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RESEARCH ARTICLE

Effect of spacing of *Casuarina equisetifolia* on growth and yield of intercrops in farmlands

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Abstract

Agroforestry systems address global challenges such as land degradation and food insecurity by enhancing soil fertility, conserving biodiversity, optimizing land use and diversifying food and income sources. This study examined the effect of spacing variations of *Casuarina equisetifolia* on the growth and yield of seven intercrops during the third plantation cycle. The research assessed how varying tree densities, resulting from four tree spacing treatments influence intercrop performance. From the results, it was found that wider spacing (2 m × 2 m) consistently produced the best results, with significant improvements in plant height, collar diameter, dry matter production and crop yield. The findings offer important information on improving tree-crop interactions to enhance agricultural productivity and ensure sustainable land management.

Keywords: agroforestry; biodiversity; growth; productivity; spacing; yield

Introduction

Agroforestry systems combine trees and crops within the same land-use system. They are increasingly promoted as sustainable solutions to address global challenges such as land degradation, food insecurity and climate change. These systems improve biodiversity, boost nutrient cycling, protect soil and provide farmers with diverse income opportunities (1, 2). Integrating trees into cropping systems requires careful planning including proper spacing, species selection and management practices. These measures help balance the benefits and competition between trees and crops (3).

Casuarina equisetifolia is one of the most grown tree species in agroforestry systems because of its quick growth, capacity to fix nitrogen and multifunctionality. It is native to Southeast Asia and Australia and has been widely planted in tropical and subtropical regions for ecological restoration, fuelwood production, pulp manufacturing and timber (4). Its ability to form symbiotic associations with *Frankia* bacteria enhances soil fertility, making it a valuable species for crop integration (5). Furthermore, its adaptability to various soil types, including saline and degraded soils, makes it suitable for diverse agro ecological zones (6).

Tree spacing is a critical factor in determining the extent of tree-crop interactions in agroforestry systems, as it affects the growth and output of intercrops by influencing access to light, water and nutrients. Narrow spacings may lead to intense competition, reducing the productivity of crops, while wider spacings can allow crops to thrive by minimizing resource competition (7). The optimization of tree spacing is therefore crucial for balancing the productivity of both trees and crops, particularly in systems designed for long-term sustainability and multiple crop rotations.

Tree-crop interactions are further complicated by rotational systems, in which tree plantations are harvested and replanted in cycles. Crop performance in the third rotation of *C. equisetifolia* can be significantly affected by the combined effects of soil nutrient depletion, residual organic matter and microclimatic variations (8). The use of nitrogen-fixing crops, fertilization and crop rotation can enhance land productivity and economic returns in successive rotations, while addressing nutrient depletion and maintaining soil fertility.

This study intends to assess how the growth and yield of intercrops during the third rotation are affected by varying *C. equisetifolia* spacing. Seven intercrops namely, Black gram

(*Vigna mungo*), green gram (*Vigna radiata*), groundnut (*Arachis hypogaea*), sesame (*Sesamum indicum*), pearl millet (*Pennisetum glaucum*), maize (*Zea mays*) and fodder sorghum (*Sorghum bicolor*) were chosen because of their ecological and economical importance in tropical agroforestry systems.

Thus, this study aims to evaluate the performance of these intercrops under different tree spacings to better understand tree-crop interactions for improved sustainability and productivity. The results are expected to expand the existing knowledge on agroforestry systems and help establish best practices for managing tree spacing in rotational systems involving *C. equisetifolia*.

Materials and Methods

Study area

The field study was undertaken at farmer's field at Naini, Allahabad (between 25^{0}27' N latitude, 81^{0}44' longitude and at 98 m above mean sea level) under irrigated condition.

Experimental design

The experiment was laid out in a randomized block design (RBD) with four tree spacing treatments:

- **M1:** 2 m × 1 m
- **M2:** 2 m × 1.5 m
- **M3:** 2 m × 2 m
- **M4:** 1.5 m × 1.5 m

Each spacing treatment was combined with seven intercrops: green gram (*Vigna radiata*), black gram (*Vigna mungo*), cowpea (*Vigna unguiculata*), groundnut (*Arachis hypogaea*), sesame (*Sesamum indicum*), tomato (*Solanum lycopersicum*) and okra (*Abelmoschus esculentus*). A pure crop without tree spacing was also maintained as a control for comparison. The treatments were replicated three times.

