AGRONOMIC, BIOCHEMICAL AND PHYSIOLOGICAL RESPONSES OF SOME SPRING WHEAT (*TRITICUM AESTIVUM* L. EM THELL) CULTIVARS TO DROUGHT STRESS AT REPRODUCTIVE STAGE

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The thesis attached hereto, entitled "AGRONOMIC, BIOCHEMICAL AND PHYSIOLOGICAL RESPONSES OF SOME SPRING WHEAT (Triticum aestivum L. em Thell) CULTIVARS TO DROUGHT STRESS AT REPRODUCTIVE STAGE", prepared and submitted by GOKARNA BAHADUR GHARTI-CHHETRI (G.C.) in partial fulfillment of the requirements for the degree of Master of Science (Agronomy) is hereby accepted.

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ABSTRACT

GHARTI-CHHETRI (G.C.), GOKARNA BAHADUR, University of the Philippines at Los Baños, October 1985. Agronomic, Biochemical and Physiological Responses of Some Spring Wheat (Triticum aestivum L. em Thell) Cultivars to Drought Stress at Reproductive Stage. Major Professor: Dr. Joveno S. Lales

Wheat crops are most likely to experience drought after anthesis under most growing conditions in the humid tropics.

Nine spring wheat cultivars (seven from Nepal and two from the Philippines) grown in pots were exposed to 4, 8, 12 and 16 days of water stress starting at 50% head emergence by withholding water under glass house conditions. The treatments were arranged on a two-factorial in Completely Randomized Design, replicated four times. Concurrent measurements of leaf water potential (LWP), upper (R_u) and lower leaf surface (R_l) stomatal resistances of flag leaf; soil moisture content (SMC) and nitrate reductase activity (NRA) determination were made through

a 16-day period after cessation of irrigation. Free proline was determined from the same flag leaves. Grain protein content, yield and its components were also determined.

Highly significant variety x stress duration interaction effect was observed on stomatal resistance (R_S), LWP, NRA, grain weight, harvest index (HI), SMC but it was not significant in number of grains/spike. NL 370, NL 496, NL 292 and Siddhartha exhibited drought avoidance by maintaining relatively higher LWP under water stress. R_S increased more on the lower than in the upper leaf surface under drought stress. Lerma 52, Triveni and Trigo 1 had sharp rise in their R_S even at mild stress in contrast to other varieties which had gradual increase in R_S as the drought progressed. Early maturing cultivars, namely: NL 496, NL 370, Siddhartha and NL 292 had higher NRA than late-maturing cultivars under both stressed and non-stressed conditions. NRA decreased with increase in drought duration. Leaf proline and grain protein content increased as the drought progressed. Leaf proline had significant correlation with LWP ($r = -0.80^{**}$), SMC ($r = -0.48^{**}$)

and R_S (r = 0.56**). Grain protein had strong negative correlation with SMC, LWP, grain filling duration and 100-grain weight. NL 496, NL 370, NL 292 and Trigo 2 had the higher SMC under different drought durations. Drought enhanced maturity and grain filling duration. Early maturing cultivars had longer grain filling duration than late-maturing ones. Drought affected the number of grains/spike and 100-grain weight. Genotypic variability in grain set was noted under water stress. Lerma 52 gave the highest but Siddhartha and NL 292 gave the lowest biological yield under water stress. Trigo 1 and Trigo 2 gave the highest grain yield under non-stress condition while Siddhartha, NL 292, NL 370 and NL 496 produced the maximum grain yield and also HI under stressed conditions. Considering the responses under different drought stress, early maturing namely: Siddhartha, NL 292, NL 370 and NL 496 are classified as the drought resistant and mid, late-maturing namely: Trigo 1, UP 262, Lerma 52 and Triveni as the drought susceptible cultivars.

LITERATURE CITED

ANGUS, J.F. and M.W. MONCUR. 1977. Water stress and phenology in wheat. Aust. J. Agric. Res. 28: 177-181.

AOAC. 1975. Methods of Analysis of the Association of Official Analytical Chemists, 12th edition, Washington, D.C.

