Quantitative Growth Analysis of Tomato (*Lycopersicon esculentum Mill.)*

Mohd Ashraf Lone[1], Sabzar Ahmad Kuchay[2*]

[1]Department of Botany, Bhagwant University Rajasthan, 305004
[2]Department of Education (J&K)
*Corresponding Author

Received:- 14 August 2021/ Revised:- 20 August 2021/ Accepted:- 25 August 2021/ Published: 31-08-2021

Abstract— *The plant growth analysis parameters like Fresh Mass, Dry Mass, Resource Allocation, Leaf Area, Leaf Area Ratio (LAR), Net Assimilation Rate (NAR), Relative Growth Rate (RGR), Leaf Weight Ratio (LWR) and Root Shoot Ratio and relation between these parameters was studied in Tomato (Lycopersicon esculentum Mill.) during entire life span i.e. from sowing till senescence in the field conditions. The values of growth analysis parameters like RGR and NAR were highest for the period of vegetative growth showing gradual decline towards the senescence. Leaf Weight Ratio (LWR) in general followed a declining trend but the decline was sharp during the transition from vegetative phase to reproductive phase. More resources were allocated towards leaves during vegetative phase to increase the photosynthetic efficiency whereas there was a shift towards reproductive parts during reproductive phase for fruiting. Leaf area followed an increasing trend with time reaching at its peak just before senescence and thereafter leaf area declined with the progress of senescence.*

Keywords— Growth Analysis Parameters, Root-Shoot Ratio and Resource Allocation.

I. INTRODUCTION

The tomato is the edible, often red, fruit/berry of the plant *Lycopersicon esculentum*, commonly known as a tomato plant. The plant belongs to Angiosperms of nightshade family, Solanaceae. The species originated in western South America. Its use as a cultivated food may have originated with the indigenous peoples of Mexico. The tomato (*Lycopersicon esculentum* Mill.) is commercially important throughout the world both for the fresh fruit market and the processed food industries. Tomato is consumed in diverse ways, including raw, as an ingredient in many dishes, sauces, salads, and drinks. While tomatoes are botanically berry-type fruits, they are considered culinary vegetables as an ingredient or side dish for savory meals. Numerous varieties of tomato are widely grown in temperate climates across the world, with greenhouses allowing its production throughout the year. In the recent decades, the consumption of tomatoes has been associated with prevention of several diseases (Willcox et al. 2003 and Sharoni et al. 2006) mainly due to the content of antioxidants including carotenes, (Lycopene as well as β-carotene), ascorbic acid, and phenolic compounds (Jesus Periago et al. 2009). The plants typically grow to 1–2.8 meters (100– 280 cm) in height and have a weak stem that sprawls. It is a perennial in its native habitat, and cultivated as an annual. Fruit size varies according to cultivar, with a width range of 0.5–4 inches (1.3–10.2 cm).

Tomato (*Lycopersicon esculentum* Mill.) is one of the most important and has the highest acreage of any vegetable crop in the world (Jensen et al., 2010). In 2010, its global production was approximately 145.6 million tons of fresh fruit and Brazil ranks ninth, with 2.7% of the world production (Matos et al. 2012). Tomato growing is considered a high-risk activity due to the great variety of environments and systems in which it is grown, high susceptibility to pests and diseases, and high demand for inputs and services, which lead to high financial investment per unit area. Furthermore, Monte et al. (2013) remark that good productivity requires availability of water throughout the cycle, as the tomato plant is very sensitive to water stress. The commercial value of the table tomato is defined by the characteristics and quality of the fruit (Ferreira et al., 2004).

All the living organisms are, at various stages in their life history, capable of growth. Given suitable conditions, this means change in size, change in form and/or change in number. These three processes together form an important part of the phenomenon of life. Among natural systems they help to distinguish the living from the non-living though, in a sense, many non-living systems also grow. Understanding the principals involved in plant growth requires a systematic approach using the tools of mathematics, physics, and other sciences along with common sense knowledge of biological variability. This teaching resource illustrates the method of interpreting plant development referred to as growth analysis (Kuchay and Zargar, 2016). The exercise can be used jointly with a series of related problems in a crop science course. Plant growth analysis refers to a useful set of quantitative methods that describe and interpret the performance of whole plant systems grown under natural, semi-natural, or controlled conditions (Kuchay and Zargar, 2016). Plant growth analysis provides an explanatory, holistic and integrative approach to interpret plant form and function. A technique of investigating growth and yield by use of growth functions was developed by British plant physiologists and has been commonly termed growth analysis (Watson, 1952 and Williams, 1946). Plant growth analysis is considered to be a standard approach to study the plant growth and productivity (Wilson, 1981). Plant growth analysis uses simple primary data like weight, area, volumes and contents of plants or plant parts to investigate processes within and involving the whole plant or crops (Hunt, 2003). Growth analysis has proved to be highly effective in studying the reaction of particular plant species to different environmental conditions and cultivation/management practices. The growth analysis studies not only help us in understanding how plant accumulates dry matter, but also discloses the underlying principles and events which can make a plant more or less productive (Ahad, 1986). The procedure for analyzing growth in terms of dry weight changes was first made by Blackman 1919, when he pointed out that growth could be regarded as a process of continuous compound interest. Any increment produced in any interval would add to the "capital" for growth in subsequent periods. The classical approach is one of the oldest methods in plant growth analysis studies introduced in the beginning of this century (Blackman 1919, West et al. 1920, Briggs et al. 1920) where the relative growth rate (RGR) is calculated by dividing the difference in loge transformed plant weight at two harvests by the time difference between those harvests. Growth analysis parameters help in studying differences in the performance of different varieties or cultivars of crops under similar or varied conditions. The growth analysis parameters like RGR and NAR directly influence the economic yield of crops (Srivastava and Singh, 1990). Similarly, dry matter production; LAR, NAR and RGR are ultimately reflected in higher yield of crops (Thakur and Patel, 1996). Karim and Fattah (2007) reported that NAR gets increased during fruiting stage. The shading of plant populations to varied degrees can be done in order to determine the effect of light intensity and the reaction of individuals can be monitored through growth analysis, like the shading of leaves can reduce NAR (Net Assimilation Rate) but the plants becomes more leafy. The reductions of light intensity can double the leaf area ratio (LAR) and similarly, more leaf surfaces can compensate the reduction in NAR so that relative growth rate (RGR) remains more or less constant.

