COMMITTEE ON PRACTICES

WORKING GROUP ON MECHANIZED IRRIGATION

THE INFLUENCE OF WIND ON SPRINKLER IRRIGATION

ANNOTATED BIBLIOGRAPHY

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FOREWORD

Concern for the valuable water resource exploited indiscreetly thus far, has attracted the prime attention of planners and managers, all the world over. As a result of their efforts, a consciousness now prevails amongst the users about its judicious use. In the domain of irrigation sector, the sprinkler irrigation methodology has prevented much of the water loss that is associated with the conventional water spreading system. However, the effect of wind on the sprinkler irrigation performance has been a subject of interest to all managers, planners and researchers lately, since the wind has been observed to have its marked influence on the application efficiency of irrigation water and agricultural chemicals that are being increasingly applied through sprinklers.

I have great pleasure in presenting this annotated bibliography on the influence of wind on sprinkler irrigation, which has been compiled by the members of the Working Group on Mechanized Irrigation of the ICID Committee on Practices, with Mr. Allan S. Humpherys as the Chairman of the Group. Mr. Humpherys has immensely contributed to this work and has provided prompt assistance at all stages. The efforts of Working Group members and the assistance rendered by the National Committees in the process of collection and compilation of literature and references are highly appreciated. The references have been presented country-wise for convenience and annotations have been added to enhance the usefulness of the work.

This bibliography is being brought out both in English and French languages. Dr. M. Decroix of Irrigation Division of CEMAGREF (French Institute of Agricultural and Environmental Engineering), France, has very ably carried out the translation of the bibliography into French, coordinated by Dr. Robert Hlavek, the then Vice-Chairman of the Working Group. I wish to place my words of appreciation and thankfulness to both of them as well.

Last but not the least, I commend Mr. K.N. Sharma, Deputy Secretary, Central Office, ICID, for his painstaking efforts over printing of this bibliography.

New Delhi
28 September 1989

R.S. VARSHNEY
Secretary-General

ANNOTATED BIBLIOGRAPHY

THE INFLUENCE OF WIND ON SPRINKLER IRRIGATION

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INTRODUCTION

The influence of wind on sprinkler irrigation performance is a major consideration for designers of agricultural sprinkler systems. The efficiency of a sprinkler system depends upon the amount of loss which occurs during irrigation and on the uniformity of application. Wind is a major factor affecting losses, and since sprinklers are used in all countries where irrigation is practiced, wind effects are of widespread concern.

Water and energy conservation awareness in recent years has resulted in greater use of low pressure sprinkler systems. Low pressure spray heads characteristically produce smaller droplet sizes which, in turn, are more susceptible to evaporation and wind drift. Agricultural chemicals such as fertilizers, pesticides and fungicides

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are being increasingly applied through sprinkler irrigation systems. There is a potential drift hazard associated with this practice, particularly under windy conditions. It is important that these chemicals reach the target area when applied with the irrigation water. Wind can distort the sprinkler distribution pattern so that both the water and chemicals are applied nonuniformly.

Much work has been done in various countries to describe the effects of wind on sprinkler irrigation systems. Study results indicate that the effects, when combined with other environmental factors, are more pronounced in some areas than in others and may vary from region to region under similar wind conditions, with daytime losses as high as 25 percent having been reported.

The ICID Working Group on Mechanized Irrigation of the Committee on Practices recognized the importance of the wind problem and felt that a bibliographical summary of available literature on this topic would be useful and satisfy a need in many areas. Consequently, a literature review was conducted, and as many references as could be found were obtained from a number of countries. These were obtained through the efforts of working group members and national committees. Annotations were added to enhance the usefulness of the bibliography. Annotations for some references were not available and hence are not shown. For convenience, the references are shown by the country where the work was done because some wind effects have regional influences; also, references from some countries may not be readily available in others. The bibliography is published in both English and French. Translation into French was made by Dr. M. Decroix, member of the French National Committee (l'A.F.E.I.D.), and coordinated by Dr. Robert Hlavek, Vice Chairman of the Working Group.

Some references were published in a language or country other than that where the work was done. For these references, letters indicating the original language and/or its availability in another language, if known, are shown by letters following the reference where:

E = English
F = French
H = Hebrew
P = Portuguese

For example, a study published in Brazil in Portuguese but also available in English would carry the letters P, E.

REFERENCES

Australia

1. CULVER, R., "The design and evaluation of sprinklers," Symposium: The irrigation of private horticultural areas on the River Murray. Water Research Foundation of Australia, Adelaide, South Australia, 1964.

   The author used test data obtained in certain wind conditions to plot the Christiansen uniformity coefficient against the ratio of the maximum to the minimum precipitation for an overlapped pattern.

2. CULVER, R., and SINKER, R.F., "Rapid assessment of sprinkler performance," J. Irrig. and Drain. Div., ASCE, 1966, v 92, n IR1, p 1-17.

   An automated testing station for rapidly assessing the performance of irrigation sprinklers is described. Data from the station is handled by a digital computer to give the performance of a particular sprinkler head under the test conditions of wind velocity, operating pressure, stand height, and jet size for any given layout. The rapid assessment of head behavior is evaluated in terms of known parameters. The relationship between Christiansen's uniformity coefficient and the ratio of maximum-minimum precipitation, as well as the coefficient of variation, are evaluated for the first hundred tests passed through the station. The value of the present data in the design of new systems and the correction of existing systems are analyzed.

3. HOWELL, D.T., "Sprinkler nonuniformity characteristics and yield," J. Irrig. and Drain. Div., ASCE, 1964, v 90, n IR3, p 55-67.

   The author examines ways in which nonuniformity of sprinkler application can be related to crop yield. An example of a parabolic yield relationship is given and is related to mean application ratio and a coefficient of variation. This paper pertains to wind only to the extent that the nonuniformity may be caused by wind.

4. TILL, M.R., "A method of conserving the evaporation loss from sprinklers," J. AIAS, 1957, p. 333-334.

   Evaporation losses from drops in transit were estimated from the increase in chloride concentration of water in travelling from the sprinkler head to the ground. These were found to be small under the conditions of test.

5. TILL, M.R., "A comparison of the variability of water distribution from four fixed overhead sprinkler types," Experimental record No. 2 of the Dept. of Agriculture, Adelaide, South Australia. 1965.

Variation in the precipitation from four overhead sprinkler types was measured in a mature citrus orchard. Wind speed largely determined the variability of the precipitation from a particular sprinkler type. The sprinklers were compared by the regression of precipitation variability against wind speed. The precipitation patterns at all wind speeds showed that with two-jet sprinklers, a zone of low precipitation occurred between the sprinkler lines. With single-jet sprinklers, the area of low precipitation was close to the sprinkler head at low wind speeds, but at higher wind speeds it was mid-way between the heads. If a variety of moderate wind speeds are to be experienced, the single-jet sprinklers would be preferred to the two-jet sprinklers. Recommendations are made for sprinklers in various conditions.

Brazil

6. ARRUDA, N.T., "Analysis of water distribution uniformity of a sprinkler irrigation lateral," Masters of Science Thesis, Vicosa Federal University, Vicosa, MG, 1981, 80 p. (P)

A method for determining water uniformity distribution of a sprinkler irrigation lateral was developed. Christiansen's Uniformity coefficient, statistical uniformity coefficient and variation coefficient were evaluated. Sprinkler and lateral spacings, nozzle pressure, sprinkler height and wind average speed effects on water distribution uniformity were analyzed.

7. BRIDI, S., BERNARDO, S., SEDIYAMA, G., and FERREIRA, P.A., "Analysis of water distribution uniformity of a center pivot sprinkler irrigation system," Master of Science Thesis, VICOSA Federal University, VICOSA, MG, 1984, 87 p. (P)

The performance of four center pivot sprinkler irrigation systems were studied under farm conditions. Christiansen's uniformity coefficient as well as distribution uniformity coefficient were determined and related to wind speed. Other operating parameters such as system rotational speed, total system flow, sprinkler wetted diameter, application time at the outer end and total revolution time were studied.

8. CHAUDHRY, F.H., "Sprinkler uniformity measures and skewness," J. of the Irrig. and Drain. Div., ASCE, n IR4, Proc. Paper 12620, 1976, p. 425-433. (E)

This paper relates the sensitivity of uniformity coefficients to the skewness of precipitation distribution. An analytical assumption that precipitation in a

sprinkler system can be described by a gamma distribution is used to predict the behavior of uniformity coefficients with their observed features. The results show that the conversion of one uniformity measure into another may not be feasible without taking skewness into account.

9. CHAUDHRY, F. H., "Nonuniform sprinkler irrigation application efficiency," J. of the Irrig. and Drain. Div., ASCE, 1978, v 104, n IR 2, Proc. Paper 13802, p 165-178. (E)

The role of asymmetry in the various efficiency parameters of nonuniform irrigation representing its areal pattern by a skew distribution were quantified. It was shown that if the application ratio or the coefficient of variation, or both, are small, the application efficiency approaches the value of the application ratio. The equality between the application ratio and the application efficiency can be obtained at relatively larger coefficients of variation for positively skewed distributions.

10. CHAUDHRY, F.H., et al., "Sprinkler evaluation-second report to the Ministry of Interior, Brasil," Hydraulic and Sanitation Department - SAO Carlos Engineering School - University of Sao Paulo, Sao Carlos, SP, 1973, 74 p. (P)

A preliminary report on the current situation and importance of research concerning agricultural sprinklers in Brazil is presented. A series of sprinklers from two manufacturers were evaluated to determine technical characteristics such as physical aspects, flow rates, rotational speed, droplet size, application depth and distribution patterns obtained through Criddle's method and a computer program which overlaps the precipitation data.

11. CHAUDHRY, F. H., et al., "Uniformity behaviour of sprinklers," Proceedings 9th International Irrigation and Drainage Congress, Moscow, USSR, 1975. (E)

Results of some investigations made on sprinklers available in Brazil are reported. The distribution characteristics include various uniformity coefficients and areal probability of various precipitation levels, determined for one sprinkler at optimum pressure and a variety of nozzle sizes. Performance data were established for a combination of spacings, pressure, and nozzle sizes under controlled external factors such as wind and topography.

12. CHAUDHRY, F. H., and SATTO, J., "Performance parameters of sprinkler irrigation systems," presented at 5th Agricultural Engineering National Congress, Lavras, MG, 1975, 10 p. (P)

A series of performance parameters of sprinkler irrigation systems are presented such as nozzle size combinations, sprinkler spacing, and water

uniformity coefficients of Christiansen and Wilcox-Swailes. Other statistical coefficients are also introduced to describe water distribution characteristics.

13. GOMIDE, R.L., "Determination and analysis of water distribution uniformity on sprinkler irrigation system," Master of Science Thesis, Vicosa Federal University, Vicosa, MG, 1978, 87 p. (P)

Water distribution uniformity of sprinkler irrigation was determined in accordance with: Christiansen's uniformity coefficient, uniformity coefficient proposed by Benami and Hore, pattern efficiency, Wilcox and Swailes statistical uniformity coefficient and variation coefficient. The following effects were studied: sprinkler and lateral spacing, sprinkler riser height, nozzle pressure and wind speed. A multiple regression equation was determined in order to estimate Christiansen's coefficient from the above factors.

14. MATSURA, E.E., "Application efficiency and uniformity of water distribution of sprinkler irrigation system," Master of Science Thesis, Luiz De Queiroz Agricultural School - ESALQ, University of Sao Paulo, Piracicaba, SP, 1987, 124 p. (P)

The scope of this study was to verify the relationship between uniformity coefficients and irrigation efficiency for sprinkler systems. A computer program was utilized to overlap the precipitation data and to estimate the uniformity coefficients of Christiansen, Wilcox, Hart, Benami, and Criddle standard efficiency. The linear and normal models were fitted to the water distribution data; a linear regression was performed to relate the data of dimensional depths of land area adequately irrigated to the data of Christiansen's uniformity coefficient and Criddle's standard efficiency.

