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Section 2 Test Methodology and Assessment

Subgroup 4 : Evaluation of Superficial Treatments for Preventative Action against Basidiomycetes

A NON-PRESSURE METHOD OF PROTECTION BASED ON HURDLE THEORY TO CONTROL THE SPECTRUM OF INTERNAL ENVIRONMENTAL FACTORS WHICH AFFECT THE DECAY OF POLES IN SOIL CONTACT

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SUMMARY

A field trial was conducted to establish whether superficial barrier linings on poles in soil contact could function as environmental hurdles against the growth of biological agents and thus provide preventative methodology to preclude premature failure of vineyard poles under flood-irrigation. Assessment after 52 weeks´ exposure to the prevailing conditions and sub-tropical environment showed that open-ended cylindrical linings of biologically inert heat-shrink polyethylene applied to the vertical soil-contact surfaces of _Eucalyptus grandis_ poles unequivocally prevented termite-induced failure of untreated poles, basidiomycete decay of creosote-treated poles and fungal colonisation of CCA-treated poles. The success of the liners in prevention of incipient decay of these poles was explainable on the basis of hurdle theory and was therefore attributed to the ability of the former to control essential growth factors and create internal conditions inimical to the proliferation of decay agents in the poles. Consequently, sub-optimal conditions of Aw, Eh, and nitrogen content were considered to have arisen to function as environmental hurdles which decay agents could not overcome at wood-soil interfaces.

KEY WORDS : poles; premature failure; preventative treatment; barrier lining; growth factors; hurdle theory.

INTRODUCTION

Premature failure of preservative-treated poles in soil contact has been the subject of intense debate on the various platforms of the International Research Group on Wood Preservation for two decades. Most of the debate has correctly focussed on possible reasons for premature failure according to the rationale that an explanation of the phenomenon would in turn lead to an effective solution of the problem. However the elusiveness of satisfactory explanations to date has not benefited the many end-users who have often been obliged to place treated poles in soil-contact without certainty that such poles would not fail (Fig. 1) before the predicted service life had elapsed. For example, a recent survey has shown that 20% of treated gum poles in South African vineyards had failed after 10 years' service, and 358,000 such poles are replaced annually at a cost of approximately US$ 1m (pers. comm., V. Kriel, Boeresake, Cape Province). Similarly, another survey has shown that transmission poles also suffer premature failure in South Africa, where approximately 110,000 new wooden poles are currently placed in service annually (pers. comm., H.P.J. Fouche, ESKOM, Transvaal). A need therefore exists for reliable predictability of service life.

Fig. 1. A creosote-treated Eucalypt vineyard pole showing onset of premature failure below the (arrowed) ground line after 3 years of service under flood irrigation on the banks of the Orange River.

Remedial treatment of poles decayed in soil contact is practised widely, but this is relatively expensive, with the result that wine farmers in South Africa have considered the introduction of alternative materials, e.g., cement or plastics, as substitutes for wooden poles in vineyards under flood-irrigation. Such a market-shift would adversely affect many business sectors of the local timber industry. In these circumstances this writer tested and assessed an apparently simple method designed to reassure farmers that premature pole failure could be prevented.

The preventative method used in this work has been described elsewhere (Baecker, manuscript currently under review by Material und Organismen) and will be only briefly reviewed here to facilitate the assessment of its success in the present paper. Although the device used in this method is physically simple, the writer believes that assessment of its success is complex. It is felt that the preventative action of this device can only be fully explained by consideration of its possible effects on several interdependent mechanisms which affect the growth of microorganisms in soil. The argument developed in this assessment therefore uses biological principles to establish points of logic in a theoretical explanation which shows how factors which affect microbial growth may have been controlled by the device, thus effecting its success as a preventative treatment against premature pole failure.