II. MATERIALS AND METHODS

The study was carried out to have a detailed analysis of growth parameters and to determine their underlying relationships. To meet the aims and for having better understanding of plant growth analysis, we have to analyze the plant right from germination up to the senescent stage and finally the death.

2.1 Sowing and Transplantation

In order to carry out the growth analysis of tomato, the plant is to be cultivated under the field conditions. The seeds were sown in field beds of 1.5m x 1.5m dimensions to raise the nursery plantlets. When nursery plantlets attained a sufficient size after 15-20 days time interval and were easy to handle, they were transferred to main beds. The plantlets were transplanted into five beds with equal and enough spacing in between the plantlets so that the desired sized plants can be raised for better analysis.

2.2 Sampling

Sampling was done with equal time interval gaps of 15 days and the last sampling was done at the time of senescence. First samples were collected after 15 days of transplantation. Twenty plants were harvested randomly from five beds and were carried directly in polythene bags to laboratory to avoid any water loss.

2.3 Growth indices

Various growth analysis parameters (growth indices) were studied at each sampling which is enlisted below:

2.3.1 Plant height

Due to the photosynthesizing capability of plants there is an increase in the biomass of the plants which is revealed by increase in plant size, thickness etc. The height of our study plant was measured by using thread and ruler. The length of individual parts of plant like stem, roots etc. were also measured by the same technique.

2.3.2 Fresh mass

In order to measure fresh mass, it is important that the standard moisture level is maintained before and during the measurement. The fresh mass for all the plant parts such as roots, stem, leaves, fruits etc. was individually weighed by digital balance.

2.3.3 Dry mass

It is the simplest index of plant growth analysis. Dry mass is a rate of change in size, an increment in dry weight per unit time. For determining dry weight, under and over-drying must be shunned. Dry mass is the mass of the plant or plant parts after removal of moisture. For dry weight estimation the individual parts were placed in paper bags and stored in oven at 25±5°C for a week. After drying the dried individual parts where weighed separately and the dry weights were recorded. Finally, the mean weight of each part was calculated.

2.3.4 Root-Shoot Ratio

An index of the balance of growth between root and shoot components of the plant integrated over a period of time. It was determined by using the following formula:

$$K = \frac{DW_R}{DW_S} \qquad (1)$$

Where “K” is Root-Shoot Ratio, “DW_R” is Dry weight of Root and “DW_S” is Dry weight of Shoot (aerial parts).

2.3.5 Moisture content

It is the measure of water present in the plant tissue. For determining the moisture content, the fresh mass of stem, leaves and fruits was subtracted by their respective dry masses. The results were expressed as percentage by dividing the resultant moisture content by fresh mass (Kuchay and Zargar, 2016):

$$Percent\ Moisture\ Content\ (PMC) = \frac{Fresh\ Mass - Dry\ Mass}{Fresh\ Mass} * 100 \qquad (2)$$

2.3.6 Resource allocation

The food synthesized during the photosynthetic activity of the plant is allocated to different parts of plant on the basis of requirement. The percentage of resources allocated to different parts of plant was determined by the following formula (Kuchay and Zargar, 2016):

$$Resource\ Allocation = \frac{Resources\ \ or\ Dry\ Mass\ allocated\ \ towards\ \ particular\ \ plant\ part}{Total\ \ plant\ \ biomass\ \ or\ Dry\ Mass} * 100 \qquad (3)$$

2.3.7 Leaf area

In order to quantify the leaf area all the leaves from each and every sampled plant were drawn on uniformly thick paper to serve as replicas of leaves and were weighed individually for each plant. In addition to it 30 paper chits (10*10 cm^2) of same paper were also weighed in order to determine the leaf area as follows (Kuchay and Zargar, 2016):

Let weight of 100$cm^2$of paper = X g

1g of paper = 100/X cm^2 of area

Let weight of leaf replicas on paper = Y g

Therefore

$$Leaf\ Area = \frac{Y * 100\,cm^2}{X} \qquad (4)$$

2.3.8 Fruit volume

The volume is determined either by calculation, if the geometry of the fruit is simple, or, if not, by the displacement of water (employing Archimedes principle). In our study the volume of fruits was calculated by the mathematical formula:

$$Volume\ of\ Fruit = \frac{4}{3}\boldsymbol{\pi r^3} \tag{5}$$

2.3.9 Relative growth rate (RGR)

RGR is the increase in plant dry matter per unit of plant dry matter per unit time. It was calculated by using the formula given by Fisher (1921):

$$RGR = \frac{(loge\, W_2 - loge\, W_1)}{t_2 - t_1} \tag{6}$$

W_1 and W_2 represent dry weights of plant at time intervals t_1 and t_2 respectively.

2.3.10 Net assimilation rate (NAR)

It is the index used to calculate the productive efficiency of plants in relation to total leaf area. NAR was calculated according to formula given by Williams (1946):

$$NAR = \frac{(W_2 - W_1)}{t_2 - t_1} * \frac{(loge\, LA_2 - loge\, LA_1)}{LA_2 - LA_1} \tag{7}$$

LA_1 and LA_2 are leaf areas &W_1 and W_2 represent dry weights of plant at time intervals t_1 and t_2 respectively.

2.3.11 Leaf area ratio (LAR)

This morphological index was devised by G. E. Briggs and co-workers for describing the leafiness of the plant. It takes into consideration the photosynthesizing and respiring components of the plant. Mean leaf area ratio was calculated according to the formula given below:

$$LAR = \frac{(\frac{LA\,1}{W\,1} + \frac{LA\,2}{W\,2})}{2} \tag{8}$$

LA_1 and LA_2 are leaf areas of plant & W_1 and W_2 are dry weights of plant at time intervals t_1 and t_2 respectively.

2.3.12 Specific leaf area (SLA)

This index highlights the concept of "leafiness of the leaf". It is a measure of density which involves an assessment of leaf area in relation to its dry weight. Mean SLA was calculated according to the formula:

$$SLA = \frac{(\frac{LA\,1}{LW\,1} + \frac{LA\,2}{LW\,2})}{2} \tag{9}$$

LW_1 and LW_2 are leaf dry weights of plant at time intervals t_1 and t_2 respectively.