Intercrop cultivation

The intercrops were sown in rows within the spacing treatments of *C. equisetifolia* at 14 and 17 months of age. Standard agronomic practices such as irrigation, weeding and fertilization were followed uniformly for all intercrops.

Soil preparation and crop management

Before sowing, the soil was prepared by ploughing and levelling to ensure uniformity. Weeds were removed and organic manure was applied at the rate of 10 t/ha. Seeds of the selected intercrops were sown at the recommended depth and spacing for each species. Supplemental irrigation was provided during dry spells to ensure optimal crop growth. Pest and disease management practices were implemented using eco-friendly methods (9).

Observations and measurements

1. **Plant height**: The height of intercrops was measured (in cm) at 30 days after sowing (DAS) using a measuring scale.
2. **Collar diameter**: The collar diameter of the intercrops (in cm) was recorded at 30 DAS using Vernier callipers (10).
3. **Dry matter production**: Dry matter accumulation (in g/plant) was estimated by oven-drying a sample of plants to constant weight at 70 °C (11).
4. **Yield**: The yield of intercrops (kg/ha) was calculated after harvest, based on the grain weight or biomass.

Estimation of volume

The standing tree volume estimated by using the formula suggested by Chaturvedi and Khanna (12) (Eqn. 1) in the year 1982 as

$$\mathbf{V = \pi r^2 h} \qquad \text{(Eqn.1)}$$

V = Volume

r = Radius at breast height

h = Total height

Statistical analysis

The experimental databases were analysed by means of IBM SPSS Statistics 21 Software. All experiments were done in triplicate to get mean values illustrated in figure using Origin 8.5 Software.

Results and Discussion

Effect of spacing of *Casuarina equisetifolia* on intercrops

The results indicated that the spacing of *C. equisetifolia* significantly influences the performance of various intercrops in terms of plant height, collar diameter, dry matter production, yield and gross income (Fig. 1). The influence of tree spacing on tree volume is also highlighted.

Plant height

The plant height of intercrops at 30 DAS (days after sowing) showed variations across tree spacings. The highest mean plant height (19.54 cm) was recorded under the 2 m × 2 m spacing (M3), with minimal reduction compared to pure crops (Table 1). Sesame and okra were more affected, with reductions ranging from 10 % to 49 % across spacings. Wider spacing allowed better sunlight penetration and resource availability, resulting in better growth (13).

Collar diameter

The collar diameter followed a similar trend. The widest spacing (M3) recorded the maximum mean collar diameter of 3.08 cm, showing a lower percentage reduction (41 %) compared to pure crops (Table 2). Narrower spacings (M1 and M4) had higher reductions due to competition for nutrients, light and water. Higher tree density reduces intercrop growth through shading and allelopathic interactions (14).

Dry matter production

Dry matter production was significantly affected by the tree spacing, with M3 (2 m × 2 m) yielding the highest mean dry matter (1807 kg/ha) (Table 3). Intercrops like green gram and cowpea showed higher resilience under wider spacings, whereas sesame and tomato experienced the highest reductions (73-93 %). Wider spacing facilitates better light interception and reduces shading effects, which positively affects photosynthesis and biomass accumulation (15).

