countries are withdrawing groundwater faster than recharging, including India and 70% of withdrawn water is used for agricultural purposes. Annual 2 million ton consumption of herbicides, 3 million-ton consumption of pesticides and one billion ton consumption of fertilizers in the world speaks that agriculture is a big business of managing natural resources for the benefits of human society. Hence our food and nutritional security is safe guarded under the umbrella of an agro-system that utilizes natural resources in such a way that productivity is either maintained or improved over a long period of time. Thus it considers improving the quality of plant, soil and human life and works within the carrying capacity of supporting ecosystems. The term 'sustainable agriculture' has been coined for such an agro-system.

## 2. CONCEPT AND DEFINITIONS

Sustainable agriculture is a philosophy based on human goals and on understanding the impact of our activities on the environment and on other species in the long run. Farming practices in sustainable agriculture are:

(a) Crop rotations that reduce weeds, disease, insect and pest problems, reduce soil erosion and risk of water contamination by agricultural chemicals.

(b) Pest control measures that are ecofriendly, namely cultural practices, use of resistant varieties, biological pest controls etc.

(c) Soil and water conservation practices, technologies for efficient use of irrigation water (sprinkler, drip and pitcher).

(d) Application of organic manures as well as biofertilizers.

(e) Use of synthetic or natural inputs in a way that it poses no significant hazard to man, animal or environment.

Sustainable agriculture does not mean ecofriendly agriculture that is low yielding rather, sustainability is built up of sophisticated approaches that maintains high yield to meet requirements of all the people without undermining the resources on which agriculture depends. American society of agronomy defines it as "Sustainability is the ability entrusted with set goals, sustainable agriculture is the one which over long period of time enhances environmental quality and the resource base on which agriculture depends, provides for basic human food and fiber needs. It is economical, viable and enhances the quality of life of farmers and society as a whole". According to Ruttan sustainability must include the i) development of technology and practices that maintain and/or enhance the quality of land and water resources.

ii) Improvements in plants and animals and the advances in production practices that will facilitate the substitution of biological technology for chemical technology.

In terms of FAO sustainable agriculture embraces "the management and conservation of resource base and orientation of technological and institutional changes in such a manner as to ensure attainment and continued satisfaction of human needs for present and future generations. Such sustainable development is environmentally nondegrading, technically appropriate, economically viable and socially acceptable." The concept may be sublimated as intensive agriculture with ecofriendly approaches.

The continued growth of the global population until at least 2050 requires further increases in agricultural production without placing soils, water and the environment in peril. Pental (2003) concluded that prevailing circumstances forced us to perceive one more green revolution in agriculture, which should be productive and sustainable. Hence urgent steps ought to be taken to infuse sustainable farming practices in agriculture if the demands of an expanding world population are to be met without destroying the natural resources base.

## 3. CHARACTERISTICS OF SUSTAINABLE AGRICULTURE.

Sustainable agriculture is not a set of prescribed practices. Instead it seeks broad interactions of interdisciplinary nature, embracing social economical and environmental perspectives. However for the sake of individualization it may be recognized by the following features:

i) Maintains adequate productivity levels.
ii) Productivity is relatively stable.
iii) Conserves and/or improves natural resources base.
iv) Ecofriendly.
v) Diversified (It favours biological diversity)
vi) Most economical (Input use efficiency is high)
vii) Improves quality of life because of better food and nutritional securities.
viii) Prefers biological technology to chemical technology.
ix) Favours sustainable development of human society.
x) Enhances use of on-farm renewable resources and minimises use of off-farm inputs.

## 4. ASSESSMENT OF SUSTAINABLE AGRICULTURE

Sustainable agriculture involves more accurate execution of all production practices keeping quantity as well as quality of produce reasonably at good levels. Quantification of sustainability of an agro-system is a complicated process, as it must include various production, consumption, ecological and socio-economic factors. Further assessment factors differ with ecology, cropping pattern and marketing avenues etc. Stocker *et. al.* (1994) proposed evaluation system based on nine parameters namely productivity, profitability, quality of soil, water and air, energy efficiency, fish and wildlife habitats, quality of life and social acceptability while IUCN International Assessment Team considered sustainability on the basis of ecosystem and human well being (IUCN 1996) Reijntjies *et. al.* (1999) at least suggested three criteria to have valid assessment of a sustainable agriculture system.

