 2 | 528 | 335 |
| 3 | 490 | 308 |
| 4 | 515 | 327 |
| 5 | 500 | 322 |

Table 15: Table showing the Fodder at the Khabikki site

| Quadrat | Fodder in forest area | Open area (g/m²) |
|---|---|---|
| 1 | 415 | 258 |
| 2 | 438 | 272 |
| 3 | 402 | 248 |
| 4 | 427 | 262 |
| 5 | 410 | 252 |

Table 16: Fodder at the Kanhati site

| Quadrat | Fodder in forest area | Open area (g/m²) |
|---|---|---|
| 1 | 355 | 208 |

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| | | |
|---|---|---|
| 2 | 370 | 222 |
| 3 | 338 | 198 |
| 4 | 348 | 212 |
| 5 | 342 | 204 |

**Biomass as Fodder**

**Fodder at the Jabba Study Site**

The biomass of fodder at the Jabba study site is presented in Table 14. The biomass of fodder in vegetative land ranged between 490 and 528 g/m², where quadrat 2 had the highest biomass and quadrat 3 had the lowest. Quadrats other than these had an average of approximately 500 g/m². The biomass of fodder on the open ground was considerably lower, varying between 308 and 335 g/m², where quadrat 2 had the highest and quadrat 3 had the lowest, being 335 and 308 g/m², respectively.

**Khabikki Site Fodder**

The biomass of fodder at the Khabikki site is presented in Table 15. The biomass of the vegetative land ranged between 402 g/m² and 438 g/m², where quadrat 2 showed the maximum biomass, while quadrat 3 indicated the minimum biomass. The values of biomass in other quadrats ranged from 410 g/m² to 427 g/m². For the open land, the lower biomass ranged between 248 g/m² and 272 g/m².

**Kanhati Fodder for Livestock**

The data relating to fodder biomass at the Kanhati site are provided in Table 16. Quadrats 2 and 3 showed maximum and minimum amounts of vegetative land of 338 g/m² to 370 g/m², while the other quadrats showed values of 342 g/m² to 355 g/m². The minimum and maximum values of open land were 198 g/m² and 222 g/m², respectively. Open land showed a maximum value (222 g/m²) in Quadrat 2, while Quadrat 3 showed a minimum value (198 g/m²).

**Table 17: Comparison of Fodder between the Study Sites**

| Group | N | Mean | Std. Deviation | Std. Error | 95% CI Lower | 95% CI Upper | Min | Max |
|---|---|---|---|---|---|---|---|---|
| Vegetative Land | 3 | 31.11 | 3.37 | 1.95 | 22.72 | 39.5 | 24.5 | 34.3 |
| Open Land | 3 | 21.55 | 2.99 | 1.73 | 14.1 | 29 | 17 | 25.9 |
| Total | 6 | 26.33 | 5.7 | 2.33 | 20.34 | 32.32 | 17 | 34.3 |

