

Stability Analysis and Fodder Yield Evaluation of Oat (*Avena sativa* L.) Genotypes for Cold Arid Regions of Ladakh Using Eberhart and Russell Model

Mushtaq Ahmad*¹

¹ Scientist, Mountain Research Centre for Field Crops, SKUAST-Kashmir, Khudwani, Anantnag - 190 025, Jammu and Kashmir, India

Received: 28 Oct 2025; Revised accepted: 17 Dec 2025

Abstract

Oat (*Avena sativa* L.) is a premier fodder crop crucial for livestock survival in the cold arid Himalayan region of Ladakh, where winter lasts 6–8 months and green fodder scarcity is acute. Fifteen oat genotypes were evaluated for fodder yield across seven locations in Ladakh during 2019 using a Randomized Complete Block Design with three replications. The Eberhart and Russell (1966) stability model was employed to identify stable, high-yielding genotypes. India faces a net deficit of 35.6% in green fodder, while Ladakh faces a severe 72.3% deficit. Genotype EC-528919 (G6) demonstrated superior stability with mean green fodder yield of 186.2 q/ha, regression coefficient ($b_i = 0.99$), and non-significant deviation ($S^2_{di} = 0.35$). Genotype EC-528903 (G2) also showed ideal stability (184.9 q/ha, $b_i = 1.01$, $S^2_{di} = 0.28$). Genotype JPO-42 (G15) gave the highest yield (225.8 q/ha) but lower stability ($b_i = 1.18$, $S^2_{di} = 2.45$), suiting only favorable environments. Conclusion: EC-528919 and EC-528903 are recommended as the most stable, high-yielding oat genotypes for all cold arid regions of Ladakh, ensuring reliable fodder and hay during the critical lean period.

Key words: Oat, Fodder yield, Eberhart and Russell model, Stability analysis, Ladakh, Lean period, Cold arid region

Oat (*Avena sativa* L.) is an important rabi forage crop valued for its high biomass production, palatability, and nutritive quality, making it a vital component of livestock-based farming systems. In cold arid regions such as Ladakh, characterized by low temperatures, a short growing season, and erratic environmental conditions, ensuring a consistent supply of quality fodder remains a major challenge, particularly during the prolonged lean period. The identification of genotypes that can perform reliably across diverse and harsh environments is therefore essential for sustainable fodder production in these ecologically fragile areas. Genotype \times environment interaction (GEI) significantly influences the performance and adaptability of crop genotypes, often complicating the selection of superior cultivars. Stability analysis provides a robust approach to assess the adaptability and consistency of genotypes across varying environments [1].

India possesses the world's largest livestock population (535.78 million animals), contributing 4.11% to the national GDP, yet faces a chronic fodder deficit of 35.6% for green fodder and 23.4% for dry fodder [2-3]. This deficit is more pronounced in Jammu and Kashmir (45.2%) and reaches acute proportions in the cold arid Himalayan region of Ladakh, where a 72.3% green fodder deficit prevails [4]. Ladakh, situated at altitudes ranging from 2,900 to 5,900 meters above sea level, is among the coldest inhabited regions on Earth, with winter temperatures plummeting to -30°C to -70°C and a lean period of 7-8 months (October to April) during which snow cover precludes grazing, forcing livestock to depend entirely on

stored hay [5]. Given that livestock constitutes the primary livelihood source for 78% of Ladakh's rural population, supporting 2.8 lakh animals including cattle, yak, dzomo, sheep, and goats, the development of high-yielding and stable fodder crops is imperative [4]. Oat (*Avena sativa* L.) has emerged as the most promising fodder crop for such cold arid regions owing to its exceptional cold tolerance, short growing season (90-110 days), high biomass production, excellent nutritional quality (8-12% crude protein with 65-70% digestibility), and the ability to store hay for 12-18 months without significant nutrient loss [5-6]. However, genotype \times environment interaction (GEI) presents a major challenge in varietal development for Ladakh, as the region's micro-climates vary dramatically over short distances a genotype performing well in Kargil (9,000 ft) may fail in Drass (11,000 ft) or Lanskachy (14,000 ft) [1]. The Eberhart and Russell [7] stability model, which defines stability through three parameters mean yield (above grand mean), regression coefficient ($b_i = 1.0$), and deviation from regression (non-significant S^2_{di}) provides a robust framework for identifying genotypes with consistent performance across diverse environments. Accordingly, the present study aimed to evaluate 15 oat genotypes for fodder yield across seven locations in Ladakh using the Eberhart and Russell [7] stability model. The objectives were to identify stable, high-yielding genotypes suitable for hay production during the lean period and to recommend appropriate genotypes for different agro-ecological zones of Ladakh.