15. ROSA, J.A., BERNARDO, S., LOUREIRO, B.T., and DENICULI, W., "Performance evaluation of a small travelling gun sprinkler irrigation system under different operating conditions," Master of Science Thesis, Vicosa Federal University, Vicosa, MG, 1986, 72 p. (P)

The performance of a small travelling gun sprinkler, based on water uniformity distribution under different operating conditions, was determined. The equipment was set at three different speeds and nozzle pressures, and was provided with two nozzle diameters. Christiansen's uniformity coefficient and distribution uniformity coefficient recommended by USDA were determined under three path spacings. Also evaluated was the travelling gun speed, application time over the pluviometers, system total flow rate, wind speed and direction, and evaporation losses.

16. ROSENFELD, U., BAPTISTELA, J.R., LEME, E.J. and CAMPOS, H., "Sprinkling uniformity - evaluation of water application and storage efficiency," Proc., 5th Irrig. and Drain. Natl. Congress, SAO Paulo, SP, 1980, Vol. 2. (P)

The objective of the paper was to present parameters such as application efficiency, storage efficiency, excess subdrainage as well as Christiansen's uniformity coefficient for evaluating sprinkler performance obtained from a mathematical model. This model was tested in a field trial conducted with the sectorial big gun sprinkler with a 7.0 Kgf/sq cm pressure and using rectangular and triangular 84 x 84m, 96 x 96m, 108 x 108m and 120 x 120m spacing.

17. SAAD, A.M., COLOMBO, A., HARADA, J., SANTOS, J.A.S., JUNIOR, S.F., and NAKAGAWA, T., "Evaluation of water distribution uniformity coefficients of center pivot sprinkler irrigation systems," Report No. 23.966, Technological Research Institute - IPT, SAO PAULO, 1986, v 2, 103 p. (P)

Some of the most important performance parameters of center pivot irrigation systems were evaluated. The trials were done at private farms in Guaira, SP, for center pivots which carried both sprinklers and spray nozzle packages. Water distribution uniformity was calculated with the Christiansen uniformity coefficient and distribution uniformity coefficient. Wind speed and direction, air temperature, relative humidity and evaporation were recorded. Water application rates were determined and related to soil intake rates in order to establish runoff potential. The system's revolution time and application depth were also monitored.

18. SATTO, J., "Sprinklers performance evaluation," Master of Science Thesis, SAO Carlos Engineering School - University of Sao Paulo Sao Carlos, SP, 1978, 77 p. (P)

A numerical treatment of observed water distribution patterns was developed at different spacings and nozzle pressures from overlapping field data. Several uniformity parameters were calculated and some relationships between these, like Beale's pattern efficiency, Benami's Coefficient, and Wilcox - Swailes' Coefficient were studied analytically and compared with the experimental data observed.

19. SOARES, J.M., PINTO, J.M., and MAGALHAES, A.A., "Sprinkler irrigation efficiency at farm level in Senator Nilo Coelho Irrigation District," Proc., 7th Irrig. and Drain. Natl. Congress, Brasilia, DF, 1986, v 2, p 437-460. (P)

This study comprised trials carried out at seven different irrigated farms at Senator Nilo Coelho Irrigation District located at Petrolina PE. The following observations were recorded: uniformity of distribution, coefficient of uni-

formity, irrigation efficiency, sprinkler rotational speed and wind speed and direction. It was found that irrigation efficiency ranged from 57.2% to 59.4% with 1.8 and 4.0 atm nozzle pressure.

20. VILLELA, S.M., et al., "Sprinkler Evaluation - final Report Minter - USP - CNPq accord," Hydraulics and Sanitation Department Sao Carlos Engineering School- University of Sao Paulo, Sao Carlos, SP, 1979, 232 p. (P)

Results of sprinkler evaluations are presented referring to pressure and flow tests, water uniformity distribution and economical determination of sprinkler spacings. Christiansen's uniformity coefficient, Wilcox-Swailes' uniformity coefficient, Criddle's standard efficiency, variation coefficient and distribution standard deviation were determined.

Bulgaria

21. LAZAROV, R., "The wind as a factor limiting the duration of sprinkler irrigation," Hidroteh. Melior, 1975, v 20, n 6, p 22-26.

Canada

22. THOOYAMANI, K.P., and NORUM, D.I., "Performance of center pivot sprinkler irrigation systems in Saskatchewan," CSAE Paper No. 86-303. 1986.

Uniformity of water distributions under six low pressure center pivot sprinkler irrigation systems were measured to evaluate the systems. For a uniform overlapped spray pattern, uniformity of water distribution as per design was estimated from sprinkler charts for each system. This design uniformity was compared to uniformities measured under field conditions to find the suitability of design and/or management of the systems for their field conditions. It was concluded that the low pressure center pivot systems were properly designed for sprinkler discharge rates, but the resulting uniformity of overlapped spray pattern was not properly considered.

23. WILCOX, J.C., and McDOUGALD, J.M., "Water distribution patterns from rotary sprinklers," Canada J. Agric. Science, 1955, v 35, p 217-228.

Factors affecting the uniformity of distribution of water by rotating sprinklers were studied. Eight geometric curves were selected. In addition, examples of such curves were selected from field tests for study. In all cases, various sprinkler spacings were assumed, both square and rectangular; the distribution of water between sprinklers was mapped; and the degree of uniformity of distribution within the areas studied was calculated.

China (PRC)

24. CHEN XUEMIN, and LUO JINYAO, "Measurement and computation of sprinkler efficiency," Sprinkler Irrigation Technique, May 1985, v 36, n 2.

25. ZHANG XINHUA, "The change of single PY1-30 sprinkler patterns under wind conditions," Sprinkler Irrigation Technique, Mar 1985, v 35, n 1.

Czechoslovakia

26. MASEK, V., and NOVOTNY, M., "Effect of wind speed on sprinkling range of sprinklers," Zemedelska Technika. 1985, v 31, n 6, p 341-348.

France

27. BENZINA, A., "Les effets du vent sur l'irrigation par aspersion" ("The effects of wind on sprinkler irrigation") Mémoire de stage (Training course report), CEMAGREF Bordeaux, BP 3, 33610 Cestas - France, 1985, 49 p.

A literature review of the effect of wind on sprinkler irrigation is presented. The nature and importance of wind consequences as well as corrective measures such as the choice and the layout of the hardware, schedule and time of application are discussed.

28. CHATVORIAN, O.R., et al., "Le problème de l'influence du vent sur la portée du jet des asperseurs" (Traduction francaise) ["Wind effects on the pattern radius of sprinklers" (French translation)]. In: Travaux de l'Institut Arménien de Recherches Scientifiques pour les Problèmes de l'eau et de l'Hydro-technique (Research at the Armenian Institute of Scientific Research for Water and Hydrotechnical Problems (ARM NII V PIG), 1974, Tome III (VIII).

29. CHTANGEY, A.I., and CHPAK, I.S., "L'evaporation d'eau à partir des gouttes pendant leur trajectoire, au cours de l'arrosage avec l'appareil DDA 100 M," ("Water droplet evaporation when using the DDA 100 M apparatus") Meteorologia i Idrologia, 1975, n II, p 100-105.

30. JANIN, J.L., "Homogénéité des arrosages par canons automoteurs, compte tenu de l'effet du vent, et projets d'équipements à la parcelle," ("The uniformity of travelling irrigation guns taking into consideration wind and experimental plot results") Session ENGREF Irrigation, Nimes, Rodilhan, 29 Sep 1978.

Ecrire à : CEMAGREF BP 3 - 33610 Cestas - France.

The author proposes a theoretical method to select the optimum spacing between successive travelling gun passes. Water application profiles with and without wind are the bases of the study. A program then calculates application depths on a transection strip taking into consideration the angle of the strip, the speed of the gun, and spacing. A curve of depth versus area is then compiled. This is further used to evaluate water and yield losses (related to the overall water deficit). The use of various spacings allows the selection of the optimum one for a specific condition.

31. JANIN, J.L., "Effet du vent sur les arrosages par aspersion. Essais, simulation des arrosages et projets d'équipement à la parcelle (compte-rendu d'essais en cours)," ("The effect of wind on sprinkler irrigation. Sprinkler irrigation simulations and experimental plot instrumentation - preliminary report") CEMAGREF, BP 3, 33610 Cestas, France, 1979, 40 p.

A review of existing research results on solid set systems is made. A simulation method is cited aimed at determining the optimum spacing for machines travelling in strips for specific wind conditions. Field results are used and a specific example is presented for the Bordeaux area.

32. KARANTOUNIAS, G., "Utilité des brise-vent en irrigation par aspersion. Etude en soufflerie de leurs effets," ("CU and losses as functions of wind speed") Revue Génie Rural-août sept. 1979, p. 5 à 8.

The author, who made studies and experiments in Greece, reviews the main results of his research on the effects of wind and the advantages of windbreaks. He explains the known results and those he obtained, and proposes some rules to be followed using windbreaks.

33. ZANON, B., "Influence du vent sur l'arrosage en bandes par canon mobile," Mémoire de fin d'études ("The effects of wind on strip irrigation with travelling guns," Graduation report) CTGREF Bordeaux, 1980, 130 p + appendices.

The effect of wind on the application uniformity was field investigated for various wind conditions. Application depth was measured using two transects of rain gauges. Results were then processed using a simulation program that evaluates yield losses under normal winds for the area of study. The optimum spacing between successive passes was found.

Germany (FRG)

34. OEHLER, T., and SCHONNOP, G., "Effects of wind on sprinkler irrigation," Journal No. 10, Land Management Board "KFK", 1963.

35. SOURELL, H., "New technical developments to save water and energy," Journal No. 1, Irrigation Management, 1984.

36. SOURELL, H., "Techniques of field irrigation," Guideline No. 156, German Agricultural Society, 1979.

37. SOURELL, H., and THORMANN, H.H., "Spray wagon or rain cannon, which form of water distribution is suitable?", Vegetable Journal No. 9, 1984.

38. SOURELL, H., and SIEGERT, E., "Sprinkler irrigation on which wind force?", Journal No. 25, Hannover Newspaper of Land and Forestry, 1979.

39. WOLFF, P., "The evaluation of uniformity on water distribution of sprinkler irrigation equipment using the Christiansen uniformity coefficient CU," Journal No. 1, Water and Soil, 1980.

40. WOLFRAM, A., "Bewasserungs landban," Verlag Eupen Ulmer, Stuttgart, 1980, p 382-389.

Greece

41. ALLISON, S.V., and HESSE, V.L., "Simulation of wind effects on sprinkler performance," J. Irrig. and Drain. Div., ASCE, Dec 1969, v 95, n IR4, p 537-550. (E)

The authors simulated the effect of wind on sprinklers using 5 years of actual wind data from an irrigation project in the Northwestern Peloponnesus of Greece in addition to wind data from the Gortys Experiment Station. Efficiency and uniformity for the test conditions were correlated. The effects of varying wind speeds on sprinkler performance can be adequately simulated if sufficient wind data are available. They determined that interrupting sprinkling during hot, windy periods of the day cannot be justified on the basis of higher efficiency. Higher efficiencies result if laterals are parallel to wind direction and the solution to most wind problems is to reduce spacings.

Hungary

42. CSEKO, G., and SZALAI, G.Y., "Method of controlling wind effect in sprinkler irrigation." Hydrol. Kozl., 1975, n 3, p 114-122.

43. CSEKO, G., and SZALAI, G.Y., "Decreasing the wind effect of sprinkler irrigation," Proceedings of ICAE/CIGR/ 10th International Congress, Budapest, Hungary, Sept 3-7, 1984, Tomus 1., 1.2/6., p 218-227. (E)

The authors pointed out the possible increase in sprinkler irrigation effectiveness with adequate application quantity with minimum water loss by surface ponding and with uniform application. It was concluded that in Hungary, sprinkler irrigation effectiveness ceases when wind velocity exceeds 4.5 m/s.

