### Selective Reincorporation of Crop Residues in Soil: Plant Residue Quality Index (PRQI) and Ecological Potential Approach

### Abstract

Reintegration of agricultural residue into the soil is a sustainable approach for the replenishment of soil nutrients. Crop residue quality depends on plant physiology which governs the process of decomposition in the soil. Quality index determines the decomposability of the crop residue which is used to predict the efficiency of its application in the soil. Therefore, there is a need to study the chemical composition of plants and ensure their decomposition process. The present study attempts to establish a formulated approach to select quality crop residues for re-usage in soil. The study was conducted in the agriculture farms of Kedarpur village in Dehradun district, (Uttarakhand 30.2672° N, 78.0465° E) in 2016-17. The soil type of the area is sandy loam. Four major crops (wheat, rice, sugarcane and maize) were selected to analyze their qualitative potential to generate a quality index. Residue production ratio (RPR), agricultural ecological potential (AEP), and, gross residue potential (GRP) values were determined to correlate their decomposition pattern with nutrient release rate. GRP showed the availability of residue generated by crops was highest in wheat. AEP further implied that 48% of wheat and maize crop residue should be left on the field to maintain ecological services. While it was found to be less than 30% in the case of rice and sugarcane. The C: N ratio was found highest in the order of sugarcane>maize>rice>wheat, which implies that the residual properties of wheat are the most favourable for fast decomposition. The effects of PRQI on the microbial load of the soil were studied. It was observed that crop residues with low PRQI under decomposition were weighed down by a higher number of fungi than bacterial colonies. The results are studied in coherence to explain the ecological importance of retaining crop residues in the field. The chemical parameters integrated as plant residue quality index (PRQI) further confirm the high nutrient value of wheat and rice crop residues correlated with their higher decomposition rate. The present study implies that the decomposition rate of crop residues can decide their retain value depending on the nutrient release rate, it would establish the link between residue decomposition and crop growth. The use of agricultural ecological potential could prove to be an important tool to evaluate the amount of residue required for performing ecosystem services. PRQI can further be utilized to determine the relationship between crop residue decomposition rate and crop growth performance.

**Keywords** – crop residue, gross residue potential, agricultural ecological potential, decomposition rate constant, plant residue quality index.

### 1. Introduction

Agriculture is dependent on soil characteristics, weather patterns, and biodiversity, and is vulnerable to climate change (Dash et al., 2024). An agroecosystem is a smaller unit of the natural system mainly dedicated to the production of food and fiber. It is an intermediate system affected by both biotic and abiotic factors, though by implementing manipulative measures its dynamics could be controlled up to an extent. These are artificial ecosystems created or determined by human activities in which ecosystem functioning acts in complex ways resulting from human manipulations intermingled with natural ecological processes (de la Riva et al., 2023). The variety and range of anthropogenic inputs in synchronization with favorable geographical conditions can lead to higher outputs. But to obtain the desired results, its natural dynamics must be understood well.

Agroecosystem is an efficiently rich system in terms of its production value and re-usability of agri-waste. The amount of agricultural waste is mainly determined by plant physiology but also governed by agriculture inputs applied and post-harvest management. Plant physiology determines the leftover part of the plant after harvesting whereas agri-input governs the quality of the residue and harvest management decides the actual amount available for utilization. Each crop in the capacity of its unique physiology produces some amount of residue. As much as the quantity of the crop residue is important, its quality governs the process of decomposition in the soil. Crop residues are a rich source of plant nutrients and, hence have the potential to improve the resource use efficiency along with sustainability of the agro-ecosystem. India produces more than 686 million tonnes (Mt) of crop residue every year, of which 368 Mt comes from cereal crops. Among cereal crops, rice and wheat are the dominating crops, contributing about 154 and 131 Mt, respectively, in the total crop residue production (Kumar et al., 2023). The crop residue when decomposes, releases nutrient elements into the soil based on their chemical composition (Tamilselvi et al., 2015). Fast decomposing residues release nutrients at a faster rate while not necessarily improving the soil quality whereas slowly decomposing residues might positively impact the soil in the long run (Sarkar et al., 2020).   
Therefore it is important to study plant physiology as well as chemical makeup before zeroing in on its potential for reuse and reapplication in the agriculture soil.