MATERIALS AND METHODS

The device tested for prevention of premature pole failure was an open-ended cylindrical sleeve (500mm long x 70mm diam.) of heat-shrink polyethylene (180mm thick) applied to the longitudinal soil-contact surface of the treated pole (Fig. 2). Standard (SABS 457-1982) Eucalyptus grandis Hill ex Maid. dropper poles (1200 x 60mm) were treated to targeted standard soil-contact retentions of 16kg m-3 CCA (SABS 673-1987) and 100kg creosote (SABS 1290-1980) by the full-cell vacuum-impregnation and the empty-cell impregnation processes (SABS 05-1980) respectively.

Sleeved and unsleeved replicates (4) of treated and untreated poles were erected 500mm apart, in previously described (Baecker, Schnippenkoetter, Shelver and Scherer, 1991) Hutton soil, in mid-summer in the grounds of this practice on the banks of the Palmiet River in Natal. A rotary pump was used with an irrigation system to flood the test-site with unchlorinated river water for two hours twice per week for one year. Ambient temperatures in the sub-tropical environment ranged between 3-39C.

When poles were inspected after 52 weeks´ exposure they were carefully excavated, stripped of their sleeves and were then longitudinally sectioned. Macroscopically visible effects of wood decay were photographed. Samples for scanning electron microscopical examination were removed from the poles and prepared as before (Abraham, Westlake, Mackie, Putterill and Baecker, 1989).

