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LIGHT DISTRIBUTION WITHIN APPLE TREE CANOPIES UNDER DIFFERENT SLOPE ASPECTS AND ROW ORIENTATIONS

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ABSTRACT

The study (2022–2025, Central fruit-growing zone of the Republic of Moldova) evaluated the light microclimate in two contrasting apple orchard configurations: super-intensive on flat terrain ('Gala'/M9, North–South row orientation) and intensive on a 5° northern slope ('Golden Delicious'/M26, East–West row orientation). Actinometric results show that the North–South orientation on flat terrain ensures homogeneous and symmetrical illumination between the eastern and western canopy flanks (a difference of only ~3 %). In contrast, the East–West orientation on the northern slope generates a pronounced radiative asymmetry, with the northern flank experiencing a 38 % light deficit compared to the southern flank (0.45 vs. 0.73 cal/cm²·min). Furthermore, the wider canopy (B = 2.0 m) on the slope reduces basal radiation to 0.31 cal/cm²·min. For northern slopes, an H/L ratio of 0.87 causes mutual shading. Reducing tree height to 2.8–3.0 m (H/L = 0.70–0.75), limiting canopy width below 1.5 m, and performing thinning pruning in the upper canopy tier are recommended to optimize insolation.

INTRODUCTION

Light is the primary abiotic factor conditioning photosynthetic activity, vegetative development, and productive potential in intensive apple orchards. Within the total solar radiation spectrum, photosynthetically active radiation (PAR)—encompassing wavelengths between 400 and 700 nm—constitutes the direct energy source utilized in organic matter synthesis.

Optimal PAR interception within the canopy (a minimum of 30–50 % of incident radiation) governs proper carbohydrate accumulation, synthesis of anthocyanin pigments responsible for fruit coloration, and attainment of superior firmness and size (Robinson, 2007; Balan et al., 2021). Non-uniform light distribution leads to staggered ripening and commercial quality degradation. Shoots and buds exposed to adequate PAR levels initiate floral bud differentiation for the following year, whereas severe self-shading inside the canopy depresses photosynthetical rates, inhibits floral induction, and promotes alternate bearing (Babuc, 2012; Lauri et al., 2009). Uniform illumination ensures optimal fruit wall aeration, shortening leaf wetness duration and reducing pressure from major fungal diseases (*Venturia inaequalis*, *Podosphaera leucotricha*).

Although row orientation along the North–South (N–S) axis is theoretically considered the standard optimum—allowing the eastern side to intercept light in the morning and the western side in the afternoon (Balan et al., 2021; Bîlici, 2020a)—

real-world topographic conditions significantly alter this light microclimate. Southern and southwestern slopes receive higher thermal and energetic PAR inputs, whereas northern slopes experience direct insolation deficits and less favorable solar incidence angles (Cimpoieș, 2012; Babuc, 2012). On terrains with slopes exceeding 3–5 %, design priorities shift: row layout must strictly follow contour lines to prevent soil erosion (Cimpoieș, 2012; Balan et al., 2021), while in super-intensive systems, deviations from the N–S axis are accepted to optimize machinery operations (Wertheim, 1981; Babuc et al., 2013).

To maintain an optimal light microclimate tailored to terrain topography, orchard design must be mathematically calculated by correlating inter-row distance (L), tree height (H), geographical latitude (φ), and canopy inclination angle (α) (Balan, 1996).

Working Hypothesis and Objectives: This study evaluates how the light microclimate varies between two contrasting technological-topographic orchard configurations (super-intensive system on flat terrain with N–S rows vs. intensive system on a 5° northern slope with E–W rows). The research aims to analyze the spatio-temporal light flux distribution and establish site-appropriate canopy structural parameters, providing practical solutions for sustainable intensive orchard design.

MATERIAL AND METHODS

Experimental investigations were conducted from 2022 to 2025 in the Central fruit-growing zone of the Republic of Moldova. The experimental orchards were located in Zubrești, Strășeni District, and Onițcani, Criuleni District, Republic of Moldova. GPS coordinates for the two locations are: Zubrești (47.2386 °N, 28.5258 °E) and Onițcani (47.1458 °N, 29.0686 °E). The detailed radiometric study focused on two representative full-bearing orchards, whose geographical and technological characteristics are summarized in Table 1.