2.3.13 Leaf Weight ratio (LWR)

It is an index of leafiness of the plant on the dry weight basis; a measure of the "productive investment of the plant, dealing with the relative expenditure on potentially photosynthesizing organs. Mean LWR was calculated by the formula:

$$LWR = \frac{(\frac{LW\,1}{W\,1} + \frac{LW\,2}{W\,2})}{2} \tag{10}$$

LW_1 and LW_2 are leaf dry weights & W_1 and W_2 are dry weights of plant at time intervals t_1 and t_2 respectively.

III. RESULTS AND DISCUSSION

3.1 Plant Height

In general, the plant height and the length of stem and roots progressively increased throughout the study. However, the plant height and stem length showed exponential increase during the reproductive phase and diminishing towards senescence. The root length increased fairly constantly but shows sprout towards senescence due to shift in resource allocation pattern (Table 1 & Figure 1).

TABLE 1
PLANT HEIGHT (cm) AND DIMENSIONS OF VARIOUS PLANT PARTS OF *Lycopersicon esculentum* AT DIFFERENT TIME INTERVALS (DAYS).

Parameters	Time Interval (Days)									
	0	15	30	45	60	75	90	105	120	135
Stem length	-	3.6	4.7	10.5	17.6	29.3	38.5	52.3	75.2	81.2
Root length	-	3.5	4.8	7.9	10.9	11.5	13.3	16.4	18.3	25.2
Plant height	-	7.1	9.5	18.4	28.5	40.8	51.7	68.6	93.5	106.4

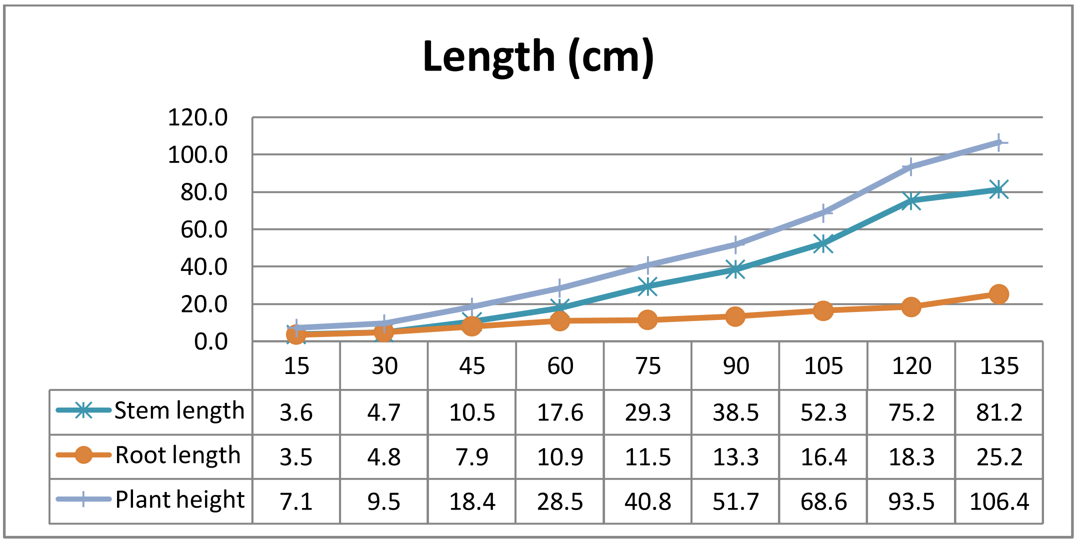


FIGURE 1: Plant height (cm) and dimensions of various plant parts *Lycopersicon esculentum* at different time intervals (days)

3.2 Fresh Mass

Fresh mass of vegetative parts showed an increasing trend from germination to senescence stage. Though the leaf fresh mass also followed the same trend but it showed a decline after the onset of senescence (Table 2 and Figure 2a & 2b). The fresh mass of reproductive parts increased during reproductive stage until senescence of the plant.

TABLE 2
FRESH MASS (g) OF VARIOUS PLANT PARTS OF *Lycopersicon esculentum* AT DIFFERENT TIME INTERVALS (DAYS)

Parameters	Time Interval (Days)									
	0	15	30	45	60	75	90	105	120	135
Stem	-	0.13	2.97	10.73	24.80	46.10	87.40	118.70	162.40	232.30
Root	-	0.05	0.35	5.16	12.92	37.10	48.40	61.90	73.30	94.20
Leaf	-	0.20	3.65	8.45	15.80	42.36	74.30	97.80	117.10	87.82
Fruit	-	-	-	-	56.90	92.60	135.70	186.30	260.00	-
Vegetative parts	-	0.38	6.97	24.34	53.52	125.56	210.10	278.40	352.80	414.32
Reproductive parts	-	-	-	-	56.90	92.60	135.70	186.30	260.00	-