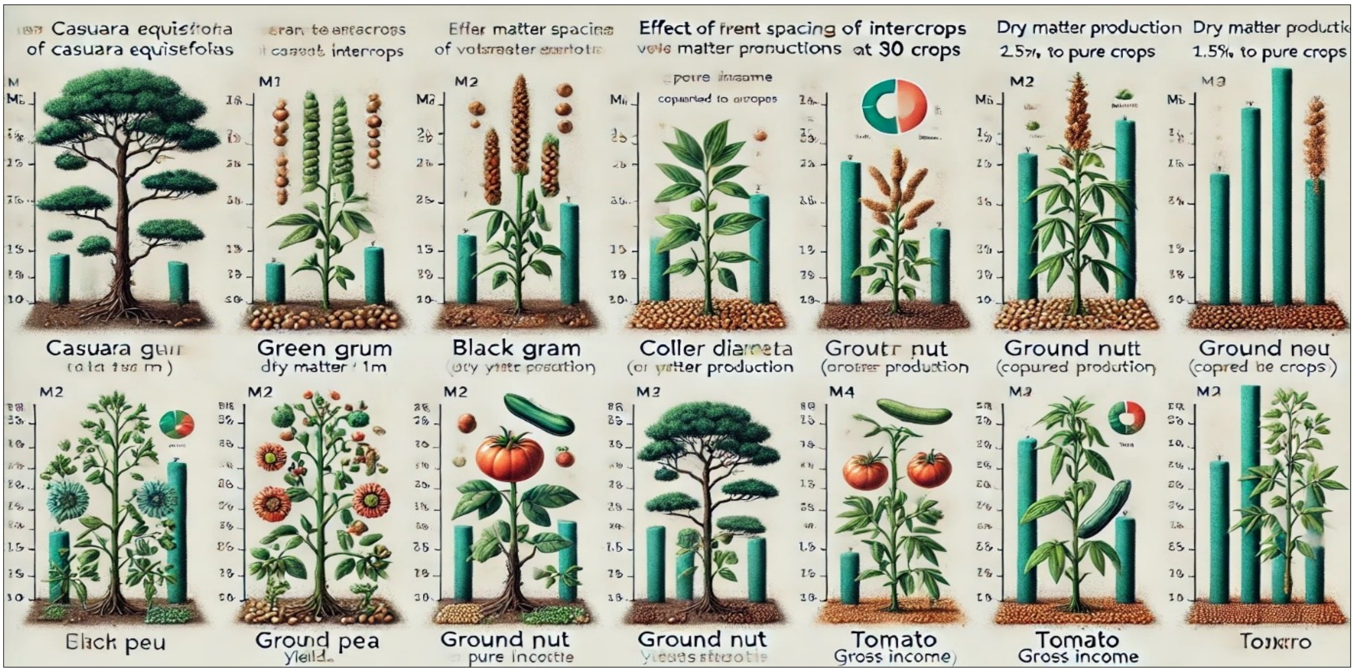

Fig. 1. Series of bar charts comparing the effect of different spacings of *Casuarina equisetfolia* on the growth parameters of intercrops at 30 DAS.

Table 1. Effect of spacing of *Casuarina equisetfolia* (14 month old) on plant height of intercrops (cm) at 30 DAS during third intercropping

Tree spacing	Green gram (cm)	Black gram (cm)	Cow pea (cm)	Ground nut (cm)	Sesame (cm)	Tomato (cm)	Okra (cm)	Mean
M1 (2 m x 1 m)	12.56 (26 %)	19.14 (7 %)	15.42 (1 %)	10.62 (6 %)	25.18 (2 %)	14.13 (21 %)	23.50 (23 %)	**17.22**
M2 (2 m x 1.5 m)	13.16 (22 %)	19.59 (5 %)	17.23 (0 %)	10.78 (5 %)	25.46 (24 %)	15.68 (12 %)	24.40 (20 %)	**18.04**
M3 (2 m x 2 m)	16.48 (3 %)	19.11 (7 %)	18.24 (6 %)	11.22 (1 %)	28.42 (1 %)	15.91 (11 %)	27.37 (10 %)	**19.54**
M4 (1.5 m x 1.5 m)	12.13 (28 %)	15.47 (25 %)	13.47 (25 %)	9.20 (19 %)	17.09 (49 %)	10.85 (39 %)	22.67 (25 %)	**14.41**
Mean	**13.58 (20 %)**	**18.33 (11 %)**	**16.09 (12 %)**	**10.45 (8 %)**	**24.04 (29 %)**	**14.14 (21 %)**	**24.49 (19 %)**	
Pure crop**	16.97	20.57	18.27	11.36	33.66	17.88	30.37	

**Pure crop data

Table 2. Effect of spacing of *Casuarina equisetfolia* (14 month old) on collar diameter of intercrops (cm) at 30 DAS during third intercropping

