TOPIC: -

# ECOSYSTEM STRUCTURE AND FUNCTION.

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**INTRODUCTION: -**

All organisms need energy to perform the essential functions such as maintenance, growth, repair, movement, locomotion and reproduction; all of these processes require energy expenditure. The ultimate source of energy for all ecological systems is Sun. The solar energy is captured by the green plants (primary producers or autotrophs) and transformed into chemical energy and bound in glucose as potential energy during the process of photosynthesis. In this stored form, other organisms take the energy and pass it on further to other organisms. During this process, a reasonable proportion of energy is lost out of the living system. The whole process is called flow of energy in the ecosystem. It is the amount of energy that is received and transferred from organism to organism in an ecosystem that modulates the ecosystem structure. Without autotrophs, there would be no energy available to all other organisms that lack the capability of fixing light energy.

A fraction i.e. about 1/50 millionth of the total solar radiation reaches the earth's atmosphere. About 34% of the sunlight reaching the earth's atmosphere is reflected back into the atmosphere, 10% is held by ozone layer, water vapors and other atmospheric gases. The remaining 56% sunlight reaches the earth's surface. Only a fraction of this energy reaching the earth's surface (1 to 5%) is used by green plants for photosynthesis and the rest is absorbed as heat by ground vegetation or water. In fact, only about 0.02 % of the sunlight reaching the atmosphere is used in photosynthesis. Nevertheless, it is this small fraction on which all the organisms of the ecosystem depend.

To understand the flow of energy within a food chain, let us consider a food chain:

Plant ⟶ Rabbit ⟶ Fox

When organic matter is produced by the green plants, some of it is oxidized or burnt inside their body and converted into carbon dioxide which is released during respiration (R) and is accompanied by loss of energy. Now the producers are left with a little less organic matter than what was actually produced by them. This is known as net primary production (NPP) and respiratory loss added to it is called as gross primary production (GPP). Thus,

NPP = GPP - R

A rabbit (or a population of rabbits) ingests plant material, which is called as ***ingestion.*** A part of this plant material is processed and used to make new cells or tissues in the body of rabbit, and this part is called as ***assimilation.*** What cannot be assimilated, for example some parts of the plant stems or roots, exits the rabbit's body, this is called ***excretion***. Thus we can calculate assimilation from the following equation:

Assimilation = Ingestion - Excretion

The efficiency of assimilation is different in organisms, ranging from 15-50% if the food is plant material, and from 60-90% if the food is animal material.

The rabbit uses a significant fraction of the assimilated energy in metabolic activities such as maintaining body temperature, protein synthesis, etc. This energy used (lost) is attributed to cellular respiration. The rest of energy goes into making biomass of rabbit by growth and reproduction. In the food chain, rabbit is consumed by a fox. The energy available to foxes that eat the rabbits is known as secondary production of rabbit. It is evident that much of energy is used in normal metabolic activities of rabbits; the energy available to foxes is much less as compared to the energy available to rabbits. The efficiency with which an organism converts assimilated energy into primary or secondary production is called as net production efficiency. This efficiency is equal to the production divided by the assimilation for animals, or the NPP divided by GPP for plants. The production here refers to growth plus reproduction.

The following points should be considered for a complete understanding of flow of energy in an ecosystem:

- **i)** Efficiency of producers in absorption and conversion of solar energy into chemical energy
- **ii)** Use of this chemical energy by the consumers
- **iii)** Total input of energy in the form of food and its efficiency of assimilation
- **iv)** The loss through respiration, heat, excretion etc. and
- **v)** The gross net production.