**a) Ecological criteria**

Balanced use of nutrients, efficient use of water resources, efficient use of energy resources, minimal negative environmental effects and minimal use of external inputs.

| | | |
|---|---|---|
| Coastal Agro-ecosystems | > Ecological fragility.<br>> Land use conversion.<br>> Poverty and illiteracy.<br>> Negative impact of anthropogenic pressure.<br>> Climate change.<br>> Uncertainty to the lives and properties, particularly those in low land due to high tidal floods and cyclones.<br>> Rapidly increasing municipal wastes, industrial effluents and domestic residues. | > Developing and adopting eco-friendly technologies.providing protection to mangrove vegetation and biodiversity.<br>> Regulating land use in coastal zones.<br>> Promoting off-farm additional income generations schemes for resource-poor farm families ensuring gender sensitivity.<br>> Focussing on improving literacy,healthcare and developing additional skills.<br>> Promoting livestock and aquaculture –based diversified agriculture systems.<br>> Developing village Knowledge centers.<br>Network ,with the help of Self-Help groups,linked to weather forecasting and early warning systems.<br>> Aiding the construction of protective embankments with wind-breaks and shelter-belts.<br>Improving drainage not only assist flood control but also to meet agricultural requirments through internal field drainage.<br>Supporting on-farm water reservoir for rainwater storage.<br>> Promoting integrated agri-horticultural systems including vegetables, plantation crops and aquaculture while managing salinity and growing salt resistant varities |

**Source:** Rana 2002

## 6. ELEMENTS OF SUSTAINABLE AGRICULTURE

Sustainable agriculture is an integral view of human philosophy based on impact of our activities on the environment and on other species. It advocates the prior applications of past experiences as well as latest scientific advances to create integrated resource conserving and equitable farming systems. The convictions as to what elements are acceptable in

sustainable agriculture vary with a place, climate, prevalent crop sequences or a cou (economical and political conditions). However, the practices that reduce environme degradation, favor higher agricultural productivity, promote economic viability in short and long terms, stabilize rural communities and improve quality of life are esse features of sustainable agriculture. Advances in such practices can be modeled to enh the sustainability of existing agro-systems. The approach is interdisciplinary and seeks operation of scientist from wide range of fields. More pertinent areas fundamenta sustainable agriculture are enumerated below: -

## 6.1 Biodiversity

Human society has diverse needs besides food, fiber and shelter, employm ecosystem stability and salubrious environment are its other concerns for sustain development. Biodiversity is the only answer to these issues. 5 to 10 million species estimated to be existing in the world that constitute terrestrial as well as marine biodiver It is now established fact that life occurs in more diverse forms in the sea than on land. Erosion of biodiversity is proceeding at an unprecedented rate of 2.5 species per (Singh 2002). Latest reports indicate that this world may be deprived of quarter of animals and plants, driving one million species into extinction by the end of year 2 (Anonymous 2004). This nature's treasure is for all. It belongs to all of us .We shoul join hands together to protect biodiversity from atrocities man and nature.

Biodiversity is well recognized at different genetic levels (Figure 3). It needs t studied and conserved at each level. Agro-biodiversity, which is part of natural biodiver must not be seen in isolation and conservational approaches should be extended to all f and faunal wealth.