Uttarakhand is a hilly state that is geographically divided into plains and tarai, the Bhabhar zone, the middle Himalayas, and the higher Himalayas. It is generally covered with forests and wastelands with a reported total land area of 56.72 lakh ha (Sharma, 2016). Only 14% of land is available for cultivation out of which 89% is under small and marginal land holders. Small land holdings face the pressure of producing maximum yield within limited fertilizer and other chemical inputs. Due to ecological and economic constraints, these farms have immense scope to develop into organic establishments (Meena and Sharma 2015 ). Crop residues and animal farm waste are the major sources of organic application in the fields. To apply plant residues into the soil to take out maximum benefits from the same the quality of a crop residue is studied based on C: N ratio, lignin, and polyphenol content. The quality index determines the decomposability of the crop residue which is used to predict the efficiency of its application in the soil. But again, keeping in mind the geographical peculiarity of the state, the crop residues which can be decomposed easily under sub-tropical weather conditions have to be distinguished. Therefore, the need to study the chemical composition of plants and their decomposition process is warranted. In the present study, the focus would be on estimating the quantity of residue from the major cereal crops as well as assessing their nutritional quality for their reusability in the agricultural system based on their quality index.

### 2. Materials and methods

The present study was conducted in the agriculture farms of Kedarpur village in Dehradun district, (Uttarakhand 30.2672° N, 78.0465° E) in 2016-17. The climate of the district is generally temperate. The area receives an average annual rainfall of 2073.3 mm. Most of the annual rainfall in the district is received during the months from June to September, July and August being the rainiest (https://dehradun.nic.in/climate/). The soil type of the area is sandy loam and its surface layer has the following properties: The soil is classified as alfisol and its surface layer (0-15 cm) has the following properties: Organic C-1.87%; total N-0.17%, pH-7.49; EC-490 µS cm-1, CEC – 10.23 me 100gm-1 and a sandy loam texture with sand, 54.9%, silt, 15.8% and clay, 26.3%.

This study involved the initial chemical characterization of four major crop residues of the plants; wheat, rice, sugarcane, and maize, their quantity estimation, and quality analysis using the plant residue quality index (PRQI). Total area, production, and average yield of rice, wheat, maize, and sugarcane in the year 2021-22 are shown in Table 1.

**Table 1**. Total area, production, and average yield under rice, wheat, maize, and sugarcane in the year 2021-22

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| District | Crop | Area (ha) | Production (Metric ton) | Average yield (ton ha-1) |
| Rice | Dehradun (hills) | 1312 | 2865 | 21.84 |
| Dehradun (plains) | 7872 | 15991 | 20.31 |
| Dehradun (total) | 9184 | 18856 | 21.00 |
| Wheat | Dehradun (hills) | 3748 | 7035 | 18.77 |
| Dehradun (plains) | 12947 | 37745 | 29.15 |
| Dehradun (total) | 16695 | 44780 | 29.15 |
| Maize | Dehradun (hills) | 3423 | 7555 | 22.07 |
| Dehradun (plains) | 3604 | 7954 | 22.07 |
| Dehradun (total) | 7027 | 15509 | 22.00 |
| Sugarcane | Dehradun (total) | 3887 | 251878 | 648 |

\*Source:- Agriculture Department, Govt. of Uttarakhand. [www.agriculture.uk.gov.in](http://www.agriculture.uk.gov.in)

Field decomposition was studied using 15x15 nylon mesh bags of 0.2 mm through the litter bag technique. Litter bags from each residue were collected from fields 7, 14, 21, and 30 days after the study of initiation of the experimental set-up. After the collection of litter bags, their contents were air-dried and further analyzed. Once dry, samples were weighed and mass loss was determined as the difference of initial and final weight.