**Fodder Biomass Comparison at the Research Sites**

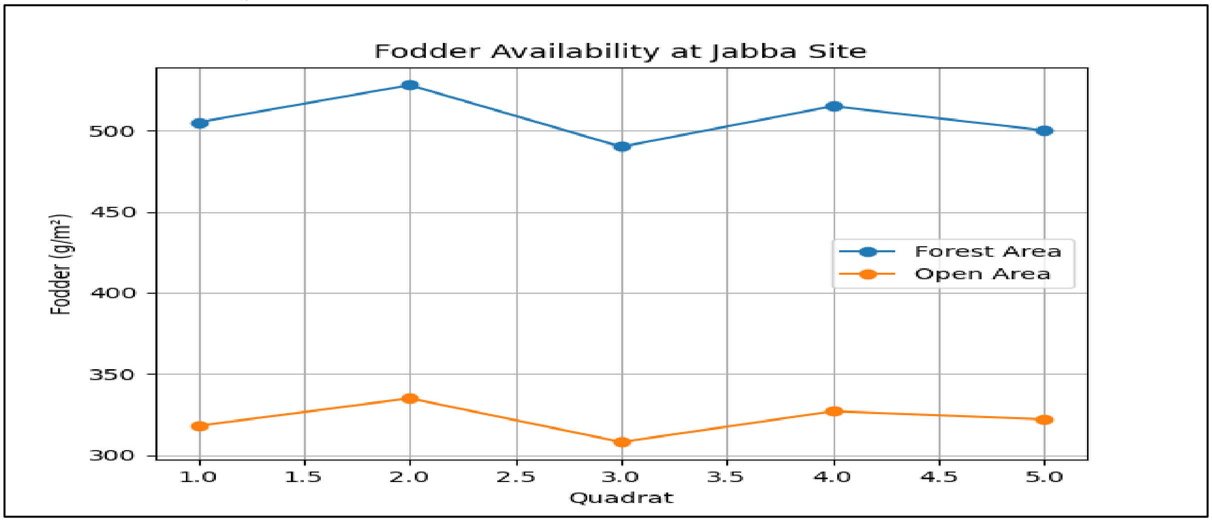

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Table 17 below presents the results of the comparison of fodder biomass. The average number in the open site (21.55) is smaller than the number in the vegetative site (31.11). This conclusion is supported by the information that both samples have moderate variability according to their standard deviations. Indeed, the confidence interval of the open site is between 14.1 and 29, while for the vegetative site, it ranges from 22.72 to 39.5.