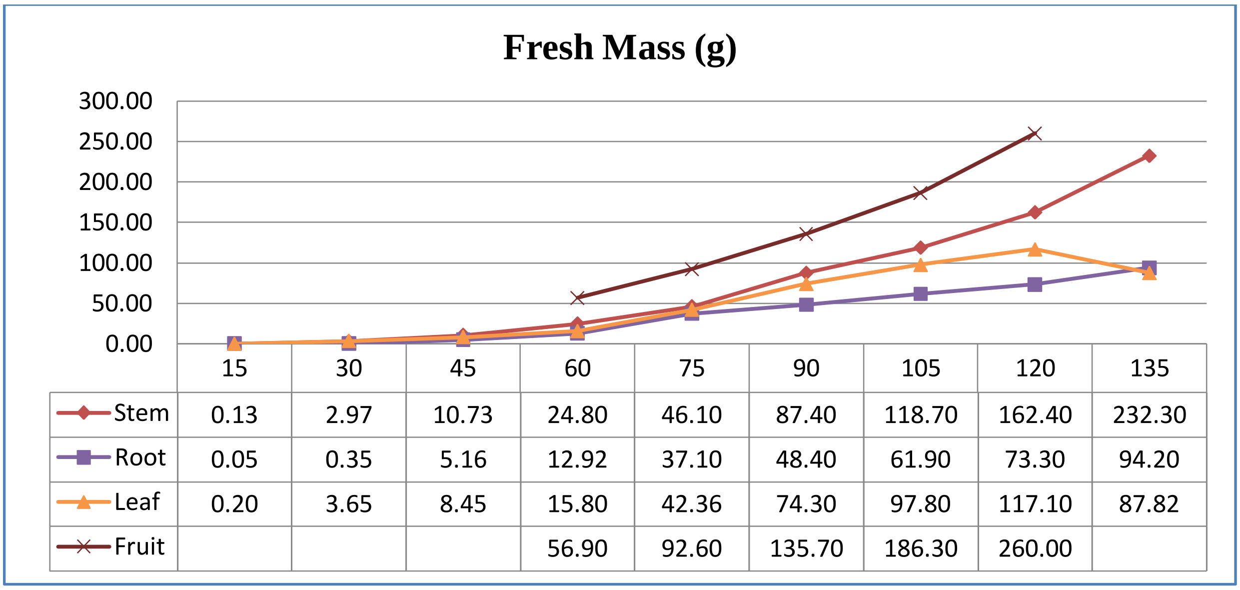


FIGURE 2a: Fresh mass (g) of various plant parts of *Lycopersicon esculentum* at different time intervals (days).

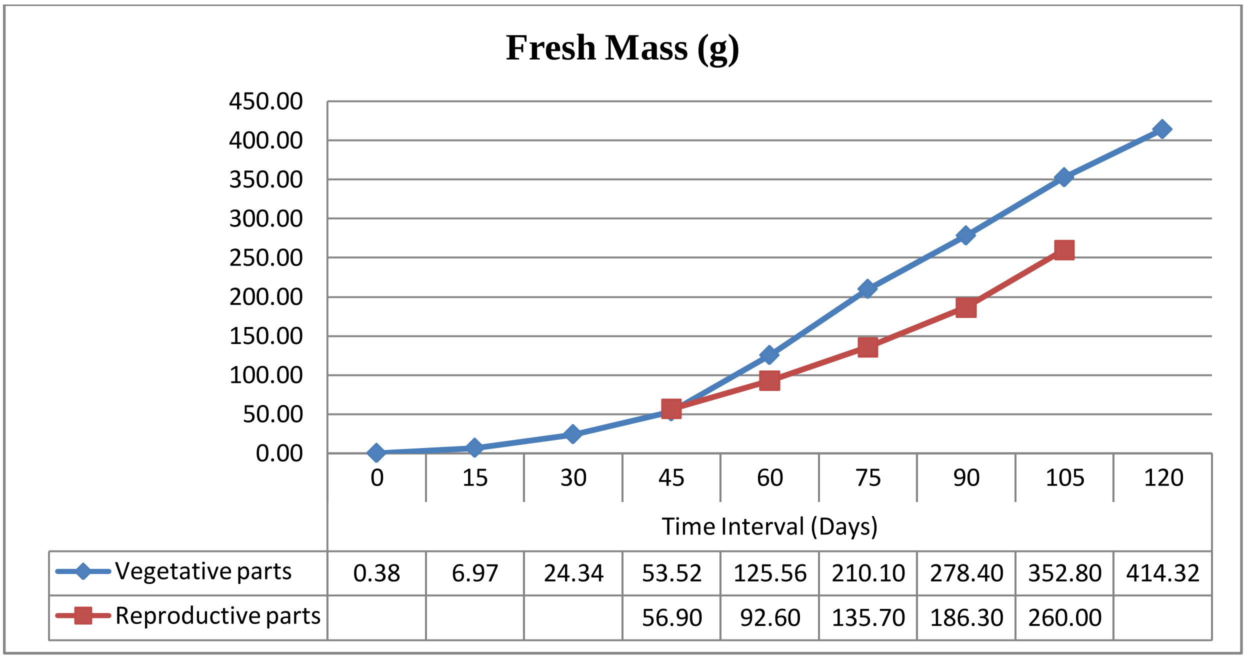


FIGURE 2b: Fresh mass (g) of various plant parts of *Lycopersicon esculentum* at different time intervals (days).

3.3 Dry Mass

The dry mass of stem and root progressively increased throughout the study time. Though the dry mass of leaves also followed the same trend but it showed a decline after the onset of senescence (Table 3 & Figure 3a). The total dry mass of whole plant increases gradually during vegetative phase and sharply during reproductive phase finally declining rapidly during senescent phase (Table 3 & Figure 3a and 3b). As compared to aerial parts the dry mass of underground parts shows an increasing trend throughout (Table 3 & Figure 3b). The total dry mass of vegetative as well as reproductive parts (fruits) increases (Table 3 & Figure 3b).

3.4 Root-Shoot Ratio

Root-Shoot ratio shows an unpredictable trend. However, the ratio decreases sharply as the plant undergoes transition from vegetative phase (from 0 to 45 days) to reproductive phase (from 60 to 120 days) as more resource are allocated towards fruits. After the onset of senescence, it again shows an increase (Table 3 & Figure 3c).

TABLE 3
DRY MASS (g) OF VARIOUS PLANT PARTS OF *Lycopersicon esculentum* AT DIFFERENT TIME INTERVALS (DAYS)

Parameters	Time Interval(Days)									
	0	15	30	45	60	75	90	105	120	135
Stem	-	0.003	0.032	1.382	9.850	28.210	47.600	83.480	96.870	161.260
Root	-	0.001	0.012	0.860	2.980	16.390	25.890	37.300	49.500	62.300
Leaf	-	0.007	0.380	2.720	7.780	24.800	46.960	64.800	79.400	60.830
Fruit	-	-	-	-	16.300	34.030	73.200	99.300	154.400	-
Vegetative parts	-	0.011	0.424	4.962	20.610	69.400	120.450	185.580	225.770	275.390
Reproductive parts	-	-	-	-	16.300	34.030	73.200	99.300	154.400	-
Aerial parts	-	0.010	0.412	4.102	33.930	87.040	167.760	247.580	330.670	213.090
Underground parts	-	0.001	0.012	0.860	2.980	16.390	25.890	37.300	49.500	62.300
Total plant	-	0.011	0.424	4.962	36.910	103.430	193.650	284.880	380.170	275.390
Root/Shoot Ratio	-	0.100	0.029	0.210	0.088	0.188	0.154	0.151	0.150	0.292