ARRIAGA, C., J.S. BOYER and R.H. HAGEMAN. 1972. Nitrate reductase activity and polyribosome content of corn at low leaf water potential. Plant Physiol. 49. (Suppl.):49.

ASANA, R.D. 1960. Bull. Res. Coun. Israel (D) 8, 97-104. (Cited by May and Milthorpe, 1962).

ASANA, R.D. 1961. Plant water relationships in arid and semi-arid conditions. Proc. Madrid Symp. 183-190, Paris, UNESCO. (Cited by May and Milthorpe, 1962).

ASANA, R.D., A.D. SAINI and D. RAY. 1958. Studies in physiological analysis of yield. III. The rate of grain development in wheat in relation to photosynthetic surface and soil moisture. Physiol. Plant. 11:655-665.

ASPINALL, D., P.B. NICHOLLS and L.M. MAY. 1964. The effect of soil moisture stress on the growth of barley. I. Vegetative development and grain yield. Aust. J. Agric. Res. 15:729-745.

AUSTIN, R.B., J.A. EDRICH, M.A. FORD and R.D. BLACKWELL. 1977. The fate of the dry matter, carbohydrates and ^{14}C lost from the leaves and stems of wheat during grain filling. Ann. of Bot. 41: 1309-21.

BALASUBRAMANIAN, V., V. RAJAGOPAL and S.K. SINHA. 1974. Stability of nitrate reductase under moisture and salt stress in some crops. Breeding Researches in Oceania. Indian J. Genet. 34A: 1055-1061.

BARDZIK, J.M., H.V. JR. MARSH and J.R. HAVIS. 1971. Effects of water stress on the activities of three enzymes in maize seedlings. Plant Physiol. 47:828-831.

BARNETT, N.N. and A.W. NAYLOR. 1966. Amino acid and protein metabolism in Bermuda grass during water stress. Plant Physiol. 41:1222-1230.

BATES, L.S., R.P. WALDREN and I.O. TEAR. 1973. Rapid determination of free proline for water stress studies. Plant and Soil 39:205-207.

BEGG, J.E. and N.C. TURNER. 1976. Crop water deficits. Adv. Agron. 28:161-217.

BIDINGER, F., R.B. MUSGRAVE and R.A. FISCHER. 1977. Contribution of stored pre-anthesis assimilate to grain yield in wheat and barley. Nature 270: 431-433.

BINGHAM, J. 1966. Variety response in wheat to water supply in the field and male sterility caused by a period of drought in a glass house experiment. Ann. Appl. Bot. 57:365-377.

BLUM, A. and A. EBERCON. 1976. Genotypic responses in sorghum to drought stress. III. Fre proline accumulation and drought resistance. Crop Sci. 16:428-431.

CAGAMPANG, G.B. and F.M. RODRIGUEZ. 1979. Methods and analysis for screening crops of appropriate qualities. IPB Bull. #2. UPLB, Philippines.

CAMPOS, F., R. TABIAN, R. CAMACHO and C. ARAGON. 1982. Synthesis of research results on wheat at Central Luzon State University. Mimeographed Paper presented during the 2nd wheat Consultative Meeting and Review held at PCARRD, Los Baños, Laguna on 31 August 1982.

CHAUHAN, D.S., S.B. HUKKERI and N.G. DASTANE. 1970. Intensive versus extensive irrigations in wheat. Indian J. Agron. Vol. 15(1).

CHEN, D., B. KESSLER and S.P. MONSELISE. 1964. Studies on water regime and nitrogen metabolism of citrus seedlings grown under water stress. Plant Physiol. 39:379-386.

CHINOY, J.J. 1960. Physiology of drought resistance wheat. I. Effects of wilting at different stages of growth on survival value of eight varieties of wheat belonging to seven species. Phyton 14(2): 147-157.

CHU, T.M., D. ASPINALL and L.G. PALEG. 1976. Stress metabolism. VII. Salinity and proline accumulation in barley. Aust. J. Plt. Physiol. 3:219-228.

CHU, T.M., M. JUSAITIS, D. ASPINALL and L.G. PALEG. 1978. Accumulation of free proline at low temperature. Physiol. Plant 43:254-260.

