Course: Principles of Plant Physiology I (Plant Water Relations and Mineral Nutrition)
Course Code: PP 501
Credit: 3(2+1)

Theory

Block 1: Plant Water Relations

Unit 1: Soil and Plant Water Relations

- Water and its importance; Molecular structure of water; Properties and functions of water
- Concept of water potential; Plant cell and soil water potential and their components; Methods to determine cell and soil water potential; Concept of osmosis and diffusion
- Soil physical properties and water availability in different soils; Water holding capacity and approaches to improve WHC; Concept of FC and PWP; Water holding polymers and their relevance

Unit 2: Water Absorption and Translocation

- Root structure and functions; Root architecture and relevance in water mining; Mechanism of water absorption and translocation; Theories explaining water absorption and translocation; Aquaporins
- Mycorrhizal association and its relevance in water mining

Unit 3: Transpiration and Evaporative Cooling

- Evaporation and transpiration; relevance of transpiration; factors regulating transpiration; Measurement of transpiration; approaches to minimize evaporation and transpiration; Concept of CCATD and its relevance
- Energy balance: Solar energy input and output at crop canopy level
- Stomata- its structure, functions and distribution; Molecular mechanisms of stomatal opening and closing; Concept of guard cell turgidity; role of K and other osmolytes; role of ABA in stomatal closure; Guard cells response to environmental signals; Signaling cascade associated with stomatal opening and closure
- Antitranspirants and their relevance in agriculture

Unit 4: Water Productivity and Water Use Efficiency

- WUE and its relevance in water productivity; Transpiration efficiency, a measure of intrinsic WUE; Approaches to measure WUE; Stomatal and mesophyll regulation on WUE; Passioura's yield model emphasizing WUE

Unit 5: Moisture Stress and Plant Growth

- Physiology of water stress in plants; Effect of moisture stress at molecular, cellular, organ and plant level
- Drought indices and drought tolerance strategies
- Drought tolerance traits

BLOCK 2: MINERAL NUTRITION

Unit 1: Nutrient Elements and Their Importance

- Role of mineral nutrients in plant's metabolism; Essential elements and their classification; Beneficial elements; factors influencing the nutrients availability; critical levels of nutrients
- Functions of mineral elements in plants
- Deficiency and toxicity symptoms in plants

Unit 2: Nutrient Acquisition

- Mechanism of mineral uptake and translocation; Ion transporters; genes encoding for ion transporters; localization of transporters; xylem and phloem mobility; Nutrient transport to grains at maturity; Strategies to acquire and transport minerals under deficient levels
- Role of mycorrhiza, root exudates and PGPRs in plant nutrient acquisition

Unit 3: Concept of Foliar Nutrition

- Foliar nutrition; significance and factors affecting total uptake of minerals; Foliar nutrient droplet size for effective entry; role of wetting agents in entry of nutrients

PRACTICALS

1. Standard solutions and preparation of different forms of solutions
2. Studies on the basic properties of water
3. Demonstration of surface tension of water and other solvents
4. Measurement of plant water status: Relative water content and rate of water loss
5. Determination of water potential through tissue volume and Chardakov's test
6. Determination of water potential using pressure bomb, osmometer, psychrometer
7. Determination of soil moisture content and soil water potential
8. Use of soil moisture probes and soil moisture sensors
9. Measurement of transpiration rate in plants; use of porometry
10. Measurement of CCATD and its relevance
11. Demonstration and use of anti-transpirants to reduce transpiration
12. Influence of potassium and ABA on stomatal opening and closing respectively
13. Deficiency and toxicity symptoms of nutrients
14. Effect of water stress on plant growth and development

Title: Principles Of Plant Physiology-II: Metabolic Processes and Growth Regulation
Course Code: PP 502
Credit: 3(2+1)

BLOCK 1: Metabolic Processes and Growth Regulation

Unit 1: Carbon Metabolism – Photochemical Processes

- Chloroplast ultrastructure with special mention of lamellar system
- Excitation, electron and proton transfers and their relevance in energy conservation
- Concepts of pigment systems and generation of powerful reductant and oxidant
- Water oxidation, Water-water cycle and other aspects of electron transfer

Unit 2: Carbon Metabolism: Biochemical Processes

- CO_2 diffusion mechanisms and diffusive conductances, concept of Ci determining Photosynthesis
- RuBisCO enzyme kinetics and Calvin cycle mechanisms, Regulation of Calvin cycle and metabolite fluxes
- Photorespiration: the advantages and inefficiencies of photosynthesis because of photorespiration
- Concepts of CO_2 concentrating mechanisms (CCM) and spatial and temporal differences in carboxylation
- Ecological aspects of $C_4$and CAM photosynthesis
- Product synthesis, Starch and Sucrose biosynthesis

Unit 3: Carbon Metabolism: Respiration

- Mitochondrial organization and functions
- Aspects of Glycolysis, TCA cycle and mitETC.
- Relevance of growth and maintenance respiration
- Concepts of CN resistance respiration – Alternate and SHAM sensitive ETC

Unit 4: Product Synthesis and Translocation Leading to Crop Growth

- Phloem loading and sugar transporting, concepts of bi-directional transport of sugars and other metabolites
- Source-Sink relationship and modulation of photosynthesis
- Concepts and definitions of Growth and Differentiation
- Growth and yield parameters, NAR, CGR, HI and concepts of LAI, LAD

Unit 5: Nitrogen Assimilation and Protein Synthesis

- Developments in d-nitrogen fixation
- Nitrate reduction and assimilation GS-GOGAT process for amino acid synthesis
- Inter-Dependence of carbon assimilation and nitrogen metabolisms

Unit 6: Lipid Metabolism and Secondary Metabolites

- Storage, protective and structural lipids.
- Biosynthesis of fatty-acids, diacyl and triacyl glycerol, fatty acids of storage lipids.
- Secondary metabolites and their significance in plant defense mechanisms.