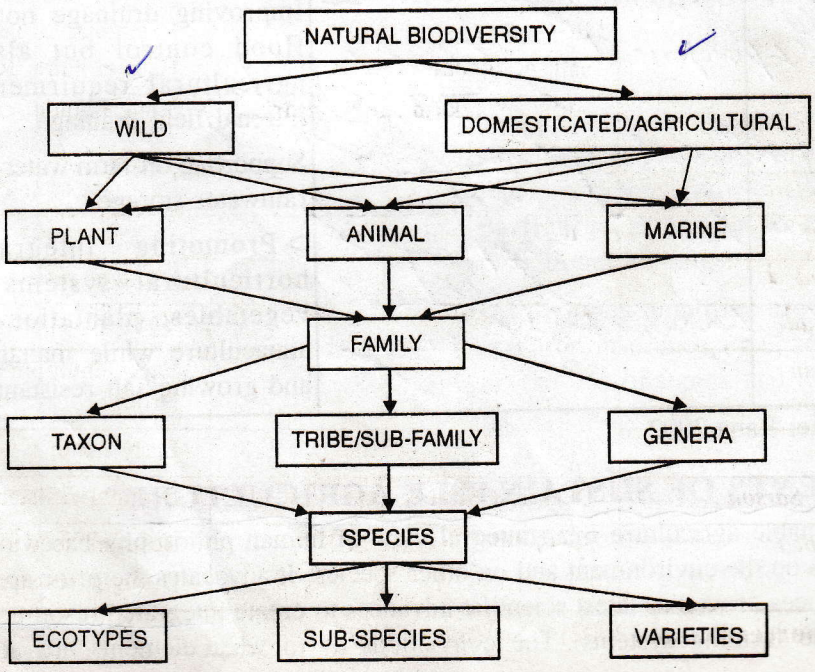


FIGURE3. DIFFERENT LEVELS OF BIODIVERSITY

## 6.2 Promising varieties

Role of promising varieties in sustaining crop productivity stems from their ability to perform better even under constrained environments. The total arable land in the world is 1730 million ha of which only 230 million ha constitute the irrigated agro-ecosystems while rest falls in rain fed agro-ecosystems. The salinity encroaches upon 8.6 million ha in India with 5.2 million ha in the irrigation commands. Agriculture in India alone faces diverse types of agro-climatic situations. Where abiotic stresses like drought, cold, salt and waterlogging are well recognized while diseases and pests have their economic importance, the world over. This fact highlights the relevance for breeding for ecotypes or developing situation specific varieties in India (Table 7). Promising varieties, over the long period of time have proven their worth through the following features: -

**Table 7. Some promising varieties of field crops.**

| Crop | Varieties | Characteristic feature(s) |
|---|---|---|
| *Rice* | IR 8, Ratna, Jaya, Pant Dhan –4<br>CSR-10, CSR-5, Pokkali | High fertility conditions<br>Salinity tolerance |
| *Wheat* | PBW 343, Raj 3077<br>Raj 3077, KRL 1-4<br>Singchen, Mansarover | High fertility conditions<br>Salt tolerance<br>High altitude, summer conditions |
| *Maize*<br><br>*Sorghum* | Ganga safed-2<br>Proteina<br>DSV 4<br>NTJ-2 | Drought resistance<br>High protein content<br>Resistant to charcoal rot<br>Early maturity, drought resistant |
| *Barley* | Azad<br>BG-25<br>SBL-4, Sindhu | Salinity tolerant<br>Resistance to yellow rust<br>High altitude, summer conditions |
| *Potato* | Kufri Chandermukhi & Kufri Sheetman | High altitude, cold tolerant |
| *Sugarcane* | Co 1007; Co 745 | Resistant to top borer |
| *Sesame* | Madhuri, OMT 11-6-3 | Short duration |
| *Linseed* | Surbhi, Janki | Drought resistant |
| *Urdbean* | Pant U-19, SUS-1 | YMV resistant |
| *Soybean*<br>*Field pea* | Girnar<br>Rachna | Early, multiple disease resistant<br>Drought |
| | PE-05 | Early maturity |
| *Gobhi Sarson* | DGS-1, GSL-1 | Drought resistant |
| *Chickpea* | GNG 469, Gaurav, SCS-1, SCS-3, PBG-1 | Resistant to wilt and root rot, Drought resistant |

**Source:** Prasad (2002) ; Sharma (2002).

a. Enhanced food security through stabilization of crop productivity.
b. Input use efficiency is better.
c. Ecofriendly, because of resistance to prevalent biotic and abiotic stresses.
d. Improved grain quality ensures nutritional security.
e. Increase employment opportunities because of sustained productivity and increase profitability.
f. Location specific breeding has resulted in development of different ecotypes an thus, has enhanced varietal diversity in agricultural crops.

### 6.3. Integrated nutrient management (INM)

Intensive cultivation of crops with about 2000 million ton of nutrients ($N+P_2O_5+K_2O$) has been able to keep pace with the rising demand of increasing human population However increased fertilizer consumption during the last three decades has led to the declin the ratio of grain: nutrient. In fact, fertilizer use is largely imbalanced with excessiv application of nitrogen. It has deteriorated soil health. It infers that to feed present populatio of 6.5 billion and that 8.5 billion of 2025, one more green revolution is needed. Therefore no way is left out except resorting to integrated nutrient management system which make combine use of chemical fertilizers, organic manures and biofertilizers. It is also termed a "Integrated plant nutrient supply system". The system ensures balanced nutrition for plan growth without much adverse effects on environment. Returns are higher and sustainabl (Maskina *et al* 1988, Pasricha 1999).