India

44. CHAWLA, J.K., and SINGH, S.R., "Sprinkler irrigation losses as affected by climatic and operating conditions," J. Agric. Engrg., India, 1977, v 14, n 1, p 20-27. (E)

The amount of evaporation, wind drift, and interception loss was determined under different conditions of temperature, vapour- pressure-deficit, wind speed and direction, nozzle size and pressure. The electrical-conductivity-measurement method was combined with the can-method to compute wind-drift losses. The tests were conducted at the Punjab Agricultural University, Ludhiana, India.

Israel

45. ELHANANI, S., "Sprinkler irrigation (fundamentals)," Extension Authority, Ministry of Agric., Israel, 1961, 59 p. (H)

The fundamentals of sprinkler irrigation system components are discussed. Factors determining uniformity of distribution and measures recommended to ensure efficient operation and adequate uniformity are noted. Test methods for determining distribution patterns are described, and the Christiansen and Dan methods for distribution uniformity analysis are presented. The distribution pattern for a specific single sprinkler operating at different pressures in windy and windless conditions is shown graphically. Distribution maps, Christiansen's uniformity coefficients, and the Dan analysis obtained for the same sprinkler under different pressures, wind speeds, and spacings are shown.

46. FARBMAN, M., "Non-uniformity of water distribution in sprinkler irrigation of wheat," Technion, Israel Institute of Technology, Haifa, 1976. (H)

The author estimates the influence of wind on non-uniformity of water distribution in supplementary sprinkler irrigation of wheat, based on the assumption that it is possible to isolate each of the various factors contributing to non-uniformity, to estimate the contribution of each factor, and to synthesize overall non-uniformity. Individual contributions of wind speed, differences in sprinkler discharge, errors in spacing overlaps, and other factors on distribution uniformity were studied.

47. KOSTRINSKY, M., "Uniformity of water distribution in sprinkler irrigation of wheat," Technion, Israel Institute of Technology, Haifa, 1973. (H, E)

Results of a field study are summarized and various methods of examining the feasibility of sprinkler irrigation in variable wind conditions and of improving application uniformity and efficiency are proposed. Distribution patterns for two sprinklers obtained over a wide range of wind speeds are given. Use of an average wind curve (summer) is proposed as a means of calculating distribution uniformity obtained in the field. Various solutions designed to improve distribution uniformity were studied; i.e., optimal alignment of sprinkler laterals, irrigation in identical wind conditions, and a method for testing the feasibility of irrigation in variable wind conditions.

48. MANTSUR, S., "Water losses at field boundaries in sprinkler irrigation," Extension Authority, Ministry of Agric., Israel, 1962, 35 p. (H)

49. SEGINER, I., "Net losses in sprinkler irrigation," Agric. Meteorol., 1967, v 4, p 281-291. (E)

Net evaporation and interception due to overhead daytime sprinkling of corn were studied. A special near-the-ground reference irrigation system was used by which spray losses and interception losses were nearly eliminated. Irrigation intervals of three days and two weeks were used. Results were significant for overhead sprinkling applied every three days; this treatment was significantly different at the 0.1 level and consumed 10% more water than the others. Rough approximations on the basis of both the present results and relationships found in the literature indicate that regular overhead daytime sprinkling (one irrigation in two weeks) would not require more than 5% more water than night irrigation or surface irrigation.

50. SEGINER, I., "Wind variation and sprinkler water distribution," J. Irrig. and Drain. Div., ASCE, 1969, v 95, n IR2, p 261-274. (E, F)

Data collected by Wiersma were used as a basis from which to calculate simulated distribution patterns by computer. Using superposition by the computer, patterns were obtained for different wind speeds and directions, sprinkler spacings, lateral spacings and movement, and irrigation durations. Uniformity coefficients were determined for the different conditions.

51. SEGINER, I., "The effect of wind on the water balance and the efficiency of irrigation by sprinkling," Dept. of Agric. Engrg., Technion, Israel Institute of Technology, Haifa, 1970, pub. n 109, 33 p.

The influence of wind on all components of the water balance of an area under sprinkler irrigation is analyzed, particularly that on evaporation and subsurface drainage which is influenced by above ground water distribution uniformity. The importance of these two components lies in their reciprocity at the first level to the area of the field. The most important marginal influences are the increase in evaporation on the upwind side of the field and spray drift losses on marginal areas downwind.

52. SEGINER, I., "Wind effect on the evaporation rate," Dept. of Agric. Engrg., Technion, Israel Institute of Technology, Haifa, 1970, pub. n 88, Chap. 4, 22 p. (H, E)

An evaporating surface which consists of a lower boundary, a vapor source, an interface with the atmosphere, and an upper level is modeled. Energy balance and continuity equations are used to solve for the various system fluxes. For any given set of boundary conditions, the surface temperature of a given evaporating medium (leaf or soil) may vary within a range as a function of wind speed. The model shows a discontinuity in the behavior of the system between very low internal resistances to vapor flow and no resistance at all (wet surface). If internal resistances vanish with an atmospheric resistance smaller than a critical value, a sudden increase in the evaporation rate and a decrease in the surface temperature are predicted. Calculations for high values of internal resistance indicate the existence of a maximum in the evaporation vs. atmospheric resistance relationship.

53. SEGINER, I., "Water losses during sprinkling," Trans. ASAE, 1971, v 14, n 4, p 656-659, 664. (E)

Water losses during sprinkling were determined for various meteorological and operation conditions. Total water loss was related to solar radiation. Spray loss was studied in relation to fineness of spray and various meteorological parameters.

54. SEGINER, I., "Operating sprinkler systems to obtain optimal distribution uniformity under wind conditions," Dept. of Agric. Engrg., Technion, Israel Institute of Technology, Haifa, 1973, pub. n 193. (H, E)

Various sprinkler operating schemes are presented which enable irrigation to be carried out in given windy conditions without significant loss of distribution uniformity. A method to obtain a system of distribution patterns free from extraneous influences apart from wind was analyzed. Thus, it is possible to estimate the number of tests required to obtain complete data on water distribution patterns in all wind conditions.

55. SEGINER, I., "Methods for designing sprinkler irrigation under changing wind conditions," HaSadeh, 1975, v 56, n 2. (H)

A planning method for single sprinkler laterals operated in variable wind conditions is given, including examples of a relatively simple case where the wind adheres to a cyclic pattern. Optimum distributions with equal distances between the center-of-mass of the sprinkler patterns are identified. The optimum is determined with simple calculations which save computer time. To give information on the final distribution level, calculation of only one overlapping is sufficient to give the optimal situation.

56. SEGINER, I., "A note on the economic significance of uniform water application," Irrig. Sci., 1978, v 1, p 19-25. (E)

A yield vs. water application diagram with uniformity of water distribution and price of water as parameters is presented. The diagram enables the optimum water application and the expected income for a certain crop to be determined. The diagram can further be used to explore the possible outcome of changing water uniformity and/or price. The diagram is based on simplified forms of yield and water-distribution functions.

57. SEGINER, I., and KOSTRINSKY, M., "Wind, sprinkler patterns, and system design," J. Irrig. and Drain Div., ASCE, 1975, v 101, n IR4, p 251-264. (E, F)

Sprinkler water distribution data were analyzed to show the distorting effect of wind on the distribution pattern. Individual distribution patterns were reconstructed to a state of "no-loss" to exhibit the distortion effect with drift and evaporation losses subtracted out. The reconstructed patterns were used to test a design rule which states: for the best possible water distribution under the major constraints of a given sprinkling system, the centers-of-mass of individual water distribution patterns should be equidistantly spaced in the field. Three design examples seeking optimal lateral direction, operation-shift timing, and distance between lateral working positions were presented. The resulting designs were checked by means of a detailed superposition program.

58. SEGINER, I., GAMLIEL, A., and FARBMAN, M., "Water distribution in sprinkled wheat and cotton fields," Dept. of Agric. Engrg., Technion, Israel Institute of Technology, Haifa, 1977, pub. n 272, p 33-43. (H)

The economic aspects of non-uniform water application were estimated quantitatively and the role of wind as a cause of non-uniformity was evaluated. Two crops, irrigated cotton and wheat, under supplementary irrigation were investigated.

59. SEGINER, I., and WEIZMAN, G., "Sprinkling strategies for the improve ment of the distribution uniformity in wheat irrigation in the Northern Negev Region in transition and winter seasons," Dept. of Agric. Engrg., Technion, Israel Institute of Tech., Haifa, 1978, pub. n 283. (H)

Means to improve the uniformity of distribution of irrigation water from a single lateral sprinkler system, used for winter irrigation in unstable wind conditions, were studied. Proposed solutions to improve distribution are based on the following controllable parameters: direction of laterals, optimal distance between sprinklers, and automatic cessation of sprinkling under certain wind conditions.

60. STERN, J., and BRESLER, E., "Nonuniform sprinkler irrigation and crop yield," Irrig. Sci., 1983, v 4, p 17-29. (E)

The influence of non-uniform water application by sprinkler on the variability of soil water content and corn yield was studied on two experimental plots differing in their texture and hydraulic characteristics. Variograms, autocorrelations, and cross-relations of soil water contents; crop yield of sweet corn; and net water application were calculated. The correlograms show trends which are similar for all three variables. Filtering the trends by scaled variograms shows that soil properties of both experimental plots may be considered homogenous so that the responses of soil water content, and in turn, of crop yield resulted mainly from the non-uniformity of water application.

61. ZASLAVSKY, D., and BURAS, N., "On the yield response of crops to nonuniformity application of irrigation water," Dept. of Agric. Engrg., Technion, Israel Institute of Technology, Haifa, 1965, pub. n 17. (H, E)

The authors present a conceptual framework within which the problem of uniformity of distribution vs. yield can be analyzed. A multivariate model was also considered pointing out the correlation which might exist between the various treatments and their possible interactions.

62. ZELOVITZ, I., "Methods for measuring and characterizing distribution uniformity of sprinklers under wind conditions," Israel Center for Water Works Equipment, PR-88578, 1978, 45 p. (H)

A standard method for testing the distribution uniformity of sprinklers in variable wind conditions is presented. The method is based on the performance of a series of distribution tests on a random sample of sprinklers in different wind speed conditions. Results of the distributions from a series of samples are analyzed and a mathematical equation enables calculation of the distribution patterns and distribution indices for different wind speeds by means of a computer program specially developed for this purpose.

Italy

63 RAVELLI, F., NAPOLI, T., and FLORIS, F., "Correlation between coefficients of uniformity for pivot irrigation and wind velocity," ("Correlazione tra il coeefficiente di uniformita del piovuto degli irrigatori e la velocita del vento") Irrigation and Drainage (Irrigazione e drenaggio), 1983, v I, II, p 117-122.

64. ZAMPIERI, E., "Determination of some parameters for sprinkling irrigation of windy areas in the Bolzano province," (Nota sulla determinatione di alcuni parametri di progettazione per la irrigatione a pioggia di Zone ventose in provincia di Bolzano").

The author made field tests in a very windy region (Alta Val Venosta) where there are big solid set sprinkler networks, in order to find the limits of their use over trees. Different trajectory angles and sprinkler heights were tested. To have a satisfactory uniformity with strong winds, a 12 degree angle and a sprinkler height smaller than tree height are needed. But, with reduced spacings, rainfall amounts are large.

Japan

65. INOUE, H., "Experimental studies on losses due to wind drift in sprinkler irrigation," Tech. Bull. Fac. Agric. Kagawa Univ., Japan, 1963, v 15, n 1, p 50-71.

From his experimental studies on losses due to wind drift during sprinkling, the author estimated drift as low as 4% at low pressure deficit and nearly zero wind. Comparable losses at a wind speed of 5 m/s were as much as 11%.

66. KATO, S., and TAKENAKA, H., "Experimental Research on the Sprinkling Method under the Influence of Wind", The Japanese Soc. of Irrig., Drain. and Reclam. Engrg., 1980, v 48, n 2, pp.13-19.

Research was carried out with sprinklers applying water on orange groves under wind velocities of 0.1 m/s to 6.1 m/s. Various combinations of riser intervals,trajectory angles and working pressures were examined under the varying wind velocities.