**ECOSYSTEM THERMODYNAMICS: -**

The laws of thermodynamics are elemental doctrine and theories to all the chemical processes taking place on earth. The laws state how the energy is transformed from one form to another. These are applicable to flow of energy in the ecosystems.

a) **The first law of thermodynamics,** also known as energy-mass conservation law, states that neither energy nor matter can be created or destroyed, but it can be transformed from one form to another; rather, the amount of energy lost in a steady state process cannot be greater than the amount of energy gained. For instance, the solar energy is converted into chemical energy in the process of photosynthesis. The conversion must be balanced, as expressed in Odum's model, such that the sum of all outputs is equal to the sum of inputs.

b) **The second law of thermodynamics,** also known as law of entropy, states that energy dissipates as it is used or it is converted from a more concentrated form to dispersed form. Any change of energy from one form to another implies an irreversible loss of useful energy in form of heat, which increases the entropy or disorder of the universe. In some systems, entropy remains constant but never decreases; only irreversible processes produce entropy. An example of the second law of thermodynamics in ecology is metabolism, in which a set of chemical reactions in an individual transforms organic matter into a more useful component. However, the cost of this conversion includes respiration, which is the energy unavailable neither to individual nor to others in the food web. This shows that as the energy flows through the food chain, there occurs dissipation of energy at every trophic level. The loss of energy takes place through respiration, loss of energy in locomotion, running, hunting and other activities. At every level there is about 90% loss of energy and the energy transferred from one trophic level to the other is only about 10%.

**ENERGY FLOW MODELS: -**

The energy flow models link the trophic levels with each other showing the inputs and losses of energy at each trophic level. Lindeman (1942) was the first to propose such model assuming that plants and animals can be arranged into trophic levels and the laws of thermodynamics hold for plants and animals. He emphasized that the amount of energy at trophic level is determined by the net primary production and the efficiency at which food energy is converted into biomass. After that, various models depicting energy flow in ecosystems are described below:

**SINGLE CHANNEL ENERGY FLOW MODEL: -**

The flow of energy in an ecosystem takes place through the food chain and it is this energy flow which keeps the system going. The most common feature of this energy flow is that it is unidirectional or one-way flow or single channel flow. Unlike the nutrients (carbon, nitrogen, phosphorus, Sulphur etc.) which move in a cyclic manner and are reused by the producers after moving through the food chain, energy is not reused in the food chain. It flows from producers to herbivores to carnivores and so on.

Figure 7.1 shows a simplified diagram of Single Channel Energy Flow Model. Two things are clear from the diagram.

- Firstly, the flow of energy is unidirectional and non-cyclic. The green plants obtain energy from the sun and it is transformed into chemical energy by the process of photosynthesis. This energy is stored in plant tissues and transformed into heat energy during metabolic activities which then passes to next trophic level in the food chain. The solar energy captured by green plants (autotrophs) never revert back to sun, however, it passes to herbivores and that which passes to herbivores does not go back to autotrophs but passes to consumers. Thus, in biological systems, the energy flows from the sun to green plants and then to all heterotrophic organisms. Due to unidirectional flow of energy, the entire system would collapse if primary source of energy were cut off.

- Secondly, at each tropic level there is progressive decrease in energy as heat in the metabolic reactions and also some of the energy is utilized at each tropic level.