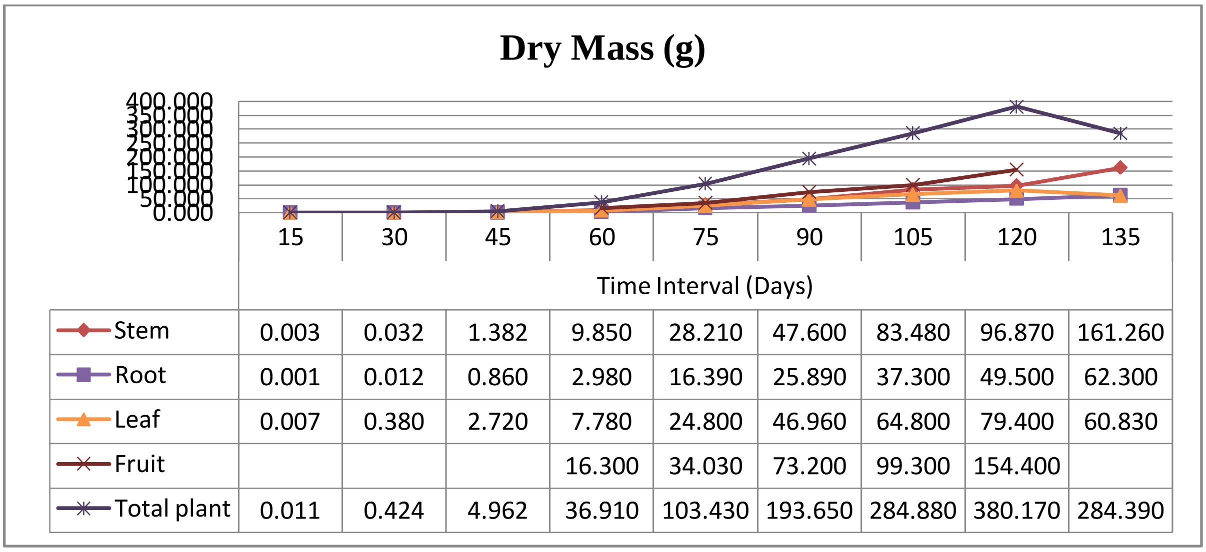


FIGURE 3a: Dry mass (g) of various plant parts of *Lycopersicon esculentum* at different time intervals (days).

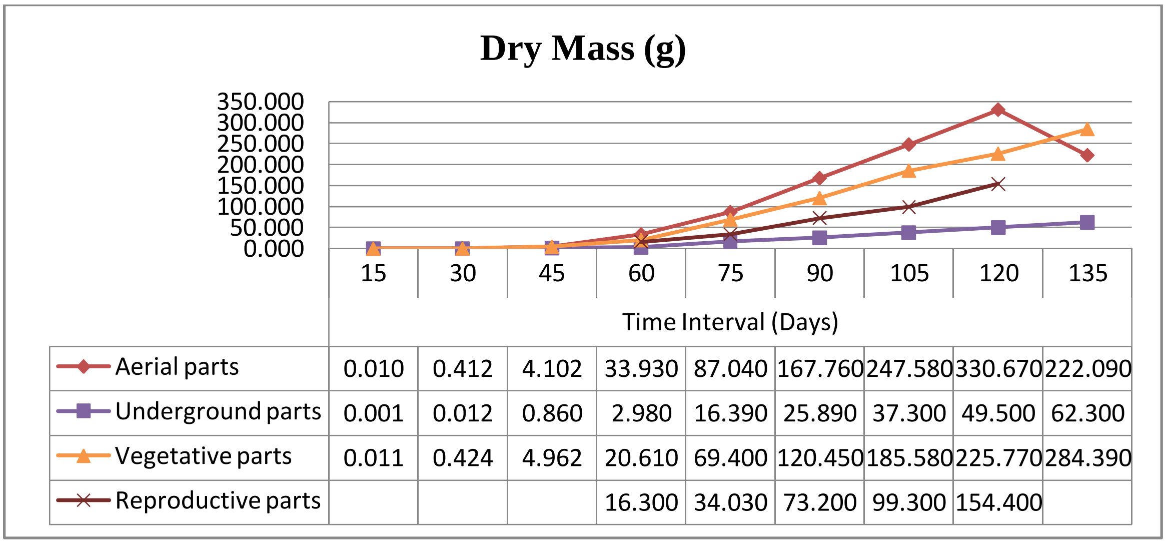


FIGURE 3b: Dry mass (g) of various plant parts of *Lycopersicon esculentum* at different time intervals (days).

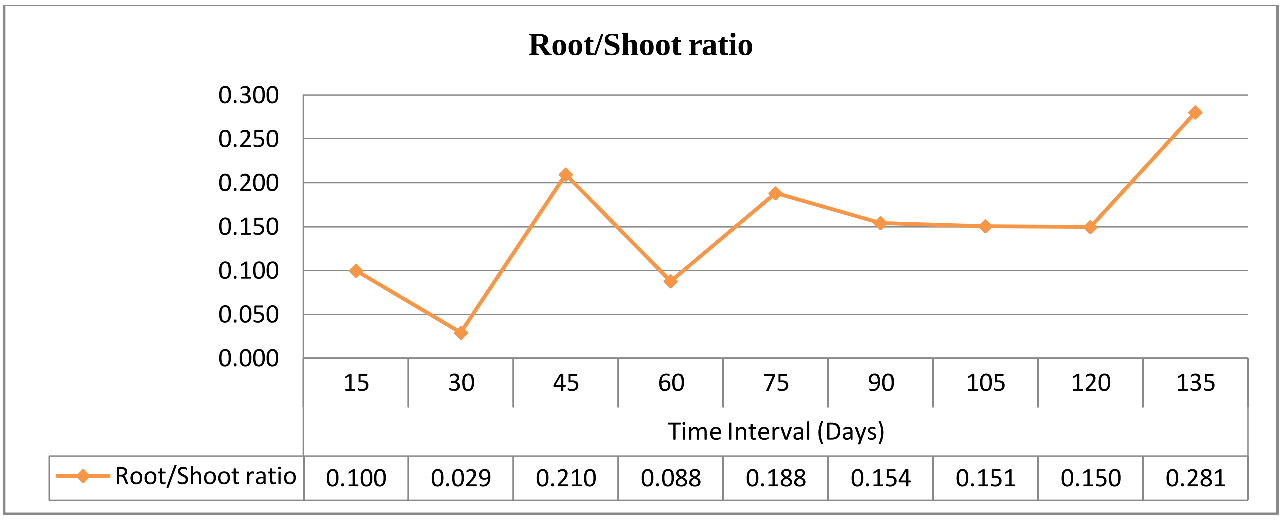


FIGURE 3c: Root/Shoot ratio (on dry mass basis) of *Lycopersicon esculentum* at different time intervals (days).