#### 2.1 Selection of crops

The plants were selected based on their highest grain productivity and the availability of maximum crop residue in the Dehradun region. Types of residues were straw from rice, wheat, and maize and leaves of sugarcane. Their respective RPR (residue production ratio) was used to measure the gross residue potential of the crop.

#### 2.2 Plant residue quality index (Tian et al. 1995)

The plant residue quality index was determined based on three factors of the residue quality that is, C: N ratio, lignin, and polyphenol contents as described by Tian et al. (1995). The PRQI equation to calculate the quality parameter was further formulated as

PRQI = [1 ∕ (a C/N + b Lignin + c Polyphenol)] × 100 (1)

where a, b, and c are coefficients of the relative contribution of the C/N ratio, lignin content (%), and polyphenol content (%) to plant residue quality. Multiple regression analysis between mean decomposition rate constants of all four plant residues, C/N ratio, and lignin and polyphenol contents are given in Table 3. Using the F value of the regression analysis in Table 4, the coefficient of relative contribution (CRC) of the three factors to the rate of decomposition was calculated as:

CRC = F value of given factor ∕ sum of F values of three factors. (2)

Hence, the insertion of the CRC values from Table 1 in eq. (1) yields:

PRQI = [1 / (0.423C/N+0.439 Lignin+0.138 Polyphenols)] × 100 (3)

#### 2.3 Estimation of crop residue biomass potential

The estimation of crop residue generated in an agro system is calculated based on three parameters which are: the area covered by the crop, yield of the crop, and, residue production ratio. Residue production ratio (RPR) is simply residue available for 1 kg of crop. Based on the mentioned criteria gross residue potential is calculated as follows:

Gross residue potential (GRP) = Crop area x Crop yield x RPR (4)

Where crop area and crop yield are the cultivation area (ha) and yield (tonnes ha-1) respectively.

#### 2.4 Agricultural Ecological Potential (AEP)

Various ecological functions are dependent on the retention of crop residues on the field, such as nutrient cycling, moisture control, and, soil organic matter. Ecological potential calculates the limitations to residue extraction for agricultural residues to maintain ecological functions.

It is calculated as:-

AEP (tonnes) = GRP – (250 x crop area)

where 250, is a constant used assuming that globally 250 tons of residues per km2 of cultivated land can reduce soil erosion and thus maintain ecological functions.

### 3. Results and Discussion

The production of agricultural residues depends on the volume of produce generated, the crops being produced, and the yield of these crops ((Daioglou et al., 2016). In this study, the crop residue is defined as the above-ground straw and leaves. The yield of any crop can affect the residue potential by affecting the residue-to-product ratio (RPR), deﬁned as the ratio of above-ground crop production to the total grain production (Lal, 2005). The collected data from various studies inferred that the RPR varies across different crop types and tends to decrease with increasing yields (Scarlat et al., 2010). This is because increased crop yield results in an increase in grain produced which is chiefly the harvestable component of the plant and therefore very limited residue is left after harvesting (Daioglou et al., 2016).

It is estimated that India generates 500 Mt of crop residue annually (NPMCR, 2014). The uses of crop residues depend on the crops grown in the area, cropping intensity, and productivity across the region. As far as the Uttarakhand region is concerned the estimated crop residue generated annually in the area is approximately 2.4 million tonnes out of which 0.78 million tonnes/year residue is burned (Bhuvaneshwari et al., 2019). To estimate the generation of crop residue within the time frame of this study, the data on crop production for 2016-17 in Dehradun was sourced from the official site of the agriculture department of the government of Uttarakhand, Table 1. The crop production was segmented into the hilly area and plain area based on the topography of the region. Wheat and rice were grown in a much larger area in comparison to maize and sugarcane. The production rate followed a similar trend in cereal crops of wheat>rice>maize, although the highest production was observed in sugarcane but keeping in view its higher biomass than the cereal crops, it is kept in the separate food-producing plant category. The Plains area of the region has a large production area therefore the crop yield was also higher accordingly. Whereas in the case of maize, irrespective of the difference in the area under the cropping system, the crop production as well as crop yield was nearly the same in both the plains and hilly areas.