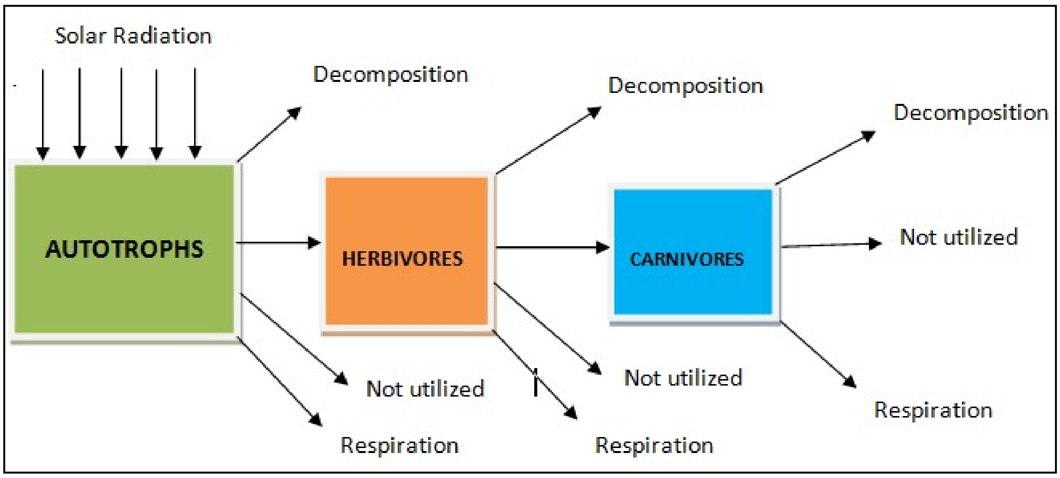


**Fig. 7.1: Simplified Single Channel Energy Flow Diagram (Modified from Lindeman, 1942)**

Figure 7.2 shows the energy flow in three trophic levels in a linear food chain. Here the boxes represent the trophic levels (producers, herbivores and carnivores) and the pipelines depict the energy flow in and out of each trophic level. Size of the box shows energy stored in the form of biomass at that trophic level. There is loss of energy (represented as pipes getting narrower) at every successive trophic level, there is also a corresponding decline in energy stored in standing crop or biomass (represented as decreased size of box) at successive trophic level. Energy inflows in the system balance the energy outflows as required by the first law of thermodynamics and each energy transfer is accompanied by loss of energy in the form of unavailable heat energy (i.e. respiration) as stated by second law of thermodynamics.

The energy flow is significantly reduced at each successive trophic level from producers to herbivores to carnivores. Thus, at each transfer of energy from one trophic level to another trophic level, major part of energy is lost in the form of heat or other form. There is successive reduction in the energy flow whether we consider it in term of total flow (I+A) or secondary productivity and respiration component.

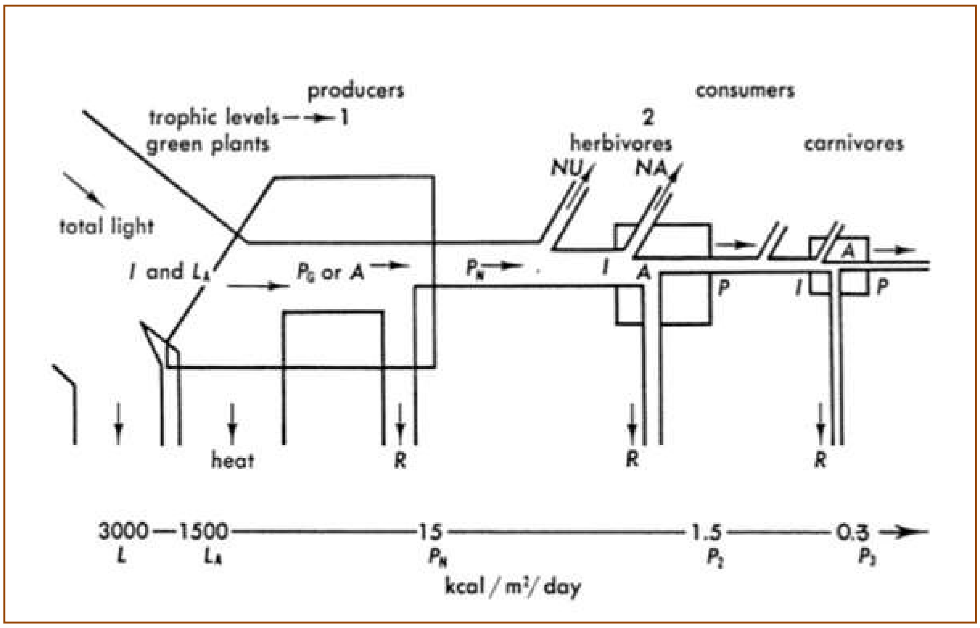


**Fig. 7.2: Single Channel Energy flow model depicting three trophic levels (box 1, 2 and 3) in a linear food chain.**

[I- total energy input, $L_A$ – light absorbed by plant cover, $P_G$ – gross primary production, A – total assimilation, $P_N$ – net primary production, P – Secondary production, NU – Energy not used (stored), NA – Energy not assimilated by consumers (egested), R – respiration. Bottom line in the diagram shows the order of the magnitude of energy losses expected at major transfer points, starting with a solar input of 3,000 Kcal per square meter per day. (After E.P. Odum, 1963)]

Thus, of the 3000 Kcal of total light falling upon green plants, approximately 50% is absorbed (1500 Kcal), 1% is converted at first trophic level (15 Kcal). Thus net primary production (PN) is 15 Kcal only. Secondary productivity ($P_2$ and $P_3$) tends to be about 10% at successive consumer level, i.e. herbivores and carnivores, although efficiency may be sometimes up to 20% at the carnivore's level (as shown in diagram $P_3$ = 0.3 Kcal). There is a successive reduction in energy flow at successive trophic levels. Thus shorter the food chain, greater would be the energy available at higher trophic levels.