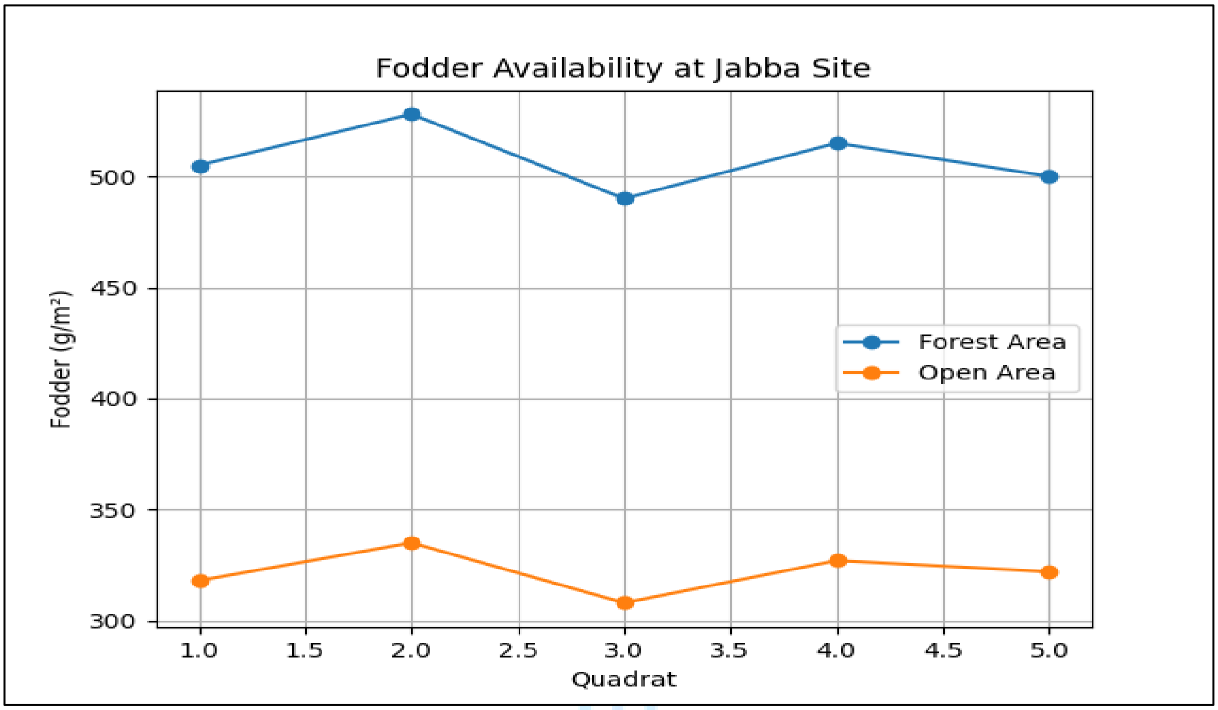


Figure 7 (7a-7b) a) Fodder at Jabba site b) Fodder at Khabikki site

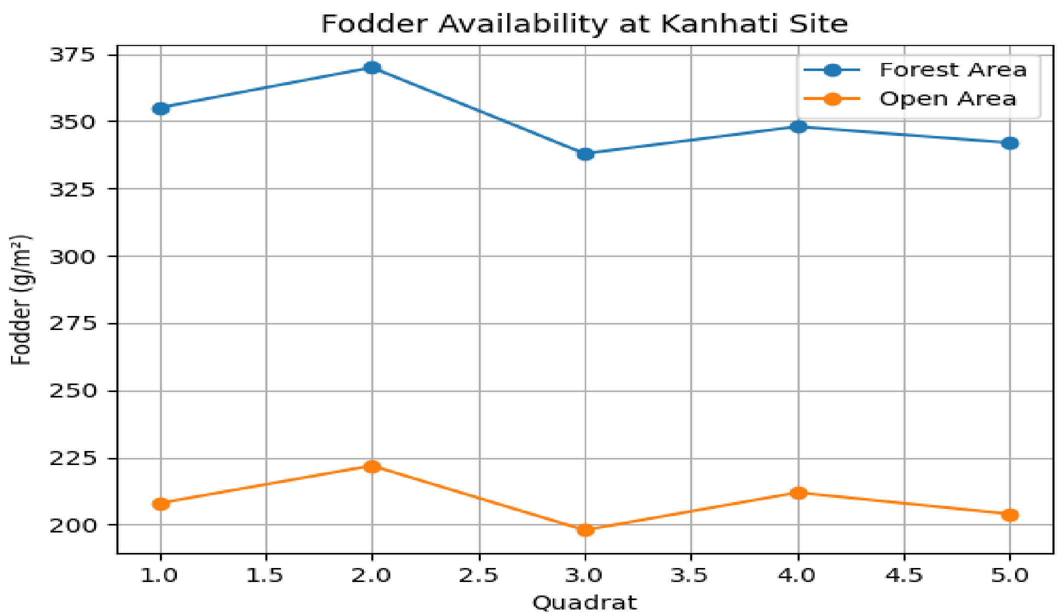


Figure 8: Fodder site at the Kanhati site

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**Discussion**

The current study compares the ecosystem service indicators of Soon Valley, Punjab, Pakistan's open and forested landscapes in terms of soil temperature, moisture content, soil organic matter (SOM), and fodder biomass. The ecological importance of vegetation cover in semiarid environments is highlighted by these metrics, which together represent both regulating and provisioning ecosystem services.

In the sites under study, vegetation cover dramatically lowered soil temperature, indicating its buffering influence on microclimatic conditions. According to recent research, plant canopies improve microbial activity and nutrient cycling by lowering soil temperatures and reducing incoming solar radiation (De Frenne et al., 2019; Zhang et al., 2024). Shading effects and evapotranspiration processes, which disperse heat energy and regulate soil thermal regimes, are also responsible for the decrease in soil temperature under plant cover. In arid and semiarid habitats, where vegetation serves as a thermal regulator to shield soil biota from drastic temperature swings, similar results have been documented (Zhao et al., 2022).