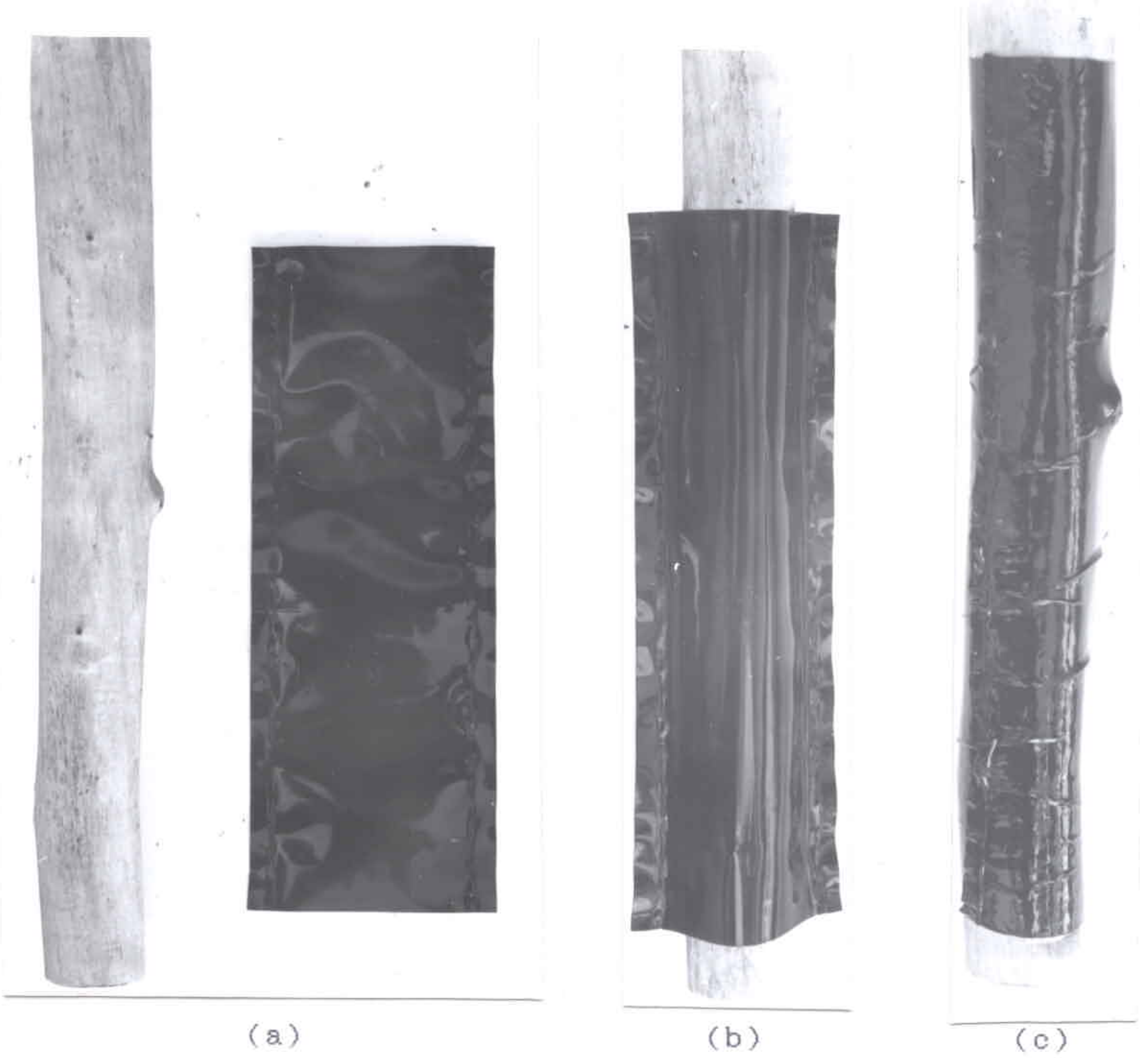
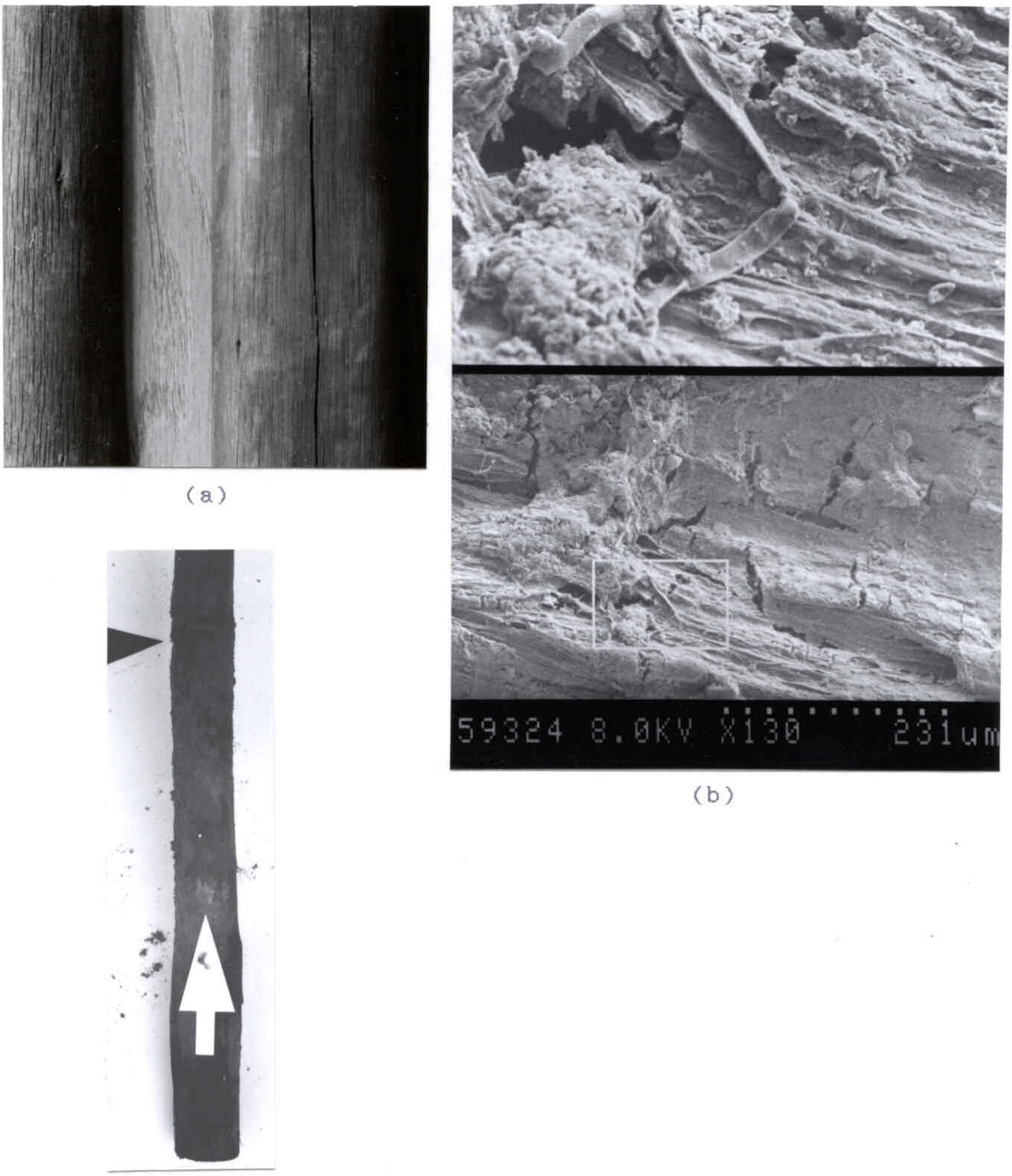