*Correspondence to: Mushtaq Ahmad, E-mail: drmushtaqdarskuastk@rediffmail.com; Tel: +91 9797725250

Citation: Ahmad M. 2025. Stability analysis and fodder yield evaluation of oat (*Avena sativa* L.) genotypes for Cold Arid Regions of Ladakh using Eberhart and Russell Model. *Res. Jr. Agril. Sci.* 16(6): 647-651.

MATERIALS AND METHODS

Experimental site

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications, wherein each plot consisted of six rows of 4 m length with row spacing of 30 cm and plant-to-plant distance of 10 cm, maintaining a plant population of 3.85 lakh plants per hectare as standard for cold arid regions, and standard fertilizer application of 60:30:30 N:P₂O₅:K₂O was followed during the growing season from May to September 2019 [5-6]. Data were recorded on nine parameters: days to 50% flowering (D 50%), plant height in cm (PH), number of leaves per plant (NL/plant), number of tillers

per plant (N TILL), culm diameter in cm (CIM DMT), leaf stem ratio (LSR), green fodder yield per plant in grams (GFYPP), dry matter yield per plant in grams (DMYPP), and green fodder yield per hectare in quintals (GFYHA). Stability analysis was performed using the Eberhart and Russell [7] model expressed as $Y_{ij} = \mu_i + \beta_i I_j + \delta_{ij}$, where Y_{ij} is the yield of the i -th genotype in the j -th environment, μ_i is the mean yield of the i -th genotype across all environments, β_i is the regression coefficient, I_j is the environmental index, and δ_{ij} is the deviation from regression. According to this model, a genotype was classified as ideally stable if it satisfied three criteria: (1) high mean yield above the grand mean, (2) regression coefficient (β_i) not significantly different from 1.0 ($P > 0.05$), and (3) deviation from regression (S^2d_i) not significantly different from zero ($P > 0.05$).

Table 1 Seven locations representing Ladakh's diverse agro-ecological conditions were selected

Location	Altitude (feet)	Growing season (days)	Mean summer temperature
Kargil	9,003	120	18°C
Drass	11,000	100	15°C
Batalik	10,023	115	20°C
Thasgam	11,045	110	17°C
Lanskarchy	14,000	90	12°C
MAR and ES Kargil	9,003	120	18°C
G. M. Pora	9,003	120	18°C

Ahmad *et al.* [4]

Table 2 Fifteen oat genotypes were obtained from NBPGR, New Delhi and ICAR-IGFRI, Jhansi

Code	Accession	Origin	Type
G1	EC-528895	Japan	Dual purpose
G2	EC-528903	Russia	Fodder type
G3	EC-529823	Japan	Fodder type
G4	EC-528905	Russia	Dual purpose
G5	EC-528894	Japan	Fodder type
G6	EC-528919	Russia	Fodder type
G7	EC-528878	Japan	Fodder type
G8	EC-528913	Russia	Dual purpose
G9	EC-528902	Japan	Grain type
G10	EC-528870	Japan	Grain type
G11	EC-528889	Unknown	Fodder type
G12	EC-528845	Russia	Fodder type
G13	EC-528877	Russia	Dual purpose
G14	EC-528913	Russia	Fodder type
G15	JPO-42	Japan	Fodder type

Ahmad *et al.* [5]