**DOUBLE CHANNEL OR Y-SHAPED ENERGY FLOW MODEL: -**

The double channel or Y-Shaped energy flow model depicts the simultaneous working of grazing and detritus food chains in an ecosystem. In nature, both grazing and detritus food chains are inter-connected in the same ecosystem. For example, dead bodies of small animals that were once part of grazing food chain become incorporated in the detritus food chain as do the faces of grazing food animals. Functionally, the distinction between the two is of time lag between the direct consumption of living plants and ultimate utilization of dead organic matter. The importance of two food chains may differ in different ecosystems, in some cases, grazing is more important and in others, detritus is more important. It happens in marine ecosystems where primary production at open sea is limited and a major portion of it is eaten by herbivores marine animals. Therefore, very little primary production is left to be passed onto the detritus pathways. On the other hand, in a forest ecosystem, the huge quantity of biomass produced cannot be all consumed by herbivores and a large part of it enters into detritus compartment in the form of litter. Hence the detritus food chain is more important there. In an example given by Singh et al (2015), in a lake open water zone, grazing food chain predominates as phytoplanktons are eaten upon by zooplanktons and other organisms. On the other hand, in the lake bottom, dead organisms are deposited and they are acted upon by detritus feeders and decomposers.

Figure 7.3 represents one of the first published energy flow models pioneered by H.T. Odum in 1956. A common boundary is also shown, sunlight and heat flows, import, export and storage of organic matter are also included in the diagram. Decomposers are placed in a separate box in order to separate grazing and detritus food chains.

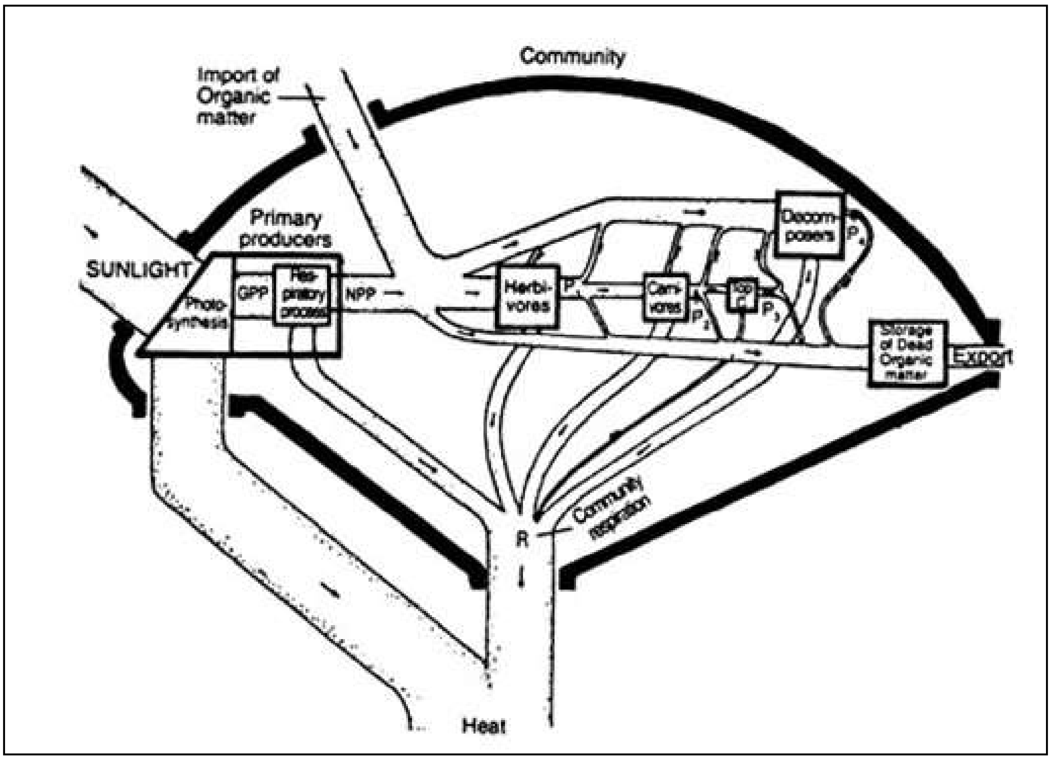


**Fig. 7.3: The relationship between flow of energy through grazing and detritus pathways.**

[GPP – Gross Primary Production, NPP – Net Primary Production, $P_1$-$P_4$ – Secondary Production, R – Respiration]