Table 1

Pedo-topographic and structural characteristics of the experimental orchards

Parameter / Factor	Onițcani, Criuleni, Orchard 1 (Flat terrain)	Zubrești, Strășeni, Orchard 2 (Sloped terrain)
GPS Coordinates	47.1458 °N, 29.0686 °E	47.2386 °N, 28.5258 °E
Altitude	62 m	145 m
Topography / Slope (i)	Flat terrain (<1º)	Northern slope (i 5º)
Aspect / Slope Exposure	Neutral	Northern (N)
Row Orientation	North–South (N–S)	East–West (E–W)
Cultivar / Rootstock	Gala Buckeye Simmons / M9	Golden Delicious / M26
Planting Distance (L x b)	3.2 x 0.8 m	4.0 x 2.0 m
Canopy Training Form	Slender Spindle	Modified Free Palmette
Tree Height (H)	3.0 m	3.5 m
Canopy Base Width (B)	1.4 m	2.0 m
Inclination Angle (α)	12º	12º
Tree Age (during trial)	12–15 years	14–17 years

Orchard structure parameters were benchmarked against algorithms established in literature (Balan, 2009, 2015; Vămășescu, 2018; Bîlici, 2020b). In professional literature, for flat terrains (slope < 3º), the recommended target ratio between tree height and row spacing is H/L = 0.75. In the studied orchards, real

measured ratio values were H/L = 0.94 (3.0 m / 3.2 m) for 'Gala' on flat terrain, and H/L = 0.87 (3.5 m / 4.0 m) for 'Golden Delicious' on sloped terrain.

Light dynamics were evaluated during maximum leaf area index development (late July). Actinometric measurements were performed on clear days between 09:00 and 17:00 at 2-hour intervals, utilizing an M-80 universal pyranometer coupled with a GSA-1 galvanometer. Determinations followed the Lukyanov & Denisov (1968) methodology across designated canopy points: along the central axis; at the canopy merging zone between adjacent trees; at heights of 0.5 m, 1.0 m, 1.5 m, and 2.0 m above ground level; within the canopy plane of symmetry; and at a lateral distance of 0.3 m toward the alleyway. Tabulated values represent multi-year averages of field measurements collected during 2022–2025 campaigns.

RESULTS AND DISCUSSION

Data regarding light microclimate registered in the super-intensive orchard on flat terrain ('Gala Buckeye Simmons' / M9, N–S oriented rows) are presented in Table 2.

Table 2

Light microclimate within 'Gala Buckeye Simmons' / M9 canopy on flat terrain (cal/cm²·min)

(Latitude 47.1458° N, 29.0686° E, H = 3.0 m, B = 1.4 m, α=12°*, N–S row orientation, planting space 3.2 x 0.8 m, multi-year averages)*

Measurement Time (Hour)	Open Field Solar Radiation	Axial Zone (Internal)			Inter-canopy Junction Zone		
		East Side	Center	West Side	East Side	Center	West Side
9^{00}	0.45	0.32	0.29	0.25	0.37	0.33	0.27
11^{00}	0.87	0.73	0.53	0.50	0.67	0.61	0.68
13^{00}	1.08	0.89	0.57	0.73	0.93	0.71	0.89
15^{00}	1.13	0.70	0.71	0.90	0.85	0.91	0.94
17^{00}	0.88	0.58	0.69	0.70	0.69	0.83	0.84
Average	0.88	0.64	0.56	0.62	0.70	0.68	0.72

Measurements in Table 2 highlight the efficiency of N–S row orientation on flat terrain for managing solar radiation interception (Jackson, 1980). Characteristic diurnal dynamics are observed: during morning hours (09:00), the eastern flank of the axial region records 0.32 **cal/cm²·min** compared to 0.25 **cal/cm²·min** on the western flank. In afternoon hours (15:00–17:00), this ratio reverses, with the western flank reaching 0.90--0.94 **cal/cm²·min.** Daily average analysis indicates symmetrical distribution between flanks (0.64 on east vs. 0.62 **cal/cm²·min** on west—a variance of only ~3% in the axial region).