Tree spacing	Green gram (cm)	Black gram (cm)	Cow pea (cm)	Ground nut (cm)	Sesame (cm)	Tomato (cm)	Okra (cm)	Mean
M1 (2 m x 1 m)	2.15 (45 %)	2.86 (45 %)	2.25 (46 %)	2.16 (31 %)	2.37 (62 %)	2.17 (59 %)	3.03 (59 %)	**2.43**
M2 (2 m x 1.5 m)	2.41 (38 %)	2.76 (47 %)	2.41 (42 %)	2.28 (27 %)	2.45 (61 %)	2.48 (53 %)	3.75 (49 %)	**2.65**
M3 (2 m x 2 m)	2.73 (30 %)	3.15 (40 %)	2.86 (31 %)	2.84 (9 %)	2.82 (55 %)	2.85 (46 %)	4.33 (41 %)	**3.08**
M4 (1.5 m x 1.5 m)	1.17 (70 %)	2.66 (49 %)	1.91 (54 %)	2.11 (33 %)	2.13 (66 %)	1.95 (63 %)	2.54 (65 %)	**2.07**
Mean	**2.11 (46 %)**	**2.85 (45 %)**	**2.36 (43 %)**	**2.35 (25 %)**	**2.44 (61 %)**	**2.36 (55 %)**	**3.41 (54 %)**	
Pure crop**	3.88	5.22	4.18	3.14	6.33	5.29	7.35	

**Pure crop data

Table 3. Effect of spacing of *Casuarina equisetfolia* (17 month old) on dry matter production of intercrops (cm) at 30 DAS during third intercropping

Tree spacing	Green gram (cm)	Black gram (cm)	Cow pea (cm)	Ground nut (cm)	Sesame (cm)	Tomato (cm)	Okra (cm)	Mean
M1 (2 m x 1 m)	1938 (33 %)	2831 (24 %)	2400 (28 %)	2045 (31 %)	983 (79 %)	241 (79 %)	773 (75 %)	**1559**
M2 (2 m x 1.5 m)	1753 (29 %)	3132 (16 %)	2763 (17 %)	2288 (23 %)	999 (78 %)	233 (80 %)	789 (75 %)	**1708**
M3 (2 m x 2 m)	1930 (21 %)	3195 (14 %)	2915 (12 %)	2372 (20 %)	1103 (76 %)	291 (75 %)	842 (73 %)	**1807**
M4 (1.5 m x 1.5 m)	1472 (40 %)	2357 (36 %)	1737 (49 %)	1033 (65 %)	361 (93 %)	122 (90 %)	365 (88 %)	**1064**
Mean	**1698 (31 %)**	**2879 (23 %)**	**2454 (26 %)**	**1935 (35 %)**	**861 (81 %)**	**222 (81 %)**	**692 (78 %)**	
Pure crop**	2454	3722	3312	2977	4653	1178	3158	

**Pure crop data

Yield

Intercrops in the 2 m × 2 m spacing (M3) recorded the highest mean yield (631 kg/ha), with minimal reductions (23-64 %) for crops such as green gram and black gram. In contrast, narrow spacings like 1.5 m × 1.5 m (M4) exhibited substantial yield reductions (39-85 %) due to increased competition (Table 4). Studies have shown that intercrops perform better under reduced competition and higher resource availability (16).

Gross income

The gross income from intercrops was also higher under wider spacing. M3 spacing generated the highest income for crops like green gram (₹ 13800/ha) and black gram (₹ 24880/ha), reflecting their higher yields (Table 5). Sesame and okra showed lower profitability due to reduced growth and yield. Wider spacing optimizes the land-use efficiency, resulting in better economic returns (17).

Tree volume

The mean tree volume of *C. equisetifolia* was the highest under M3 spacing (0.0133 m^3/ha) and lowest in M4 (0.0119 m^3/ha). Intercrops like black gram and cowpea under M3 spacing had better tree volume due to reduced competition and better intercrop-tree interaction (Table 6) (18).

Conclusion

The results in plant height, collar diameter, dry matter production, yield and gross income can be explained by the balance between competition and resource availability. Wider spacing (M3) reduced competition for sunlight, water and nutrients, which improved intercrop performance. On the other hand, narrow spacing (M1 and M4) led to increased shading and competition, which limited the growth of intercrops. The higher tree volume in wider spacing is likely due to less competition between *C. equisetifolia* trees. Intercropping systems work best when there is a good balance in resource use between the trees and intercrops.

Authors' contributions

All authors contributed to the conceptualization of the research work, the design and execution of field/laboratory experiments, data collection, data analysis and interpretation and preparation of the manuscript.