COWAN, I.T. 1965. Transport of water in the soil-plant-atmosphere system. J. Appl. Ecology. 2:221.

DAY, A.D. and S. INTALAP. 1970. Some effects of soil moisture stress on the growth of wheat (Triticum aestivum L. em Thell.). Agron. J. 62:27-29.

DAY, W., B.J. LEGG, B.K. FRENCH, A.E. JOHNSTON, D.W. LAWLOR and W. JEFFERS. 1978. A drought experiment using mobile shelters; the effect of drought on barley yield, water use and nutrient uptake. J. Agric. Sci. Camb. 91:599-623.

DEBETZ, S. and BOLE, J.B. 1973. Effect of moisture stress at early heading and of nitrogen fertilizer on three spring wheat cultivars. Canadian J. of Plant Sci. 53:1-5.

DEDIO, W., D.W. STEWART and D.G. GREEN. 1976. Evaluation of photosynthesis measuring methods as possible screening techniques for drought resistance in wheat. Can. J. Plant Sci. 56: 243-247.

DERERA, N.F., D.R. MARSHALL and L.N. BALAAM. 1969. Genetic variability in root development in relation to drought tolerance in spring wheats. Exp. Agric. 5:327-337.

DEVLIN, R.M. and F.H. WIDHAM. 1983. Plant Physiology. Fourth edition, Willard Grant Press. Boston.

DOORENBOS, J. and A.H. KASSAM. 1979. Yield response of water. FAO Irrigation and Drainage Paper #33. FAO-UN, Rome. pp. 193.

EL-MONAYERI, M.O., A.M. HEGAZI, N.H. EZZAT, H.M. SALEM, S.M. TAHOUN. 1984. Growth and yield of some wheat and barley varieties grown under different moisture stress levels. In: Field Crops Abstracts, March 1985.

FISCHER, R.A. and G.D. KOHN. 1966. The relationship of grain yield to vegetative growth and post-flowering leaf area in the wheat crop under conditions of limited soil moisture. Aust. J. Agric. Res. 17:281-295.

FISCHER, R.A. 1973. The effect of water stress at various stages of development on yield processes in wheat. In "Plant Responses to Climatic Factors" (R.O. Slateyer, ed). pp. 233-241. UNESCO, Paris.

FISCHER, R.A. and R.MAURER. 1978. Drought resistance in spring wheat cultivars. I. Grain yield responses. Aust. J. Agric. Res. 29:897-912.

FORD, C.W. and J.R. WILSON. 1981. Changes in level of solutes during osmotic adjustment to water stress in four tropical pasteur species. Aust. J. Plant Physiol. 8:77-91.

FUKUTOKU, Y. and Y. YAMADA. 1982. Accumulation of carbohydrates and proline in water stressed soybean (Glycine max L.). Soil Sci. Plant Nutr. 28: 147-151.

GALLAGHER, J.N., P.V. BISCOE and B. HUNTER. 1976. Effects of drought on grain growtn. Nature 264: 541-542.

HANSEN, G.K. 1974. Resistance to water transport in soil and young wheat leaves. Acta Agric. Scand. 24:37.

HANSON, A.D., C.E. NELSON and E.H. EVERSON. 1977. Evaluation of free proline accumulation as an index of drought resistance using two contrasting barley cultivars. Crop Sci. 17:720-726.

HELLMAN, D.B. 1975. The effect of soil moisture stress (SMS) on wheat grain yields and the determination Et/E0 ratios for eliminating water use by wheat. Crop Production 4:119-124.

HSIAO, T.C. 1973. Plant responses to water stress. Ann. Rev. Plant Physiol. 24:519-570.

HSIAO, T.C. and E. ACEVEDO. 1974. Plant responses to water deficits, water use efficiency and drought resistance. Agric. Meteorol. 14:59-84.

HSIAO, T.C., E. FERERES, E. ACEVEDO and D.W. HENDERSON. 1976. Water stress and dynamics of growth and yield of crop plants. (In: Lange et al. (edn.) 1976. Water and Plant Life: Problems and Modern Approaches. Springer-Verlag, Berlin).