3.5 Percentage Moisture Content

The moisture content of stem, roots and leaves shows a decreasing trend along the course of growth due to buildup of more matter and maturation of plant. In case of reproductive structures (fruits) the moisture content also shows decreasing trend as they proceed towards maturity (Table 4 & Figure 4).

TABLE 4
PERCENTAGE MOISTURE CONTENT OF VARIOUS PLANT PARTS OF *Lycopersicon esculentum* AT DIFFERENT TIME INTERVALS (DAYS).

Parameters	Time Interval (Days)									
	0	15	30	45	60	75	90	105	120	135
Stem	-	97.692	98.923	87.120	60.282	38.807	45.538	29.671	40.351	30.581
Root	-	98.000	96.571	83.333	76.935	55.822	46.508	39.742	32.469	33.864
Leaf	-	96.500	89.589	67.811	50.759	41.454	36.797	33.742	32.195	30.733
Fruit	-	-	-	-	71.353	63.251	46.057	46.699	40.615	-

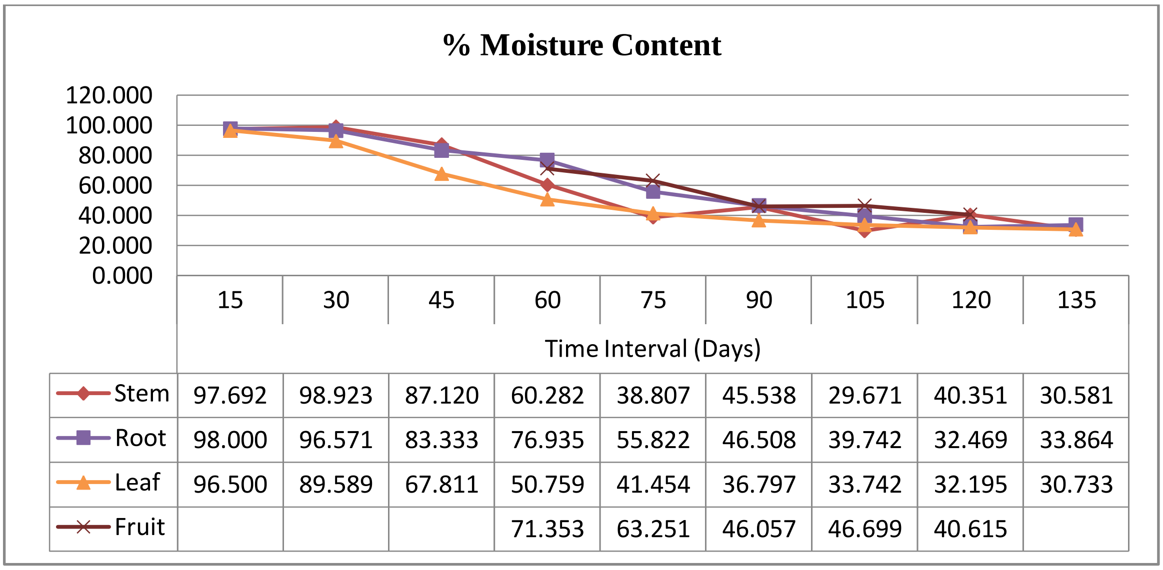


FIGURE 4: Percentage Moisture Content of various plant parts of *Lycopersicon esculentum* at different time intervals (days).

3.6 Resource Allocation

During vegetative growth more resources are allocated towards leaves followed by stem and then roots but during reproductive phase more resources are allocated towards fruits followed by leaves, stem and then roots (Table 5 & Figure 5).

TABLE 5
RESOURCE ALLOCATION (PERCENT) OF *Lycopersicon esculentum* AT DIFFERENT TIME INTERVALS (DAYS)

Parameters	Time Interval (Days)									
	0	15	30	45	60	75	90	105	120	135
Stem	-	27.27	7.55	27.85	26.69	27.27	24.58	29.30	25.48	56.70
Root	-	9.09	2.83	17.33	8.07	15.85	13.37	13.09	13.02	21.91
Leaf	-	63.64	89.62	54.82	21.08	23.98	24.25	22.75	20.89	21.39
Fruit	-	-	-	-	44.16	32.90	37.80	34.86	40.61	-

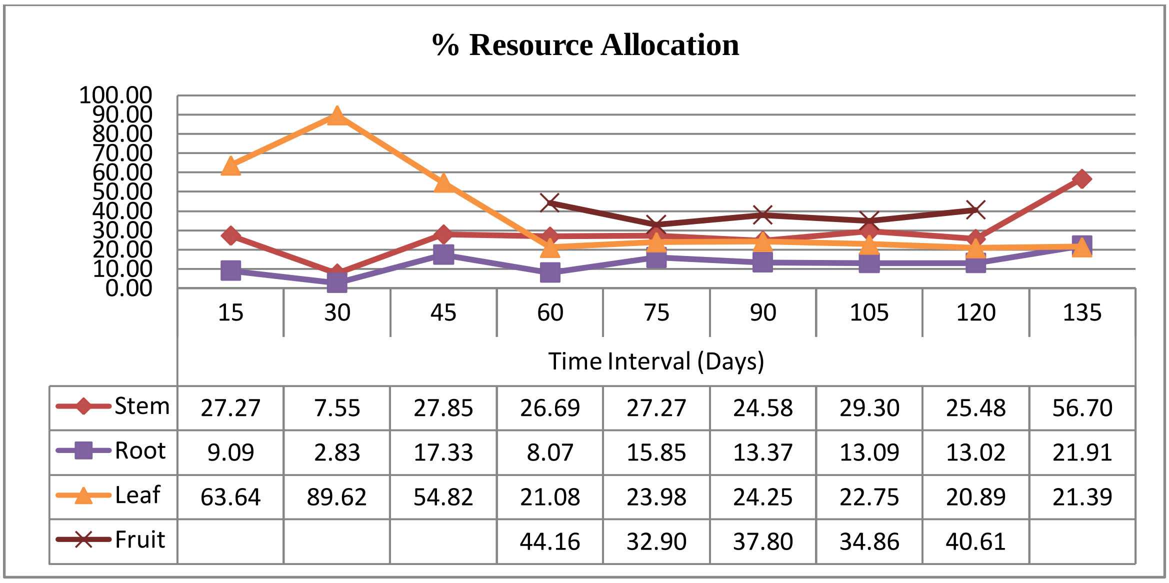


FIGURE 5: Resource Allocation (percent) of *Lycopersicon esculentum* at different time intervals (days).