67. OKAMURA, S., "Theoretical Study on Sprinkler Sprays (part one) under Wind Conditions," The Japanese Soc. of Irrig., Drain. and Reclam. Engrg., 1968, v 26, p 49-55.

A theoretical trajectory of a falling water drop is studied as a theoretical base for motion of sprinkler sprays. The equation of motion is introduced on the assumption that a water drop holds a spherical shape during flight and the factors affecting the motion of a water drop, such as air drag force and evaporation during flight, are examined.

68. OKAMURA, S., "Theoretical Study on Sprinkler Sprays (part two) under Condition of Wind Drift," The Japanese Soc. of Irrig., Drain. and Reclam. Engrg., 1968, v 26, p 56-61.

The author carried out theoretical studies on the behavior of water drops under the influence of wind on the assumption that the velocity is horizontally uniform and vertically either uniform or in logarithmic distribution. The trajectory of a water drop emitted from a nozzle under conditions of various pressures and wind velocity is calculated. The discussions on the behavior of a water drop under unsteady velocity are also made.

69. OKAMURA, S., and NAKANISHI, K., "Theoretical study of sprinkler sprays: IV. Geometric pattern from a single sprinkler under wind conditions," Japanese Soc. of Irrig., Drain. and Reclam. Engrg., 1969, v 28, n 2, p 35-43.

The authors use a standard drag equation to calculate the wind distortion of sprinkler spray for 2, 4, and 6 m/s wind speeds.

70. OKAMURA, S., NAKANISHI, K., and FUKLUI, Y., "Parameters for designing the sprinkler irrigation system undewind condition," J. Society of Agricultural Machinery, Kagoshima, Japan, 1982, v 44, n 1, p 31-36.

71. SHIRAI, K., "Water losses in sprinkler irrigation," Published in Japan. 1959.

Sprinkler application losses of 10% were reported practically constant and independent of nozzle pressure at low winds.

Netherlands

72. YAZER, A., "Evapotranspiration and drift losses from sprinkler irrigation systems under various operating conditions," Agricultural Water Management, Amsterdam, 1984, v 8, n 2, p 439-449. (E)

Experiments were made in Nebraska during the season July to Nov. 1979. Evaporation losses varied exponentially with wind speed, and also with water vapor pressure deficit. Measured losses varied from 1.5 to 16.8% for evaporation, from 1.5 to 15.1% for drift (function of the square value of windspeed), from 1.7 to 30.7% for evaporation and drift.

New Zealand

73. CARRAN, P.S., "The prediction of wind affected sprinkler performance," Agricultural Engineering thesis, University of Canterbury, Christchurch, New Zealand.

The author has written the tridimensional equations of droplet movement in a constant wind, and verified these equations by experiments.

74. McBRIDE, S.D., FITZGERALD, P.D., and RYDE, D.H., "The effect of climate on the field performance of irrigation sprinklers," Winchmore Irrigation Research Station, Ministry of Agriculture and Fisheries, Ashburton, New Zealand, Technical Report No. 6, 1973, 20 p.

The authors tested five different sprinklers under various wind conditions and operating pressures. Overlapping sprinkler patterns were used to represent different lateral spacings. Relationships between water loss, wind speed and relative humidity were determined. Design lateral spacings can be determined from graphical plots relating wind speed to uniformity coefficient and lateral spacing.

Saudi Arabia

75. NIMAH, M.N., BASHOUR, I., and HAMRA, A., "Field evaluation of low pressure center pivots," ASAE Paper No. 85-2061, ASAE, 1985, 9 p. (E)

The Distribution Uniformity (DU) and the Potential Application Efficiency (PAE) for a low pressure spray nozzle center pivot system in Saudi Arabia were evaluated under different combinations of wind speed and operational pressures. The maximum DU and PAE achieved were 82.5% and 75%, respectively at 414 kpa pressure and in the 4.4 to 6.7 m/s range of wind speeds.

South Africa

76. ECKHART, J.H., "Wind and sprinkler irrigation," Division of Agricultural Engineering, Department of Agricultural Technical Services, Private Bag X515, Silverton, S.A., Leaflet No. C14, 1973, 1 p.

Practical summary of wind effects and advice to users (questions and responses).

United States

Note: Because of the large number of references to ASAE (Am. Soc. of Agric. Engrs.), the address is shown here rather than repeatedly in the text: 2950 Niles Rd., St. Joseph, Michigan 49085, USA.

77. ALI, S.M.A., and BAREFOOT, A.D., "Performance of center-pivot sprinkler irrigation systems operating at reduced pressures," ASAE Paper No. 78-2005, ASAE, 1978, 19 p.

Spray distribution obtained from a single stationary sprinkler head was used to determine the effects of reduced operating pressure on evaporation loss, application uniformity, sprinkler spacing, and application rate of a center-pivot sprinkler system. At reduced pressure, the sprinkler performances were satisfactory. Contours of application depth were used to show the effect of wind on the distribution pattern.

78. ALI, S.M.A., and BAREFOOT, A.D., "Low trajectory sprinkler patterns and evaporation loss," ASAE Paper No. 81-2085, ASAE, 1981, 24 p.

This paper presents the results of 72 tests conducted at Stillwater, Oklahoma, on a low-trajectory sprinkler to determine the water loss as a function of relative humidity, temperature, wind speed, pressure, and riser height. Computer plots of distribution patterns visually show the effects of pressure and wind on the distortion of the patterns.

79. AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS, "Procedure for sprinkler distribution testing for research purposes," ASAE Standard: ASAE S330.1, ASAE, 3 p.

This engineering standard provides a standard basis for the accumulation of data on the distribution characteristics of sprinklers and a uniform method for presentation of the data. It describes the types and methods of obtaining and recording pertinent climatic data including that for wind.

80. AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS, "Procedure for sprinkler testing and performance reporting," ASAE Standard: ASAE S398.1, ASAE, 2 p.

This engineering standard provides a standard basis for test procedures and the collection, interpretation, and reporting of data for sprinkler performance. Detailed criteria are given for wind measuring equipment and wind data collection.

81. AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS, "Test procedure for determining the uniformity of water distribution of center pivot, corner pivot, and moving lateral irrigation machines equipped with spray or sprinkler nozzles," ASAE Standard: ASAE S436, ASAE, 2 p.

This engineering standard establishes a uniform method of collecting water distribution data for center pivot, corner pivot, and moving lateral irrigation machines. Criteria for wind measuring equipment and data collection are given.

82. BRANSCHEID, V.O., and HART, W.E., "Predicting field distributions of sprinkler systems," Trans. ASAE, 1968, v 11, n 6, p 801-803, 808.

Single sprinkler and a lateral line of 13 sprinklers were tested simultaneously under various wind conditions. The HSPA uniformity coefficient was used to characterize the sprinkler pattern uniformity and the influence of spacing and wind speed on the coefficient for overlapped single and lateral line sprinklers was determined. The uniformity coefficients for various wind speed sequences or histories were compared. The single sprinkler data, when juxtaposed and overlapped, predicted the field distribution as indicated by the uniformity coefficient.

83. CHAIRATANA, S., WU, I-PAI, and REYNOLDS, W.N., "Skewness and kurtosis influence on uniformity coefficient and application to sprinkler irrigation design," Trans. of the ASAE, 1972, v 15, n 2, p 266-271.

By use of a computer, statistical parameters and uniformity coefficients of sprinkler data were computed and tabulated. The values of the summarized means, standard deviation, variance, skewness, kurtosis, Christiansen's coefficient, HSPA's coefficient, and Wilcox and Swailes' coefficient were summarized. Data from 156 single sprinkler tests made in Hawaii were used for the study.

84. CHRISTIANSEN, J.E., "Irrigation by sprinkling," Univ. of California, Agric. Expt. Sta. Bull. 670, 1942, 124 p.

This bulletin presents general information on the design and operation of sprinkler systems. It contains information on the effect of wind, speed of rotation and sprinkler spacing on water distribution obtained from a series of tests conducted at Davis, California.

85. CHRISTIANSEN, J.E., Discussion of "Nonuniformity and sprinkler application efficiency," by David T. Howell, J. Irrig. and Drain. Div., ASCE, 1965, v 91, n IR1, p 224-226.

The author presents a discussion of the paper by Howell and uses data presented in an M.S. thesis by Dabbous, 1962.

86. CLARK, R.N., and FINLEY, W.W., "Sprinkler evaporation losses in the Southern Plains," ASAE Paper No. 75-2573, ASAE, 1975.

Wind velocity and vapor pressure deficit have the greatest influence on evaporation losses from sprinklers. When wind velocities were greater than 4.5 m/s, losses increased exponentially with wind velocity. Annual average evaporation from sprinklers can be expected to exceed 15% in the Southern Plains.

87. DABBOUS, B.J., "A study of sprinkler uniformity evaluation methods," Master of Science thesis, Utah State Univ., Logan, Utah 84322, 1962.

The author, as reported by Christiansen, J.E., 1965, used test data obtained earlier by Christiansen in California, including sprinkler patterns in wind, to compare three different measures of uniformity: (1) Christiansen's uniformity coefficient, (2) Wilcox-Swailes' uniformity coefficient, and (3) the USDA pattern efficiency.

88. DAVIS, J.R., "Measuring water distribution from sprinklers, Trans. ASAE, 1966, v 9, n 1, p 94-97.

An analysis of parameters for describing uniformity of water distribution from sprinklers is presented. Four sprinkler patterns which were characterized by different operating pressures and wind speeds were evaluated.

89. DEBOER, D.W., and BECK, D.L., "Field evaluation of reduced pressure sprinklers," ASAE Paper No. 83-2024, ASAE, 1983, 24 p.

Eight sprinkler devices were field tested during 1981 and 1982 with operating pressures ranging from 41 to 344 kPa. The sprinkler devices included impact sprinklers, a vortex nozzle, and spray nozzles on booms and on top of the pipe. Surface runoff depths increased and soil water contents decreased with a decrease in operating pressure. Wind was uncontrolled and its effect was variable and inconsistent.

90. DISRUD, L.A., LYLES, L., and SKIDMORE, E.L., "Effects of drop size and wind velocity on the motion and path of falling water-drops," ASAE Paper No. 68-210, ASAE, 1968, 17 p.

The effects of wind on the velocity, path, and shape of water drops falling in a wind tunnel were measured. These effects were evaluated in terms of their influence on the water drop parameters used in rainfall erosion studies.

91. DYLLA, A.S., and SHULL, H., "Estimating losses from a rotating-boom sprinkler," Trans. ASAE, 1983, v 26, n 1, p 123-125.

Estimates of evaporation and wind drift losses from a rotating-boom sprinkler system in Minnesota were obtained by equating the differences between measured volumes of water pumped through the system and the calculated amounts of water reaching vegetation and ground surfaces. A grid array of sprinkler water collectors was used to calculate the latter amount for each irrigation test run. Water loss amounts and climatic data for 31 sprinkler runs were used to calculate a multiple linear regression equation for estimating water losses for a windy, humid temperate climate.

92. EDLING, R.J., and CHOWDHURY, P.K., "Kinetic energy, evaporation, and wind drift of droplets from low pressure irrigation nozzles," Trans. ASAE, 1985, v 28, n 5, p 1543-1550.

A simulation model was developed to estimate kinetic energy, evaporation and wind drift of droplets from low pressure irrigation sprinklers. The model was partially verified using data from literature. Droplet size; height, size, flow rate and deflection plate angle of the nozzle; air temperature; wind direction and velocity; and air humidity were changed to determine the influence on evaporation and travel of the droplet. To represent the complete nozzle, droplet sizes were weighted according to percentage volume data. Two nozzles, one representing low pressure and the other high pressure were simulated. Evaporation decreases rapidly when droplet diameter is increased from 0.3 mm to 1 mm. The influence of air temperature is more evident at small droplet size. Evaporation estimates for different wind velocities and nozzle elevations indicate high dependence on these parameters. The kinetic energy of droplets at lower elevations with deflection plate angles either horizontal or upward (10 degrees) were relatively low. Small droplet wind drift at higher wind speeds and nozzle elevations was large.