HUFFAKER, R.C., T. RADIN, G.E. KLEINKOLF and E.L. COX. 1970. Effects of mild water stress on enzymes of nitrate assimilation and of the carboxylative phase of photosynthesis in barley. Crop Sci. 10:471-474.

HURD, E.A. 1971. Can we breed for drought resistance? Drought Injury and Resistance in Crops. K.L. Larson and J.E. Eastin (eds.) CSSA Spec. Publ. #2. Crop Sci. Soc. Amer. Madison, Wis.

HURD, E.A. 1974. Phenotype and drought tolerance in wheat. Agric. Meteorol. 14:39-55.

INNES, P. and R.D. BLACKWELL. 1981. The effect of drought on water use and yield of two spring wheat genotypes. J. Agric. Sci. Camb.96:603-610.

JAWORSKI, E.G. 1971. Nitrate reductase assay in intact plant tissue. Biochem. Biophys. Res. Comm. 43(6):1274-1279.

JOHNSON, R.R., N.M. FREY and D.N. MOSS. 1974. Effect of water stress on photosynthesis and transpiration of flag leaves and spikes of barley and wheat. Crop Sci. 14:728-731.

KANEMASU, E.T., G.W. THURTELL and C.B. TANNER. 1969. Design, calibration and field use of a stomatal diffusion porometers. Plant Physiol. 44:881-885.

KRAMER, P.J. 1983. Water relations of plants. Academic Press. New York. pp. 342-389.

KUDREV, T.G. 1967. The effect of drought on the amount of free and bound glutamic acid and proline in pumpkins. C.R. Acad. Bulg. Sci. 20: 61-63.

LALES, J.S. 1982. Cultural management practices in wheat production - fertilizer and water requirements. Mimeographed. Paper presented during the First Wheat Research Workshop held at the IPB, UPLB on 22-26 March 1982. 22 p.

LANGE, O.L., L. KAPPEN, E.D. SCHULZE. 1976. Water and Plant Life: Problems and Modern Approaches. Springer-Verlag. Berlin, Heidelberg. New York.

LEE-STADELMANN, O.Y. and E.G. STADELMANN. 1976. Cell permeability and water stress. In: "Water and Plant Life" (O.L. Lange, L. Kappen and E.D. Schulze, edn.). pp. 268-280. Springer-Verlag, Berlin and New York.

LEVITT, J. 1980. Responses of plants to environmental stress. Vol. II. Academic Press, N.Y.

LUNDEGARTH, H. 1941. Einige Bedigungen del Bildung und Auflosung der starke. Jahrb-Swiss. Bot. 53: 421-463 (cited by Navarro, 1984).

MASAJO, T.M. 1981. Wheat varietal improvement research in the Philippines. Mimeographed. Inaugural lecture delivered on 28 May 1981 for SEARCA Professorial Chair in Agronomy. 28 p.

MAY, I.H. and F.L. MILTHORPE. 1962. Drought resistance of crop plants. Field Crop Abstr. 15: 171-179.

MILLAR, B.D. and O.T. DENMEAD. 1976. Water relations of wheat leaves in the field. Agron. J. 68: 303-307.

MILTHORPE, F.L. 1960. Plant-water relationships in arid and semi-arid conditions. Rev. Res. 9-36, Paris, UNESCO (cited by May and Milthorpe, 1962).

MISHRA, N.M., H. PAL and D.P. DWIVEDI. 1980. Performance of wheat varieties under rainfed condition. Indian J. Agron. 25:577-580.

MORGAN, J.M. 1977. Differences in osmoregulation between wheat genotypes. Nature (London) 270, 234-235.

MORGAN, J.M. 1980a. Osmotic adjustment in the spikelets and leaves of wheat. J. Expt. Bot. 31(121):655-665.

MORGAN, J.M. 1980b. Possible role of abscisic acid in reducing seed set in water-stressed wheat plants. Nature 285:655-657.

MOTHES, K. 1956. Der Eifluss des Wasserzustandes auf Ferment Prozesse und Stoffunsatz "Encyclopedia of Plant Physiology", 3, 656-664. Springer-Verlag. OHGM, Berlin (cited by Navarro, 1984).