RESULTS AND DISCUSSION

Mean performance across locations

The mean performance of 15 oat (Table 3) genotypes evaluated across seven diverse locations in Ladakh revealed substantial variability for all agronomic traits. The grand mean for green fodder yield per hectare (GFYHA) was 165.9 q ha⁻¹, with genotype means ranging from 89.7 q ha⁻¹ (G12) to 225.8 q ha⁻¹ (G15). The critical difference (CD) at $p = 0.05$ was 14.8 q ha⁻¹, indicating significant genotypic differences. Genotypes G15 (JPO-42), G14, G6 (EC-528919), and G2 (EC-528903) recorded the highest mean yields of 225.8, 187.4, 186.2, and 184.9 q ha⁻¹, respectively, all exceeding the grand mean. For plant height (PH), the grand mean was 73.7 cm, with G15 being the tallest (108.3 cm) and G9 the shortest (35.0 cm). Number of

tillers (N TILL) averaged 3.5 per plant, with G6 exhibiting the highest tillering (5.1). Leaf-to-stem ratio (LSR), a key determinant of fodder quality, averaged 28.9, with G14 (37.9) and G3 (34.4) showing superior values. Dry matter yield per plant (DMYPP) ranged from 4.8 g (G12) to 11.4 g (G15), with a grand mean of 8.5 g. The significant genotypic variance for all traits underscores the scope for selection of stable, high-yielding genotypes for the cold arid region.

Stability analysis [7]

Stability parameters for green fodder yield were estimated following the Eberhart and Russell [7] model, which defines a stable genotype as one having a high mean yield, a regression coefficient (β_i) not significantly different from unity, and a deviation from regression (S^2d_i) not significantly different

from zero. The analysis identified genotypes G2 (EC-528903) and G6 (EC-528919) as the only entries meeting all three criteria for ideal stability. G2 exhibited a mean green fodder yield per hectare (GFYHA) of 184.9 q ha⁻¹, $b_i = 1.01$ (not significantly different from 1.0), and a non-significant $S^2d_i = 0.28$. Similarly, G6 recorded a mean of 186.2 q ha⁻¹, $b_i = 0.99$ (non-significant deviation from 1.0), and a non-significant $S^2d_i = 0.35$. These values indicate that both genotypes possess average responsiveness to environmental changes and predictable performance across locations and years. In contrast, genotype G15 (JPO-42), despite having the highest mean yield (225.8 q ha⁻¹), showed $b_i = 1.18$ (significantly >1) and a significant $S^2d_i = 2.45$, classifying it as responsive but unstable, with above-average sensitivity to favorable environments and unpredictable performance under stress. Other genotypes such as G1, G4, G5, G9, G10, and G12 exhibited b_i significantly less

than 1.0 and significant S^2d_i , indicating adaptation only to poor environments or general instability. Genotypes G3, G11, and G14 had $b_i > 1.0$ with significant deviations, making them suitable only for high-input or favorable zones.

Ideal stable genotypes

Based on the Eberhart and Russell [7] criteria, G6 (EC-528919) and G2 (EC-528903) were identified as the ideal stable genotypes. Both satisfied all three conditions: (i) mean yield above the grand mean (186.2 and 184.9 q ha⁻¹ vs. 165.9 q ha⁻¹), (ii) b_i not different from 1.0 (0.99 and 1.01, respectively), and (iii) non-significant S^2d_i (0.35 and 0.28, respectively). These findings are consistent with previous studies that reported stable oat genotypes for cold regions exhibiting b_i values between 0.95 and 1.05 with non-significant deviations. These findings are in accordance to the observations of [5-6].

Table 3 Mean performance of 15 oat genotypes across seven locations in Ladakh

Genotype	Green fodder yield per hectare (q/ha)	Plant height (cm)	Number of tillers	Leaf-to-stem ratio	Dry matter yield per plant (g)
G1	154.4	66.2	3.0	23.6	7.9
G2	184.9	61.3	4.1	33.2	9.2
G3	182.7	94.5	4.0	34.4	9.5
G4	165.2	96.1	3.0	31.0	8.6
G5	138.2	75.6	4.0	28.1	7.2
G6	186.2	74.4	5.1	32.8	9.3
G7	174.3	63.5	3.0	21.2	9.2
G8	170.6	86.5	4.0	28.9	8.5
G9	130.2	35.0	3.0	26.8	6.7
G10	141.8	40.5	3.0	25.6	7.4
G11	172.5	76.1	3.0	23.3	9.1
G12	89.7	63.4	3.0	22.2	4.8
G13	166.0	77.7	3.0	31.3	8.7
G14	187.4	97.1	4.0	37.9	9.7
G15	225.8	108.3	4.0	33.0	11.4
Grand mean	165.9	73.7	3.5	28.9	8.5
CD (P=0.05)	14.8	5.9	0.5	3.1	0.8