INM is based on constant uptake and response of nutrients by crops (table 8) Nutrien consumption by crops reveals that a follow-up action on following points are required t keep INM economical and more effective.

i) NPK recommendations must be backed by proper soil tests.
ii) Balanced fertilization through organic manures, chemical fertilizers, biofertilizer and micronutrient applications. This will maintain physical, chemical and biologica potential of soils.
iii) Constant soil fertility watch by study of nutrient response of crops and nutrien removal by crops.
iv) Developing INM technology for different crop sequences in different cro situations.
v) Besides FYM, other sources of organic manures such as crop residues, gree manuring and composting should be evaluated and recommended.
vi) Inclusion of a legume in crop rotation and inoculation with efficient strains o *Rhizobium* needs to be promoted.

### 6.4. Tissue culture and biotechnology

Tissue culture and biotechnology are contributing towards sustainable crop productio via generating organisms capable of rendering services to human society in a better way Their application in amelioration of agriculture summed up as under: -

i) **Wide hybridization :** It refers to the crossing or gene transfer between tw species, genera, families or sometimes even two kingdoms. Biotechnologica

techniques like embryo rescue, embryo transfer technology and recombinant DNA technology assist in achieving distant genetic hybridization.

ii) Somaclonal variation

iii) *In vitro* mutagenesis

iv) Anther culture for hastening varietal development programmes in crop plants.

v) Elucidation of various development processes through single cell study.

vi) Micropropogation.

vii) Cryopreservation for germplasm conservation.

viii) DNA finger printing for varietal or species characterization.

ix) Genome mapping.

x) Transgenic plants for herbicide tolerance, insect resistance, disease resistance, male sterility and high protein quality.

xi) Micro- organisms genetically transformed to produce medicinal chemicals, degrading pesticides and various industrial effluents

## 6.5 Multipurpose trees (Agro-forestry and horticulture)

Trees communities are by and large visualized as major source for all kinds of wood. Hardly one recognizes their pivotal role in sustaining the biological society. Some quotations certainly reflect importance of trees in our society like.

"Trees mean water, water means bread and bread is life" or "A tree is a peculiar organisms of unlimited benevolence. It makes no demand for its sustenance and extends generously its products of life activity. It affords protection to all beings, offering shade to even to the axe man who destroys it".

Services of trees in the form of fuel, wood, industrial wood, medicines, fodder, shelter to birds, regulation of hydrological cycle and aesthetic value are well recognized. Trees help fighting air, dust and noise pollutions (Singh 1991). Sharma and Sharma (2000) have enumerated various socio-economic and ecological benefits from agro-forestry system. They emphasized essentiality of tree crop combinations for sustainable development of a region.

National forest policy of India advocates that at least 33% of total land area should be under forest for a balanced agrarian economy however forest cover is now only 20.8% of the geographical area (Shrotriya, 1999). Human population pressure is still building up, seeking increase in productivity and production area under crops indicating mute chances of enhancing area under forestry. Nevertheless, area under tree cover can be raised by mean of agro-forestry or social forestry where tree plantation finds place in farmer fields or community lands.

Keeping in view elevating demands for tree products, preference should be given to plantation of multipurpose trees (MPTs) in different agro-silviculture, silvi-pasteral or agro-horticultural systems. Some MPTs are enlisted in Table 9 that can be grown in different ago-ecological zones.

## 6.6 Integrated pest management

Voracious nature of several pests has been well recognized by man since the dawn settled agriculture. Many a time outbreaks of pests were considered a curse of God. In du course of time, the occurrence of pest was well established in relation to a crop or cro variety, climate and place. By the 20th century multiple suppression techniques such sanitation, crop combinations, crop sequence, resistant varieties and chemicals were deploye to control pest populations. Miracle effects of DDT and 2,4-D marked the indiscrimina use of chemicals in agriculture. Subsequently, it was realized that many of the chemica were not biologically degradable. They persist in environment and become concentrate through food chains. Non-target organisms are also affected sometimes. This seeks judicio use of chemicals and integration of several other practices to minimize the chemic application.

