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Key Points:
- Kornev's subsurface irrigation method is resurrected
- Philip's analytical description of subsurface emitters is matched with Kornev's irrigation technology
- 2-D fields of Kirchhoff's potential/pressure and flow velocity are presented

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Analytical solution for tension-saturated and unsaturated flow from wicking porous pipes in subsurface irrigation: The Kornev-Philip legacies revisited

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Abstract The Russian engineer Kornev in his 1935 book raised perspectives of subsurface "negative pressure" irrigation, which have been overlooked in modern soil science. Kornev's autoirrigation utilizes wicking of a vacuumed water from a porous pipe into a dry adjacent soil. We link Kornev's technology with a slightly modified Philip (1984)'s analytical solutions for unsaturated flow from a 2-D cylindrical pipe in an infinite domain. Two Darcian flows are considered and connected through continuity of pressure along the pipe-soil contact. The first fragment is a thin porous pipe wall in which water seeps at tension saturation; the hydraulic head is a harmonic function varying purely radially across the wall. The Thiem solution in this fragment gives the boundary condition for azimuthally varying suction pressure in the second fragment, ambient soil, making the exterior of the pipe. The constant head, rather than Philip's isobaricity boundary condition, along the external wall slightly modifies Philip's formulae for the Kirchhoff potential and pressure head in the soil fragment. Flow characteristics (magnitudes of the Darcian velocity, total flow rate, and flow net) are explicitly expressed through series of Macdonald's functions. For a given pipe's external diameter, wall thickness, position of the pipe above a free water datum in the supply tank, saturated conductivities of the wall and soil, and soil's sorptive number, a nonlinear equation with respect to the total discharge from the pipe is obtained and solved by a computer algebra routine. Efficiency of irrigation is evaluated by computation of the moisture content within selected zones surrounding the porous pipe.

Plain Language Summary Subsurface irrigation by automatic gadgets like pitchers or porous pipes is a water saving technology which minimizes evaporative losses and deep percolation. Moisture is emitted by capillary suction of a relatively dry soil and thirsty roots just in right quantities, spontaneously and continuously, i.e. without any electronic or mechanical controls. Almost a century ago the Russian engineer Vasily Kornev designed and tested this smart watering technology in France and USSR. Later, the Australian soil physicist John Philip developed mathematical models which predicted how much water is emitted from a porous pipe and how this moisture is distributed in the near-emitter soil. We develop further Philip's theory and match it with Kornev's farmers-level design and irrigation practices. Namely, we predict how the pipe wall properties and negative water pressure in porous pipes are controlling soil water conditions.

1. Introduction

Subsurface irrigation is used in arid and semiarid regions for increasing the water use efficiency and other agronomical and environmental benefits [see, e.g., *Lamm and Camp*, 2007]. The Soviet Engineer Vasily Kornev was one of a group of Russian soil scientists engaged in using and modifying the earlier invented tensiometer [see, e.g., *Or*, 2001]. He coined the concept of the water retention curve [see *Kutilek and Novak*, 1997]. In 1935, *Kornev* [1935, hereinafter K-35] published a book where he presented a ubiquitous field evidence of the efficiency of a technology of automatic subsurface irrigation which was based on suction of water from porous pipes.

The pipes worked as wicks for the ambient dry soil into which water was supplied by siphoning from a buried water supply container where the water level was below the locus of porous pipes. Physically, the exterior of porous pipes walls should be in a good contact with the ambient soil because otherwise, as K-35