Gross residue potential is calculated to estimate the theoretical availability of residue generated based on the crop produced, area under production, and RPR. It is estimated that rice, sugarcane, wheat, and cotton are the major contributors to India’s crop residue biomass pool (Hiloidhari et al., 2014). In the selected crops of the present study, the highest GRP was calculated in the decreasing order of wheat>maize>rice>sugarcane (Table 2). This observation differs from the data on the national trend of GRP. The reason could be attributed to the fact that RPR value differs for different crops. Various factors also affect the length of the residue portion of the harvested crop, yield being the most imperative factor. Crop yield determines the harvestable part of the crop, the higher the crop yield lesser the residual part of the plant. In the present context although maize has a comparable yield to rice it has a high RPR value which resulted in increased GRP of maize residue.

**Table 2.** Available and ecological potential for cereals and sugarcane crop

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Crops | RPR | GRP (MT) | AEP (MT) | % AEP TO GRP |
| Rice Hills | 1.5 | 4727.92 | 1447.92 | 30.62 |
| Rice Plains | 1.5 | 26380.25 | 6700.25 | 25.39 |
| Rice Total | 1.5 | 31822.56 | 8862.56 | 27.84 |
| Wheat Hills | 1.5 | 11607.74 | 2237.74 | 19.27 |
| Wheat Plains | 1.5 | 62271.83 | 29904.33 | 48.02 |
| Wheat Total | 1.5 | 80298.78 | 38561.28 | 48.02 |
| Maize Hills | 2 | 16620.03 | 8062.53 | 48.51 |
| Maize Plains | 2 | 17498.86 | 8488.86 | 48.51 |
| Maize Total | 2 | 34010.68 | 16443.18 | 48.34 |
| Sugarcane Total | 0.05 | 13853.27 | 4135.77 | 29.85 |

**Table 3.** Initial residue quality variables

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Chemical properties** | **Rice** | **Wheat** | **Sugarcane** | **Corn** |
| **pH** | 5.85 | 6.23 | 6.00 | 5.88 |
| **EC (µS/cm)** | 101.7 | 143 |  |  |
| **Organic carbon (g/kg)** | 223 | 302 | 232 | 348 |
| **Total Carbon (%)** | 44 | 51 | 34 | 46 |
| **Total Nitrogen (%)** | 6.7 | 1.47 | 0.12 | 0.95 |
| **Dry weight g/m2** | 339 | 443 | 482 | 421 |
| **Lignin %** | 13.98 | 16.2 | 13.25 | 14.5 |
| **Cellulose%** | 39.1 | 38.4 | 42.13 | 37.9 |
| **Hemicellulose%** | 26.40 | 35.2 | 40.11 | 35.7 |
| **Lignin:N** | 2.08 | 10.9 | 110.41 | 15 |
| **C: N** | 6.5 | 34.69 | 283 | 48.42 |

**Table 4**. Results of multiple regressions between mean decomposition rate constants of four plant residues and C/N ratio, lignin content (%) and polyphenol content (%), and the resulting coefficients of relative contribution (CRC) of chemical factors to decomposition

|  |  |  |  |
| --- | --- | --- | --- |
| Chemical factor | Regression Coefficient | F-value | Coefficient of relative contribution |
| C/N | 0.0038 | 16.6 | 0.423 |
| Lignin | 0.0030 | 17.2 | 0.439 |
| Polyphenol | 0.0189 | 5.4 | 0.138 |