The center of the main axis represents the zone with the most pronounced light attenuation: at 13:00, when open-field incident radiation reaches 1.08 **cal/cm²·min** inner canopy light decreases to 0.57 **cal/cm²·min** (a 47.2 % reduction). Nevertheless, the daily average of 0.56 **cal/cm²·min** exceeds the minimum 30–40 % external insolation threshold cited in literature as necessary to prevent spur wood dieback (Robinson, 2007; Balan et al., 2021). The canopy merging region (0.8 m intra-row tree spacing, α=12°) maintains an average light level of 0.70 **cal/cm²·min**

(79.5% of incident radiation), demonstrating that the Slender Spindle training system prevents the formation of an opaque continuous hedgerow.

Radiometric values recorded in the orchard situated on a 5° northern slope with E–W row orientation ('Golden Delicious' / M26) are detailed in Table 3.

Table 3

Light microclimate within 'Golden Delicious' / M26 canopy on a 5° northern slope (cal/cm²·min)

(Latitude 47.2386° N, 28.5258° E, 5° slope N aspect, H = 3.5 m, B = 2.0 m, α=12°*, E–W row orientation, planting space 4.0 x 2.0 m, multi-year averages)*

Measurement time (Hour)	Solar radiation		Axial zone (Internal)			Inter-canopy junction zone		
	Open field	Under canopy	South side	Center	North side	South side	Center	North side
9^{00}	0.50	0.22	0.50	0.35	0.25	0.48	0.34	0.28
11^{00}	0.82	0.35	0.80	0.58	0.44	0.78	0.56	0.43
13^{00}	1.11	0.25	0.97	0.75	0.64	0.96	0.77	0.48
15^{00}	0.89	0.37	0.85	0.66	0.59	0.82	0.65	0.56
17^{00}	0.57	0.33	0.55	0.43	0.33	0.54	0.50	0.34
Average	0.78	0.31	0.73	0.55	0.45	0.72	0.56	0.42

Results in Table 3 highlight the cumulative impact of E–W row orientation, northern slope aspect, and larger canopy volume (B = 2.0 m, H = 3.5 m). A pronounced and persistent radiative asymmetry between flanks is observed: the southern ("sunlit") side captures an average of 0.73 **cal/cm²·min** whereas the northern side receives only 0.45 **cal/cm²·min** (a 38 % mean reduction caused by self-shading and terrain slope).

Under the canopy, mean light levels fall to 0.31 **cal/cm²·min** (representing only 39.7 % of external insolation averaging 0.78 **cal/cm²·min.** At 13:00, under-canopy insolation drops to 0.25 **cal/cm²·min.** This basal attenuation is exacerbated by wider canopy base dimensions (B = 2.0 m) and the higher vigor of rootstock M26, which generates a denser canopy volume compared to M9.

Comparing both systems confirms that although peak open-field incident radiation was similar at both sites (sim 1.1 **cal/cm²·min** at solar noon), internal light distribution is markedly superior in the super-intensive system on flat terrain. The measured H/L = 0.87 ratio on the northern slope induces mutual row shading on the northern flank of adjacent rows, whereas on flat terrain, an H/L = 0.94 ratio is effectively compensated for by N–S orientation and narrower canopy base dimensions (B = 1.4 m).

CONCLUSIONS

This study highlights the complex interaction between row orientation, slope aspect, and canopy architecture, leading to the following key conclusions:

1. **Impact of Topography and Row Orientation:** E–W row orientation on a 5° northern slope ('Golden Delicious' / M26) creates marked radiative asymmetry, with the northern flank experiencing a 38 % mean light intensity reduction compared to the southern flank (0.45 vs. 0.73 **cal/cm²·min.** Conversely, N–S orientation on flat terrain ('Gala' / M9) provides homogeneous diurnal light distribution between eastern and western flanks (sim 3\% daily average variance).