**Soil Temperature**

Microbial metabolism, nutrient mineralization, root development, and soil respiration are just a few of the biochemical and ecological processes that are fundamentally regulated by soil temperature. With substantial statistical significance ($p = 0.001$), the study found that the soil temperature was much lower in forested regions (mean ≈ 36.08°C) than in open land (≈ 39.17°C). The main causes of this temperature drop behind vegetation are canopy shading, evapotranspiration, and decreased solar radiation, all of which work together to buffer microclimatic extremes. Chen et al. (1999) reported similar findings, showing that forest canopies considerably lower soil temperature variability. Similarly, De Frenne et al. (2019) demonstrated how trees mitigate temperature extremes under climate change by acting as microclimate refugia.

In open spaces, higher soil temperatures may hasten the breakdown of organic matter and raise soil respiration rates, which could result in carbon loss (Davidson & Janssens, 2006). This is consistent with the findings of Lloyd and Taylor (1994), who showed that soil respiration and temperature have an exponential relationship. High temperatures can have a detrimental effect on microbiological stability and soil moisture retention, which lowers the overall quality of the soil. The results are in line with research performed in semiarid ecosystems, where the loss of vegetation increases soil heating and decreases ecosystem resilience (Breshears et al., 1997; Shukla et al., 1990). Vegetation cover is therefore essential for preserving thermal stability and controlling ecosystem functions.

**Moisture Content**Plant productivity, microbial activity, and nutrient availability are all significantly influenced by soil moisture. In comparison to open areas, the current investigation consistently revealed increased soil moisture beneath vegetation at every site. Through a variety of processes, including canopy interception, decreased evaporation, increased infiltration, and organic matter accumulation, vegetation improves soil moisture. According to Brady and Weil (2016), soils with a large amount of organic matter can hold more water. In a similar vein, Hillel (1998) emphasized how plants shade the soil surface to reduce evapotranspiration losses.

The observed variations are consistent with the findings of Sala et al. (1988), who found that vegetated systems use water more efficiently than bare soils. Additionally, Rodriguez-Iturbe (2000) showed that interactions between vegetation, soil, and water are essential to ecosystem functioning, especially in regions with restricted water resources. On the other hand, because of their direct exposure to sunlight and lack of protective litter layers, open plains exhibited noticeably lower moisture levels. This may result in decreased microbial activity and plant development, which would ultimately limit ecosystem productivity (Schlesinger & Bernhardt, 2013).

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Additionally, it was discovered that vegetated regions had a higher soil moisture content than open land, underscoring the importance of vegetation in water conservation. Through root systems and the buildup of organic matter, vegetation improves infiltration, decreases surface runoff, and increases soil water retention. This link is complicated, however, because vegetation also raises evapotranspiration, which in some circumstances may decrease water availability (Liu et al., 2025). The idea of ecohydrological balance, in which vegetation concurrently aids in water loss and retention processes, is supported by these observations (Rodriguez-Iturbe, 2000). This equilibrium is especially important in semiarid environments such as the Soon Valley because of the high rates of evaporation and little precipitation.

**Soil Organic Matter (SOM)**

One of the most crucial markers of soil health is soil organic matter, which affects carbon sequestration, water retention, and nutrient cycling. With strong statistical evidence ($p = 0.001$), SOM was significantly greater in forest regions (0.76–0.86%) than in open fields (0.54–0.58%). Continuous litter deposition, root biomass input, and slower decomposition rates in colder climates are all factors contributing to higher SOM in wooded environments. Six et al. (2002) explained that soil aggregation and physical protection mechanisms enhance carbon stabilization in vegetated systems. In a similar vein, Lal (2004) highlighted how plants might improve soil carbon sequestration and reduce climate change.

Reduced organic inputs and higher breakdown rates as a result of rising temperatures are linked to lower SOM in open spaces (Parton et al., 2007). Additionally, Guo and Gifford (2002) noted that substantial soil carbon losses result from land-use changes from forest to nonforest systems. These results show that by preserving soil carbon reserves, vegetation not only increases soil fertility but also supports long-term ecosystem sustainability.