Bartlett (1956) coined the term 'Integrated Pest control' and defined it as the blendi of biological control agents with chemical control measures. 'Food and Agricultu Organization (1967) defined integrated pest management as system that in the context of t associated environment and population dynamics of pest species utilizes all suitable techniqu and methods in as compatible manner as possible and maintains the pests population leve below those causing economic injury. Dhaliwal and Arora (1994) defined IPM as a dynam and constantly evolving system in which all suitable tactics, available surveillance a forecasting formation are combined into a holistic management programme delivered to farmer at requisite intervals as a part of sustainable crop production technology. Hen IPM integrates all the available pest control method to provide a farmer most effectiv economical and sustainable technology where pesticides are a last resort and priority is eco-friendly control measures. Soon (1999) has described IPM success stories in some Asian countries.

**Techniques for IPM**

i) Host plant resistance
   a) Resistant varieties
   b) Pest resistant transgenics
ii) Biological control.
iii) Cultural control.
iv) Insecticidal control
   a) Bio-pesticides.
   b) Botanical pesticides.
   c) Chemical pesticides.

**BENEFITS**

Integrated pest management is based on ecological principal and has broad and lo lasting socio-economic benefits far beyond plant protection activities. IPM is a prov alternative to the overuse of chemical pest control (Soon 1999). Advantages can be consider from large scale impact on human health, environment to production cost such as

i) Lower production cost because of reduced application of chemical pesticides.
ii) A safer environment to live.

iii) Brings in ecological sustainability by conserving natural enemies.
iv) Enormous government savings from pesticides import and subsidies.
v) Farmers are relieved off of pesticide poisoning and other related hazards.
vi) Frequency of pest resistance and resurgence is reduced.
vii) Reduced pesticidal Residues in the crop produce and food products.

The concept of IPM has established its worth, the world over. Even then there are limited number of IPM programmes functioning at the farmers level. Atwal and Dhaliwal (1997) attributed this limitation to lack of theoretical framework into which various components of IPM could be fitted to develop a viable system. As a matter of fact, IPM systems for different crops need to be developed. They should be periodically refined through intensified research efforts so that they remain environmentally sound and economically viable.

## 6.7 Legume based cropping systems

Indian agriculture underwent transformation following green revolution in early seventies. Consequently intensive agriculture took over subsistence agriculture. Rice-wheat cropping sequence encroached upon the other crop sequences due to better market access and profit. However the compound production growth of cereals- based intensive cropping systems has declined from 2.74% during 1981-90 to 1.66% during 1991-2000 (Ali and Shiv Kumar 2002). Reduction in productivity is due to cereal crop rotation (shallow root system), imbalance in crop-soil nutrients, more diseases and pests attack and more unit of water per unit of productivity. It is now acknowledged fact that continuous persistence of a crop rotation in a field causes 'soil sickness', mining of certain nutrients while accumulation of others and unification in farmers diet (responsible for enhancing malnutrition).

In spite of increased overall food production, availability of pulses has gone down from 69g in 1961 to 36g in 2000. Pulses are poorman's proteins and provide tangible solution to the prevalent malnutrition in the world. In addition, cultivation of pulses is endowed with several advantages such as: -

i) Growing legumes in rotation with cereal improves nitrogen mineralization potential in soil (Singh *et. al.*1996).
ii) Green manuring with legumes gives an advantage of 40 to 90 kg of nitrogen per hectare.
iii) Make the crop sequence sustainable by favoring soil, plant and environment health.
iv) Some legumes have character of high phosphorus efficiency i. e, Phaseolus vulgares (Pasricha1999).
v) Enhance crop productivity per unit area by increasing cropping intensity such as Rice- wheat replacement by Rice –Wheat –Moong/ Urd (summer).
vi) Improve soil structure, soil microbial activity, water holding capacity, buffering capacity and release of growth promoting substances (Pasricha 1999).
vii) Act as soil binding crops.
viii) Legumes are drought resistant.

ix) Legumes provide diverse service to human society such as timber, fodder, oilseed, medicine, pulses and ornamentals.

x) Richer harvest of proteins per unit area.