Surplus residue potential is calculated after taking into account the other competing uses of the crop residues and it is only available for bioenergy production (Hiloidhari et al., 2014). In the present study surplus fraction is not studied since the data for the competing uses of residues is not available widely. Furthermore, there could be a discrepancy in the data since no recent studies have been done to establish the multiple uses of crop residues state-wise. There is limited data available, therefore an agency BRAI which calculated the surplus residue potential level at the national level, did so assuming that since 2004 there has been no change in the pattern of the competing use of the crop residues (Suresh et al., 2016)

Agricultural ecological potential (AEP) is more concerned with the ecological services that could be provided by crop residues. AEP is defined as the theoretical potential minus residue requirements to avoid environmental degradation which is equivalent to 250 t km-2 (Daioglou et al., 2016). Other than utilizing crop residues for either household or commercial purposes, it is known to provide various ecosystem services which entail maintaining SOC, water retention in the soil, prevention from soil diseases, and prevention of biodiversity (Blanco-Canqui & Lal, 2007; Devi et al., 2017).

The quantity of crop residue required to provide these ecosystem services is a tedious task and would require a lot of data collection. The level of detail required to be able to come up with a certain quantity is not possible. Therefore, Gallagher et al. (2003) used a constrained value that could be applied globally to ensure the retention of crop residue amount in agricultural fields for environmental protection. The value is assumed on the dependence of soil fertility on SOC. Determining the amount of residue to be required to confer all the ecological services is dependent on multiple factors like soil conditions, climatic conditions, and other field management activities. SOC is a prime factor that is often affected by all the above-mentioned biotic and abiotic components of the soil. Though tillage affects the SOC embedded in the soil, increased farm techniques can improve residue removal activity without affecting the SOC in the soil (Johnson et al., 2006). To deduct the constrained value, a direct relationship between ecosystem services and soil erosion was established which describes the interdependence such as all the ecosystem services could be maintained if there is no soil erosion when retention of crop residue in the fields (Gallagher et al., 2003; Papers et al., 2014)**.**

The results in Table 2 imply that approximately 48% of gross agricultural residues of wheat and maize have to remain on the field for ecological services. While it was found to be less than 30% in the case of rice and sugarcane. The ecological use directly depends on the land area being used and increases accordingly. But, in the case of intensive agriculture having lower land area but higher agricultural output is found to have larger ecological potential. The results explain the ecological importance of retaining crop residues in the agriculture field to maintain the overall quality status of the soil of the area (Bhatt et al., 2016). The higher the crop production more should be the amount of crop residues left on the fields.

Applications of plant residues have a beneficial effect on soil nutrients, physicochemical properties, and biological dynamics (Elliott et al., 1978; Hiloidhari et al., 2014; Kotroczó et al., 2014; Purohit et al., 2017). However, the effect of plant residues on the quality of the soil depends on the decomposition pattern and nutrient release rate of the residues. Both slow and fast decomposing plant residues pose different productivity effects on the soil as the fast decomposing residues will provide nutrients at the initial stages of the sowing without affecting the physical properties of the soil, whereas slow decomposed residues will have the opposite effect of affecting soil aggregates or moisture retention but nutrient release will be slow in the initial phases of the crop growth (Tian et al. 1995). The decomposition process is affected by the C/N ratio, its lignin, and polyphenol contents. The plant quality index given by Tian et al. (1995) integrated the above-mentioned parameters to develop a residue quality index, to understand the chemical nature of the residue which influences its decomposition pattern. In the present study, the formula is being used to study the appropriation of crop residues for its utility in improving the soil nutritional quality. Table 3 describes the initial chemical properties of the crop residues before it applies to decomposition. The results showed that soil pH for rice and maize is slightly acidic while it is basic for wheat and sugarcane crops. The lowest lignin content was present in the wheat straw which explains its faster decomposability whereas the rest of the residues having higher lignin content take time longer than wheat to decompose. Imperatively, the C: N ratio was found highest in the order of sugarcane>maize>rice>wheat, which implies that the residual properties of wheat are the most favorable for fast decomposition. The nearest ratio to C: N of 24:1 is said to be most conducive for the microbes to work upon the waste of any nature (Lynch et al., 2016). By incorporating the observed values in the formula given in eq (1) the PRQI was calculated for the selected crop residues. The resultant PRQI was highest for wheat and rice and lowest for sugarcane (Table 5). It is proposed that the decomposition rate is directly correlated to the quality index of the plant as quality parameters of crop residue decide the decomposition rate constant. It is also proved by the correlation between PRQI and the decomposition rate constant of the selected crops shown in Figure 1.