2. **Under-Canopy Attenuation:** In the sloped orchard system with wider canopy dimensions (B = 2.0 m), average under-canopy radiation drops to 0.31 **cal/cm²·min** ($< 40 % of ambient solar radiation), signaling a high risk of basal shading and premature spur wood degradation in lower canopy tiers.

3. **Management Hypothesis for the H/L Ratio:** The measured H/L = 0.87 ratio (H = 3.5 m, L = 4.0 m) on northern slopes causes excessive inter-row shading onto adjacent northern row flanks. We formulate the management hypothesis—to be validated in future research—that restricting tree height to 2.8--3.0 m (H/L = 0.70--0.75) and limiting canopy base width below 1.5 m are essential requirements to optimize light microclimates on northern exposures.

4. **Phytotechnical Recommendations:** In sloped orchards with E–W rows, thinning pruning in upper canopy tiers is mandatory to facilitate light penetration toward the central axis during afternoon hours. The critical illumination threshold of 0.50 **cal/cm²·min** (cited in literature for optimal floral bud differentiation and fruit quality) is not met on northern flanks or lower canopy regions under sloped conditions, requiring structural adjustments to canopy geometry.

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REFERENCES

Babuc V. **2012.** Pomicultura. Chişinău. 662 p. ISBN 978-9975-53-067-5.

Babuc V., Peşteanu A., Gudumac E., Cumpanici A**. 2013.** Producerea merelor: manual tehnologic. Chişinău, 240 p. ISBN 978-9975-80-590-2.

Balan V. **1996**. Metoda de stabilire a distanţei dintre rândurile de pomi fructiferi. Brevet de invenție nr. 361. Data depozit 06.01. Publicat 31.01.1996. În: BOPI. nr.1/96.

Balan V. **2009**. Sisteme de cultură în pomicultură. Randamentul producţiei de fructe. În: Akademos. nr. 4(15), pp. 82-89. ISSN 1857-0461.

Balan V. **2015.** Tehnologii pentru intensificarea culturii mărului şi cireşului. In: *Akademos*. nr. 3(38), pp. 82-87. ISSN 1857-0461.

Balan, V., Peşteanu, A., Nicolaescu, Gh. **(2021).** Bunele practici de creştere a fructelor, strugurilor şi pomuşoarelor în contextul schimbărilor climatice. Chişinău: Bons offices, 150 p. ISBN 978-9975-87-781-7.

Bîlici I. **2020 a.** Evaluarea unor soiuri noi de măr în sistemul de cultură superintensiv în condițiile R. Moldova. tz. doct. în şt. agricole. Chişinău. 37 p.

Bîlici I**. 2020 b.** Formarea suprafeței foliare la soiurile noi de măr în condițiile Republicii Moldova. In: *Ştiinţa agricolă*. nr. 1, pp.

Cimpoieș Gh. **2012)** Cultura mărului. Chișinău: Editura Bonus Offices. 382 p. ISBN 978-9975-80-547-6

Jackson J. E. **1980.** Theory of light interception by orchard and a modeling approach to optimizing orchard design. In: Acta Horticulturae. vol. 114, pp. 69-79. ISSN 0567-7572.

Robinson T.L. **2007.** Effect of tree density and tree shape on light interception, tree growth, yield and economic performance of apples. In: *Acta Horticulturae*. no. 732, pp. 405-414. ISSN 0567-7572.

Vămăşescu S. **2018.** Sporirea cantității și calității producției de mere prin aplicarea fertilizării și normării încărcăturii cu rod: autoref. tz. doct. in agricultura. Chișinău, 29 p.

Wertheim, S.J. **1981.** High-density planting: development and current achievements in the netherlands, belgium, and west germany. Acta Hortic. 114, 318-330. DOI: 10.17660/ActaHortic.1981.114.44 https://doi.org/10.17660/ActaHortic.19-81.114.44

Лукьянов В. М., Денисов А. М. **1968.** Методика определения светового режима в кронах плодовых деревьев. В: *Сельскохозяйственная биология*. т. 3, № 4, с. 582-584. ISSN 0131-6397**.**