Fig. 2. Application of sleeve, showing (a) unsleeved pole and sleeve (b) sleeved pole prior to heat treatment and (c) shrunken sleeve after heat treatment.

RESULTS

Within 6 months′ exposure, unsleeved untreated poles had been totally mineralised by termites and fungi below the soil surface however their sleeved counterparts were only slightly decayed at the wood-sleeve interfaces (Fig. 3) and remained sound, even after 12 months′ exposure. Similarly, the soil-contact surfaces of unsleeved creosote-treated poles showed incipient basidiomycete decay within 6 months, whereas their sleeved counterparts were uncolonised and remained in pristine condition at their wood-sleeve interfaces (Figs. 4a and b). After 12 months′ exposure, the soil-contact surfaces of unsleeved creosote-treated poles supported a biofilm 2mm thick and when this was scraped off (Fig. 4c), widespread fungal mycelium was macroscopically visible. Similarly, the soil-contact surfaces of CCA-treated poles without sleeves were superficially colonised by decay fungi, whereas their sleeved counterparts were again uncolonised after 12 months´ exposure (Fig. 5).

Fig. 3. Untreated poles after 6 months´ in soil-contact showing that unsleeved poles (left and centre) were mineralised below the ground line (arrowed), whereas sleeved poles (right) were not.