**Table 5.** Plant residue quality index of the selected crops

|  |  |
| --- | --- |
| **Crop residue** | **PRQI** |
| Wheat | 4.5 |
| Rice | 4.2 |
| Sugarcane | 1.8 |
| Maze | 3.7 |

**Fig.1** Correlation between PRQI and decomposition rate constant of crop residues in the 2016-17 cropping season. (S-sugarcane leaves residue; M-maize leaves residue; R-rice straw; W-wheat straw)

Mulching plays an important role in defining the microclimate of the region, it is placed on. As it generally covers the topsoil of the area, restricting the solar penetration into the soil, thus affects the soil temperature by reduction in the degrees just beneath the mulch. Crop residue decomposition puts similar conditions when comes in contact with the soil. The temperature of the soil further influences the moisture being negatively correlated to each other. In the present study, the effect of PRQI in correlation with both soil temperature and moisture defines the impact of the quality parameter of crop residue on the mentioned soil physical parameters. Figure 2 shows that crop residues with lower PRQI do not decompose quickly, and remain in the soil for a longer duration thus bringing microclimatic changes in the under soil. Sugarcane having low PRQI is observed to have decreased soil temperature and correspondingly increased moisture content than the highest PRQI wheat straw. Whereas wheat straw decomposed at a faster rate therefore did not influence the soil temperature and moisture as an immediate effect. The decomposition of crop residues progressively decreases the soil moisture and temperature (Mary et al., 1996; Quemada & Cabrera, 1997; Thongjoo et al., 2005). Even though retention of soil moisture is a beneficial aspect of soil quality in terms of nutrient release faster decomposition rate has a superfluous effect on the mineralization process than slow decomposing crop residues.

**Fig.2**. Correlation between PRQI and mean soil temperature (10 cm) and mean soil moisture content (0-10 cm) during the decomposition of the crop residues. (S-sugarcane leaves residue; M-maize leaves residue; R-rice straw; W-wheat straw)

Further effects of PRQI on the microbial load of the soil were studied and the results are represented in Figure 3. It was observed that crop residues with low PRQI under decomposition were weighed down by a higher number of fungi than bacterial colonies. High moisture supports the growth of fungi; since sugarcane leaves residue had higher moisture content during initial phases of decomposition therefore it can be attributed to optimum growth conditions for the dwelling of fungal population. On the contrary, slightly less humid conditions with an optimum temperature near 370 C led to the propagation of more bacterial growth in the wheat straw residue (Rui et al., 2009). The plant litter decomposition is highly dependent on the C: N ratio as it also entails information about the maturity stage of the residue. Mature plants have more complex compounds in their structural frame and hence require more log-phased microflora to decompose the stable compounds (Alexander, 1977). The bacterial-to-fungal ratio determines the response of the microbial community to the availability of mature or young plant litter. As mature plants have more recalcitrant compounds such as lignin content so will be prevailed by fungus growth and younger plant litter is richer in nitrogen content and therefore attracts more bacterial community for its decomposition (Astaraei, 2008). In the present study, it was more evident that a higher bacterial-to-fungal ratio supports grain crop residues than sugarcane leaves residue. Though the lignin content of sugarcane leaves residue was comparable to other crop residues due to its low nitrogen content it takes more effort to decompose than the other crops. But with the aid of PRQI the decomposability of any crop residue could be easily predicted before its application in the agriculture fields for various soil-improving mechanisms.

