International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Nutrient Use Efficiency and Yield Performance of Apple Cultivars Under Mid- Hill Conditions

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Abstract
Nutrient wastage is a major challenge in mid hill orchards of apple which enhances fertilizer cost and degrading environment. The present study evaluates nutrient use efficiency of seven apple cultivars- Early Red One, Scarlet Spur II, Oregon Spur II, Golden Delicious, Granny Smith, Gale Gala and Gibson Golden- using yield, canopy development, and nutrient efficiency matrices under mid-hill conditions. Significant variation is noticed among cultivars for fruit yield and tree canopy volume. Gale Gala recorded the highest yield (9.91 Kg tree^{-1}), followed by Granny Smith (7.76 Kg tree^{-1}), while Oregon Spur II produced the lowest yield. Yield efficiency and partial factor productivity (PFP) unfiltered significant differences in nutrient utilization patterns among cultivars. Scarlet Spur II shows the highest yield efficiency (4.70 Kg m-3) whereas Gale Gala and Granny Smith achieved the highest PFP values (6.61 and 5.17 Kg fruit Kg-1 nutrients, respectively). The results illustrate that high yield does not relate to high nutrient efficiency and is focused on relevance of cultivar specific nutrient management strategies in apple orchards.

Keywords: Apple, Nutrient use efficiency, Yield efficiency, Partial factor productivity, Canopy volume

Introduction

In the temperate region of western Himalayan, the apple is the main commercial crop belonging to the Rosaceae family (Attri *et al.,* 2019). The apple is the major crop for livelihood and economy of the state like Himachal Pradesh, Jammu and Kashmir, and some parts of Uttarakhand (Basannagari and Kala, 2013). Apple is known to be a core temperate region for profitable crops (Gautam *et al.,* 2024).
Hilly areas are still dependent on the traditional delicious cultivars of apple which are easily affected by climate variation and pollination, as well as achieving low productivity (Sharma *et al.,* 2025). Considering these challenges, investigation of varied cultivar is becoming a need to encourage productivity and profitability of farmers in the mid hill range of western Himalayas. It is noticed that exotic cultivars such as Gala and Spur perform better in this region in terms of yield compared to traditional delicious cultivars (Sharma *et al.,* 2017). However, canopy volume plays a critical role in apple yield due to its role in photosynthesis, light interception, fruit quality, and nutrient use efficiency (Lakso *et al.*, 1997; Robinson *et al.,* 2011). It indicates the canopy volume to enhance the yield performance as well as nutrient use efficiency of the cultivar.
Low nutrient use efficiency is noticed in apple orchards, causing nutrient wastage which is not absorbed or utilized by trees (Wen *et al.,* 2023; Tan *et al.,* 2021). The excess nutrient accumulates in the soil or is lost in the environment (Wen *et al.,* 2023). The fertilizer nitrogen uptake efficiency in orchards is less than 24 percent, shows nutrient losses by leaching, volatilization, or soil deposition (Gentile *et al.,* 2022). A

study showed that high input fertilization leads to high macronutrient levels in soil of orchards indicating nutrient wastage and environmental risks (Sharma *et al.,* 2019). To address this challenge of nutrient wastage, we need to apply nutrients according to the need for crops and cultivate the cultivar with high nutrient use efficiency.

Therefore, the following objective of the study are:

1. To determine the best performing cultivars in terms of yield.
2. To determine the cultivar having high nutrient use efficiency.

Material and methods

The study was done in our apple research orchard, which is in apple Jelam Joshimath, Chamoli, Uttarakhand. We found that which has a cool winter and mild summer which is very good for apple growth. Also, we had well drained soil which was very much suited for apple culture. We looked at 7 different cultivars in this research, i.e., Early Red One, Scarlet Spur II, Oregon Spur II, Golden Delicious, Granny Smith, Gale Gala, and Gibson Golden. Also, we chose trees that were of the same age, size and health to put out the results as much as we could. Our experiment was done in a randomized block design, and we had 3 replications of a single tree per each cultivar. Equal proportion of nutrients should be applied in all the cultivar i.e., 700g nitrogen, 350g phosphorus, and 700g potassium per year per tree.