Compliance with ethical standards

Conflict of interest: The research is original and the findings have neither been published nor are under consideration elsewhere. All authors who contributed to the preparation of this manuscript do not have any conflict of interest.

Ethical issues: None

Table 4. Effect of spacing of *Casuarina equisetfolia* (17 month old) on yield of intercrops (kgha^{-1}) at 30 DAS during third intercropping

Tree spacing	Green gram (kgha^{-1})	Black gram (kgha^{-1})	Cow pea (kgha^{-1})	Ground nut (kgha^{-1})	Sesame (kgha^{-1})	Tomato (kgha^{-1})	Okra (kgha^{-1})	Mean
M1 (2 m x 1 m)	284 (37 %)	417 (35 %)	323 (37 %)	586 (37 %)	085 (83 %)	702 (77 %)	677 (79 %)	**439**
M2 (2 m x 1.5 m)	293 (35 %)	458 (28 %)	337 (34 %)	693 (26 %)	108 (79 %)	746 (76 %)	746 (71 %)	**512**
M3 (2 m x 2 m)	345 (23 %)	622 (3 %)	373 (27 %)	780 (17 %)	115 (78 %)	1102 (64 %)	1102 (64 %)	**631**
M4 (1.5 m x 1.5 m)	226 (29 %)	317 (50 %)	315 (39 %)	490 (48 %)	070 (36 %)	457 (85 %)	562 (85 %)	**348**
Mean	**287** (36 %)	**454** (29 %)	**337** (34 %)	**637** (32 %)	**095** (82 %)	**752** (76 %)	**817** (74 %)	
Pure crop**	448	641	513	937	517	3064	3275	

**Pure crop data

Table 5. Effect of third rotation of intercropping with *Casuarina equisetfolia* (17 month old) at different spacing on gross income of intercrops (Rs.ha^{-1})

Tree spacing	Green gram (Rs.ha^{-1})	Black gram (Rs.ha^{-1})	Cow pea (Rs.ha^{-1})	Ground nut (Rs.ha^{-1})	Sesame (Rs.ha^{-1})	Tomato (Rs.ha^{-1})	Okra
M1 (2 m x 1 m)	11360	16680	12920	29440	4250	7020	5320
M2 (2 m x 1.5m)	11720	18320	13480	27720	5400	7460	2800
M3 (2 m x 2 m)	13800	24880	14920	31200	5750	11020	4695
M4 (1.5 m x 1.5 m)	9040	12680	12600	19600	3500	4570	2700
Mean	**17920**	**25640**	**20520**	**347480**	**25850**	**50000**	**1500**

Table 6. Effect of stand density and intercrops on mean tree volume of *Casuarina equisetfolia* at 18 month age (m^3ha^1)

Tree spacing	Green gram (m^3ha^{-1})	Black gram (m^3ha^{-1})	Cow pea (m^3ha^{-1})	Ground nut (m^3ha^{-1})	Sesame (m^3ha^{-1})	Tomato (m^3ha^{-1})	Okra (m^3ha^{-1})	Tree alone (m^3ha^{-1})	Mean
M1 (2 m x 1 m)	0.0129	0.0129	0.0124	0.0105	0.0114	0.0116	0.0111	0.0119	0.0118
M2(2 m x 1.5 m)	0.0133	0.0151	0.0143	0.0126	0.0122	0.0127	0.0118	0.0126	0.0128
M3 (2 m x 2 m)	0.0147	0.0155	0.0151	0.0135	0.0129	0.0130	0.0125	0.0133	0.0127
M4 (1.5 m x 1.5 m)	0.0139	0.0134	0.0137	0.0114	0.0104	0.0124	0.0101	0.0102	0.0119
Mean	**0.0137**	**0.0142**	**0.0139**	**0.0120**	**0.0117**	**0.0124**	**0.011**	**0.0120**	

References

1. Nair PK. State-of-the-art of agroforestry research and education. Agroforestry Systems. 1993;23:95-119. https://doi.org/10.1007/978-94-011-1608-4

2. Garrity DP. Agroforestry and the achievement of the Millennium Development Goals. Agroforestry Systems. 2004;61:5-17. https://doi.org/10.1023/B:AGFO.0000028986.37502.7c