Unit 7: Hormonal Regulation of Plant Growth and Development

- Growth promoting and retarding hormones: biosynthesis, transport, conjugation
- Mode of action of these hormones and their application in plant physiology

Unit 8: Synthetic Growth Promoters

- Different synthetic hormones: Salicylic acid, strigolactones etc
- Roles and biological activities of various synthetic hormones
- Commercial application of hormones to maximize growth and productivity

Unit 9: Morphogenesis and Reproductive Phase

- Photoperiodism: Phytochromes, their structure and function
- Circadian rhythms,
- Blue light receptors: Cryptochrome and morphogenesis.
- Vernalization and its relevance in germination.

PRACTICALS

1. Radiant energy measurements
2. Separation and quantification of chlorophylls
3. Separation and quantification of carotenoids
4. O2 evolution during photosynthesis
5. Anatomical identification of C3 and C4 plants
6. Measurement of gas exchange parameters, conductance, photosynthetic rate, photorespiration
7. Measurement of respiration rates
8. Estimation of reducing sugars, starch
9. Estimation of NO3, free amino acids in the xylem exudates, quantification of soluble proteins
10. Bioassays for different growth hormones- Auxins, Gibberellins, Cytokinins, ABA and Ethylene
11. Demonstration of photoperiodic response of plants in terms of flowering

Title: Plant Developmental Biology: Physiological and Molecular Basis
Course Code: PP 503
Credit: 3(2+1)

BLOCK 1: PLANT DEVELOPMENTAL BIOLOGY

Unit 1: Evolutionary Development of Plants and Role of Environment

- Plant development and plasticity, evolution, Biodiversity
- Novel features of plant growth and development, Concept of plasticity-evolution and biodiversity, Model plants for study; Environment and development.
- Developmental stages and program; Cell-cycle, totipotency and regeneration.

Unit 2: Physiological and Molecular Determinants of Seed Biology

- Seed development- Physiology of seed development, role of hormones in embryo development; seed development and maturation.
- Seed dormancy- Physiological and molecular mechanism of seed dormancy regulation. Seed germination- seed structure and Hormonal regulation of germination, Mobilization of food reserves during seed germination.

Unit 3: Vegetative Growth and Organ Development

- Regeneration and totipotency- organ differentiation and development – role of hormones-developmental control genes in crop plants.
- Meristems in plant development.
- Shoot, Leaf, Trichome and stomate development and differentiation.
- Axillary shoot branching; Bud dormancy and growth
- Root development; Nodule development; Tuber development- hormonal control, signaling and molecular regulation- genes involved.
- Vascular bundle development- xylem and phloem differentiation

Unit 4: Physiological and Molecular Aspects of Reproductive Growth and Development

- Floral Induction and Development: Molecular and physiological mechanism of transition-vegetative to reproductive phase- floral organ initiation and development their controls.
- Development of male and female gametophyte; gametophytic mutants: pollen-stigma interaction- Pollen germination and tube growth; role of imprinting; Male sterility: and fertility restoration; Self incompatibility; Sterility and fertility restoration, Maternal gene effects, Zygotic gene effects.
- Sex determination in plants, mate choice in plants.
- Embryo and endosperm development- fertilization, role of imprinting; Parthenocarpy and apomixes

Unit 5: Ripening and Senescence

- Fruit development, enlargement, maturation and ripening; climacteric and non-climacteric fruit ripening mechanism.
- Hormonal, biochemical & Molecular aspects of fruit ripening
- Senescence and its regulation; Hormonal and environmental control of senescence; PCD in the life cycle of plants.

Unit 6: Physiological and Molecular Regulation of Plant Development Influenced by Light and Temperature

- Light control of plant development: Phytochromes and cryptochromes, phototropins, their structure, biochemical properties and cellular distribution
- Molecular mechanisms of light perception, signal transduction and gene regulation
- Photoperiodism and its significance, vernalization and hormonal control
- Circadian rhythms-biological clocks and their genetic and molecular determinants
- Thermomorphogenesis- Thermoperiodism

Block 2: Application Of Morphogenesis and Its Practical Application

Unit 7: Tissue culture and micro-propagation

- Applications of tissue culture for plant production, callus induction, somatic embryogenesis, regeneration from different explants.
- Micro-propogation, tip and axillary node culture of commercially important crops, hardening and ex-vitro establishment, concept of somatic hybridization and protoplast culture.

Unit 8: Application of in-vitro techniques for crop improvement

- Development of somoclones, identification and exploitation of somoclonal variants
- Haploid production, pollen/anther, ovule/ovary culture
- Production of secondary metabolites by tissue culture, concept of bio-fermenters.
- Plant transformation, development of transgenic plants and their characterization
- Germplasm storage, cryopreservation and regulation

PRACTICALS

1. Studying shoot apical meristem, floral meristem development and pollen tube development
2. Phenotyping photomorphogenesis: a) Studying effect of day length (short day and long day) in regulating floral induction/ flowering time in short day/long day/day neutral plants and b) effect of light on seed germination in light-sensitive and - insensitive seeds.
3. Studying effect of temperature on- a) thermomorphogenesis- measuring hypocotyl elongation under different temperature conditions and b) sex determination using cucurbits/sesame plants.
4. Measure physiological paramters of fruit ripening and study the expression of key genes

regulating ripening.