MUNNS, R., C.T. BRADY and E.W.R. BARLOW. 1979. Solute accumulation in the apex and leaves of wheat during water stress. Aust. J. Plant Physiol. 6:379-389.

MUNNS, R. and R. WEIR. 1981. Contribution of sugars to osmotic adjustment in elongating and zones of wheat leaves during moderate water deficits at two light levels. Aust. J. Plant Physiol. 8:93-105.

MUSICK, J.T. and D.A. DUSEK. 1980. Planting date and water deficit effects on development and yield of irrigated winter wheat. Agron. J. 72: 45-52.

NAVARRO, T.E. 1984. Agronomic and morphological responses of three sweet potato varieties to moisture tension at different growth stages. M.S. thesis (Unpublished). UPLB. Study.

NAYLOR, A.W. 1972. Water deficits and nitrogen metabolism. In "Water Deficits and Plant Growth". (T.T. Kozlowski, edn.). 3:241-254. Academic Press, N.Y.

O'TOOLE, J.C. and R.T. CRUZ. 1980. Response of leaf water potential, stomatal resistance, and leaf rolling to water stress. Plant Physiol. 65: 428-432.

PAL, B.P. 1966. Moisture requirement of wheat. In wheat. Indian Council of Agricultural Research, New Delhi. pp. 302-312.

PALEG, L.G. and D. ASPINALL. 1981. The physiology and biochemistry of drought resistance in plants. Academic Press, Sydney.

PALIS, R.K. and A.R. BUSTRILLOS. 1974. Nitrate accumulation and nitrate reductase in some leafy vegetables. Paper presented in the 5th Annual Conference. CSSP. Naga City.

PANDEY, D.K. 1982. Free proline accumulation in response to water stress in wheat seedlings. Current Science 51(3):141-143.

PARVATIKAR, S.R. 1968. Physiological studies on drought in wheat. In "Proceedings of the Seminar on Drought". Univ. of Agric. Sciences. Hebbal. pp. 270-274. (1972).

PASSIOURA, J.B. 1972. The effect of root geometry on the yield of wheat growing on stored water. Aust. J. Agric. Res. 23:745-752.

PASSIOURA, J.B. 1976. Physiology of grain yield in wheat growing on stored water. Aust. J. Plant Physiol. 3:559-565.

PASSIOURA, J.B. 1977. Grain yield, harvest index and water use of wheat. J. Aust. Inst. Agric. Sci. 43:117-120.

PETRI, A.H. and J.S. WOOD. 1938. Studies on the nitrogen metabolism of plants. I. The relation between the content of proteins, amino acids and water in the leaves. Ann. Bot. 2:33-60.

PHILIPPINE COUNCIL FOR AGRICULTURE RESOURCES RESEARCH AND DEVELOPMENT (PCARRD). 1980. Environmental adaptations of crops. Los Baños, Laguna, Phils.

RAJAGOPAL, V., V. BALASUBRAMANIAN and S.K. SINHA. 1977. Diurnal fluctuations in relative water content, nitrate reductase and proline content in water-stressed and non-stressed wheat. Physiol. Plant. 401:69-71.

RAWSON, N.M. and L.T. EVANS. 1971. The contribution of stem reserves to grain development in a range of wheat cultivars of different height. Aust. J. Agric. Res. 22:851-863.

RAYMUNDO, M.E., D.A. CARANDANG and R.C. BRUCE. 1963. The soils of U.P. College of Agriculture and Central Experiment Station. The Phil. Agric. 47:298-320.

REITZ, L.P. 1974. Breeding for more efficient water use. Is it real or mirage? Agric. Meteorol. 14: 3-11.

RICHARDS, R.A. 1983. Manipulation of leaf area and its effect on grain yield in droughted wheat. Aust. J. Agric. Res. 34:23-31.

RICHARDS, L.A. and C.H. WADLEIGH. 1952. Soil water and plant growth. pp. 73-251. In: B.T. Shaw (edn.) soil physical conditions and plant growth. Academic Press, Inc., N.Y.