3.7 Leaf Area

The leaf area increases with time reaching its peak at 120th day of sowing and after that due to onset of senescence it starts decreasing with time (Table 6 & Figure 6).

3.8 Fruit Volume

Fruit volume gradually increases over the entire growing season after fruiting as more resources are allocated towards fruits and also due to decrease in the moisture content as fruits proceed towards maturity (Table 6 & Figure 6).

TABLE 6
LEAF AREA (cm2) AND FRUIT VOLUME (cm3) OF *Lycopersicon esculentum* AT DIFFERENT TIME INTERVALS (DAYS)

Parameters	Time Interval (Days)									
	0	15	30	45	60	75	90	105	120	135
Leaf Area (cm2)	-	35.2	58.1	120.2	205.45	397.7	506.9	728.3	910.4	802.76
Fruit Volume (cm3)	-	-	-	-	11.02	25.3	34.12	49.15	60.4	-

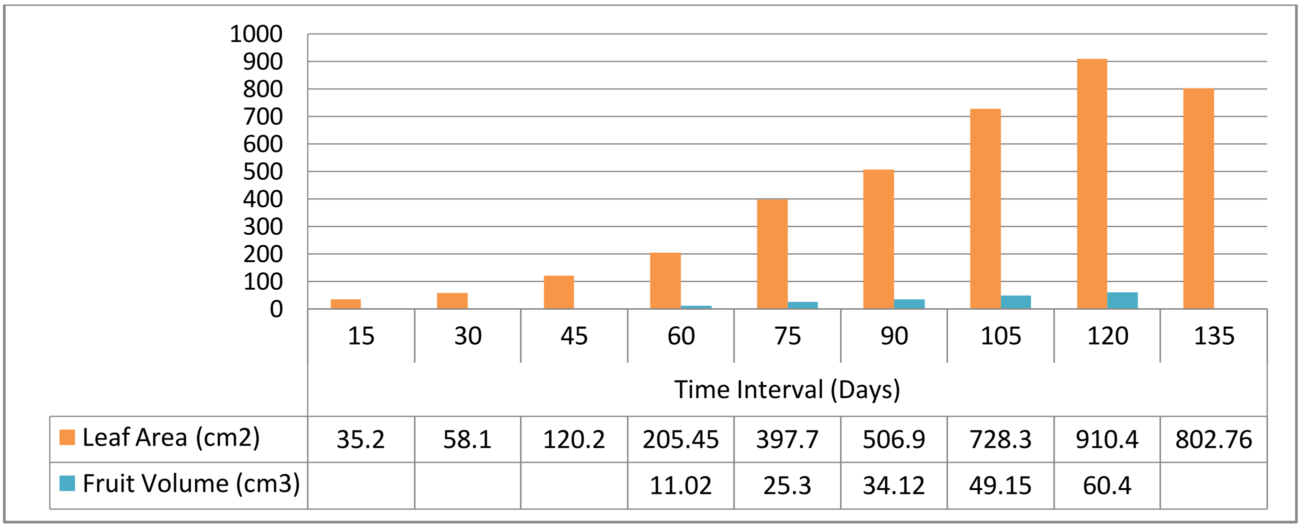


FIGURE 6: Leaf area (cm2) and Fruit Volume (cm3) of *Lycopersicon esculentum* at different time intervals (days).

3.9 Relative Growth Rate (RGR)

Mean RGR is highest during the first intervals thereafter decreasing and becoming negative (relative decay rate) at senescent stage. RGR is at its peak at the start of vegetative phase (Table 7 & Figure 7).

3.10 Net Assimilation Rate (NAR)

Mean NAR remains relatively constant. It follows more or less the same path as that of RGR becoming negative at the senescent stage (Table 7 & Figure 7).

3.11 Leaf Area Ratio (LAR)

Mean LAR was maximum at first time interval after that it sharply decreases during vegetative phase. It remains more or less constant during the reproductive phase as during this phase more resources are allocated to the developing fruits than to any other plant part (Table 7 & Figure 7).

3.12 Specific Leaf Area (SLA)

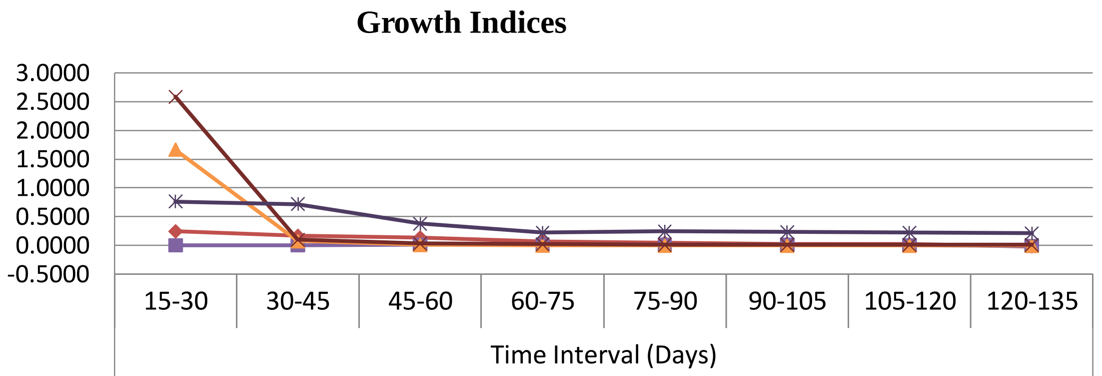
It shows a declining trend throughout the study period but the decrease is quite rapid during vegetative phase (Table 7 & Figure 7).

3.13 Leaf Weight Ratio (LWR)

It is highest at the initial stages showing a sharp decline during transition from vegetative to reproductive phase and then declining constantly (Table 7 & Figure 7).

TABLE 7
GROWTH INDICES OF *Lycopersicon esculentum* AT DIFFERENT TIME INTERVALS (DAYS).