E.P. Odum (1983) gave a generalized model of Y-shaped or double channel energy flow (Fig. 7.4), which is applicable to both terrestrial and aquatic ecosystems. In energy flow diagram, one arm represents the grazing food chain and another represents detritus food chain. The important point in this model is that both the chains are not separated from each other. Odum regarded this model as more realistic than single channel energy flow model for the following reasons:

a) It confirms to the basic stratified structure of ecosystem by including both grazing and detritus pathways.

b) It separates the grazing food chain from detritus food chain in both time and space as shown by direct consumption of living plants and utilization of dead organic matter respectively.

c) Macroconsumer (animals) and microconsumers (bacteria and fungi) differ greatly in size-metabolism relations.

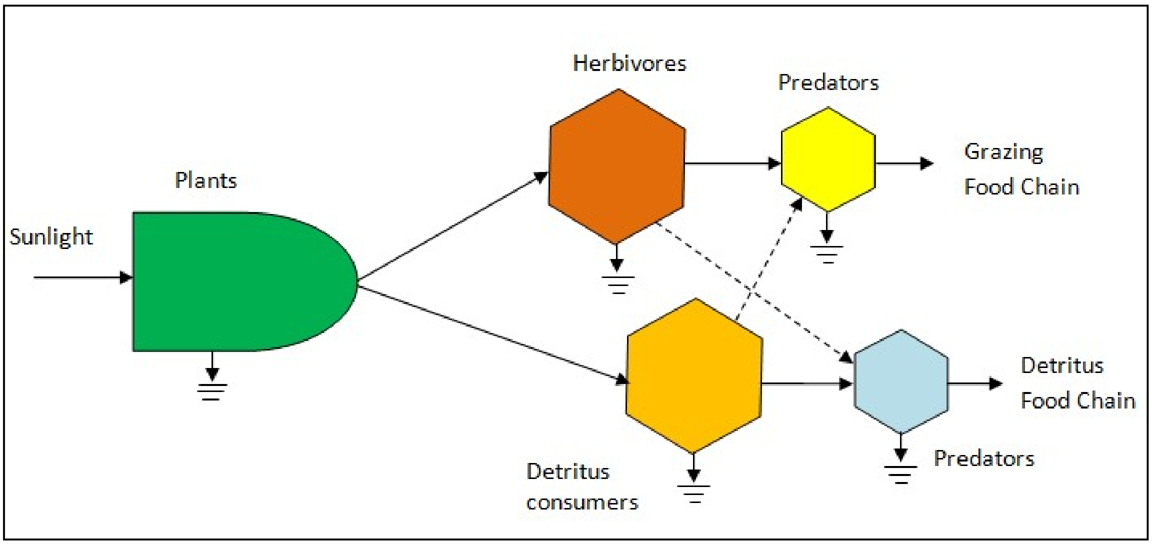


**Fig. 7.4: Double Channel or Y-shaped Energy Flow Model (based on Odum, 1983)**

The two arms differ fundamentally in the way they can influence primary producers. In grazing food chain, herbivores feed on living plants, therefore they directly affect the plant population. Whatever they do not eat is available to the decomposers after death. As a result, decomposers are not able to directly influence the rate of supply of their food.