Fruit yield at harvest was recorded per tree and reported in kg tree^{-1}. We determined tree canopy volume using standard geometric formulas which we based on tree height and spread measures. As for the computation of nutrient use efficiency indices we did this:

Yield efficiency was calculated as the ratio of fruit yield to tree canopy volume:

Yield efficiency (Kg m^{-3}) $= \frac{Fruit\ yield\ (Kg\ per\ tree)}{Tree\ volume\ (m^3)}$

Partial factor productivity (PFP) was calculated as:

PFP (Kg fruit Kg^{-1} Nutrient applied) $= \frac{Fruit\ \ yield\ (Kg\ tree^{-1})}{Total\ nutrient\ applied\ (Kg\ tree^{-1})}$

In our study, we analyzed yield and tree volume data. We used R software to determine standard error of mean (SEM) and critical difference (CD) at 5% probability. Also, we did not subject the derived nutrient-use efficiency indices to statistical analysis.

Results and interpretations

Table 1. Yield and canopy characteristics of apple cultivars under uniform nutrient application.

Cultivar	Yield (kg tree^{-1})	Tree volume (m^3)
Early Red One	2.51	3.28
Scarlet Spur II	2.68	0.57
Oregon Spur II	0.65	0.60
Golden Delicious	2.29	1.29
Granny Smith	7.76	3.56

Gale Gala	9.91	5.60
Gibson Golden	3.19	2.59
SEM (±)	0.49	0.67
CD (P=0.05)	1.44	2.00

Among analysis of these apple cultivars, Gale gala produced highest yield, average around 9.21 kg tree^{-1}, along with largest tree canopy volume of 5.6 m^3, followed by Granny smith having average yield of 7.76 kg tree^{-1} and canopy volume around 3.56m^3. However, Oregon spur II showed the lowest yield of 2.68 kg tree^{-1} as well as the smallest tree canopy volume (0.6 m^3). Whereas other remaining cultivars founded as intermediate performer: scarlet spur II yielded 2.68 kg tree^{-1} with 0.57 m^3, Gibson golden produced 3.19 kg tree^{-1} with a volume of 2.59 m^3, early red one had 2.51 kg tree^{-1} with 3.28m^3, and golden delicious had yield of 2.29 kg tree^{-1} with volume of tree canopy around 1.29m^3. The standard error of mean showed moderate variability (SEM: ±0.49 for yield, ±0.67 for volume) with significant difference among cultivars (CD at P = 0.05: 1.44 kg tree^{-1} for yield, 2.00 m^3 for volume). Ultimately, Gale gala and Granny smith showed a superior performance in both yield and tree canopy volume under the condition of this study.

Table 2. Yield efficiency and partial factor productivity of different apple cultivars under uniform nutrient application.

Cultivar	Yield efficiency (kg m^{-3})	PFP (kg fruit kg^{-1} nutrient)
Early Red One	0.77	1.67
Scarlet Spur II	4.70	1.79
Oregon Spur II	1.08	0.43
Golden Delicious	1.77	1.53
Granny Smith	2.18	5.17
Gale Gala	1.77	6.61
Gibson Golden	1.23	2.13