3. Jose S, Gillespie AR, Pallardy SG. Interspecific interactions in temperate agroforestry. Agroforestry Systems. 2004;61:237-55. https://doi.org/10.1007/978-94-017-2424-1_17

4. Parrotta JA. Productivity, nutrient cycling and succession in single -and mixed-species plantations of *Casuarina equisetifolia*, *Eucalyptus robusta* and *Leucaena leucocephala* in Puerto Rico. Forest Ecology and Management. 1999;124(1):45-77. https://doi.org/10.1016/S0378-1127(99)00049-3

5. Buvaneswaran C, Kumar KV, Velumani R, Senthilkumar S. Experimental design for evaluation of clones of *Casuarina* for windbreak agroforestry system. Journal of Tree Sciences. 2018;37(1):11-8. http://dx.doi.org/10.5958/2455-7129.2018.00002.X

6. JK JJ, Veerapur M, Hegde R, Dhananjaya BC, Hareesh TS. Assessment of *Casuarina* clones and intercrops in agroforestry; 2022. PREPRINT (Version 1) available from: https://doi.org/10.21203/rs.3.rs-2141586/v1

7. Viswanath S, Peddappaiah RS, Subramoniam V, Manivachakam P, George M. Management of *Casuarina equisetifolia* in wide-row intercropping systems for enhancing productivity. Indian Journal of Agroforestry. 2004;6(2):19-25.

8. Dagar JC, Singh G. Evaluation of crops in agroforestry with *Casuarina equisetifolia* (Linn.) plantations. Indian Journal of Agroforestry. 2004;3(1):47-50.

9. Chavan SB, Dhillon RS, Sirohi C, Uthappa AR, Jinger D, Jatav HS, et al. Carbon sequestration potential of commercial agroforestry systems in Indo-Gangetic Plains of India: Poplar and eucalyptus-based agroforestry systems. Forests. 2023;14(3):559. https://doi.org/10.3390/f14030559

10. Moreira B, Gonçalves A, Pinto L, Prieto Lage MA, Carocho M, Caleja C, et al. Intercropping systems: an opportunity for environment conservation within nut production. Agriculture. 2024;14(7):1149. http://dx.doi.org/10.3390/agriculture14071149

11. Dissanayaka DM, Udumann SS, Atapattu AJ. Synergies between tree crops and ecosystems in tropical agroforestry. Agroforestry. 2024:49-87. https://doi.org/10.1002/9781394231164.ch3

12. Chaturvedi AN, Khanna LS. Forest mensuration. Dehradun: International Book Distributors; 1982.

13. Sahoo SK, Lenka B, Raj A, Jhariya MK. Climate change impacts and mitigation through sustainable agroforestry practices. In: Advances in sustainable development and management of environmental and natural resources. New York: Apple Academic Press; 2021. https://doi.org/10.1201/9781003187455-8

14. Fahad S, Chavan SB, Chichaghare AR, Uthappa AR, Kumar M, Kakade V,et al. Agroforestry systems for soil health improvement and maintenance. Sustainability. 2022;14(22):14877. https://doi.org/10.3390/su142214877

15. Ramaswamy V, Sivakumar K, Thiyageshwari S, Anandham R. Assessment on the impact of various agroforestry systems on soil quality parameters. International Journal of Plant & Soil Science. 2022;34(20):312-9. https://doi.org/10.9734/ijpss/2022/v34i2031157

16. Dinesha S. Short-rotation tree-based biofuel production in ndia from agroforestry and marginal lands without compromising food security. Journal of Agriculture and Technology. 2023;10(2):58-71.

17. Hussnain M, Maheswarappa V, Hegde R, Ganapati JM. Evaluation of early growth and morphological variation in *Casuarina* hybrid clones. International Journal of Current Microbiology and Applied Sciences. 2020:950-8. https://doi.org/10.20546/ijcmas.2020.909.117

18. Prajapati VM, Jilariya DJ, Mevada RJ, Tandel MB, Bhanderi BN, Patel DP, et al. Effect of windbreaks (*Casuarina equisetifolia* L.) on productivity of paddy in South Gujarat. International Journal of Plant & Soil Science. 2024;36(5):800-7. https://doi.org/10.9734/ijpss/2024/v36i54578

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