Further, the amount of net production energy that flows down the two pathways varies in different kind of ecosystems and often in the same ecosystem; it may vary seasonally or annually. In heavily grazed grassland, 50% or more of the net production may pass down the grazing pathway. But aquatic systems like marshes or forests operate as detritus systems, for, over 90% of primary production is not consumed by heterotrophs until plant parts die and reach water, sediments and soils. This delay in consumption of primary production increases structural complexity of the ecosystem. Since all the food is not assimilated by the grazers, some is diverted to the detritus route. So the impact of grazers on the community depends on the rate of removal of living plants and the amount of energy in the food that is assimilated. Marine zooplanktons commonly graze more phytoplanktons than they can assimilate, the excess being egested to the detritus food chain. Thus energy flow along different path is dependent on the rate of removal of living plant material by herbivores as well as on the rate of assimilation in their bodies.

**UNIVERSAL ENERGY FLOW MODEL: -**

E.P. Odum (1968) gave Universal Energy Flow Model (Fig. 7.5) which represents the basis for a general explanation of ecosystem trophic flows. The model can be applied to any living component, whether it is plant, animal, microorganism, individual, population or trophic group. Such a model may depict food chain as already shown in previous models or the bioenergetics of an entire ecosystem. In the figure, the living structure or biomass of the component is represented as the shaded box. Further, I - is the ingested energy which is solar radiation in case of autotrophs and ingested food in case of heterotrophs. Since not all the energy supplied is utilized, the lost part is called as energy not utilized (NU). The assimilated energy (A) is known as gross production.

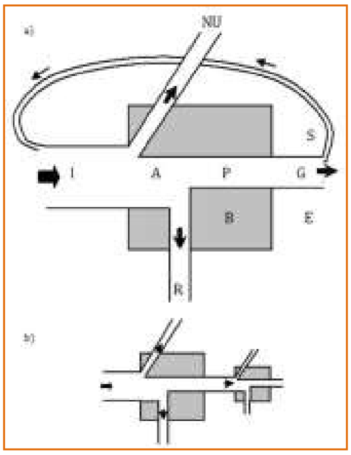


**Fig. 7.5: Universal Energy Flow Model**

[I- Input solar radiations or ingestion of food; A- Assimilated energy; P-net production; G-Growth and Reproduction; B- Standing Crop Biomass; R-Respiration; S-Stored energy; E-Excreted energy; NU-energy not utilized]

Part of A is used for system structural maintenance, that is the respiration (R), and the other part is transformed into organic matter (P), known as net production. P is the energy available for other individuals or trophic levels. Individuals use part of the net production for growth (G) or, in the case of populations or trophic levels, for biomass accumulation (B). A part of net production can be stored (S) to at individual level in the form of organic compounds of higher energetic content (lipids) or, at ecosystem level, as a nutrients deposit or detritus. Some production can be excreted by individuals or, analogously, exported from the ecosystem (E).

The universal energy flow, can be used in two ways: i) The model can represent a species population in which case the appropriate energy inputs and links with other species would be shown as a conventional species oriented food web diagram or ii) the model can represent a discrete energy level in which case the biomass and energy channels represent all or parts of many populations supported by the same energy source. Foxes, for example, usually obtain part of their food by eating plants (fruits etc.) and part by eating herbivores (rabbit, field mice model etc.). A single box diagram (Fig 7.5 a) could be used to represent the whole population of foxes if to express intrapopulation energetic. On the other hand, two or more boxes (Fig 7.5 b) may be used if we wish to represent two or more trophic levels.

Energy partitioning between P and R is of vital importance to the individual and species. Different organisms have different patterns of energy consumption. Large organisms require more maintenance energy as they have more biomass to maintain. The warm blooded animals (birds and mammals) require more energy than the cold blooded animals. Predators use a large part of assimilated energy in respiration than herbivore, to find and overcoming the prey. The species adapted to unstable, recently derived or under populated area, generally allocate a large portion of their energy to reproduction. The species adapted to stable and more favorable habitats, allocate little energy to reproduction.

## ECOLOGICAL EFFICIENCIES: -

Ecological efficiency can be defined as the product of efficiencies in which organisms utilize their food resources and convert them into biomass for next higher trophic level. The amount of energy reaching each trophic level depends on the net production of the primary producers at the base of the food chain

and the extent of energy transfer at each trophic level. Ecological efficiency is dependent on two factors: the proportion of assimilated energy incorporated in growth, storage and reproduction. The first proportion is called as **assimilation efficiency** and second is **net production efficiency**. The product of the assimilation efficiency and net production efficiencies is called as **gross production efficiency.** It is the proportion of food energy that is transformed into consumer biomass energy. Net production efficiency of plants is the ratio of net production to gross production. This index varies between 30-85%, depending on habitat and growth form. The rapidly growing plants in temperate zones have high net production efficiencies (75 - 85%). Similar vegetation types in the tropics exhibit lower net production efficiencies, perhaps 40-60% respiration increases relative to photosynthesis at low latitudes.