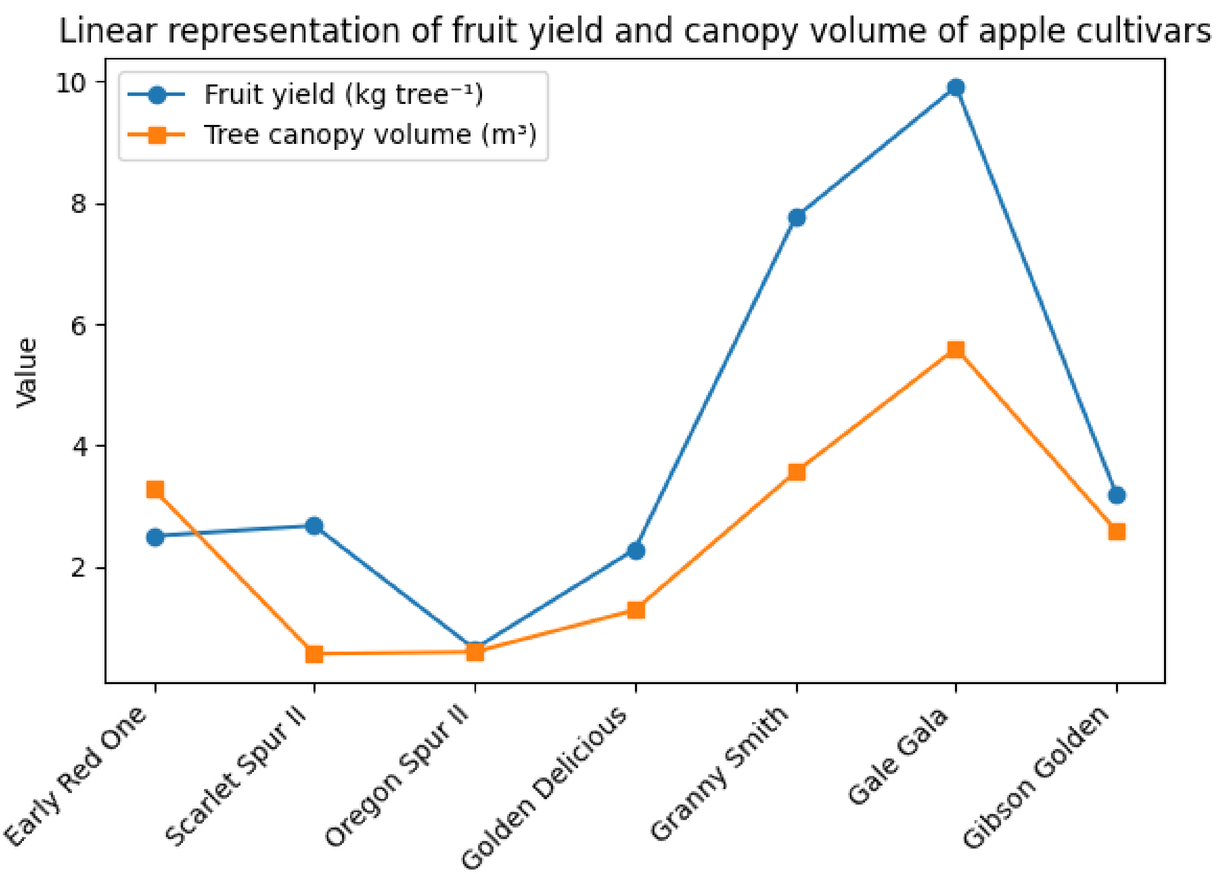
The cultivars varied notably in yield efficiency and nutrient use. Scarlet spur II showed the highest yield efficiency (4.7 Kg m^{-3}), whereas early red one and oregon spur II noted the lowest efficiency with 0.77 and 1.08 Kg m^{-3} respectively. In term of partial factor productivity (PFP), Gale gala showed highest nutrient use efficiency (6.61 Kg fruit per kg nutrient), followed by Granny smith (5.17 Kg Kg^{-1}), whereas oregon spur II had lowest PFP of around 0.4 Kg Kg^{-1}. Other cultivars scarlet spur II (1.79), Gibson golden (2.13), Golden delicious (1.53), and Early red one (1.67) showed intermediate PFP. Hence, scarlet spur II was most efficient in yield per tree volume, whereas gale gala and granny smith were superior in converting applied nutrients into fruits.

Discussion

The present research indicates that apple cultivars vary significantly in conversion of applied nutrient into economic yield irrespective of nutrient management. This level of variability depicts the need to evaluate cultivar response using nutrient use efficiency indices alongside fruit yield, provide more precise assessment of sustainability in perennial fruit systems.

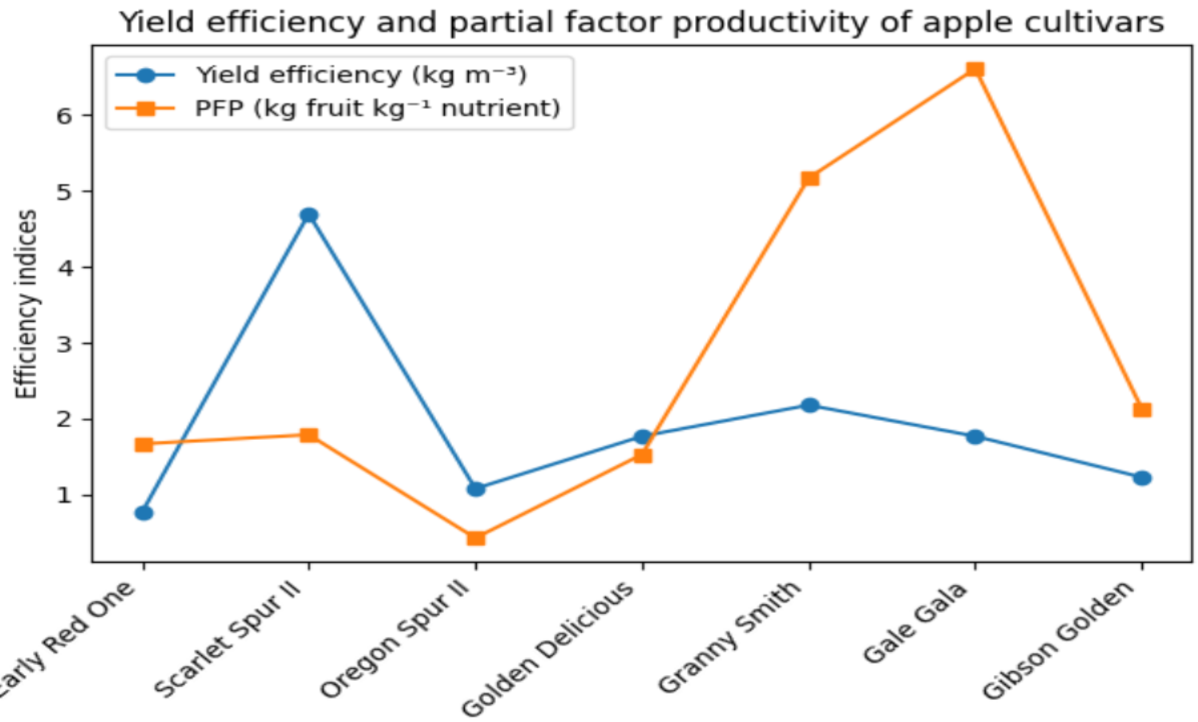
Galle gala and granny smith also achieved the highest yield and canopy volume. The increase in yield of these cultivars is driven by robust growth patterns and a larger canopy for photosynthesis which facilitates more nutrient absorption and utilization. Galle gala had moderate yield efficiency despite larger canopy cover showing that yield per unit of canopy volume is not proportional to canopy size.