ROBINS, J.S. and C.E. DOMINGO. 1953. Some effects of several soil moisture deficits at specific growth stages of corn. Agron. J. 41:618-621.

ROBINS, J.S. and C.E. DOMINGO. 1962. Moisture and nitrogen effects on irrigated spring wheat. Agron. J. 54:135-138.

SAINI, H.S. and D. ASPINALL. 1981. Effect of water stress on sporogenesis in wheat (Triticum aestivum L.). Annals of Botany 48:623-633.

SALIENDRA, N. 1984. Response of wheat cultivars of different maturity to amounts and frequencies of irrigation. M.S. thesis (Unpublished), UPLB, Philippines.

SALTER, P.J. and J.E. GOODE. 1967. Crop responses to water at different stages of growth, Common W. Bur. Hort. Plant Crops Res. Rev. #2, pp. 15-48.

SCHOBERT, B. and H. TSCHESCHE. 1978. Unusual solution properties of proline and its interaction with proteins. Biochem. Biophys. Acta. 541:270-277. Elsevier Press.

SCHOLANDER, P.F., H.T. HAMMEL, E.D. BRADSTREET and E.A. HEMMINGSEN. 1965. Sap pressure in vascular plants. Science 148:339-346.

SEATON, K.A. 1969. The development of internal water deficits in wheat as a function of stomatal aperture and soil water potential. Hons. Thesis in Agric., Univ. of Western Australia.

SEATON, K.A., J.J. LANDSBERG and R.H. SEDGLEY. 1977. Transpiration and leaf water potentials of wheat in relation to changing soil water potential. Aust. J. Agric. Res. 28:355-367.

SHANER, D.L. and T.S. BOYER. 1976a. Nitrate reductase activity in maize (Zea mays L.) leaves. I. Regulation by nitrate flux. Plant Physiol. 58:499-504.

SHANER, D.L. and T.S. BOYER. 1976b. Nitrate reductase activity in maize (Zea mays L.) leaves. II. Regulation by nitrate flux at low leaf water potential. Plant Physiol. 58:505-509.

SINGH, M.R., T. GANDHI and P.C. RAHEJA. 1960. A critical review of the methods used to determine water requirements of crops and suggestions for planning future irrigation experiments in India. Indian J. Agric. 4:272-285.

SINGH, T.N., D. ASPINALL and L.G. PALEG. 1972. Proline accumulation and varietal adaptability to drought in barley: a potential metabolic measure of drought resistance. Nature (London) 236:188-190.

SINGH, T.N., D. ASPINALL, L.G., PALEG and S.F. BOGGESS. 1973a. Stress metabolism.II. Changes in proline concentration in excised plant tissues. Aust. J. Biol. Sci. 26:57-63.

SINGH, T.N., L.G. PALEG, D. ASPINALL. 1973b. Stress metabolism. III. Variations in response to water deficit in the barley plant. Aust. J. Biol. Sci. 26:65-76.

SINGH, T.N., D. ASPINALL and L.G. PALEG. 1973c. Stress metabolism. IV. The influence of (2-chloroethyl) - trimethyl-ammonium chloride and gibberellic acid on the growth and proline accumulation of wheat plants during water stress. Aust. J. Biol. Sci. 26:77-86.

SINHA, S.K. and M.S. SWAMINATHAN. 1984. New parameters and selection criteria in plant breeding. In (eds.) Vose, P.B. and Blixt, S.G., Crop Breeding, A. Contemporary Basis, Pergamon Press.

SIONIT, N., H. HELLMERS and B.R. STRAIN. 1980a. Growth and yield of wheat under CO_2 enrichment and water stress. Crop Sci. 20:687-690.

SIONIT, N., I.D. TEARE and P.J. KRAMER. 1980b. Effects of repeated application of water. Stress on water status and growth of wheat. Physiol. Planta. 50:11-15.

SLATEYER, R.O. 1973. The effect of internal water status on plant growth, development and yield. In (edn.) Slateyer, R.O. "Plant response to climatic factors". Boc. Uppsala. pp. 177-191.