Higher quantities of soil organic matter (SOM) were found beneath vegetation, indicating a significant difference between vegetated and nonvegetated areas. Increased litter input, root biomass, and less erosion in vegetated areas can all account for this. SOM is an important indication of soil health and ecosystem productivity since it is essential for preserving soil fertility, structure, and water-holding capacity (Lal, 2004; Six et al., 2002). Vegetation greatly increases soil carbon storage and nutrient availability, which helps mitigate climate change through carbon sequestration, according to recent meta-analyses (Du et al., 2024; Wang et al., 2024).

**Fodder biomass**

A direct provisioning service that promotes livestock production and rural livelihoods is fodder biomass. In this study, fodder biomass was consistently higher in wooded areas than in open lands. This rise can be attributed to better soil conditions, such as increased organic matter and moisture content, which encourage plant development. According to Tilman et al. (1996), ecosystems with more variety and resource availability typically have higher production. In a similar vein, Sala et al. (1996) discovered a favourable correlation between biomass production and vegetation diversity.

Despite being used for grazing, open fields had decreased biomass because of nutrient scarcity, moisture stress, and degraded soil. By decreasing plant cover and soil stability, overgrazing makes these circumstances worse (Milchunas & Lauenroth, 1993). The findings highlight how long-term agricultural productivity and the preservation of fodder resources depend on appropriate vegetation management.

The supply of the ecosystem service fodder biomass was considerably higher in vegetated areas, highlighting the significance of plant cover for rural livelihoods and animal productivity. This result is in line with research showing that fodder availability and primary productivity in grassland ecosystems are strongly influenced by vegetation density and diversity (Sala et al., 1988; Milchunas & Lauenroth, 1993). Maintaining plant cover is crucial for sustainable livestock

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management and food security in semiarid areas where grazing is the predominant land use.

**The Perspective of Integrated Ecosystem Services**

When all factors are taken into account, it is evident that forest ecosystems offer better provisioning (fodder) and regulating (temperature, moisture, soil quality) functions than open landscapes. The concept put forth by the Millennium Ecosystem Assessment (2005), which emphasizes the vital role ecosystems play in promoting human well-being, is highly supported by these findings. Ecosystem stability is largely dependent on vegetation cover, especially in semiarid regions with high levels of climate stress. According to the study, ecological imbalance and lower production can result from the substantial reduction in ecosystem service delivery caused by land degradation and vegetation loss. To improve ecosystem resilience, plant cover should be given priority in conservation and restoration methods. Broader processes of climate regulation are also reflected in the relationship between vegetation and soil characteristics. By absorbing atmospheric carbon dioxide and storing it in biomass and soil, vegetation helps sequester carbon, lowering the concentrations of greenhouse gases (Bonan, 2008; IPBES, 2019). Furthermore, plant–soil feedback systems affect energy exchange and nutrient cycling, both of which are essential for preserving ecosystem resilience in the face of changing climatic circumstances (Sun, 2025).

## Conclusion

The present study clearly demonstrates that vegetation cover plays a pivotal role in enhancing both regulating and provisioning ecosystem services in semiarid landscapes. Vegetated areas exhibited significantly lower soil temperatures and higher moisture content, indicating improved microclimatic regulation and water retention capacity. In addition, higher levels of soil organic matter and fodder biomass in vegetated lands reflect enhanced soil fertility, carbon sequestration potential, and productivity. The statistically significant differences ($p = 0.001$) between vegetated and open lands confirm that land use strongly influences ecosystem functioning. Open lands, characterized by higher temperatures, lower moisture, and reduced organic matter, are more vulnerable to degradation and reduced ecological productivity. The results emphasize that maintaining and restoring vegetation cover is essential for sustaining ecosystem stability, improving soil health, and supporting livestock-based livelihoods in semiarid regions. The study provides strong scientific evidence to support the implementation of sustainable land management and conservation strategies aimed at enhancing ecosystem resilience under changing climatic conditions.

## Declarations

**Consent for publication**

Not applicable

**Availability of data and materials**

The data will be available from author on reasonable request

**Competing Interest**

All authors declare that there are no competing interests.

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