Final ranking and recommendations

Based on mean yield and stability parameters, G6 (EC-528919) and G2 (EC-528903) ranked first and second, respectively, and are recommended for cultivation across all zones of Ladakh. G15 (JPO-42), despite its highest yield (225.8 q ha⁻¹), ranked third due to its instability ($b_i = 1.18$, $S^2d_i = 2.45$) and is recommended only for favorable environments. G14 and G3, with mean yields of 187.4 and 182.7 q ha⁻¹ but with $b_i > 1.0$ and significant deviations, are suitable only for good environments [8].

Zone-wise recommendations

For all zones across an altitudinal range of 9,000–14,000 ft, including marginal areas such as Drass and Lanskarchy, genotypes G2 and G6 are recommended for both green fodder and hay production. For favorable zones with altitudes of 9,000–10,000 ft (e.g., Kargil, Batalik, G.M. Pora), G15 (JPO-42) can be cultivated for high yield under good management. For marginal zones at 11,000–14,000 ft, genotypes G4 and G1, though less stable, may serve as alternative hay sources [9].

Severity of fodder deficit in Ladakh

The results corroborate earlier reports that Ladakh faces a 72.3% green fodder deficit, the most severe in India [2-3]. With a winter lean period of 7-8 months (October-April), livestock survival depends entirely on stored hay. The dry matter yield per plant (DMYPP) of the recommended genotypes G2 and G6 was 9.2 and 9.3 g, respectively, translating to an

estimated hay yield of 35-36 q ha⁻¹. This quantity is sufficient for 12-18 months of storage, thereby ensuring fodder security through the extended winter [6].

Why G2 and G6 are ideal

According to the Eberhart and Russell [7] model, an ideal genotype must possess high mean yield, unit regression coefficient ($b_i = 1.0$), and non-significant deviation from regression (S^2d_i). Both G2 and G6 exceed the grand mean by 11–12%. Their b_i values of 1.01 and 0.99 are not statistically different from 1.0, indicating proportional responses to environmental changes neither over-responsive (which would confer instability in poor environments) nor under-responsive (which would limit yield potential in good environments). Their non-significant S^2d_i values (0.28 and 0.35) confirm that performance is predictable across years and locations, a critical attribute for marginal agricultural environments where farmers cannot risk genotype-by-environment interaction. These results align with previous findings where stable oat genotypes for cold arid regions had b_i values between 0.95 and 1.05 and non-significant S^2d_i [5-6].

Why G15 (JPO-42) is not recommended for all zones

Although G15 recorded the highest mean green fodder yield (225.8 q ha⁻¹), its $b_i = 1.18$ (significantly >1) and significant $S^2d_i = 2.45$ indicate above-average responsiveness to environmental improvements combined with unpredictable performance. Such genotypes perform well only in favorable,

high-input environments but fail in marginal zones such as Drass and Lanskachy, where cold stress and short growing seasons prevail. This pattern is consistent with Ahmad *et al.* [1], who reported that high-yielding but unstable genotypes are unsuitable for wide adaptation in cold arid regions. Therefore, G15 is recommended exclusively for favorable zones (Kargil, Batalik, G.M. Pora) under good management.

Importance for hay during the lean period

The suitability of G2 and G6 for hay production is further supported by their agronomic traits. Both genotypes exhibited favorable dry matter yield per plant (9.2–9.3 g), leaf-to-stem

ratios of 33.2 and 32.8, which are associated with higher protein content and digestibility, and culm diameters of 1.29 cm and 1.38 cm, respectively, conferring lodging resistance. These characteristics are essential for producing high-quality hay that can be stored for 7–8 months of winter without significant deterioration. Previous work by Ahmad *et al.* [6], Ahmad *et al.* [3] similarly emphasized that hay yield and quality traits are paramount for genotype recommendation in the trans-Himalayan region, where green fodder is unavailable for most of the year. Thus, the release and large-scale cultivation of G2 and G6 will directly address the chronic fodder deficit and enhance livestock productivity in Ladakh (Table 3-8).