5. Study the effect of ethylene, its inhbibitor and scruber on ripening (tomato).
6. Study different sterilization techniques, prepare media stocks and plant hormones.
7. Inoculate explant (seed and leaf tissue) of model plant for callus induction.
8. Subculture the callus and standerdize regeneration protocol for shoot and rootinduction using callus and leaf explant.
9. Micro-propagation using meristem tip and axillary node culture.
10. Standerdize anther/ pollen culture for haploid production in model/crop/horticulturalplant.
11. Isolation of protoplast from Arabidopsis/tobacco and its culturing
12. Study about selectable marker, reporter gene, PCR, southern and northern blottingtechniques.
13. Transformation of tobacco callus or leaf explant by *Agrobacterium tumefacines* and *Agrobacterium rhizogenes* for production of transgenic
14. Molecular characterization of transgenic- PCR, southern blotting, gene expression.

Title: Physiological And Molecular Responses of Plants to Abiotic Stresses
Credit: 3(2+1)
Course Code: PP-504

THEORY

BLOCK 1: ABIOTIC STRESSES

Unit 1: Introduction to Abiotic Stresses

- Abiotic stresses major constraints to realize potential yields of crop plants, yieldlosses.
- Drought prone areas in India- Frequency of occurrence of drought, Rainfed- kharif, Rabi, Areas affected by salinity, heavy metals, water logging, high temperature scenario due to global warming.

BLOCK 2: DROUGHT STRESS

Unit 1: Moisture Stress Responses in Plants

- Drought-characteristic features; water potential in the soil-plant-air continuum.
- Physiological and biochemical processes affected by drought. Oxidative stress- generation of ROS and other cytotoxic compounds, their effect on cellular process.
- Effect on total carbon gain- decrease in photosynthetic area and function, protein turn over and lipid characters, phenology-reproductive aspects, critical stages.

Unit 2: Stress Perception and Molecular Responses of Plants to Drought Stress

- Stress perception and signal transduction leading to expression of regulatory genes, stress specific kinases, stress specific transcription factors, functional genes associated with adaptive mechanisms

Unit 3: Plant Adaptive Mechanisms to Drought

a. Escape and desiccation avoidance mechanism

- Concept of stress escape- exploiting genetic variability in phenology, Drought avoidance mechanisms- Maintenance of cell turgor, water mining by root characters.
- Moisture conservation- Regulation of transpiration- traits reducing heat load, Stomatal factors guard cell metabolism, moisture conservation by waxes
- Water use efficiency (WUE) and concept of water productivity- regulation of transpiration efficiency-stomatal conductance, mesophyll efficiency, relevance of WUE and Passioura's model.

b. Desiccation tolerance- Concept of acquired tolerance

- Decreased turgor mediated upregulation of cellular tolerance mechanisms, Osmolytes, managing cytotoxic compounds, ROS, RCC, scavenging - enzymatic and non-enzymatic, protein turnover, stability, chaperones, membrane stability, photo-protection of chlorophylls.

Unit 4: Approaches to Improve Drought Tolerance

- Development of genetic resources- donor genotypes for specific traits, Genomic resources- genes, QTL's regulating adaptive mechanisms, Conventional, transgenic and molecular breeding approaches to improve relevant adaptive traits, concept of trait introgression

Block 3: Salt, Heavy Metal, Water Logging, Temperature and Light Stress

Unit 1: Salt Stress

- Soil salinity-Effect of salt stress, ionic and osmotic effects; species variation in salt tolerance; glycophytes and halophytes, Salt tolerance mechanisms - exclusion, extrusion and compartmentalization, Signaling during salt stress – SOS pathway, Approaches to improve salt tolerance.

Unit 2: Heavy Metal Stress and Water Logging

- Heavy metal toxicity in plants (eg., Al, Cd), tolerance mechanisms and approaches to improve.
- Plant response to water logging, role of hormones- ethylene, mechanism of tolerance and approaches to improve.

Unit 3: Temperature and Light Stress

- High and low temperatures; effect on plants; adaptive mechanisms, evaporation cooling, concept of cellular tolerance, protein stability, chaperones, HSPs, HSFs, membranes.
- High light and high ionizing radiation- photo oxidation and photo-inhibition; mechanisms of tolerance, plant adaptation to low light, concept of shade avoidance response (SAR)

PRACTICALS

1. Measurement of soil and plant water status.
2. Drought stress imposition and measurement of physiological and biochemical changesin plants under stress –gas exchange and fluorescence measurements.
3. Determination of water use efficiency as a drought resistant trait.
4. Drought Susceptibility Index (DSI) -precise field technique to identify productive genotypes under stress.
5. Approaches to quantify root characters
6. Determination of stomatal parameters and canopy temperature as a reflection of transpiration and root activity.
7. Determination of Salinity Tolerance Index.
8. Studying acclimation response - Temperature induction response.
9. Heat tolerance and membrane integrity- Sullivans heat tolerance test.
10. Quantification of osmolytes – proline under stress.
11. Oxidative stress imposition- Quantification of oxidative stress
12. Quantification of ROS under stress.
13. Estimation of ABA content in leaf and root tissues under stress.
14. Determination of Sodium and Potassium in plant tissue grown under salt stress.
15. Estimation of antioxidant enzymes.

