# Calorific Value of Forest Surface Fuels in the Eastern Tianshan Mountains of Xinjiang (Postprint)

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## Abstract

Surface fuels are one of the important factors in forest fire spread, and calorific value is a key indicator characterizing fuel combustibility. Taking surface fuels under four typical vegetation types in the eastern Tianshan Mountains of Xinjiang as the research subject, this study analyzes the calorific value characteristics of surface fuels and their relationships with ignition point and absolute moisture content. The results showed that: in coniferous and broad-leaved forests, significant differences existed between herbaceous and litter components; in shrublands, significant differences existed between shrub and litter components. In the eastern Tianshan forest region, the calorific value ranking of different components within the same forest type was: litter > herbaceous > shrub > humus. Among herbaceous fuel components, coniferous forests exhibited the highest calorific value (19.38±0.08 $kJ \cdot g^{-1}$), while among litter fuel components, coniferous forests also showed the highest calorific value (19.55±0.05 $kJ \cdot g^{-1}$). The relationship between calorific value and ignition point varied among different surface fuel components: an extremely significant relationship existed between ignition point and calorific value for shrub fuel components P<0.05); however, no significant correlation was found between ignition point and calorific value for herbaceous and humus fuel components (P>0.05). Additionally, no significant correlation existed between calorific value and absolute moisture content for surface fuels across all forest types. It is evident that forest type, tree species, and physicochemical properties comprehensively influence the calorific value content of fuels. The research results aim to provide a theoretical basis for forest managers in the eastern Tianshan Mountains to accurately predict the calorific energy of forest fuels and potential forest fire risk, and to provide data support for in-depth regional research on surface fuels.

# Full Text

## Preamble

**Title:** Calorific Values of Forest Surface Fuels in the Eastern Tianshan Mountains, Xinjiang, China

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**Abstract:** Forest surface fuels are a critical factor in wildfire propagation, and their calorific values represent a key indicator of combustibility. This study examined surface fuels from four typical vegetation types in the eastern Tianshan Mountains of Xinjiang, analyzing the characteristics of fuel calorific values and their relationships with ignition points and absolute moisture content. The results revealed significant differences between herbaceous and litter components in coniferous and broad-leaved forests, as well as between shrub and litter components in shrubland. Within the same forest type, the calorific values of different fuel components followed the order: litter > herbaceous > shrub > humus. Among herbaceous fuel components, coniferous forests exhibited the highest calorific value ($19.38 \pm 0.08$ kJ·g$^{-1}$), while coniferous forests also showed the highest values for litter components ($19.55 \pm 0.05$ kJ·g$^{-1}$). The relationship between calorific value and ignition point varied among fuel components: shrub fuels showed a highly significant correlation ($R^2 = 0.81$, $P < 0.01$), and litter fuels showed a significant correlation ($R^2 = 0.38$, $P < 0.05$), whereas no significant correlations were found for herbaceous or humus components ($P > 0.05$). Furthermore, no significant relationship existed between calorific value and absolute moisture content for any fuel type. These findings demonstrate that forest type, tree species, and physicochemical properties collectively influence fuel calorific values. This research provides a theoretical basis for forest managers in the eastern Tianshan Mountains to accurately predict fuel energy content and potential fire risks, while offering data support for regional surface fuel research.

**Keywords:** forest; calorific value; surface fuel; ignition point; absolute moisture content; eastern Tianshan Mountains

# 1. Introduction

## 1.1 Study Area Overview

The study area is located in the eastern Tianshan Mountains of Xinjiang, extending from the mountainous regions and intermontane basins of Yiwu County in Hami Prefecture in the east to the Jinghe Forest Farm in Bortala Prefecture in the west. Bounded by the Tianshan watershed to the south and the northern foothills to the north, the region spans five prefecture-level cities (Hami, Tacheng, Changji, Urumqi, and Bortala) and 11 counties, with a length of approximately 1,300 km from east to west and a maximum width of 250 km from north to south. The total forest area covers $1.08 \times 10^6$ ha, including $3.11 \times 10^5$ ha of timber forest and a total living stock volume of $5.28 \times 10^7$ m$^3$, yielding a forest coverage rate of 22.79%. The region features mountainous terrain with a temperate desert base zone and a temperate continental climate. Geographic coordinates range from 42°24 to 44°14 N and 84°01 to 93°42 E, with elevations between 1,400 and 2,710 m. Vegetation exhibits distinct vertical zonation due to topographic and climatic variations, comprising three primary forest types: (1) coniferous forests dominated by *Picea schrenkiana* and *Larix sibirica* with understory shrubs and grasses including *Rosa platyacantha*, *Sorbus tianschanica*, *Lonicera tatarica*, *Aegopodium alpestre*, *Poa sibirica*, and *Deyeuxia pyramidalis*, with litter composed mainly of leaves and branches from dominant species; (2) broad-leaved forests dominated by *Populus tremula* and *Betula tianshanica* with understory shrubs and herbs including *Sorbus tianschanica*, *Rosa platyacantha*, *Spiraea tianschanica*, *Calamagrostis epigeios*, *Bromus inermis*, and *Elymus gmelinii*, with litter primarily from dominant vegetation leaves and branches; and (3) shrubland dominated by *Sabina saltuaria*, *Rosa platyacantha*, *Spiraea tianschanica*, and *Lonicera* species, with herbaceous species including *Calamagrostis epigeios*, *Bromus inermis*, and *Elymus gmelinii*, and litter composed mainly of leaves and branches from dominant shrubs.