Table 4 Stability [7] parameters for green fodder yield (q/ha)

Genotype	Mean Green fodder yield per hectare	bi	S ² di	Stability classification
G1	154.4	0.92*	2.15*	Unstable, poor environments
G2	184.9	1.01	0.28 (NS)	Stable, ideal ✓
G3	182.7	1.12*	1.85*	Responsive
G4	165.2	0.88*	2.45*	Unstable
G5	138.2	0.79*	3.20*	Unstable
G6	186.2	0.99	0.35 (NS)	Stable, ideal ✓
G7	174.3	0.96	1.45*	Moderately stable
G8	170.6	1.05	1.92*	Moderately stable
G9	130.2	0.72*	3.85*	Poorly adapted
G10	141.8	0.82*	2.95*	Unstable
G11	172.5	1.08	1.65*	Responsive
G12	89.7	0.65*	5.20*	Very poor
G13	166.0	0.95	2.35*	Moderately stable
G14	187.4	1.15*	1.95*	Responsive
G15	225.8	1.18*	2.45*	Responsive, high yield

*Significantly different from 1.0 (bi) or from zero (S²di) at P < 0.05; NS = Non-significant

Table 5 Ideal stable genotypes

Criterion	G2 (EC-528903)	G6 (EC-528919)
Mean yield > 165.9 q/ha?	✓ 184.9	✓ 186.2
bi not different from 1.0?	✓ 1.01	✓ 0.99
S ² di non-significant?	✓ 0.28	✓ 0.35

✓ Both meet ALL three Eberhart and Russell [7] criteria for ideal stability

Table 6 Final ranking and recommendations

Rank	Genotype	Mean (q/ha)	bi	S ² di	Recommendation
1	G6 (EC-528919)	186.2	0.99	0.35	✓ All zones
2	G2 (EC-528903)	184.9	1.01	0.28	✓ All zones
3	G15 (JPO-42)	225.8	1.18	2.45	⚠ Favorable zones only
4	G14	187.4	1.15	1.95	⚠ Good environments
5	G3	182.7	1.12	1.85	⚠ Good environments

Table 7 Zone-wise recommendations

Zone	Altitude	Recommended genotypes	Use
All zones	9,000 – 14,000 ft	G2, G6	Green fodder + Hay
Favorable zones (Kargil, Batalik)	9,000 – 10,000 ft	G15 (JPO-42)	High yield under good management
Marginal zones (Drass, Lanskachy)	11,000 – 14,000 ft	G4, G1	Hay production

Table 8 Importance for hay during lean period

Parameter	G2	G6	Significance
Dry matter yield per plant (g)	9.2	9.3	Hay yield ~35–36 q/ha
Leaf stem ratio	33.2	32.8	Higher protein content
Culm diameter (cm)	1.29	1.38	Lodging resistance

The data presented in (Table 8) highlight the comparative importance of selected traits contributing to hay production during the lean period, particularly for genotypes G2 and G6. Both genotypes exhibited nearly similar dry matter yield per plant (DMYPP), with values of 9.2 g and 9.3 g, respectively, corresponding to an estimated hay yield of approximately 35-36 q/ha. This indicates their potential suitability for ensuring adequate fodder availability under resource-constrained conditions. The leaf stem ratio, a key indicator of fodder quality, was marginally higher in G2 (33.2) compared to G6 (32.8). A higher leaf proportion is generally associated with improved palatability and enhanced crude protein content, suggesting that G2 may offer slightly better nutritional quality of hay [10-11]. However, the difference between the two genotypes is minimal, indicating comparable performance in terms of fodder quality. In contrast, G6 demonstrated a relatively higher culm diameter (1.38 cm) than G2 (1.29 cm), which is an important trait associated with lodging resistance [12]. Thicker culms contribute to better structural strength, reducing the risk of lodging under adverse weather conditions, particularly in the cold arid regions where wind and soil conditions may affect crop stability. Overall, both genotypes G2 and G6 showed desirable attributes for hay production during the lean period, combining moderate to high biomass yield with acceptable quality parameters [13]. While G2 may be preferred for slightly better fodder quality due to a higher leaf stem ratio, G6 offers an advantage in terms of

lodging resistance. Therefore, both genotypes can be considered suitable candidates for cultivation in cold arid regions, depending on the specific production priorities of yield, quality, or resilience. These traits make G2 and G6 ideal for hay production, which is stored for 7-8 months of winter [3], [6].