Title: Hormonal Regulation of Plant Growth and Development
Course Code: PP 505
Credit: 3(2+1)

Block 1: Plant Growth and Development: Hormonal Regulation

Unit 1: Introduction to Plant Hormones

- Growth, differentiation and development regulated by plant growth substances
- Definition and classification of growth regulating substances: Classical hormones
- Definition and classification of growth regulating substances: Endogenous growth substances other than hormones, Synthetic chemicals

Unit 2: Plant Hormones - Discovery and Metabolism

- Discovery, biosynthetic pathways and metabolism of Auxin
- Discovery, biosynthetic pathways and metabolism of Gibberellins
- Discovery, biosynthetic pathways and metabolism of Cytokinins
- Discovery, biosynthetic pathways and metabolism of Abscisic acid
- Discovery, biosynthetic pathways and metabolism of Ethylene
- Discovery, biosynthetic pathways and metabolism of Brassinosteroids
- Discovery, biosynthetic pathways and metabolism of Strigolactones

Unit 3: Physiological Role of Hormones in Plant Growth and Development

- Physiological functions of Auxin and use of mutants and transgenic plants in elucidating the physiological functions
- Physiological functions of Gibberellins and use of mutants and transgenic plants in elucidating the physiological functions
- Physiological functions of Cytokinins and use of mutants and transgenic plants in elucidating the physiological functions
- Physiological functions of Abscisic acid and use of mutants and transgenic plants in elucidating the physiological functions
- Physiological functions of Ethylene and use of mutants and transgenic plants in elucidating the physiological functions
- Physiological functions of Brassinosteroids and Strigolactones and use of mutants and transgenic plants in elucidating the physiological functions
- Discovery, biosynthetic pathways metabolism and physiological roles of Salicylicacid and Peptide hormones

Unit 4: Endogenous Growth Substances other than Hormones

- Discovery, biosynthetic pathways metabolism and physiological role of Polyamines and Karrikins
- Discovery, biosynthetic pathways metabolism and physiological roles of Jasmonatesand Tricontanol
- Discovery, biosynthetic pathways metabolism and physiological roles of systemins Concept of death hormone
- Recent developments in elucidating responses of Salicylic acid, Peptide hormones and Polyamines at physiological and molecular level
- Recent developments in elucidating responses of Jasmonates, Systemins, Karrikinsand Tricontanol at physiological and molecular level

Unit 5: Hormone Signaling

- Hormone signal perception, transduction - Receptors, components and mechanism (Auxin, Gibberellin, Cytokinin, ABA and Salicylic acid)
- Hormone signal perception, transduction - Receptors, components and mechanism

(Ethylene, Jasmonate, Brassinosteroids and strigolactones)

- Advances in elucidating the structure and function of receptors and signaling components of important hormones

Unit 6: Key Genes Regulating Hormone Levels and Functions

- Genomics approaches to regulate hormone metabolism and its effect on plant growth and development – case studies

Unit 7: Crosstalk of Hormones in Regulation of Plant Growth and Development Processes

- Crosstalk of Hormones in Regulation of Plant Growth and Development Processes: Floral transition, reproductive development, Shoot and root apical meristem development

Unit 8: Practical Utility of Growth Regulators in Agriculture and Horticulture

- Practical Utility of Growth Regulators in Agriculture and Horticulture: Rooting of cuttings, Vine and brewing industry, Promotion of gynoecious flowers, hybrid rice production, induction of flowering in pine apple, cucurbits.
- Practical Utility of Growth Regulators in Agriculture and Horticulture: Delaying of senescence and ripening, Production of dwarf plants for ornamental purpose, As herbicides, Reduction in flower and fruit drop

PRACTICALS

1. Extraction of Auxins from plant tissue
2. Separation and detection of Auxins by GC / GC-MS / HPLC / Immunologicaltechnique
3. Bioassay of auxin- effect on rooting of cuttings
4. Extraction of abscisic acid (ABA) from plant tissue
5. Separation and detection of ABA by HPLC/Immunological technique
6. ABA bioassays- effect on stomatal movement
7. Preparation of samples for ethylene estimation in plant tissue
8. Estimation of ethylene in plant tissues using gas chromatography
9. Ethylene bioassays, estimation using physico-chemical techniques- effect on breaking dormancy in sunflower and groundnut
10. Extraction of Gibberellins from plant tissue- GC / GC-MS / HPLC
11. Separation and detection of GA by GC / GC-MS / HPLC/Immunological technique
12. GA bioassays- effect on germination of dormant seeds
13. Cytokinin- extraction from plant tissue
14. Separation and detection of cytokinin by GC / GC-MS / HPLC
15. Cytokinin bioassays- effect on apical dominance and senescence / stay green

Title: Physiological and Molecular Mechanisms of MineralNutrient Acquisition and Their Functions

Course Code: PP 506

Credit: 3(2+1)

BLOCK 1: Mineral Nutrient: Classification, Function, Availability, Deficiency and Toxicity

Unit 1: Mineral Elements: Classification, Function, Deficiency and Toxicity

- Classification based on mobility and characteristic features; physiological role in regulating plant growth, metabolism, development and human health- Regulatory Dietary Allowance (RDA)
- Deficiency and toxicity of macro, micro and beneficial elements
- Tolerance of plants to nutrient toxicity, hyper-accumulators of nutrients: Concept of phytoremediation

Unit 2: Nutrient Availability at Rhizosphere

- Biological and chemical reactions influencing nutrient availability near the root system, interaction between ions in the rhizosphere
- Rhizosphere chemistry in relation to plant nutrition- chemical reactions, root exudates to mobilize nutrients

Block 2: Nutrient Uptake, Translocation and Acquisition

Unit 1: Ion Uptake Mechanisms

- Mineral salt absorption- chemical potential of solute- Nernst equation- passive uptake- diffusion, ion exchange-Donnan Equilibrium, mass flow of ions
- Mediated transport- Facilitated diffusion -ionophores; membrane transport proteins-active transport-ion channels, Primary and secondary transport- carriers and pumps

Unit 2: Ion Transport to Shoot and Grains

- Long distance transport in plants - Mechanism of xylem and phloem transport, Radialmovement of ions across the root
- Mechanism of phloem transport, remobilization of mineral nutrients - phloem loading,phloem unloading

Unit 3: Physiological and Molecular Mechanism of Nutrient Acquisition and Transport:Macronutrients

- Molecular structures of LAT and HAT, their localization and regulation by variousexternal factors
- Nitrate transporters and their functional regulation - Nitrate transporters (NRT1, NRT2, dual-affinity nitrate transporter NRT1.1/CHL1)
- Phosphate transporters and their functional regulation - PT1/PHT1, PHT2, PHT3, PHT4
- Potassium transporters and their functional regulation - KT/HAK/KUP family
- Ion transporters involved in transport of multiple elements, for example, sulphate transporter for Selenate transport, phosphate transporter for Arsenate transport, etc.