93. FROST, K.R., "Factors affecting evapotranspiration losses during sprinkling," Trans. ASAE, 1963, v 6, n 4, p 282-283, 287.

A weighing evapotranspirometer was used to determine sprinkler evaporation losses under various climatic, crop, and operating conditions with winds less than 8 km/hr.

94. FROST, K.R., and SWALEN, H.C., "Sprinkler evaporation losses," Trans. ASAE, 1955, v 36, n 8, p 526-528.

Sprinkler evaporation losses under high temperatures and low humidity conditions in Arizona were studied. Losses with various nozzles and wind speeds up to 16 km/hr were measured. A nomograph was developed for estimating sprinkler spray losses under various climatic (including wind) and operating conditions.

95. GARVIN, P.C., BUSCH, J.R., LONGLEY, T.S., and WRIGHT, J.L., "Effects on evapotranspiration from evaporation and wind drift from a line source," ASAE Paper No. PNR 85-201, ASAE, 1985, 42 p.

An experimental analysis was conducted to determine the extent of the effects of evaporation and wind drift from self-propelled low-pressure sprinkler systems on evapotranspiration and the aerial environment of alfalfa. Results showed that evapotranspiration is significantly reduced in all positions downwind of the sprinklers that were tested.

96. HART, W.E., and HEERMAN, D.F., "Evaluating water distribution of sprinkler irrigation systems," Colorado State Univ. Exp. Sta, Tech. Bul. 128, Ft. Collins, CO, 80523, 1976, 39 p.

This bulletin presents ways of evaluating the distribution of water under sprinkler systems to provide optimum returns. The authors simulated the effect of 9 m/s wind on a center pivot system by overlapping test distribution patterns obtained under the wind condition.

97. HEERMAN, D.F., and KOHL, R.A., "Fluid dynamics of sprinkler systems," Chap. 14, In: Design and Operation of Farm Irrigation Systems, M.E. Jensen, Ed., ASAE Monograph No 3, ASAE, 1980, p 583-618.

Wind speed and direction are discussed as design parameters with brief literature reviews. Wind effects on measured distributions for stationary systems, continuously moving laterals, and traveling gun sprinklers are discussed. Design tables with guidelines for sprinkler spacing under different wind-speed ranges up to 11 m/s are presented for stationary systems. A range of nozzle sizes are shown for square or rectangular spacings.

98. HERSMEIER, L.F., "Evaporation during sprinkler application in a desert climate," ASAE Paper No 73-216, ASAE, 1973, 14 p.

The author studied evaporation from sprinklers in the Imperial Valley of California and found that air temperature and application rate were more important factors for estimating sprinkler evaporation than wind velocity and relative humidity at that location. Evaporation losses were three to four times greater during the day than at night.

99. HILLS, J.H., YUPING, Gu, and WALLENDER, W.W., "Sprinkler uniformity for oscillating low water pressure," Trans. ASAE, 1987, v 30, n 3, p 729-734.

Field tests assessed the effect of a sinusoidal pressure oscillation on application uniformity of impact sprinklers and lawn sprayers. Impact sprinkler nozzle size, nozzle shape, and operating pressure were evaluated under a variety of wind conditions. A sprinkler with a 4 mm circular nozzle operated at a low pressure oscillation of 69 to 207 kPa, 1 cycle/min, provided an application uniformity superior to that of either a similarly equipped sprinkler or one equipped with a 3.5 mm square nozzle--both operated continuously at 138 kPa. An annual cost analysis indicated a slight cost benefit for a pressure oscillating system. With higher energy costs, this benefit would increase.

100. IRRIGATION ASSOCIATION, "Sprinkling pattern spacing and selection," Chap. 7, In: Irrigation, 5th Ed., C.H. Pair, Ed., Irrigation Association, Arlington, Virginia 22209, 1983, p 217-227.

The effects of wind are discussed in the handbook along with all aspects of irrigation system planning, design, and operation.

101. JAMES, L.G, BEST, K., WENDT, D., and KROEGER, M., "Evaporation and wind drift from low pressure irrigation sprinklers," ASAE Paper No. PNR 84-207, ASAE, 1984, 19 p.

The application efficiencies of standard and diffuser nozzle impact sprinklers and selected fixed head spray sprinklers were determined from catch device data. These data were used for sprinkler comparisons and to evaluate the influence of climate and riser height on application efficiencies of these sprinklers.

102. JAMES, L.G., and BLAIR, S.K., "Effect of wind on center pivot application uniformity," ASAE Paper No. 84-2582, ASAE, 1984, 10 p.

The James-Blair center pivot model was modified to consider wind and was used to evaluate the effect of wind on center pivot performance. It was found that winds greater than 4 m/s affect uniformity and that impact-sprinkler spacings of less than 6.1 m (20 ft) had the highest uniformities in winds greater than 4 m/s.

103. JONES, L.K., "Evaluation of water application of a center-pivot sprinkler irrigation system," Unpublished M.S. thesis, Oklahoma State University, Stillwater, OK, 74078, 1974.

The author tested the effect of wind velocity on the uniformity of application for a center-pivot sprinkler system. The relationship appeared to be linear. The uniformities obtained ranged from 81.5 to 90.4 for the system tested.

104. KARNEY, B.W., and PODMORE, T.H., "Performance of stationary gun irrigation systems," J. Irrig. and Drain. Engrg., ASCE, 1984, v 110, n 1, p 75-87.

The field performance of stationary giant gun irrigation systems was evaluated from the results of 70 distribution tests conducted in the interior of British Columbia, Canada. Maximum application rate was found to be a function of average wind speed in the principal wind direction. Evaporation and spray losses were dependent on climatic and operating conditions, primarily the atmospheric vapor density deficit and the average wind speed. The uniformity of application was strongly influenced by both the gun spacing and the average wind speed. Regression equations were developed to relate the various parameters studied. The utility of the relationships in designing and operating giant gun systems is illustrated.

105. KELLER, J., MOYNAHAN, M.D., and PTACEK, R.L., "Sprinkler profile analysis to predict field performance," ASAE Paper No. 71-756, ASAE, 1971.

The authors discuss sprinkler design criteria based on the shift of the center of mass of a sprinkler pattern due to wind velocity and direction.

106. KINCAID, D.C., "Application uniformity of stationary sprinkler laterals at reduced pressure," ASAE Paper No. PNR 84-206, ASAE, 1984, 13 p.

Single sprinkler pattern tests were used to predict uniformity of application from a standard high pressure nozzle and several reduced pressure nozzles at various windspeeds and spacing combinations.

107. KINCAID, D.C., "Minimizing energy requirements for sprinkler laterals," ASAE Paper No. 84-2585, ASAE, 1984, 12 p.

A computer model was developed to utilize single sprinkler pattern tests in simulating stationary lateral sprinkler systems operating under variable wind conditions. The performance of a low pressure nozzle was compared to that of a standard high pressure round nozzle on a typical multiple set lateral system.

108. KINCAID, D.C, NABIL, M., and BUSCH, J.R., "Spray losses and uniformity with low pressure center pivots," ASAE Paper No. 86-2091, ASAE, 1986, 20 p.

Very low pressure, 70-140 kpa, spray heads were evaluated in comparison to high pressure impact type sprinklers for use on center pivots. Application uniformity and spray drift loss were evaluated. Optimum pressure, nozzle spacing, and elevation were determined to minimize energy requirement and spray losses and to maintain acceptable uniformity.

109. KOHL, R.A., "Drop size distribution from medium-sized agricultural sprinklers," Trans. ASAE, 1974, v 15, n 2, p 690-693.

Drop size distributions from medium size sprinklers were measured to study the effects of pressure and nozzle size on the distributions. These are two parameters that farmers can change on existing systems to alleviate field problems of low intake rates and runoff. Drop size distribution in sprinkler spray is important because small droplets are subject to wind drift and pattern distortion while large drops possess high kinetic energy which causes soil particle dislodgement, soil crusting, and runoff.

110. KOHL, K.D., KOHL, R.A., and DEBOER, D.W. "Measurement of low pressure sprinkler evaporation loss," Trans. ASAE, 1987, v 30, n 4, p 1071-1074.

The data presented substantiates theoretical calculations of sprinkler droplet evaporation loss. Losses were less than 1.5% even under moderate wind conditions.

111. KOHL, K.D., KOHL, R.A., and DEBOER, D.W. "Chemigation drift and volatilization potential," Applied Engineering, ASAE, 1987, v 3, n 2, p 174-177.

A sprinkler evaporation and wind drift study was conducted during wind speeds from 4.7 to 9.4 m/s with potassium chloride tracer used to simulate a non-volatile chemical applied via the irrigation water. Low pressure sprinklers mounted at a 4 m height simulated a center pivot or a linear move machine. Tracer distribution downwind were presented for both smooth and coarse spray plate sprinklers for two wind speeds each. The downwind drift zone was relatively short with tracer concentrations of less than 1.0 percent at distances beyond 25 m for the test conditions.

112. KRAUS, J.H., "Application efficiency of sprinkler irrigation and its effects on microclimate," Trans. ASAE, 1966, v 9, n 5, p 642-645.

The author investigated water losses due to evaporation and spray drift and studied evapotranspiration in the drift zone under both low and high wind conditions. Graphical relationships for these were presented. Total losses ranged from 3.4 to 17.0 percent with an average of 36 percent of the loss due to drift. ET in the drift zone is related to wind speed.

113. LIVINGSTON, P., LOFTIS, J.C., and DUKE, H.R., " A wind tunnel study of sprinkler catch-can performance," Trans. ASAE, 1985, v 28, n 6, p 1961-1965

An indoor wind tunnel was constructed to evaluate wind effects on sprinkler catch-can performance. A rain simulator in the tunnel ceiling was used to represent application from a sprinkler. Can- catch depths were compared to known precipitation depths at varied can heights, wind speeds, and surface roughness. An inverse relationship was found between wind speed and percent catch.

114. LONGLEY, T.S., "Evaporation and wind drift from reducepresspriklers," PhD dissertation in Civil Engineering, University of Idaho, Moscow, ID 83843, 1984, 123 p.

A computer model is described for prediction of evaporation and wind drift from a single low pressure spray sprinkler. The evaporation portion of the model is based on energy balance concepts while the trajectory or wind drift portion is based on simple Newtonian mechanics. The model was verified in the laboratory and showed excellent agreement between predicted droplet temperatures, evaporation rates, and impact positions compared to experimentally determined values. Field results were reasonably well predicted, especially after droplet size distribution inputs were altered to account for droplets smaller than 0.3 mm, which could not be measured with conventional stain paper techniques.

115. LONGLEY, T.S., GARVIN, P.C., and STARK, J.C., "Wind drift effects on evapotranspiration under low pressure sprinklers," ASAE Paper 83-2590, ASAE, 1983, 12 p.

Reductions in evapotranspiration (ET) of four crop species were measured down wind of an operating low pressure sprinkler system. The reductions in ET appeared to be directly related to large reductions in dry bulb temperature and the resultant decrease in vapor pressure deficit.

116. LYLE, W.M., and BORDOVSKY, J. P., "LEPA irrigation system evalation," Trans. ASAE, 1983, v 26, n 3, p 776-781.

The LEPA (Low Energy Precision Application) technique was compared to furrow and sprinkler methods. Distribution uniformity and application efficiency were determined for a center pivot sprinkler system near Plainview, Texas under different wind conditions with speeds up to 35.6 km/hr.

117. MACHMEIER, R.E., and ALLRED, E.R., "Operating performance of a boom sprinkler - a field study"" Trans. ASAE, 1962, v 5, n 2, p 220-225.

The authors studied the distribution of water from a boom type sprinkler as affected by wind speed, boom rotation speed, nozzle elevation angle and nozzle pressure. The boom sprinkler was evaluated in winds up to 26 km/hr.

A theoretical relationship between windspeed, maximum boom speed and rotation coefficient of uniformity was developed.

118. MYERS, J.M., BAIRD, C.D., and CHOATE, R.E., "Evaporation losses in sprinkler irrigation," Florida Water Resources Research Center, University of Florida, Gainesville, Fla., 32601, Publication No. 12, 1970, 39 p.