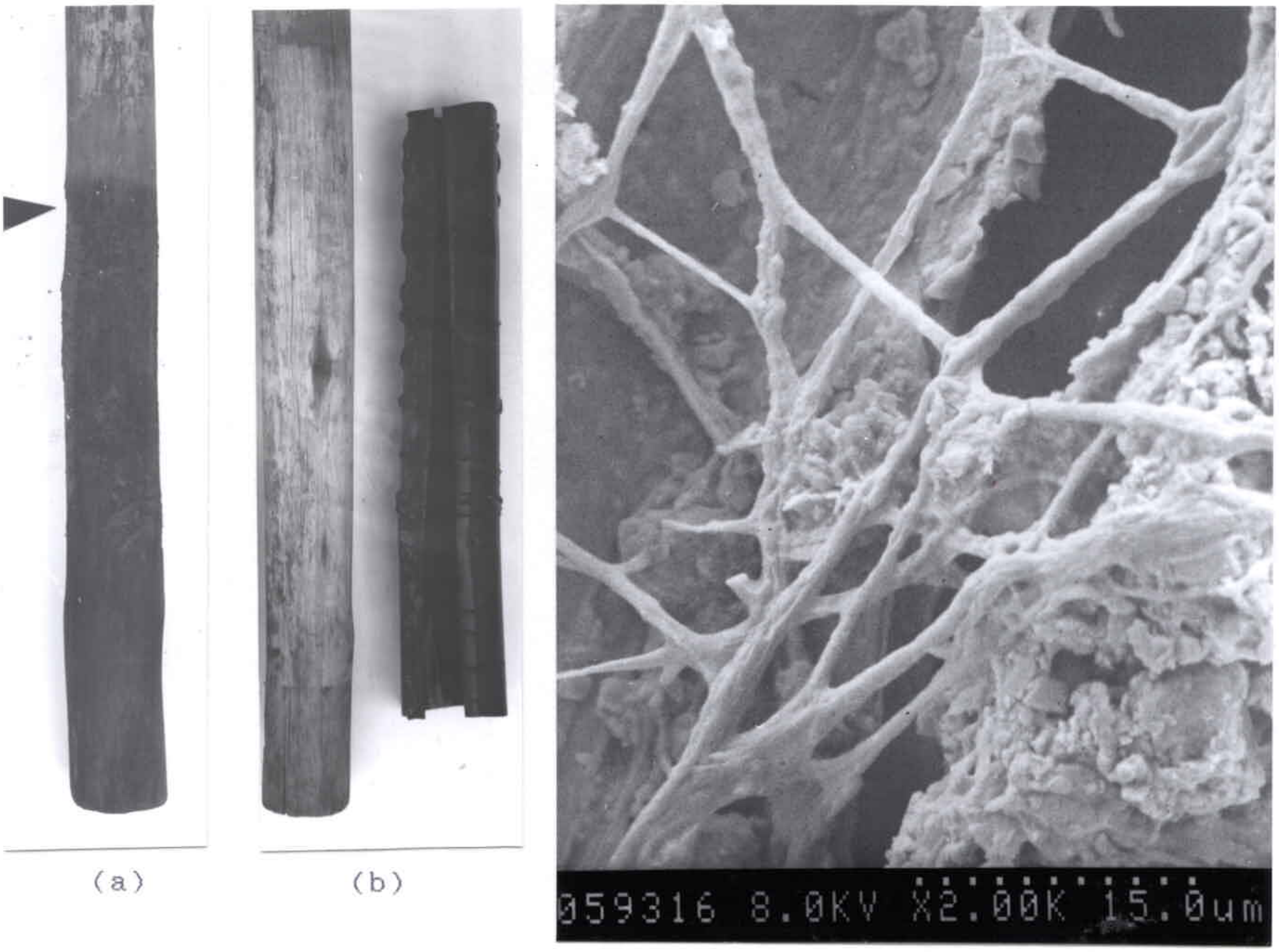


(a)

(b)

(c)

Fig. 4. Creosote-treated poles after (a and b) 6 months in soil. The unsleeved poles (a, left) showed incipient decay and were colonised by fungi (b), but sleeved poles remained undecayed (a, right). After 12 months' exposure (c) the unsleeved poles were extensively biofilmed (white arrow) below the ground line (black arrow).



(a) (b) (c)

Fig. 5. CCA-treated poles after 12 months' soil-contact showing (a) surface of unsleeved pole darkened with black fungal mycelium below ground line (arrowed), in contrast with (b) uncolonised appearance of sleeved pole. The mycelium on soil-contact surfaces of unsleeved poles (c) grew as biofilms in association with bacteria.

DISCUSSION

The primary conclusions of this work are simple and unequivocal, viz., under the test conditions used, the sleeves prevented :-

i) failure of untreated poles,

ii) incipient decay of creosote-treated poles, and,

iii) colonisation of CCA-treated poles.

The debatable aspects of this work arise when mechanisms are sought to explain the success of this device, which insulated the wood only partially below the ground line, in prevention of microbiological attack of that wood from the soil. There is no doubt, however, that a failed pole represents a source of nutrition which has been spoiled by microorganisms. It was consequently felt that the obvious starting point at which to assess the findings of the present work was to consider a piece of wood as a niche interfacing with soil as an ecological domain (Wimpenny, 1981), and that the niche is available to the soil microorganisms which can decay its microstructure as a direct consequence of their central carbon metabolism. However, to decay such wood, soil microorganisms firstly require to colonise it, and to do that, their basic requirements would necessarily be for growth to cross the wood-soil interface. Microorganisms fill niches by adopting ecological strategies. Ecological strategy concepts developed for higher plants (Grime, 1977) have now been extended to saprotrophic and plant pathogenic fungi (Pugh, 1980; Cooke and Rayner, 1984; Rayner and Boddy, 1988; Andrews, 1991). Broadly speaking, to metabolise in an ecological niche, microorganisms require access to, followed by colonisation of, the niche, which should provide the following for proliferative growth :-