## 6.8 Secondary and micro-nutrient applications

Revolution in agricultural production occurred because of steady supply of macronutrients such as N, P, and K to crops. Productivity levels have gone too high in certain regions of the world. In India increase has been to the tune of 76% merely from 50 million ton in 1950-51to 211million ton in 2000-01 with fertilizer consumption to the level of 91kg/ha. Now the productivity levels are stagnant rather declining in some high productive zones. The reason has been deficiency of secondary and micronutrients namely Ca, Mg, S, Fe, Mn, B, Zn, Co, Mo, and Cu, in soils.

Secondary and trace elements remained subject of only theoretical studies until their declining levels interfered with crop productivity. However, they have importance beyond crop nutrition and deserved to be evaluated and assessed for their role in soil health and human nutrition.

It is alarming that cost of production has gone up in certain crops because of decreased responses to fertilizers. Tewari (2002) reported that threats to Indian Agriculture were certain because of inadequate and unbalanced use of fertilizers and micro-nutrients where replenishment negative to the order of 8-10 million ten per annum is acknowledged.

Inadequate macro- and micronutrients application result in one or more of the following problems:

i) Deterioration of soil health in terms of physical, chemical, and biological properties.
ii) Low nutrient use efficiency.
iii) More pollution due to increased leaching, volatilization and run – off of nutrients.
iv) Adverse effects on soil flora and fauna.
v) Crop produce of low quality.
vi) Reduce crop yield.
vii) More proneness to disease and pest due to reduce plant vigor.

Agricultural crops, particularly cereals are the major source of calorie and micronutrients to human diet in developing countries. According to Graham et al (2001) over half of the world's population does not consume enough of micronutrients in their food to support good health. Predominant among them are iron, iodine, vitamin A other being zinc, selenium, folic acid, Vitamin C, Vitamin E, Vitamin D, Thiamin, Vitamin B12 and niacin. As adequate genetic variation for these characters is available in major field crops that, too with simple genetic control so it justifies a breeding programme of nutrient-dense staple food that can give resource-poor populations a better-balanced nutritional base. Beta-carotene enriched rice, iron enriched rice and designer potato feats of latest successes in food crop breeding to fight against ghost of malnutrition.

Thus neglect towards secondary and micronutrients application on food crops can have multi-dimensional adverse effects on soil, plant, animal, and human nutrition in the

long run. Consequences may challenge short-term remedial measures putting the human society in very ackward situation on outbreak of their deficiencies.

### 6.9 Water harvesting technology

Three fourth of earth's surface is covered by water but only fraction of it is available as fresh water. 70% of the withdrawn water is used in agriculture. FAO estimates that 60% more food will be required in next 30 years by world's population. Increase will mostly come from intensive agriculture. As growing water scarcity is already an international problem so improvement in agriculture productivity has to be in line with efficient water management. Further maintaining the productivity of existing 230 million ha of irrigated and1500 million ha of dry land agriculture demands application of principle "more crop per drop." It emerges that in future water harvesting technology for the various agro-ecosystems will be the key factor in sustaining the crop productivity in different regions of the world.

Conservation, sustainable use and equal accessibility to water are the most pertinent issues of immediate consideration. Misappropriation of water resources at the world level is visible in the form ground water depletion, increased salinization, water logging and low water use efficiency of 30 –50 percent

Water harvesting technologies need to be developed in relation to prevailing agriculture, cropping sequences and availability of quantity and quality of water. Following points must receive due consideration in implementation of water harvesting technologies.

i) Proper irrigation scheduling.
ii) Conjunctive use of ground and surface water for irrigation.
iii) Practise surge flow method of irrigation for better water distribution and low percolation losses.
iv) Appropriate drainage provision.
v) Recycling and re- use of wastewater.
vi) Development of micro- watershed for proper rainwater harvesting.
vii) Soil moisture conservation technology through agronomic, breeding and soil management techniques.

## 7. SUSTAINABLE AGRICULTURE AND SUSTAINABLE DEVELOPMENT

**The ultimate goal in advocating adoption of sustainable agriculture is attainment of sustainable development which means development that distributes the benefits of economic progress more equitably, protects both local and global environments for future generations and improves quality of life.** Environmentally sound technologies with efficient use of resources are key to both sustainable agriculture and sustainable development. Both the aspects demand global partnership in resource utilization, pricing policy, socio-economic development and environmental protection. Broadly it necessitates the integration of following issues, however prioritization may vary depending upon status of natural resources and economic capabilities.