Unit 4: Physiological and Molecular Mechanism of Nutrient Acquisition and Transport: Micro and Beneficial Nutrients

- Plant Strategies: Different Strategies I & II adopted by plants for uptake of Fe underFe deficient condition
- Transporters and genes regulating uptake and transport of micronutrients, genes encoding transport/channel proteins, Examples of genes encoding mineral ion transporters for Zn, Fe, Mn, Cu, B, Mo, Ni, Cl, Na, Si, Se
- Beneficial nutrients and their role in plant growth and development – Sodium, Silicon, and Cobalt

Unit 5: Microbes, Fungal Association for Nutrient Acquisition

- Microbes to improve nutrient availability – Bio-inoculation technology- P solubilizersand Zinc solubilizers in nutrient absorption
- Microbial systems for biological nitrogen fixation – process of nodulation, biochemistry of N2-fixation
- Endophytes to improve nutrient availability, Mycorrhiza- Mycorrhizal symbiosis on nutrient uptake by root. Role of AMF on nitrogen, phosphorus and zinc uptake.

Unit 6: Nutrient Delivery

- Foliar application of nutrients, absorption and their compartmentation, Concept ofslow release fertilizers and chelates (organic and inorganic)
- Soil less cultures- aeroponics, hydroponics, fertigation

BLOCK 3: NUTRIENT EFFICIENCY OF CROP

Unit 1: Improving Nutrient Acquisition and Efficiency of Crops

- Concept of nutrient uptake and use efficiency- Genotypic differences- physiology and molecular mechanisms, Nutrient use efficiency in selected crops
- Root system architecture (RSA), root characters associated with nutrient acquisition, Genes and QTLs to improve nutrient acquisition and efficiency for important nutrients in few crop species
- Transgenic and molecular breeding approaches to improve traits associated with acquisition and efficiency- Case studies
- Biofortification strategies – for micronutrients, agronomic approaches
- Influence of nutrition status on plant response to biotic and abiotic stresses

PRACTICALS

1) Techniques to develop the deficiency symptoms of nutrients – Hydroponics/Aeroponics- diagnosis of deficiency symptoms in agriculturally important crop plants
2) Physiological and biochemical markers to identify nutrient deficiency levels
3) Biochemical markers for essential elements: Assay of nitrate reductase activity for N
4) Estimation of chlorophyll concentration in leaves of N deficient and N sufficient plants
5) Collection of acid phosphatase from root exudates and enzyme assay for P
6) Measuring anthocyanin and chlorophyll pigments concentration in leaves for P
7) Collection of organic acid in root exudates, characterization and quantification for P
8) Assay of carbonic anhydrase activity for Zn
9) Assay of SOD Activity for Cu, Zn and Mn

10) Estimation of nitrogen concentration in plant tissue - Kjeldhal and Dumas method
11) Estimation of phosphorus concentration in plant tissue – colorimetric method
12) Estimation of potassium, magnesium and sodium concentration in plant tissue - flame photometer
13) Estimation of micronutrients (Zn, Cu, Fe, Mn, Co etc) concentration in plant tissue - atomic absorption spectrometer/ ICP-OES
14) Measurement of simple root traits such as root length, angle, volume, surface area, etc. (using conventional methods or root scanner and WinRhizo)
15) 'Shovelomics' in the field grown crops (for measuring root architecture) and using 'Image J' for analysis
16) Non-invasive techniques to quantify nutrients – XRF (X-Ray Fluorescence) and hyper spectral reflectance

Title: Photosynthetic Processes, Crop Growth and Productivityand Concepts of Crop Modelling
Course Code: PP-507
Course Credit: 3(2+1)

BLOCK 1: PHOTOSYNTHETIC PROCESSES

Unit 1: Canopy Architecture and Energy Utilization

- Parameters associated with canopy architecture that determine radiation interceptionand absorption
- Energy absorption by primary and accessory pigments and energy utilization efficiency
- Light distribution inside the canopy and concepts of light extinction coefficient

Unit 2: Photochemical Processes

- Ultrastructure of chloroplast: structure and composition of lamellar system
- Components of electron transport, Water oxidation system and energy conservationprocesses
- Pigment systems and the generation of a powerful oxidant and a powerful reductant
- Chlorophyll fluorescence and fluorescence quenching: qN, qP, NPQ

Unit 3: Biochemical Processes

- CO_2 diffusion and resistances (g_s and g_m). Concept of Ci determining CO_2 diffusion.
- RuBisCO activation state, kinetics and catalytic properties
- Carboxylation processes in C_3, C_4 and CAM plants and their relevance
- CO_2 concentrating mechanisms and their importance in improving carbonassimilation
- Ecological significance of C_4 and CAM photosynthesis
- Photorespiration and Mitochondrial respiration and net carbon gain
- Carbon isotope discrimination and its importance as a surrogate of Ci

Unit 4: Product Synthesis and Translocation

- Triose phosphate utilization and regulation of Calvin cycle mechanisms
- Product synthesis and partitioning between starch and sucrose
- Concepts of end-product inhibition or Pi-regeneration limitation
- Phloem transport and factors that regulate phloem loading and un-loading

Unit 5: Growth and Yield forming Mechanisms

- Carbon gain and the concepts of Canopy photosynthesis. Relevance of LAI andLAD in determining total carbon gain and crop growth rates
- Source : Sink relationship and its relevance in governing differences in crop growthrates and productivity.
- Concepts of HI and partitioning coefficient and remobilization of carbon fromvegetative organs to reproductive structures
- Growth analysis and parameters that explain growth rates: NAR, CGR, HI and theirinter-dependence.