Data are presented to predict the independent effect of water application rate, wind velocity, water temperature and dry bulb and dew point temperature of the ambient air on evaporation losses by water droplets and water droplets in combination with plant intercepted water. The tests were made in a climatic control chamber under simulated Florida conditions.

119. OAKES, P.L., and ROCHESTER, E.W., "Simulation of wind affected application from traveler irrigators," ASAE Paper 81-2086, ASAE, 1981, 18 p.

The authors have written a simulation program for studying travelers working in windy conditions. Their conclusions are: (1) wind parallel to traveler movement is more unfavorable than wind perpendicular; (2) the greater the wind speed, the closer the traveler passages; (3) and the uniformity is always bad at the ends of the strips, but can be improved by start and stop delays.

120. PAIR, C.H., "Water distribution under sprinkler irrigation," Trans. ASAE, 1968, v 11, n 5, p 648-651.

Under southern Idaho conditions, the author studied water distribution under various wind conditions from a handmove sprinkler system, five types of mechanical move and solid set systems operating individually and from three types of systems operating simultaneously with the same wind and system operating conditions. Coefficients of uniformity were determined at different wind speeds. Water application rates were determined for all systems and compared to measured soil infiltration rates. Seasonal cumulative coefficient of uniformity under windy conditions for a handmove system was generally greater than that for individual irrigations.

121. PAIR, C.H., "Application rates and uniformity of application from mechanical move sprinkler systems," Proc. Sprinkler Irrig. Tech. Conf., Atlanta, Ga., 1975, p 71-82. (F)

The author's data demonstrate that wind is not as much of a problem with moving systems as with stationary set systems.

122. REDDITT, W.M., REYNOLDS, W.N., and VAZIRI, C.M., "Effects of operating parameters and wind conditions on uniformity of water distribution by rotating head sprinklers," ASAE Paper No. 68-750, ASAE, 1968, 17 p.

Sprinkler distribution pattern uniformity is shown to be higher under conditions of close spacing, low wind speeds, larger nozzles, intermediate pressures, higher sprinklers, longer set times, increased wind variability, and wind directions parallel to long side of rectangular spacing. Conditions having little effect on uniformity are wind direction on square spacings, and square versus triangular spacings. Different models of sprinklers under similar conditions resulted in differences in uniformity unpredictable without field testing.

123. SCOTT, V.H. and CORRY, J.A., "Sprinkler and lateral spacing," California Agriculture, Apr 1957, p 31-32.

The authors conducted sprinkler tests under wind conditions at Davis, California, and concluded that uniformity of distribution could always be brought within acceptable limits by reducing sprinkler head and lateral spacings.

124. SHEARER, M.N., "Water distribution from a sprinkler lateral moving continuously in a linear direction," Oregon State Univ. Agric. Exp. Sta. Spec. Rpt. 342. 1971.

Coefficients of uniformity under low to moderate wind speeds and wind direction in relation to the moving lateral are reported for a water-drive straight-moving lateral.

125. SHEARER, M.N., "Maintaining uniform distribution with low pressure impact sprinklers," ASAE Paper No. PNR 83-207, ASAE, 1983, 8 p.

Hand move and side roll sprinkler systems can be retrofitted with reduced pressure sprinklers to conserve energy without reducing distribution uniformity by following current spacing recommendations for different wind conditions. Using offsets, tag-along pipe or minor system redesign are suggested for handling wind skip problems.

126. SHULL, H., and DYLLA, A.S., "Traveling gun application uniformity in high winds," Trans. ASAE, 1976, v 19, n 2, p 254-258. (F)

Field tests of a traveling gun sprinkler irrigation system showed that increases in wind velocity must be accompanied by decreases in travel lane spacing if a water application uniformity of 0.85 is to be maintained. Travel lane spacing must be decreased further as the wind direction and travel direction become more nearly parallel. An empirical equation is presented to estimate lane spacing as a function of wind velocity and direction, and sprinkler water pressure, for the sprinkler tested.

127. SHULL, H., and DYLLA, A.S., "Wind effects on water application patterns from a large single nozzle sprinkler," Trans. ASAE, 1976, v 19, n 3, p 501-504. (F)

This report describes a study to determine the effects of wind on the water application pattern for a stationary, single nozzle, gun type irrigation sprinkler. The effects of wind on application uniformity were determined by comparison of the wind- affected application patterns with calculated no-wind patterns. Deviation of the measured patterns from the no-wind patterns increased as wind velocity increased.

128. SHULL, H., and DYLLA, A.S., "Operating large traveling gun sprinklers in winds," Sc. J. series 9558, 1978. (F)

Field tests of travelers in the central western part of Minnesota, where there are strong winds during the irrigation season, have shown that an acceptable value of CU can be observed in 90% of cases for winds not stronger than 4.5 m/s, if the strip widths are limited to 25% of the diameter wetted in still air (manufacturer figures).

129. SHULL, H. and DYLLA, A.S., "Traveling boom sprinkler operation in wind," Trans. ASAE, 1979, v 22, n 3, p 537-539.

Traveling boom sprinkler irrigation system tests show that the system is not well adapted to operation in windy areas. With fixed travel-lane spacing, no spacing will give 85 percent CU 100 percent of the time under all wind conditions using travel-lane spacing wide enough to be field-acceptable. The boom system will provide satisfactory application uniformity if wind speed does not exceed 2 m/s, and the proper lane spacing is used.

130. SILVA, W.L.C. and JAMES, L.G., "Modeling evaporation and micro-climate changes in sprinkle irrigation: I. Model formulation and calibration," Trans. ASAE, 1988a, v 31, n 5, p 1481-1486.

The formulation and calibration of a computer model for estimating spray evaporation and its effect on microclimate downwind from a low pressure, fixed head spray sprinkler are presented. The model is an adaptation of the PSI-Cell model which considers the coupling of mass, momentum and thermal energy between a gaseous phase (the ambient air), and a liquid phase (the spray droplets). Model verification and applications are presented in Silva and James, 1988b.

131. SILVA, W.L.C, and JAMES, L.G., "Modeling evaporation and micro-climate changes in sprinkle irrigation: II. Model assessment and applications," Trans. ASAE, 1988b, v 31, n 5, p 1487-1493.

The model presented in Part I of this paper was found to accurately predict droplet evaporation while predictions of total spray evaporation were reasonably good except when water temperatures were high. Predictions of air temperature and vapor density profiles 15 and 30 m downwind of the sprinkler were within 10% of measured values for wind speeds up to 5.64 m/s. Spray evaporation was very sensitive to droplet size, and moderately sensitive to relative humidity and sprinkler mounting height. Wind speed had an important effect on spray evaporation when droplets were very small and/or sprinklers were mounted high above the ground surface. Downwind microclimate was less sensitive than spray evaporation to changes in wind speed, upwind air temperature and relative humidity, droplet size, sprinkler mounting height, and water temperature.

132. SOLOMON, K., "Variability of sprinkler coefficient of uniformity test results," Trans. ASAE, 1979, v 22, n 5, p 1078-1080, 1086.

The author evaluated the variability to be expected in determining the coefficient of uniformity under nearly identical wind conditions using the same sprinkler nozzle and operating pressure. The standard deviations of uniformity coefficients from individual, independent tests were 2, 4, and 6 when the uniformity coefficients were 90, 80, and 70, respectively.

133. SPURGEON, W.E., THOMPSON, T.L., and GILLEY, J.R., "Irrigation management using hourly spray evaporation loss estimates," ASAE Paper No. 83-2591, ASAE, 1983, 27 p.

Sprinkler spray evaporation losses occurring during hot, dry, and windy conditions can result in low uniformity of application. The authors discuss the possibility of controlling application rates using hourly estimates of the spray evaporation loss to improve the evaporation uniformity and reduce the gross amount of water applied.

134. STEINER, J.L., KANEMASU, E.T., and CLARK, R.N., "Spray losses and partitioning of water under a center pivot sprinkler system," Trans. ASAE, 1983, v 26, n 4, p 1128-1134.

The efficiency of a center pivot sprinkler system was analyzed by monitoring spray losses under various climatic conditions and by examining the partitioning of water within a corn crop canopy. Average spray losses were 12% in 1980 and 16% in 1981. Spray losses included a correlation with climatic variables when the data were]divided into periods with parallel and cross winds. The losses were correlated with vapor pressure deficit, temperature and a wind-vapor pressure deficit term.

135. STERNBERG, Y.M., "Analysis of sprinkler irrigation losses," J. Irrig. and Drain. Div., ASCE, 1967, v 92, n IR4, p 111-124.

The author studied spray/drift and evapotranspiration losses during sprinkling at Davis, California. With wind velocities of 3.2 to 6.4 km/hr (2-4 mi/hr) the combined daytime losses varied from 17 to 25 percent of full sprinkler discharge while nighttime losses were 11 to 16 percent. Sprinkling lowered dry bulb temperature 2.8 to 5°C within the pattern. Efficiencies may be similar for both daytime and nighttime irrigation under low wind velocities.

136. THOMPSON, A.L., GILLEY, J.R., and NORMAN, J.M., "Simulation of sprinkler droplet evaporation above a plant canopy," ASAE Paper No. 86-2108, ASAE, 1986, 50 p.

A simulation model was developed for estimating sprinkler droplet flight and evaporation. The model was coupled with a crop energy balance model to estimate sprinkler evaporation loss as a function of the plant-environment and irrigation system characteristics. The combined model was validated for a solid-set irrigation system above a corn canopy for a range of environmental parameters including wind speed.

137. UMBACK, C.R., and LEBKE, W.D., "Effects of wind on falling water drops," Trans. ASAE, 1966, v 9, n 6, p 805-808.

This is a wind tunnel study wherein the authors developed an empirical relationship between the drift of water particles, windspeed, and droplet size.

138. VON BERNUTH, R.D., "Software for sprinkler system design in windy conditions" ("Progiciel de calcul de réseaux d'aspersion en conditions ve ntées"), International Conference on Agricultural Engineering. AG-ENG, Paris 88 (2 à 6 mars 1988). (F)

Methods used for the design of sprinkler systems under windy conditions are poorly defined as well as contradictory. The University of Tennessee, Knoxville, initiated a study to define new design criteria. However, since the software used requires large amounts of CPU time, their utilization is limited. Still, data from this study allows the determination of U.C. under specific conditions (spacing, wind speed, nozzle type, etc.). The University of Tennessee (U.S.A.) jointly with the Technion of Haifa (Israel) are conducting additional research in this field. Their work should lead to the determination of more accurate design criteria.

139. VON BERNUTH, R.D., "Effect of trajectory angle on performance of sprinklers in wind," J. Irrig. and Drain. Engrg., ASCE, 1988, v 114, n 4, p 579-587.

The effect of changing the trajectory angle of a medium-sized irrigation sprinkler operating in windy conditions was studied using a computer-simulation model. The model, which has been verified both in still air and under windy conditions, shows that the trajectory angle that maximizes distance of throw is a function of the wind velocity and varies from 29° in still air to less than 5° in winds greater than 8 m/s. The advantage gained from trajectory angles greater than 25° in still air is quickly overcome by the disadvantages in range reduction and drift in relatively light winds. When choosing the appropriate trajectory angle, consideration should be given to the drop-size distribution and the wind velocity, because wind drift and range both depend upon drop size and trajectory angle.

140. VON BERNUTH, R.D., and GILLEY, J.R., "Sprinkler droplet size distribution estimation from single leg test data." Trans. ASAE, 1984, v 27, n 5, p 1435-1441.

Droplet size distribution data are useful for predicting evaporation, wind drift, and droplet effects on the soil. The theory and technique for estimating such data using droplet ballistics are described whereby droplet size data can be estimated from routinely collected single leg data. The model was tested for five sets of conditions including three nozzle sizes and three pressures and proved to fit published droplet size data very well. The distributions produced by the estimation technique are presented.