**Fig.3.** Correlation between the PRQI and fungal count and bacterial count during the decomposition of the crop residues. (S-sugarcane leaves residue; M-maize leaves residue; R-rice straw; W-wheat straw)

The influence of climatic factors (Campos, 2023a; Campos et al. 2023), soil quality (Araya-Alman et al. 2020), and agronomic management plays a crucial role in determining the sustainability of agroecosystems (Parra et al. 2012; Campos, 2014a; 2014b). Temperature (Guevara et al. 2014), precipitation (Olivares et al. 2016; Olivares and Zingaretti, 2019), and humidity directly affect the decomposition rate of crop residues and the subsequent release of nutrients into the soil (Campos, 2023b). In the context of this study, the Plant Residue Quality Index (PRQI) serves as a valuable tool for assessing the suitability of crop residues for soil reintegration. The study's findings highlight that crops like wheat and rice, with high PRQI values, decompose rapidly and contribute significantly to soil nutrient availability. Conversely, residues with lower PRQI, such as sugarcane leaves, decompose more slowly, influencing soil microclimate by retaining moisture and altering microbial activity. Understanding these interactions is essential for optimizing residue management strategies tailored to specific environmental conditions (Rodriguez et al. 2013; Rodriguez et al. 2015).

Soil quality, characterized by its organic matter content, pH, cation exchange capacity, and texture, is a key determinant in nutrient cycling and ecological balance (Calero et al. 2022; Olivares et al. 2022a; 2022b). The decomposition process of crop residues varies depending on their C: N ratio and lignin content, impacting soil fertility and long-term productivity. High-quality residues, such as those from wheat and rice, provide faster nutrient release, benefiting crop growth in early stages, whereas lower-quality residues enhance soil structural properties over extended periods (Rodriguez et al. 2023a; 2023b). The integration of the Agricultural Ecological Potential (AEP) approach in this study underscores the importance of retaining approximately 48% of wheat and maize residues in the field to maintain essential ecological services (Hernandez et al. 2020). This balance ensures that soil organic carbon levels are preserved, reducing risks of degradation while enhancing crop productivity (Rey et al. 2022; Hernandez and Olivares, 2019).

Agronomic practices, including conservation tillage (Hernandez et al. 2018a) and strategic residue retention (Hernandez et al. 2018b), are pivotal in sustaining soil health and mitigating environmental challenges (Hernandez et al. 2017). In regions with irregular precipitation, the use of crop residues as mulch helps conserve soil moisture and regulate temperature fluctuations (Hernandez and Olivares, 2020). However, determining the optimal proportion of residues for reintegration is essential to prevent soil nutrient depletion while maximizing ecological benefits (Lobo et al. 2023; Lopez et al. 2019; Lopez and Olivares, 2019). The AEP methodology, applied in this study, provides a framework to quantify the amount of residue that should remain in the field to sustain ecosystem functions. By correlating PRQI with decomposition rates and soil properties, this approach facilitates the development of targeted strategies for residue management, enhancing agricultural sustainability and resource efficiency (Montenegro et al. 2020; 2021).

### 4. Conclusion

In the present study, the selection of crop residues was done based on their applicability in the agricultural fields for improving soil quality and drawing out ecosystem services. The use of agricultural ecological potential could prove to be an important tool to evaluate the amount of residue required for performing ecosystem services. Differences between production methods and ecological constraints restricts the utilization of crop residues for soil coverage. The AEP method should be used to calculate the amount of residue allowed to be removed to incorporate into the soil as mulch or compost. The feedback of residue incorporation of distinct residues should further be investigated as to how it impacted the other competing uses. Further, the application of different crop residues in the fields could be studied through PRQI dependent on lignin, C/ N, and polyphenol content. The decomposition rate of the crop residues can decide their applications in the soil of standing crops depending on the nutrient release rate in the initial phases of the growth. PRQI can further be utilized to determine the relationship between crop residue decomposition rate and crop growth performance. Research with more plant residue species under a wider range of ecological conditions can be summarised in a data set to establish the relationship between quantities of decomposing residue requirements and with crop growth of a particular species.

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