BLOCK 2: YIELD IMPROVEMENT AND MODELLING

Unit 1: Molecular Options to Improve Photosynthesis, Growth and Productivity

- Characteristic features of the Chloroplast genome: its structure and genes associated with various photosynthetic mechanisms, coordinated expression of chloroplast and nuclear genome for maintaining photosynthetic activities.
- Genomic and genetic resources such as specific genes and QTL associated withphotosynthetic processes
- Transgenic options to enhance photosynthetic performance such as transferring genes to mitigate oxidative stress damage (SOD, APX, AKR etc)
- Theoretical concepts of crop improvement through inducing CCM in C_3 plants andreducing photorespiration

Unit 2: Fundamentals of Dynamic Simulation Models

- Collection of crop specific genetic coefficient,
- Crop, soil and historic weather data

Unit 3: Description of Well-established Yield Models

- Application and limitations of modeling;
- Yield prediction models such as APSYM, PeanutGrowetc
- Machine learning approaches and IoT for making informed on-farm decisions

Unit 4: Examples of Robust Models Extensively Used

- Duncan'syield prediction model
- Passioura'smodelfor growth maximising

PRACTICALS

1. Plant sampling for leaf area and biomass estimation; analysis of growth and yieldparameters – LAD, NAR. CGR, LAI, LAR, SLA portioning efficiency, HI.
2. Measurement of light interception, light extinction coefficient, energy utilization efficiency based energy intercepted, and realized.
3. Gas exchange: principles and uses to assess variations in CO_2 and water vapour transfer, determination of A/gs and intrinsic WUE
4. Quantification of chlorophyll content by various methods: colorimetric and SPADmeter. The concept of SLN
5. Chlorophyll fluorescence and quenching coefficients
6. Theoretical aspects of carbon isotope fractional and its use in determining WUE
7. Quantification of RuBisCO content by ELISA (if possible)
8. Determination of RuBisCO activity and activation state using radioactive CO_2
9. CO_2 and light response curves and computation of carboxylation efficiency, quantumefficiency, relative limitations of photosynthesis at single leaf level.
10. Adoption of crop models: Growth and yield prediction by Duncan's and Passioura's models.

TITLE: PHYSIOLOGY OF FIELD CROPS
Credit: 2+0
Course Code: PP 508

BLOCK 1: PHYSIOLOGY OF FIELD CROPS

Unit 1: **Introduction**

- Origin- Variability in physiology of crop plants between wild species and cultivated. Adaptability to growing environments (ecosystems), Importance in food grain contribution

Unit 2: **Crop Establishment, Crop Growth and Development**

- Seed characteristic features, dormancy, viability, concept of seed priming seedling establishment and crop stand
- Different crop growth stages, concept of source establishment and optimum LAI, Canopy architecture, light interception/radiation use efficiency, thermal time, heat units, GDD, determining growth duration.

Unit 3: Reproductive Growth

- Photo and thermo-periodic response for flowering, sink development, sink source relationship, partitioning efficiency, improvement in HI, yield determining factors, genetic gain in yield over years, structuring of ideal plant type, limitations to improve source to sink size, options to improve yield potential

Unit 4: Seed Nutrient Quality

- Seed quality, seed as a source of nutrients, seed constituents and their improvement, concept of pathway engineering to improve seed quality

Unit 5: Plant Nutrition

- Nutrient requirement, genetic variability in nutrient acquisition under constraint conditions, specific nutrient disorders

Unit 6: Abiotic Stress Response

- Response to different abiotic stresses, plant traits/mechanics to improve adaptation to realize potential yields.
- Global warming responses, thermomorphogenesis, approaches to overcome the constraints.

Unit 7: Crop Specific Physiological Processes and Importance

- Choosing location specific crop species exposure will be given on physiological process as described above. Besides, emphasis is on providing information on crop specific features/productivity constraints

TITLE: PHYSIOLOGY OF HORTICULTURE CROPS
Course Code: PP 509
Credit: 2 (2+0)

BLOCK 1: PHYSIOLOGY OF HORTICULTURAL CROPS

Unit 1: Introduction

- Origin, distribution and adaptability of crops to different agro-climatic conditions

Unit 2: Crop growth and Development

- Internal factors (hormone etc.) influencing various physiological processes linked to vegetative growth or growth of specific organ, correlative and algometric growth.
- External factors (water, nutrition, temperature etc.) influencing various physiological processes linked to vegetative growth or growth of specific organ, correlative and algometric growth
- Propagation methods, grafting, cutting, budding, air layering. Physiology of pruning, dwarfing, branch bending, canopy management etc
- Physiological and biochemical aspects of scion and root stock interaction and compatibility

Unit 3: Reproductive Growth

- Physiology of flowering, photo- and thermo-periodism and response to vernalization
- Factors influencing reproductive growth, fruit and seed set/retention, physiology of flower sex ratio
- Physiological processes governing source-sink relationship and productivity.