According to Singh et al, 2015, some of the important efficiencies are given below:

- **Assimilation efficiency:** This is a measure of efficiency with which a consumer population extracts energy from the food ingested.

  = [energy fixed by plants/light absorbed] x 100 (For plants)

  = [Food energy absorbed (assimilated)/food energy ingested] x 100 (For animals)

- **Utilization or Consumption efficiency:** This is the proportion of total productivity available at a trophic level that is actually consumed by the organisms of a succeeding trophic level.

  = [ingestion at trophic level *n*/net production at trophic level *n*-1] x 100

- **Growth or Production efficiency:** This is the efficiency with which the assimilated energy is incorporated into the protoplasm.

  = [Production at trophic level *n* /assimilation at trophic level *n*] x 100

- **Ecological Growth efficiency:**

  = [Production at trophic level *n* /ingestion at trophic level *n*] x 100

- **Transfer efficiency:**

  = Production at trophic level *n* /production at trophic level *n* -1

The nutritional value of plant foods is determined by the amount of lignin, cellulose and other indigestible materials present in the plant. The animal food is more easily digested when compare with plant food. Assimilation efficiency can vary in different predatory species from 60-90%. The vertebrate prey species can be digested efficiently as compared to insect prey. This is because the insects have larger proportion of indigestible exoskeletons of body than the hair, feathers and scales of the vertebrates. Moreover, the assimilation efficiencies of insectivores can differ in between 70-80%, and most of the carnivores have about 90% efficiency. In warm homoeothermic (warm-blooded) animals, energy is needed for maintenance, movement and heat production that otherwise could be utilized for growth and reproduction. The homoeothermic animals exhibit low net production efficiency. For example, birds show less than 1% and small mammals with high reproductive rates exhibit up to 6% of net production efficiency. However, sedentary poikilothermic animals (cold-blooded) of aquatic species can direct up to 75% of their assimilated energy into the growth and reproduction.

**CONCLUSION: -**

- The ultimate source of energy for all ecological systems is Sun. The solar energy is captured by the green plants and transformed into chemical energy and bound in glucose as potential energy during the process of photosynthesis. In this stored form, other organisms take the energy and pass it on further to other organisms.
- The flow of energy in ecosystem follows first and second law of thermodynamics.
- The solar energy is captured and converted by green plants into chemical energy, confirming first law of thermodynamics.
- As the energy flows through the food chain, there occurs dissipation of energy at every trophic level. The loss of energy takes place through respiration, loss of energy in locomotion, running, hunting and other activities. At every level there is about 90% loss of energy and the energy transferred from one trophic level to the other is only about 10%.
- The energy flow models link the trophic levels with each other showing the inputs and losses of energy at each trophic level.

- The flow of energy in an ecosystem takes place through the food chain and it is this energy flow which keeps the system going. The most common feature of this energy flow is that it is unidirectional or one-way flow or single channel flow.
- Single Channel Energy Flow Model depicts that the flow of energy is unidirectional and non-cyclic and at each tropic level there is progressive decrease in energy as heat in the metabolic reactions and also some of the energy is utilized at each tropic level.
- The double channel or Y-Shaped energy flow model depicts the simultaneous working of grazing and detritus food chains in an ecosystem.
- In nature, both grazing and detritus food chains are inter-connected in the same ecosystem. For example, dead bodies of small animals that were once part of grazing food chain become incorporated in the detritus food chain as do the faces of grazing food animals.
- Universal Energy Flow Model represents the basis for a general explanation of ecosystem trophic flows. The model can be applied to any living component, whether it is plant, animal, microorganism, individual, population or trophic group.
- Ecological efficiency can be defined as the product of efficiencies in which organisms utilize their food resources and convert them into biomass for next higher trophic level.