141. VORIES, E.D., and VON BERNUTH, R.D., "Single nozzle sprinkler performance in wind," Trans. ASAE, 1986, v 29, n 5, p 1325-1330.

Set type sprinkler irrigation systems are used extensively throughout the world and their application uniformity is strongly affected by wind. The effects of wind were investigated through computer simulation. Several combinations of nozzle size, water pressure, spacing, and wind direction were simulated over a range of wind speeds. For the conditions studied, triangular spacing patterns were found to be no better than rectangular, and the optimal orientation in a wind was with the wind blowing parallel to the shorter leg of the rectangular spacings.

142. VORIES, E.D., VON BERNUTH, R.D., and MICKELSON, R.H., "Simulating sprinkler performance in wind," J. Irrig. and Drain. Engrg., ASCE, 1987, v 113, n 1, p 119-130.

A method is presented for simulating the operation of a sprinkler system in wind. Equations describing the motion of airborne water droplets are shown. The trajectories of water droplets ejected from a sprinkler were numerically computed. Composite results led to predictions of application patterns. Sprinkler droplet size distribution was used to predict the pattern around a sprinkler, and patterns were superimposed to represent a set (not continuously moving) system. Coefficients of uniformity were then computed. The model was validated by comparing predictions with observed application patterns. Individual and multiple sprinkler tests were compared. The simulation system appeared to be an effective predictor of sprinkler performance in wind. Use of this type model can lead to improved sprinkler designs, although variability of the wind vector affects the accuracy of prediction.

143. WIERSMA, J.L., "Effect of wind variation on water distribution from rotating sprinklers," Tech. Bull. 16, South Dakota Agric. Exp. Sta., Brookings, 1955, 18 p.

This bulletin contains the results of field tests conducted to determine the effect of wind on water distribution from rotating sprinklers. The variables include different sprinkler heads and nozzle combinations, line and riser spacings, naturally occurring approach angles and wind speeds from about 1.8 to 8.9 m/s (4 to 20 mi/hr) four riser heights and water pressures from 170 to 520 kPa (25 to 75 lb/sq in). Wind effects on the uniformity coefficient were determined and presented in a series of regression plots of uniformity coefficient vs. wind speed for the variables studied.

144. WIERSMA, J.L., "Influence of low rates of water application by sprinklers on the microclimate," Pub No. PB-197, Natl. Tech. Information Serv., Spring field, Va 22161, 1970, p 112.

An analysis was made of water losses due to evaporation within the wetted area of a low application rate sprinkler system operating during daylight hours under conditions of slight to moderate breezes. The magnitude of evaporation loss from the sprinkled area was determined by measuring the absolute humidity, temperature, and wind speed profiles immediately upwind and downwind from a large bromus grass field where near-horizontal homogeneity existed prior to operation of the sprinkler. Sprinkler discharge rate and operating pressure had minimal effect on water loss. The losses were mainly evaporation from plant surfaces, which were as high as one-half of the sprinkler water discharge. The greatest decrease in evapotranspiration was adjacent to the wetted area. A field 70 meters downwind from the sprinkler was unaffected. Approximately one-eighth of the water that evaporated within the sprinkled area was offset by a decrease in evapotranspiration in the first 70 meters downwind.

145. WOLFE, D., and DUKE, H.R., "Variability of center pivot uniformity measurement," ASAE Paper No. 86-2092, ASA E, 1986, 16 p.

An experimental study was conducted to evaluate the procedure that is used to determine the uniformity and applied depth of a center pivot irrigation system. The effects of collector spacing, number of rows of collectors, evaporation and drift, type of collector, wind speed and direction, and time of day on the uniformity coefficient and applied depth were determined.

USSR

146. ANISIMOV, V.A., "Calculation method for wind resistant sprinkling through a system with a rotating boom." VNIIGiM, 1986, p 70-79.

Calculation method for wind resistant sprinkling through a system with a rotating boom is described. Plots of poor wetting zone formation during water application and the location of rain reproducing devices over the rotating boom are presented.

147. ANISIMOV, V.A., and MANSUROV, M.S., "Water evaporation losses during sprinkling," Gidrotekhnika i melioratsija, 1969, n 8.

Data on water evaporation losses depending on wind velocity during sprinkling are given.

148. ANONYMOUS, "Evaporation losses during the flight of water-drops in air under sprinkling," Thesisy dokladov 4 nauchno-tekhnicheskoi konferantsyi molodykh rabonnikh aspirantov po gidrotekhnike i melioratsyn, AzNIIGiM, 1966.

Experimental data to determine evaporation losses during the flight of water-drops are given.

149. ANONYMOUS, "Correction of irrigation scheduling for crops based upon water evaporation losses and wind drift during the operation of sprinkler irrigation systems," Vremennye recomendatsyi, StavNIIGiM, 1981.

A recommendation is given which includes data on irrigation water losses for evaporation and wind drift during the operation of sprinkler systems in different soil-climatic conditions of the Stavropol region as well as tables to determine stop time and sprinkler irrigation system speed.

150. ANONYMOUS, "Testing and improving of systems for Kuban linear move," NTO UkrNIIGiM, 1984.

A means of testing and improving auxiliary systems for "Kuban" linear move systems by using an irrigation efficiency coefficient are given.

151. BREDIKHIN, N.P., "About water distribution uniformity from an individual big gun under water wind condition," Voprosy oroshaemogo zemledelija i selskokhozjaistvennogo vodosnabzhenija, vypusk 11, 1967.

Study results concerning wind velocity influence on the irrigation pattern size and on water distribution uniformity are given. A new method of sprinkler pattern computing is used.

152. BREDIKHIN, N.P., "Objective criteria for water application efficiency through a sprinkler under wind conditions," Voprosy on hydrotechnik and melioratsiya IUZHNIIG. M., 1967.

Analysis of spray patterns showed that at the same rotation speed different sprinklers had different sector coefficients. This means that all sprinklers had different "wind resistance." It is possible to determine permissible wind velocities for different sprinklers by using suggested coefficients and to compare sprinkler models.

153. BREDIKHIN, N.P., "Improving efficiency of water application through big guns under wind conditions," Gidrotekhnika i melioratsiya, 1970, n 8.

High, stable water application efficiency through big guns under wind conditions can be obtained by means of designing special wind resistant sprinklers. Operated under wind conditions, the angle of the sprinkler body inclination is automatically changed (during rotation) depending upon the velocity and direction of the wind.

154. BULAVKO, A.G., "About water losses during sprinkling," Melioratsia i vodnoe khoziaistvo, 1973, vypusk 24, Kiev.

Average values of water consumption by winter wheat, spring wheat, barley and potatoes during different vegetation phases are presented.

155. CHICHASOV, V.J., and CHERNOMORTSEV, V.N., "To the question on water losses for evaporation during sprinkling," Sovremennye orositelnye systemy i puty ikh sovershenstvovania, 1974, p 78-84.

Questions on water losses from evaporation during sprinkling are considered, method and results of field study are given.

156. CHUBIKOV, N.E., and PRJACHINA, V.M., "Close-to-ground sprinkler irrigation on soil," Sovershenstvovanije meliorativnykh sistem, sposobov i tekhniki poliva selskokhosjaistvennykh kultur v Povolzhje, vypusk 1, VNIIGiM, Moscow, 1977, p 56-63.

The results of close-to-ground irrigation experiments are described. It was stated that this method does not have a harmful influence on physical soil properties.

157. DANILCHENKO, N.V. "Wind influence on sprinkler systems efficiency," Shirokosakhvatnnaja polivnaja teknika u optimizatsia ejo parametrov, 1984, p 35-49.

Relationships of water jet radius; lines and hydrant spacings to wind velocity are given.

158. ERKHOV, N.S., "Permissible application rate sprinkling," Gidritekhnika i melioratsiya, 1967, n 5, p 74-76.

Tables with data on mean sprinkling intensity for different soil types and slopes as well as permissible rain intensity for sprinkler systems working under wind conditions are presented.

159. FEDORENKO, I.D., "About water evaporation during sprinkling and its' dependence on water-drop size," Sbornik nauchnykh troudov VNIIGiM, tom 22, 1938.

Results of studies on evaporation losses due to water-drop size under wind conditions are presented.

160. FRENKEL, J.I., "Evaporation of fluid drops in the air stream," News of a U.S.S.R. Series Geography, 1944, v. VIII, n 6.

Method and data to determine the structure and value of evaporation losses are given.

161. GORDON, S.M., and BEREZHNOVA, V.N., "Wind influence on sprinklig efficiency through a "Volzhanka" system," Troudy Tekhnika i tekhnologia mekhanizirovannogo oroshenia, 1982, p 34.

The authors state that permissible wind velocity in relation to distribution uniformity for a "Volzhanka" sprinkler system depends on the system pipeline position relative to prevailing winds.

162. GUBER, K.V., and IVANTSOVA, T.I., "Influence of meteorological conditions on evaporation and microclimate formation in Povolzhye during sprinkling," Sbornik nauchnykh troudov VNIIGiM, 1986, p 58-65.

The influence of meteorological conditions on the microclimate created during sprinkling was studied and territories of the Povolzhye region were defined on the basis of the coefficient which characterizes water losses for evaporation and formation of microclimate.

163. GVARAMADZE, I.D., "Wind influence on irrigation water distribution," Sbornik nauchnykh troudov VNIIGiM, vypusk 3, 1976.

Relationships between water distribution and wind velocity are presented. Water application patterns are formed on the basis of these relationships.

164. HABAROV, V.E., "Water losses from evaporation and wind drift during sprinkling," Sbornik nauchnykh troudov Juzh NIIGiM, 1981, p 69-74.

Study results of water losses for evaporation and wind drift from big gun and "Volzhanka" sideroll systems are presented.

165. HABAROV, V.E., "Water losses consideration during sprinkling," Selskie zori, 1981, n 5, p 17. (F)

A table of water losses for evaporation and wind drift from sprinkler irrigation systems and other sprinkler installations is presented.

166. IVANOVA, E.V., and IVANOV, V.M. "Considering water losses for evapo ration during sprinkling," Sbornik nauchnykh troudov, Volgogradsky SHI, tom 76, 1981, p 128-133.

An evaluation of water losses during sprinkling was made. All factors influencing evaporation were taken into account.

167. IVANTSOVA, T.I., "Peculiarities of wind characteristics in Povolzhye and their influence on sprinkling system selection," VNIIGiM. 1986, p 80-88.

An analysis of main wind characteristics of the Povolzhye economics region during the vegetation season (April-September) was presented.

168. KALASHNIKOV, A.A., "Water distribution over the irrigated area through a DDN-45 sprinkler irrigation system under wind conditions of the Stavropol region," Mekhanizatsija selskokhoziast vennogo proizvodstva, vypusk 30, 1968.

The method of nozzle angle variation depending on wind velocity is described.

169. KALASHNIKOV, A.A., "DKSH-64 sprinkler system operation in wind," Sborn ik nauchnych troudov, Stavropolskiy SHI, vypusk 37, tom 2, 1979.

Changes of some operational characteristics of a DKSH-64 sprinkler system due to wind velocity are described.

170. KALASHNIKOV, A.N., and LUSINOV, V. "Water radius of a DDN-45 big gun sprinkler irrigation system under wind conditions of Stavropol region," Sbornik nauchykh troudov Stavropolskij SHI, vypusk 30, 1968.

Data on the DDN-45 sprinkler irrigation system operation in the Stavropol region depending on wind velocity are presented.

171. KALJANOV, G.S. "Evaporation during sprinkling in Zavolzhje," Dostizhenija nauki i peredovogo opyta v selskom khozjaistve, n 5, 1953.

A plot of evaporation as a function of air humidity deficit and wind velocity is presented.

172. KALJANOV, G.S. "About irrigation water losses during sprinkling," Gidrotekhnika i melioratsija, n 11, 1954.

Study results are presented on irrigation water losses determined as a function of air humidity deficit and wind velocity.

173. KHANZAFAROV, V.V., "Water loss for evaporation from drop surfaces during sprinkling through a DDF-100 sprinkler system," Doklady VASHNIL, 1981, n 4, p 41-42.