Unit 4: Pre and Post Harvest Physiology

- Preharvest factors influencing postharvest physiology
- Physiological and molecular mechanisms of ripening
- Physiological and molecular mechanisms of senescence
- Hormonal and chemical control of postharvest deterioration of fruits/vegetable/flowers
- Regulation of ripening at physiological and molecular levels
- Regulation of senescence at physiological and molecular levels
- Approaches to improve shelf life and storability
- Approaches to improve postharvest management
- Approaches to improve processing and value addition

Unit 5: Plant Nutrition and Abiotic Stress Responses

- Nutrient acquisition and requirement, plant phenology and nutrient requirement
- Role of rootstocks in nutrient acquisition and in abiotic stress tolerance.
- Adaptive mechanisms and approaches to improve performances under drought and high temperature
- Adaptive mechanisms and approaches to improve performances under frost, chilling and nutrient deficient conditions
- Root physiology in abiotic stress tolerance

Unit 6: Specific Aspects and Unique Crop Features specific Aspects:

- Polyhouse cultivation
- Hormones/PGRs for improving crop performance
- Major and micronutrients for improving crop performance
- Light interception, shade regulation, dwarfing root stocks
- Chilling requirement for flowering, photoperiodic response, pollen viability, stigma receptivity
- Flower (blossom) and fruit drop

Unique crop features:

- Maturity and maturity indices
- Source-sink relations
- Vegetative propagation,
- Physiology of tuberization and rhizome initiation and formation
- Virus free planting material
- Bulbs/tubers dormancy, bud break
- Physiological disorders
- Storage
- Packaging
- Quality

Title: SEED PHYSIOLOGY
Course Code: PP-510
Credit: 3(2+1)

BLOCK 1: PHYSIOLOGY OF SEED DEVELOPMENT

Unit 1: Introduction to Seed Physiology

- Importance of seed as a propagule, seed structure and functions; chemical composition of seeds. Embryogenesis: pollination and fertilization, pollen and pistil interaction, signal for interaction; pollen load hypothesis; genetical and environmental influence on seed development.
- Source-Sink relationship affecting seed yield and quality.
- Concept of seed viability and seedling vigour and their relevance; approaches to improvethe storability of seeds
- Physiological and molecular mechanisms of seed germination; approaches to improve seed germination; seed size and its influence on seed germination

Unit 2: Seed Development

- Physiology and molecular mechanisms of embryo, endosperm and seed coat development; cellularization during endosperm development; morphological and cellular changes during seed coat development, anatomy and function of seed coat, programmed cell death (PCD) in seed coat, Deposition of seed storage reserves during development

Unit 3: Seed Maturation

- Seed maturation and maturation indices; physiological and anatomical changes during seed maturation;
- Seed drying and acquisition of desiccation tolerance in seeds; mechanisms of desiccation tolerance; role of ABA LEA's, HSP's, dehydrins and other stress proteins during seed maturation and drying,
- Seed abortion and approaches to reduce it.

Unit 4: Metabolism in Developing Seed

- Chemical composition of seeds (carbohydrates, proteins, fats etc.), source of assimilates for seed development, pathways of movement of assimilates to developing seed,approaches to increase the chemical composition of seeds.
- Seed respiration and mitochondrial activity; seed respiration rate and storability of seeds.

- Seed ageing, Mobilization of stored resource in seeds; Chemistry of oxidation of starch, proteins and fats; Utilization of breakdown products by embryonic axis.

BLOCK 2: PHYSIOLOGY OF SEED GERMINATION AND DORMANCY

Unit 1: Seed germination

- Seed germination, types of germination, imbibition kinetics of germinating seed; Physiological events during germination: seed respiration, mitochondrial activity, mobilization of food reserve; energy utilization by the germinating seed.
- Environmental regulation of germination: hydro-time, thermal time and hydrothermal time models; Influence of environmental factors on germination; Role of plant hormones/PGR's during seed germination.

Unit 2: Seed Dormancy and Viability

- Physiological and molecular basis of seed dormancy, hormonal regulation of dormancy, After ripening, dormancy breaking treatments; Ecological perspective of seed dormancy.
- Seed viability: concept and physiology of seed viability, theories of seed ageing, seed storage and regulation of storage life of seeds; methods to prolong seed viability; Conservation of orthodox and recalcitrant seeds
- Seed vigour: concept, importance, measurement; Physiological, biochemical and molecular basis of seed vigour

PRACTICALS

1. Determination of seed reserves: carbohydrates, proteins and lipids
2. Study of different seed structures
3. Kinetics of seed imbibition; Seed germination test, enzymatic activities and respirationduring germination and vigour testing methods etc.
4. Accelerated ageing test to know the seed vigour and storability
5. Measurement of seed moisture content
6. Determination of amylase activity in germinating seeds
7. Measurement of electrical conductivity in seed leachate
8. Measurement of seed viability using tetrazolium chloride
9. Determination of dehydrogenase activity
10. Seed germination study- Determination of Germination Index and seedling growth
11. Measurement of seed vigour index
12. Dormancy breaking treatments
13. Seed priming techniques
14. Effect of environmental stresses on seed germination and seedling growth
15. Effect of hormones on seed germination

Course Code: PP 511
Credit: 2(2+0)

BLOCK 1: PHENOTYPING PHYSIOLOGICAL PROCESSES

Unit 1: Concept of Phenotyping

Phenotyping technologies are essential component for assessing plant responses, identify superior trait donors, mitigation responses, trait introgression and trait based breeding.