Figure 1. Representing fruit yield and canopy volume of different apple cultivars.



Although the scarlet spur II achieved the highest level of yield efficiency, even with its moderate yield production. Its compact canopy results in an increased yield per unit of canopy volume and better utilization of nutrients. It is known that spur type cultivars allocate higher rates of transport of assimilates toward sink, thereby encouraging yield efficiency. Characteristics of scarlet spur II make it a better choice for high density planting systems and limited nutrient conditions where precise resource use is important. In addition, partial factor productivity further showed different nutrient-use behaviors among cultivars. The highest PFP values resulted from Gale gala and Granny smith, demonstrating their strong ability to convert applied nutrient into marketable High PFP in these cultivars shows better assimilation, translocation and absorption indicating their ability to achieve more yields under recommended fertilizer regimes. In contrast, the diminished PFP of Oregon spur II indicates an inability to efficient use of nutrients possibly due to week sink demand or less canopy growth.

Figure 2. Representation of yield efficiency and partial factor productivity of different cultivars.



The results show that superior PFP and yield efficiency are not interlinked and may be different within the same cultivar. During scarlet spur II achieved high yield efficiency but with moderate PFP whereas Galle gala achieved better PFP with only averaged yield efficiency. It shows the need for cultivars selection according to specific production objectives whether increasing the high yield per unit area or optimizing nutrient productivity.

Table 3. Nutrient-use efficiency classification of apple cultivars based on yield and efficiency indices

Cultivar	Yield level	Yield efficiency	PFP	Nutrient-use class
Gale Gala	Very high	Medium	Very high	High nutrient responsive
Granny Smith	High	High	High	Efficient and stable
Scarlet Spur II	Medium	Very high	Medium	Highly efficient dwarf
Gibson Golden	Medium	Medium	Medium	Moderately efficient
Golden Delicious	Medium	Medium	Medium	Moderate responder

Early Red One	Low	Low	Low	Poor responder
Oregon Spur II	Low	Low	Very low	Nutrient inefficient

Overall, we see that there is value in cultivar specific nutrient management practices which improve nutrient use efficiency in apple orchards. We put forward that which cultivars to grow should be based on integration of canonical structure, yield projection, and nutrient efficiency data. This we put forth as a solution to issues of high input costs of nutrients and the environmental issues that arise from their inefficient use in agricultural systems.

Conclusion

In a uniform environment which regards all the same in terms of nutrient delivery, we see that different apple cultivars present different efficiencies in the use of those nutrients. Scarlet spur II did very well in terms of production per unit of canopy volume. Gale gala and Granny smith has very productive indicated by these results. In future, the other nutrient use efficiency matrices should analyze for further extraction of valuable insight for increasing yield and reducing cost by minimizing nutrient wastage and encouraging efficiency of fertilizers.

Acknowledgement

The authors are thankful to apple orchards Jelam, Joshimath, Uttarakhand, India to provide all the facilities and supports in research. Appreciation is extended to all technical and field staff who assisted in the experiment.

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