Conditions of evaporation from drop surfaces during sprinkling through a DDF-100 system were studied.

174. KORJAGIN, A.N., DANILCHENKO, N.V., et al., "Irrigation technologic of pastures," Kolos, 1983.

Wind influence on water jet radius and on irrigation patterns on pastures are given.

175. KORSHIKOV, A.A., Cone-deflector kapron nozzles for DDA-100M sprinkler system," Gidrotekhnika i melioratsiya, 1969, n 6, p 84.

Modifying models of deflector spray-nozzles is one of the ways to improve sprinkler systems distribution uniformity and reliability under wind conditions.

176. KOVALENKO, P.J., "Irrigation water losses and methods of decreasing them," Melioratsia, 1981, n 5, p 74-78

Tables of water losses for many irrigation projects are given.

177. KWAN, R.A., and NEMCHENKO, V.V., "Irrigation water losses determination during sprinkling," Sbornik nauchnykh troudov Sredneasiatskiyo NII irrigatsyi, vypusk 155, 1978, p 95-104.

Irrigation water losses from a DDA-100M(A) sprinkler system depending on temperature, air humidity, wind velocity and direction are experimentally determined.

178. LABUTINA, B.V., "A study of water evaporation losses during sprinkling," Sbornik nauchnykh troudov Volgogradskijo SHI, tom 84, 1984, p 114-119.

Water evaporation losses from a "Volzhanka" side roll sprinkler are presented as determined by volumetrical and chemical methods. Data on water losses due to wind drift are given.

179. LAMPERT, G.P., "Sprinkling under wind conditions through a DDN-70 system at variable angles of the gun," Novoe v teknike i tekhnologii poliva, Moscow, 1980, p 54-58.

Drawing of a sprinkler gun with variable angle, a table of the study results and a diagram of application efficiency and average effective intensity as a function of wind velocity are given.

180. LAMPERT, G.P., and VUKOLOV, V.V, "Sprinklers for water application under wind conditions," Tractory i selskokhozyaist-vennye Mashiny, 1983, n 4, p 15-16.

DVD-80 and DVP-80 sprinkler drawings and a drawing of the sprinkler operating due to wind velocity are presented.

181. LEBEDEV, V.M., and LAMPERT, G.P., "Wind resistant sprinklers," Tekhnika i tekhnologia, Moscow, 1982, p 27-34.

Sprinklers considered in this paper possess better characteristics in comparison with DD-80 sprinklers.

182. LEYBENZON, L.C., "Drop evaporation in a gas stream," An U.S.S.R. Ne8s, Series Geophysica i geographia, 1940, n 3.

Taking into consideration air stream effect on drop evaporation, Leybenzon introduced into the Maxwell equation a new coefficient called "wind multiplier".

183. MANSUROV, M.S., "Water evaporation losses calculation during sprinkling," Sbornik nauchnych troudov AZNINCIM, 1973.

Formulas of different authors are analyzed for calculating water evaporation losses during sprinkling.

184. NAZARENKO, B.A., "Water losses during sprinkling through a DDAA-100MA the system," Sbornik nauchnikh troudov IUZHNIIGiM, 1980, p 141-146.

Evaporation data, and data from wind and surface run-off loss investigations are given. Method of pre-plant and post-plant irrigation through a DDA-100 MA sprinkler system is proposed.

185. NEVDAKH, V.I., "Influence of wind on water distribution efficiency of DKSH-64 and DDN-70 sprinkler systems," Sbornik nauchnykh troudov Belorusskoi akademyi, vypusk 17, 1976, p 94-99.

Water distribution efficiency of DKSH-64 and DDN-70 sprinkler systems under the influence of wind velocity was described. Change of spray radius, area of coverage and coefficient of irrigation were determined.

186. OSTAPCHIK, V.P., "Calculation method for evaporation from the soil during water application," Vestnik selskokhozyaistvennoi nauki, 1981, n 2, p 49-54.

A table and a block-diagram of an algorithm for calculation of evaporation from the soil is given.

187. OVCHAROV, V.A., "Qualitative characteristics of Volzhanka side-roll," Voprosy oroshenija v Povolzhje., VNIIGiM, 1980, p 107-114.

Head influence on water application efficiency from medium ranged sprinkler mounted on native and imported irrigation systems is considered. Wind influence on water distribution uniformity at the optimal head is determined.

188. OVCHAROV, V.A., et al., "Water evaporation losses under sprinkler irrigation systems in Povolzhje," Voprosy oroshenija v Povolzhje, VNIIGiM, 1980, p 88-92.

Water evaporation losses under the lateral move sprinkler irrigation systems: "Fregat" centre-pivot and side-roll "Volzhanka" and "Dnepr" were studied. Dependence of evaporation on air temperature and wind velocity was determined.

189. OVCHAROV, et al., "Study of water evaporation losses during the operation of Fregat and Dnepr sprinkling systems," Voprosy ekspluatatsyi orositelnykh system povolzhia. Sbornik nauchnykh troudov VolzhNIIGIM, 1982, p 123-128.

A linear function of water evaporation losses with temperature and humidity under preset wind velocities was determined. A table of water losses for evaporation under centre pivot and linear sprinkler systems in operation was presented.

190. PONOMARJOV, V.V., "Mist irrigation sprinkler for use in wind conditions," Traktory i selkhosmashiny, 1986, n 7, p 44-59. (F)

The drawings of a MD sprinkler as well as tables are presented.

191. POSPELOV, A.M., "Spray travel time for sprinklers," VNIIGIM, "Dozhdevanie", 1936, v. 2, Selchozgis.

Calculations of spray travel time showed that its mean value for sprinklers with a working head of 50-60 m varies from 3.1 to 3.5 S and is in good agreement with field data.

192. PYLENTIKOV, V.V., "Model, algorithm and calculation of sprinkler jets under wind conditions," Raschet, construcsia i effectivnost osushitelno-uvlazhnitelnykh system v nechernozemnoi zone RSFSR (a book), 1983, p 19-29.

A mathematical model of sprinkler jet dynamics which reflects real processes of the big gun pattern formation under wind condition is presented.

193. RACHINSKY, A.A., and SEVRUGIN, V.K., "Water losses in the air during sprinkling," Gidrotekhnika i melioratsia, 1984, n 11.

The authors state that mean daily value of rain drop evaporation in the air during sprinkler system performance in an arid zone does not exceed 1 per cent.

194. SAKHAROV, A.K., "Water losses for evaporation and wind drift durin sprinkler irrigation," Melioratsia oroshaemyhzemel, 1980.

A table of water losses for evaporation and wind drift from a nozzle to the field surface and a table of possible water losses for evaporation over the vegetative period are presented.

195. SHATVORYAN, O.R., and GAMBARYAN, A.O., "To the question of wind effect on jet length," Troudy ArmNII vodnykh problem i gidrotechniky, 1975, tom 8, p 177-273.

The authors considered wind effects on water radius and made an effort to provide a calculation method to determine the shape of the area covered by the sprinkler under wind conditions.

196. SHOROBOKOV, A.V., "Reduction of water losses during sprinkling by means of optimization of tail water length," Sbornik nauchnikh troudov YuzhNIIGiM, 1980, p 74-75.

Experimental data on the influence of tail water length on distribution uniformity over the field during water application through a DDA-100M sprinkler system, are given. Real dependence of total water losses on tail water length is presented.

197. SHTANGEI, A.I., "Water evaporation from a raincloud during sprinkling," Voprosy gidrotekhniki i melioratsyi na Ukraine, 1982.

Method used and results of an evaporation loss study from the DDA-100M sprinkler irrigation system and the "Fregat" centre-pivot system are presented in the form of graphical and analytical relationships.

198. SHULYAKOV, L.V., et al., "Daily water losses for evaporation and wind drift," Sbornik nauchnykh troudov Belorusskoi selskhozyaistvennoi akademii, 1981, v 72, p 32-38.

Relationships and nomographs to calculate water loss for evaporation into the atmosphere and wind drift during sprinkling are presented.

199. SLIPCHENKO A.A., "Evaporation losses during sprinkling of agricultural crops in North Kasakhstan," Sbornik nauchnykh troudov Tselinnyi SHI, 1985, tom 85.

Experimental study results on the determination of evaporation losses due to wind velocity and air humidity deficit are presented.

200. STANGEI, A.I., "A new method of calculating evaporation losses during sprinkling," Gidrotekhnika i melioratsia, 1975, n 9, p 51-53.

The determination of evaporation losses in the southern part of the Ukraine according to the Cl ion concentration in irrigation water is described.

201. STANGEI, A.I., and SHPAK, I.S., "Water evaporation in the process of water drop movements from a DDA-100M sprinkler installation," Melioratsia i gidrologija, 1975, N11.

Evaporation losses during sprinkling from a DDA-100M sprinkler installation are determined,depending on air humidity and wind velocity.

202. STEPANENKO, P.S., "About water evaporation during short range sprinkling," Sbornik nauchnykh troudov. Institut energetiki i vodn go khoziaistva AN Kirgizskoi SSR, 1959, v 5.

Main experimental data on water evaporation during sprinkling are presented.

203. STRELNIKOV, L.A., "Nomograph to determine water evaporation losses during sprinkling," Hidrotekhnika i melioratsia, 1976, n 8, p 83-84.

The author states that the suggested method to determine water losses for evaporation does not require special researches and can be used for irrigation scheduling.

204. SVINTSOV, N.D., "Determining water losses by sprinkling at Borodaevsk experimental station," Troudy MGMI, 1979, tom 55, p 12-22.

Preliminary results of experimental work near Saratov to determine total losses by groups are given.Losses as a percent of application rate for each group are given and the value of total losses of water application through the DKSH-64 system is obtained.

205. VUKOLOV, V.V., "Big gun for water application under wind conditions," Problemy i sovremennye sredstva oroshayemogo zemledelia, Moscow, 1985.

The concept of big gun operation under wind conditions is described. Distribution uniformity and irrigated area were compared.

206. ZAITSEV, A.A., and SVINTSOV, N.D., "About methods to determine evaporation during sprinkling," Selskokhoziastvennaya melioratsia, Moscow, 1982, p 13-19.

The present state-of-the-art of determining water losses from the surface of a spray was studied. A formula to determine water losses from the surface of a jet was suggested. The formula comprises four parameters, two coefficients, type and operation schedule of the system.

207. ZAK, E.G., "Kinematics of water evaporation in the air flux," Geophisica, 1936, tom 6, v 5.

A formula to determine the life time of a drop during evaporation is presented. It shows that duration of drop life is directly proportional to the square of the drop diameter.

Yemen (People's Democratic Republic)

208. ATEF AB DEL SALAM, et al., "Sprinkler Irrigation - Results of an experimental program on sprinkler irrigation carried out in Fiyush pilot farm," Chapter 3. Wind effect _____ field irrigation efficiency. Project U N D D FAO, 1976, p. 3-7.

The authors made four tests (with windspeeds of 0.6, 2.7, 3.7, and 4.7 m/s) with 18 x 18 m, 18 x 12 m and 12 x 12 m spacings, and calculated Christiansen's CU. Conclusion: above 3 m/s, there is much water loss and for 18 x 18 m, the field irrigation efficiency is not acceptable. If spacings are reduced, the uniformity becomes acceptable for windspeeds larger than 3 m/s, but the rainfall is too heavy. Moreover, the wind speed and direction were analyzed from 0 to 24 h. The authors conclude that irrigation must be limited to the night hours (from 1900 to 0700 hr). Where wind is less than 3 m/s, 18 x 18 m spacing can be used.

Zimbabwe (Rhodesia)

209. STRONG, W.C., "Advanced irrigation design," Africa and Irrigation, Proc. of an International Irrig. Symp. sponsored by Wright Rain, Ltd, Salisbury, Southern Rhodesia, 1961, p 242-246. (E)

Using his own and other data, Strong compiled design tables for stationary sprinkler systems dependent on wind speed. He selected an effective diameter, which was less than the maximum wetted diameter, for design purposes and the prediction of coefficients of uniformity under windy conditions.