## 1.2 Methods

**1.2.1 Sample Plot Establishment and Sample Collection** Sample plots were established across seven forest regions: Hami (Barkol), Hutubi, Jimusar, Manas, Qitai, Urumqi South Mountain, and Wusu [Figure 1: see original paper]. Four main forest types were selected based on species composition: coniferous forest (coniferous species > 65% of total stock volume), broad-leaved forest (broad-leaved species > 65%), coniferous-broadleaved mixed forest (either coniferous or broad-leaved species accounting for 35–65%), and shrubland (shrub species > 65%). Each sample plot measured 25.82 m × 25.82 m (666.7 m$^2$). Within each plot, three shrub layer samples and three herb, litter, and humus layer samples were collected from locations 5 m from each corner vertex [Figure 2: see original paper].

**Shrub layer:** In each 2 m × 2 m quadrat, 3–5 standard shrubs were selected. Dry mass, branches, and leaves were collected in equal proportions (by weighing to ensure each component represented 10–20% of the total mass of the sampled shrubs) and mixed. Samples from three quadrats were combined by species, with each composite sample weighing at least 500 g (fresh weight, measured to 0.01 g precision) for moisture content determination.

**Herbaceous layer:** All living herbaceous vegetation (including shrubs $<$ 30 cm tall) was harvested at ground level from each 1 m $\times$ 1 m quadrat. Fresh weight was measured (0.01 g precision), and material from all quadrats in a plot was thoroughly mixed. Approximately 300 g of the composite sample was weighed (0.01 g precision), bagged, labeled, and transported to the laboratory for dry weight ratio determination.

**Litter layer:** Litter thickness was measured before collecting all material (twigs, leaves, fruits, dead grass, and semi-decomposed organic matter) from each 1 m $\times$ 1 m quadrat using a rake. Non-organic materials (stones, soil clumps) were removed, and litter was categorized into three size classes: $<$ 0.6 cm (small twigs, leaves, and weeds), 0.6–2.5 cm (twigs), and $\geq$ 2.5 cm (branches). Each fraction was weighed separately (0.01 g precision). Samples from all quadrats were combined by size class, with 200 g taken from each composite for laboratory analysis.

**Humus layer:** Humus thickness was measured before complete removal of the humus layer from each quadrat. Stones, soil clumps, and visible roots were removed, and the wet weight of humus in each quadrat was recorded. All quadrat samples were mixed, and 200 g was taken for laboratory determination of dry weight ratio.

**1.2.2 Moisture Content Determination** The absolute moisture content of fuel samples was determined using the oven-dry method. Field-collected samples in kraft paper envelopes were weighed to obtain wet mass (subtracting envelope weight). Samples were then oven-dried at 105°C to constant weight, with drying considered complete when mass variation was $<$ 0.01 g between measurements. Absolute moisture content (D) was calculated as: D = (Wet Mass - Dry Mass) / Dry Mass $\times$ 100%.

**1.2.3 Calorific Value and Ignition Point Determination** Samples were air-dried at 60–80°C to constant weight, then ground using a Retsch MM400 grinder. Powder passing through a 60-mesh sieve was stored in sealed bags. For calorific value determination, 1.0 g of sieved sample was pelletized and analyzed using an automatic calorimeter, with each sample measured three times and averaged. For ignition point determination, 0.10 g of sieved sample was mixed with 0.075 g of oxidizer (sodium nitrite) and analyzed using an automatic ignition point detector, with each sample measured three times and averaged.

**1.2.4 Data Analysis** Statistical analysis was performed using SPSS 19.0 software. One-way ANOVA, two-way ANOVA, and Duncan's multiple range test were used to compare differences among parameters.

## 2. Results and Analysis

### 2.1 Comparison of Calorific Values Among Different Fuel Components

Calorific values of litter components were generally high across all forest types, averaging 19.27 $kJ \cdot g^{-1}$, while humus components showed lower values, averaging 13.25 $kJ \cdot g^{-1}$. Within the same forest type, most differences among fuel components were not statistically significant. However, significant differences were observed between herbaceous and litter components in coniferous and broad-leaved forests ($P < 0.05$), and between shrub and litter components in shrubland ($P < 0.05$). No significant differences were detected among components in mixed coniferous-broadleaved forests [Figure 3: see original paper].