Unit 2: Phenotyping for Traits for Crop Establishment

- Seed viability, seed dormancy, seed hydration rates, seed density and weight
- Seedling vigour in normal and adverse conditions

Unit 3: Concept and Approaches to Identify Genotypes with Superior Growth Rate

- Phenotyping for leaf expansion, leaf area index, light interception and crop extinction coefficient
- Pigment quantification for nitrogen and chlorophyll status - SPAD, anthocyanin and flavonoids – Duolex
- Growth rates by non-invasive techniques like NDVI, Concept of Net assimilation rate and DM/LAD; surrogates for photosynthetic traits; stomatal characteristic

Unit 4: Identifying Photo-insensitive Genotypes-options and Approaches

- Exposing to longer and shorter photoperiod by staggered sowing; extending the day length-light interception by red light; days to heading/ anthesis, approaches for synchronization of flowering

Unit 5: Identifying Thermo-insensitive Genotypes-options and Approaches

- Altering total degree days- staggered sowing at lower latitudes or by growth chambers; quantifying heading, anthesis, maturity and grain filling days, grain number and weight, grain filling rate.

Unit 6: Yield Structure Analysis- Relevant Yield Attributes

- Pollen biology, stigma receptivity, spikelet sterility (cereals), floral abscission (other crops), fruiting points / productive tillers, number of grains/ fruits per panicle/ inflorescence and grain characteristic
- Phenotyping for lodging- culm traits, intermodal length, lignification, Phenylalanine ammonia lyase (PAL) and Tyrosine ammonia lyase (TAL)
- Approaches to identify genetic resources with traits to improve yield potential

Unit 7: Source-sink Relationship- Assessment of Limitation

- Phenotyping for source-sink size, Concept of sink-source limitation- defloration and defoliation
- Remobilization of stored metabolites and concept of stay green; estimation of water soluble carbohydrates; partitioning coefficient and harvest index.

Unit 8: Identify Genetic Resources for Abiotic Stress Constraints

- Approaches for precise stress imposition to diverse stresses

- Identify trait donor lines for different stresses: approaches by Stress Susceptibility Index (SSI), Stress Induction Response (SIR)
- Capturing variability for adaptive traits: root traits, stomatal factors/wax, osmolyte, surrogate approach for acquired tolerant traits, Flowering response, Spikelet fertility, Abscission and Senescence
- Screening high density response-based on SSI – root adaptation and Shade Avoidance Response (SAR)

TITLE: CROP GROWTH REGULATION AND MANAGEMENT
Course Code: PP 512
Credit: 2(2+0)

BLOCK 1: PROPAGATION - CROP ESTABLISHMENT

Unit 1: Seed as a Propogule

- Concept of improving seed characteristics for crop establishment. Mechanisms of regulating seed dormancy, precocious germination, ways to control pre-harvest sprouting in crop plants
- Seed viability and its regulation, factors to minimize loss of viability and improve seedling vigour.
- Concept of seed priming, techniques of priming, seed priming to induce tolerance to stresses.
- Role of media, nutrition and PGPR's on seedling vigour and subsequent crop establishment

Unit 2: Vegetative Propogule

- Chemical and hormonal regulation of vegetative propagation
- Regulation of rooting, bud sprouting, Bulb/tuber dormancy
- Chemical regulation of graft union.
- Concept of *invitro* micropropogation

BLOCK 2: REGULATION OF PLANT GROWTH PROCESSES

Unit 1: Regulation of Plant Growth and Flowering

- Chemical and hormonal regulation of plant architecture, tillering, branching, bud breaking
- Regulation of flowering by photo and thermoperiod, nutrients, chemicals and hormones,concept of speed breeding
- Flowering synchrony in hybrid seed production
- Sex ratio alteration, flower and fruit thinning
- Pollen viability in relation to environment, harvesting, storage and transportation
- Prevention of abscission, flower and fruit drop, seed and fruit growth regulation- role of hormones.

Unit 2: Fruit Ripening and its Regulation

- Approaches to improve shelf life – storage environment, water loss, respiration
- Modified atmosphere, gaseous environment for storage , storage disorders, chilling injury

Unit 3: Concept of Senescence and its Retardation

- Physiology of senescence and options to regulate.
- Chemical regulation of senescence, maintenance of chlorophyll during storage, role of hormones/micronutrients in reducing senescence.
- Concept of stay green, advantages and limitations. Relevance of stay green traits in plant breeding for crop improvement.

BLOCK 3: PROTECTIVE CULTIVATION –STRESS MITIGATION

Unit 1:Protective Cultivation Interventions to Alter Physiological Processes andGrowth

- Spectral characteristics of light in polyhouse, light regulation to optimize plantphotosynthetic and photomorphogenic processes and plant growth
- LED sources of monochromatic light to regulate growth, etiolating and flowering
- High temperature induced thermomorphogenic processes
- Artificial growing media, soilless cultures, aeroponics, fogoponics
- Concept of CO_2 fertilization. Effect of humidity on leaf expansion and growth.

Unit 2: Drought Mitigation Options and Approaches

- Moisture conservation options at soil and plant level
- Concept of increasing water holding capacity, role of Hydrogels – water and mineral nutrients release pattern.
- Approaches to improve transpiration over Evapo-transpiration, stomatal and non-stomatal regulation of water loss, antitranspirants.
- Osmoprotectants, ROS scavengers, plant nutrients.
- Root stocks in improving tolerance
- Chemical regulation of flower drop due to temperature

Chemicals to improve pollen viability during abiotic stress

Unit 3: Specific Plant Processes Regulated by Chemicals and Growth Hormones

- Rooting of cuttings
- Wine brewing industry
- Promotion of gynoecious flower
- Hybrid rice production
- Induction of flowering in pine apple, cucurbits
- Delaying of senescence and ripening
- Production of dwarf plant for ornamental purpose
- Reduction in flower and fruit drop
- Increase in berry size in grapes