CONCLUSION

This study successfully identified stable, high-yielding oat genotypes for the cold arid Himalayan region of Ladakh using the Eberhart and Russell (1966) stability model. Among the evaluated genotypes, G6 (EC-528919) exhibited the highest stability (186.2 q ha^{-1} ; $b_i = 0.99$; $S^2d_i = 0.35$), followed closely by G2 (EC-528903) (184.9 q ha^{-1} ; $b_i = 1.01$; $S^2d_i = 0.28$), both satisfying all three criteria for ideal stability, whereas G15 (JPO-42) demonstrated the highest yield (225.8 q ha^{-1}) but was unstable ($b_i = 1.18$; $S^2d_i = 2.45$), making it suitable only for favorable environments such as Kargil, Batalik, and G.M. Pora. Given that Ladakh faces a severe fodder deficit of 72.3% the highest in India with a lean period lasting 7-8 months (October-April), the release and large-scale cultivation of EC-528919 and EC-528903 are strongly recommended across all cold arid regions of Ladakh to ensure reliable green fodder and hay production during the critical lean season. Furthermore, the methodological approach prioritizing the Eberhart and Russell model holds significant potential for application to other fodder crops in marginal agricultural environments worldwide.

LITERATURE CITED

1. Ahmad M, Zafar G, Mir SD, Dar ZA, Razvi SM, Iqbal S, Habib M. 2014. Genetic analysis for fodder yield and its important traits in oats (*Avena sativa* L.). *Indian Journal of Genetics and Plant Breeding* 74: 112-114.
2. Ahmad M, Ahmad F, Dar EA. 2018. Breeding strategies and conservation techniques for improvement of buckwheat under cold arid conditions of Ladakh. *International Journal of Pure and Applied Bioscience* 6: 246-257.
3. Ahmad M, Ahmad F, Zaffar G, Dar EA, Qayoum S, Wani TA, Lone AA, Iqbal S, Majeed A. 2019. Buckwheat as a nutritive and health-promoting crop of tribal populations: Revival strategies. *SKUAST Journal of Research* 21: 115-127.
4. Ahmad M, Ahmad F, Dar EA. 2018. Evaluation of oat genotypes under high altitude cold arid regions of Kargil (J&K). *International Journal of Pure and Applied Science* 8(3): 220-228.
5. Ahmad M, Zafar G, Razvi SM, Dar ZA. 2015. Genetic analysis for beta glucan, grain protein and other important traits in oats (*Avena sativa* L.). *Indian Journal of Genetics and Plant Breeding* 75(1): 136-139.
6. Ahmad M, Zafar G, Wani BA, Mehraj U, Dar ZA, Lone AA, Rather MA. 2016. Genotype \times environment interaction and stability analysis for grain quality and yield in oats (*Avena sativa* L.). *Electronic Journal of Plant Breeding* 7: 1132-1135.
7. Eberhart SA, Russell WA. 1966. Stability parameters for comparing varieties. *Crop Science* 6: 36-40.
8. BIRTHAL PS, NEGI DS. 2019. Livestock and livelihoods in India: Current status and emerging challenges. *Indian Journal of Agricultural Economics* 74(3): 321-338.
9. Kumar R, Singh M, Singh BP. 2019. Fodder scarcity in Himalayan region: Causes, consequences and coping strategies. *Indian Journal of Animal Sciences* 89(5): 471-482.
10. Mehraj U, Ahmad M. 2016. Participatory breeding of forage oats in Kashmir valley. *Indian Journal of Genetics and Plant Breeding* 76(2): 217-220.
11. Ram H, Singh G, Singh T. 2018. Oat: A promising fodder crop for cold arid regions of India. *Forage Research* 44(1): 1-8.
12. Saleem N, Ahmad M, Vashnavi R, Bukhari A, Dar ZA. 2015. Stability analysis in wheat: an application of additive main effects and multiplicative interaction. *African Journal of Agriculture Research* 10(4): 295-300.
13. Wani SA, Hassan GI, Bhat MA. 2017. Fodder production in mountainous regions of Jammu and Kashmir: Status and strategies. *Indian Journal of Agronomy* 62(3): 289-296.