### 2.2 Comparison of Calorific Values Among Forest Types for the Same Component

Calorific values of the same fuel component varied among forest types . For shrub components, shrubland exhibited the highest value ($18.99 \pm 0.03$ $kJ \cdot g^{-1}$), with significant differences between coniferous and mixed forests ($P < 0.05$). For herbaceous components, coniferous forests showed the highest value ($19.38 \pm 0.08$ $kJ \cdot g^{-1}$), with significant differences between coniferous and shrubland forests ($P < 0.05$). For litter components, coniferous forests again displayed the highest value ($19.55 \pm 0.05$ $kJ \cdot g^{-1}$), with significant differences between coniferous and mixed forests, and between broad-leaved and shrubland forests ($P < 0.05$). For humus components, shrubland showed the highest value ($15.76 \pm 0.10$ $kJ \cdot g^{-1}$), though no significant differences were detected among forest types.

### 2.3 Relationship Between Calorific Value and Ignition Point

The relationship between calorific value and ignition point varied among fuel components [Figure 4: see original paper]. Shrub fuel components showed a highly significant positive correlation ($R^2 = 0.81$, $P < 0.01$), while litter fuel components exhibited a significant correlation ($R^2 = 0.38$, $P < 0.05$). In contrast, no significant correlations were found for herbaceous or humus fuel components ($P > 0.05$).

### 2.4 Relationship Between Calorific Value and Moisture Content

Moisture content varied among components, decreasing in the order: herbaceous (16.3–42.1%) > shrub (37.5%) > litter (31.2%) > humus. However, no significant correlations were observed between calorific value and absolute moisture content for any fuel component across all forest types [Figure 5: see original paper].

## 3. Discussion

Research on forest fuels provides a theoretical foundation for fire prevention, suppression, and sustainable management, with fuel calorific value serving as a crucial indicator of combustibility. This analysis of different surface fuel components (shrubs, herbs, litter, and humus) across various forest types in the eastern Tianshan Mountains represents a fundamental component of flammability research and a key focus of wildfire studies. The results indicate that within the same forest type, the calorific value ranking of litter > herbaceous > shrub > humus aligns with findings from Wuyishan National Park, though our study additionally incorporates humus effects, providing a more comprehensive analysis of dead surface fuel characteristics. As the component with the lowest calorific value, humus proportion may represent a critical factor in wildfire risk assessment. The general lack of significant differences among components within the same forest type, consistent with Wuyishan research, suggests these variations may be related to vegetation type and photosynthetic intensity. However, specific significant differences emerged: between herbaceous and litter components in coniferous and broad-leaved forests, and between shrub and litter components in shrubland, indicating that herbs (in broad-leaved and shrub forests) and litter (in coniferous and mixed forests) warrant particular attention for fire management, while humus—with consistently low calorific values across all forest types—may provide some fire resistance.

Wildfire occurrence is closely related to surface fuel calorific values, which significantly influence combustion rate and fireline intensity, thereby reflecting fire severity. The observed variations in calorific values among forest types demonstrate the necessity of this research for the eastern Tianshan region. Comparative analysis suggests the flammability ranking of major forest types from high to low is: coniferous forest > shrubland > mixed forest > broad-leaved forest. Consequently, coniferous forests and shrublands should be prioritized as key areas for fire protection. The differing relationships between calorific value and ignition point across components—highly significant for shrubs, significant for litter, and non-significant for herbaceous and humus components—indicate that litter and humus are less flammable than herbs and shrubs. This contrasts with studies from northeastern Liaoning Province showing significant correlations for all components, suggesting regional variations. Research indicates that volatile oils and fats are closely related to fuel calorific values and ignition points, warranting future comparative studies on oil and fat content across components to further elucidate these relationships.

The absence of significant correlations between calorific value and absolute moisture content across all fuel types suggests that calorific value is independent of flammability in this region. Previous studies in the central Tianshan Mountains demonstrated that lower moisture content increases flammability, but moisture content is influenced by multiple factors (species, topography, temperature, humidity, precipitation, wind, and solar radiation) that cannot be evaluated in isolation. Developing accurate predictive models based on significant forecast factors for specific regional conditions will provide robust data support for future forest fire forecasting research in China.

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## 4. Conclusion

This study examined surface fuel calorific values across four typical vegetation types in the eastern Tianshan Mountains of Xinjiang and their relationships with ignition points and absolute moisture content. Key findings include: (1) Within the same forest type, calorific values ranked as litter > herbaceous > shrub > humus; (2) Coniferous forests exhibited the highest calorific values for both herbaceous ($19.38 \pm 0.08$ kJ · g$^{-1}$) and litter ($19.55 \pm 0.05$ kJ · g$^{-1}$) components; (3) The relationship between calorific value and ignition point varied by component, with highly significant correlations for shrubs ($R^2 = 0.81$, $P < 0.01$) and significant correlations for litter ($R^2 = 0.38$, $P < 0.05$), but no significant relationships for herbaceous or humus components ($P > 0.05$); and (4) No significant correlations existed between calorific value and absolute moisture content for any component. These results provide a theoretical basis for determining energy release parameters and fire intensity in the eastern Tianshan region, offering data support for precise management of forest surface fuels.

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*Note: Figure translations are in progress. See original paper for figures.*