SOJKA, R.E., L.H. STALZY and R.A. FISCHER. 1981. Seasonal drought response of selected wheat cultivars. Agron. J. 73:838-845.

STEWART, C.R. 1972. The effect of wilting on proline metabolism in excised bean leaves in the dark. Plant Physiol. 51:508-511.

STEWART, C.R. and S.F. BOGGESS. 1978. Metabolism at /5-3H/ proline by barley leaves and its use in measuring the effects of water stress on proline oxidation. Plant Physiol. 61:654-657.

STEWART, C.R. and J.A. LEE. 1974. The role of accumulation in halophytes. Planta 120:279-289.

SUMAYAO, C.R., E.T. KANEMASU and T. HODGES. 1977. Soil moisture effects on transpiration and carbon dioxide exchange of sorghum. Agric. Meteorol. 18: 401-408.

SYME, J.R. 1970. A high yielding Mexican semi-dwarf wheat and the relationship of yield to harvest index and other varietal characteristics. Aust. J. Expt. Agric. Anim. Husb. 10:350-353.

SYME, J.R. 1971. Features of high yielding wheat grown at two seed rates and two nitrogen levels. Aust. J. Expt. Agric. Anim. Husb. 11:165-170.

THORNE, G.N. 1966. Physiological aspects of grain yields in cereals. In "The Growth of Cereals and Grasses", (edn.). F.L. Milthorpe and H.D. Ivins. 359 pp. Butterworths, London.

TODD, G.W. 1972. Water deficits and enzymatic activity. In "Water Deficits and Plant Growth". (T.T. Kozlowski, edn.). 3:177-216. Academic Press, N.Y.

TURNER, N.C. 1979. Drought resistance and adaptation to water deficits in crop plants. In "Stress Physiology in Crop Plants". H-Mussel and R.C. Staples (edn.), John Wiley and Sons, N.Y.

TURNER, N.C. and P.J. KRAMER (edn.). 1980. Adaptation of plants to water and high temperature stress. Wiley and Sons, N.Y. pp. 105-122.

UDOL'SKAJA, N.L. 1936. Drought resistance of spring wheat varieties (Russian) (Osmiz, Omsk) (cited by Salter and Goode, 1967).

VAN DER PAAUW, F. 1949. Water relations of oats with special attention to the influence of periods of drought. Plant and Soil 1:303-341.

VANLOON, C.D. 1981. The effect of water stress on potato growth, development and yield. Amer. Potato J. 58:51-69.

WARDLAW, I.F. and H.K. PORTER. 1967. The redistribution of stem sugars in wheat during grain development. Ibid. 20:309-318.

WARING, R.H. and B.D. CLEARLY. 1967. Plant moisture stress. Evaluation by pressure bomb. Science 155:1248, 1253-1254.

WELLS, S.A. and S. DUBETZ. 1970. Reation of two barley cultivars to a period of water stress during heading. Can. J. Plant Sci. 50:701=704.

WEST, S.H. 1962. Protein, nucleotide and ribonucleic acid metabolism in corn during germination under water stress. Plant Physiol. 37:565-571.

WOODHAMS, D.H. and T.T. KOZLOWSKI. 1954. Effects of soil moisture stress carbohydrate development and growth in plants. Amer. J. Bot. 41:316-320.

YAMADA, Y. 1984. Plant nutrition under water stress conditions. Food and Fertilizer Technology Centre. Technical Bull. No. 80. Taiwan.

YAROSH, N.P. 1958. Effect of water supply on biochemical changes in cotton leaves and seeds. Fiziol. Rast. 6:211.

YOUNIS, M.A., A.W. PAULI, H.L. MITCHELL and F.C. STICKLER. 1965. Temperature and its interaction with light and moisture in nitrogen metabolism of corn (Zea mays L.) seedlings. Crop Sci. 5:321-326.

ZABLUDA, G.V. 1939. Dokl. Akad. Nauk-SSSR 23: 370-2 (cited by Salter and Goode, 1967).

ZADI, M.S. 1983. Drought stress influence on some physiological processes in winter wheat (Triticum aestivum L.). Dissertation Abstracts International B 44(3):670. Oklahoma State Univ., Stillwater.