Growth Indices	Time Interval (Days)							
	15-30	30-45	45-60	60-75	75-90	90-105	105-120	120-135
RGR (Day-1)	0.2435	0.1640	0.1338	0.0687	0.0418	0.0257	0.0192	-0.0194
NAR (g/cm2/day)	0.0006	0.0035	0.0134	0.0152	0.0134	0.0100	0.0078	-0.0075
LAR (1000cm2/g)	1.6685	0.0806	0.0149	0.0047	0.0032	0.0026	0.0025	0.0026
SLA (1000cm2/g)	2.5907	0.0985	0.0353	0.0212	0.0134	0.0110	0.0114	0.0123
LWR	0.7663	0.7222	0.3795	0.2253	0.2411	0.2350	0.2182	0.2114



	15-30	30-45	45-60	60-75	75-90	90-105	105-120	120-135
RGR (Day-1)	0.2435	0.1640	0.1338	0.0687	0.0418	0.0257	0.0192	-0.0194
NAR (g/cm2/day)	0.0006	0.0035	0.0134	0.0152	0.0134	0.0100	0.0078	-0.0075
LAR(1000cm2/g)	1.6685	0.0806	0.0149	0.0047	0.0032	0.0026	0.0025	0.0026
SLA (1000cm2/g)	2.5907	0.0985	0.0353	0.0212	0.0134	0.0110	0.0114	0.0123
LWR	0.7663	0.7222	0.3795	0.2253	0.2411	0.2350	0.2182	0.2114

FIGURE 7: Growth Indices of *Lycopersicon esculentum* at different time intervals (days).

IV. CONCLUSION

The study made it evident that growth occurred during all the growing stages but crop yield is extremely related to reproductive stage. The values of growth analysis parameters like Relative Growth Rate and Net Assimilation Rate were highest for the period of vegetative growth showing gradual decline towards the senescence and becoming negative at senescent stage. More Resources (Photosynthates) were allocated towards leaves during vegetative phase to increase the photosynthetic efficiency whereas there was a shift towards reproductive parts during reproductive phase for fruiting. The productivity of crop and the dry mass of fruits are dependent on the Leaf area of plants.

REFERENCES

[1] Ahad, M. A. (1986). Growth analysis of Rice bean (Vignaumbellata Thunb.) under different management practices and their agronomic appraisal. *PhD Diss in Agro*.

[2] Blackman, V. H. (1919). The compound interest law and plant growth. *Annals of Botany*, *33*(131), 353-360.

[3] Ferreira, S. M. R., Freitas, R. J. S. D., &Lazzari, E. N. (2004). Identity and quality standards of tomatoes (Lycopersicon esculentum Mill.) for fresh consumption. *Ciência Rural*, *34*(1), 329-335.

[4] Fisher, R. A. (1921). Some remarks on the methods formulated in a recent article on "The quantitative analysis of plant growth.". *Annals of Applied Biology*, *7*(4), 367-372.

[5] Hunt, R. (2003). Growth and development/growth analysis, individual plants. In 'Encyclopaedia of applied sciences. (Eds B Thomas, DJ Murphy, D Murray.) pp. 579–588.

[6] Jensen, C. R., Battilani, A., Plauborg, F., Psarras, G., Chartzoulakis, K., Janowiak, F., ... & Liu, F. (2010). Deficit irrigation based on drought tolerance and root signalling in potatoes and tomatoes. *Agricultural Water Management*, *98*(3), 403-413.

[7] Jesus Periago, M., García-Alonso, J., Jacob, K., Belén Olivares, A., José Bernal, M., Dolores Iniesta, M., ... &Ros, G. (2009). Bioactive compounds, folates and antioxidant properties of tomatoes (Lycopersicum esculentum) during vine ripening. *International Journal of Food Sciences and Nutrition*, *60*(8), 694-708.

[8] Karim, M. F., & Fattah, Q. A. (2007). Growth analysis of chickpea cv. Bari chhola-6 as affected by foliar spray of growth regulators. *Bangladesh Journal of Botany*, *36*(2), 105-110.

[9] Kuchay, S. A., & Zargar, M. A. (2016). Analysis of growth in some cultivars of *Solanum melongena* grown in Kashmir. *Imperial Journal of Interdisciplinary Research (IJIR)*, *2*(5), 397-405.

[10] Matos, E. S., Shirahige, F. H., & de Melo, P. C. T. (2012). Performance of tomato hybrids of indeterminate growth depending on training systems. *Horticultura Brasileira*, *30*(2), 240-245.

[11] Monte, J. A., Carvalho, D. F. D., Medici, L. O., da Silva, L. D., & Pimentel, C. (2013). Growth analysis and yield of tomato crop under different irrigation depths. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *17*(9), 926-931.

[12] Sharoni, Y., & Levi, Y. (2006). Cancer prevention by dietary tomato lycopene and its molecular mechanisms. *Tomatoes, lycopene & human health*, 111-125.

[13] Srivastava, B. K., & Singh, R. P. (1990). Morpho-physiological response of garden pea (*Pisumsativum L.*) cultivars to sowing dates II. Growth and development pattern. *Vegetable Science*, *17*(2), 140-148.

[14] Thakur, D. S., & Patel, S. R. (1996). Growth and Sink Potential of Rice as Influenced by the Split Application of Potassium. *Journal of Maharashtra Agricultural Universities*, *21*(3), 460-461.

[15] Watson D. J. "The Physiological Basis of Variation in Yield," Advances in Agronomy, Vol. 4, 1952, pp. 101-145.

[16] West, C.,Briggs, G. E. and Kidd, F. 1920. Aquantitative analysis of plant growth-II. *Annals of Applied Biology* 7: 202-223.

[17] West, C., Briggs, G. E., & Kidd, F. (1920). Methods and significant relations in the quantitative analysis of plant growth. *New Phytologist*, *19*(7), 200-207.

[18] Willcox, J. K., Catignani, G. L., & Lazarus, S. (2003). Tomatoes and cardiovascular health.

[19] Williams, R. F. (1946). The physiology of plant growth with special reference to the concept of net assimilation rate. *Annals of Botany*, *10*(37), 41-72.

[20] Wilson, J. W. (1981). Analysis of growth, photosynthesis and light interception for single plants and stands. *Annals of Botany*, *48*(4), 507-512.