i) water, at suitable water activity (Aw),

ii) air, to provide suitable partial pressure of oxygen (pO2) for oxidative organisms; or, lack of air to provide suitable redox potential (Eh) for the metabolism of facultative and/or obligate anaerobes,

iii) substrate containing, inter alia, macronutrients such as carbon (C) and nitrogen (N) in proportions which are suitable (e.g., 15C : 10N) for sustainable microbial growth,

iv) suitable temperature and pH, and,

in addition to the above growth factors, the microorganisms require :-

v) time, in which to grow and manifest their effects on the substrate.

In summary, assuming that pH and temperature are suitable for microbial growth, and that time is available for decay to proceed, the organisms only need access, water, air and nutrients to penetrate the microstructure of the niche and decay the wood elements. However, any of these factors, if deficient, will limit growth and any such deficiency can thus be regarded as an obstacle which the organism must overcome in order to colonise the given niche and utilise the substrate. In such terms, the obstacles which fungi must overcome to decay untreated wood in air are twofold, viz., the inimical Aw of dry wood and the limiting N status of wood (Merrill and Cowling, 1966), which can be as great as 500C : 1N (Allison, Murphy and Klein, 1963).

On the basis of the above logic, it was consequently felt that the phenomenon of pole failure correctly lent itself to analysis in terms of the concept of hurdle theory as recently described by Liestner (1987), who adopts an ecosystem approach to food preservation. Briefly, the principle which forms the basis of Liestner´s hurdle theory is that four groups of parameters affect microbial growth and survival on food, viz.,

i) extrinsic factors, which comprise all that surrounds the food, such as temperature and relative humidity,

ii) intrinsic factors, which are inherent aspects of the food, such as preservatives, or the shell of an egg,

iii) processing factors, which affect the magnitude and diversity of resident microbial populations in the food, and,

iv) implicit factors, which are those that are dependent on the properties of the microorganisms themselves and therefore encompass the microbial ecology of the food, where only the fittest will survive.

First and foremost, intrinsic chemical and physical parameters affect the fate of the food and, in declining order of selective pressure exerted, such growth factors comprise Aw, pH and buffering capacity, Eh and nutrient status (Mossel, 1983). When the values of these parameters are inimical to microbial growth, they are considered to constitute hurdles which the microorganisms must overcome to affect the food. Furthermore, it is well known that given growth factors influence the effects of others on microbial growth. The complex way in which all the above growth factors interact will determine the "net effect" of the microorganisms on the food (Fig. 6). If the "net effect" of the four groups of parameters is +ve, microbial colonisation of the substrate wiil occur. If the "net effect is 0 or -ve, the resident microbial populations will not grow, they may die, and importantly, secondary colonisers cannot overcome the hurdles.

In the above example of dry untreated wood in a domain of air, two hurdles against its decay exist, viz., Aw, since its value is inimical to microbial growth, and N, since its concentration in wood is limiting to microbial growth. If we now apply the principles of hurdle theory to an unsleeved untreated pole in a domain of in moist soil :-

i) extrinsic H2O is increasingly present in the descending soil profile (Fig. 7a) and by diffusion across the wood-soil interface, the wood moisture values reach levels which would provide an intrinsic Aw suitable for microbial growth in a zone we will refer to as the danger zone (Fig. 7b), since one of the intrinsic hurdles, viz., Aw, has disappeared,

ii) extrinsic air is increasingly present in the ascending soil profile (Fig. 7b) and, also by

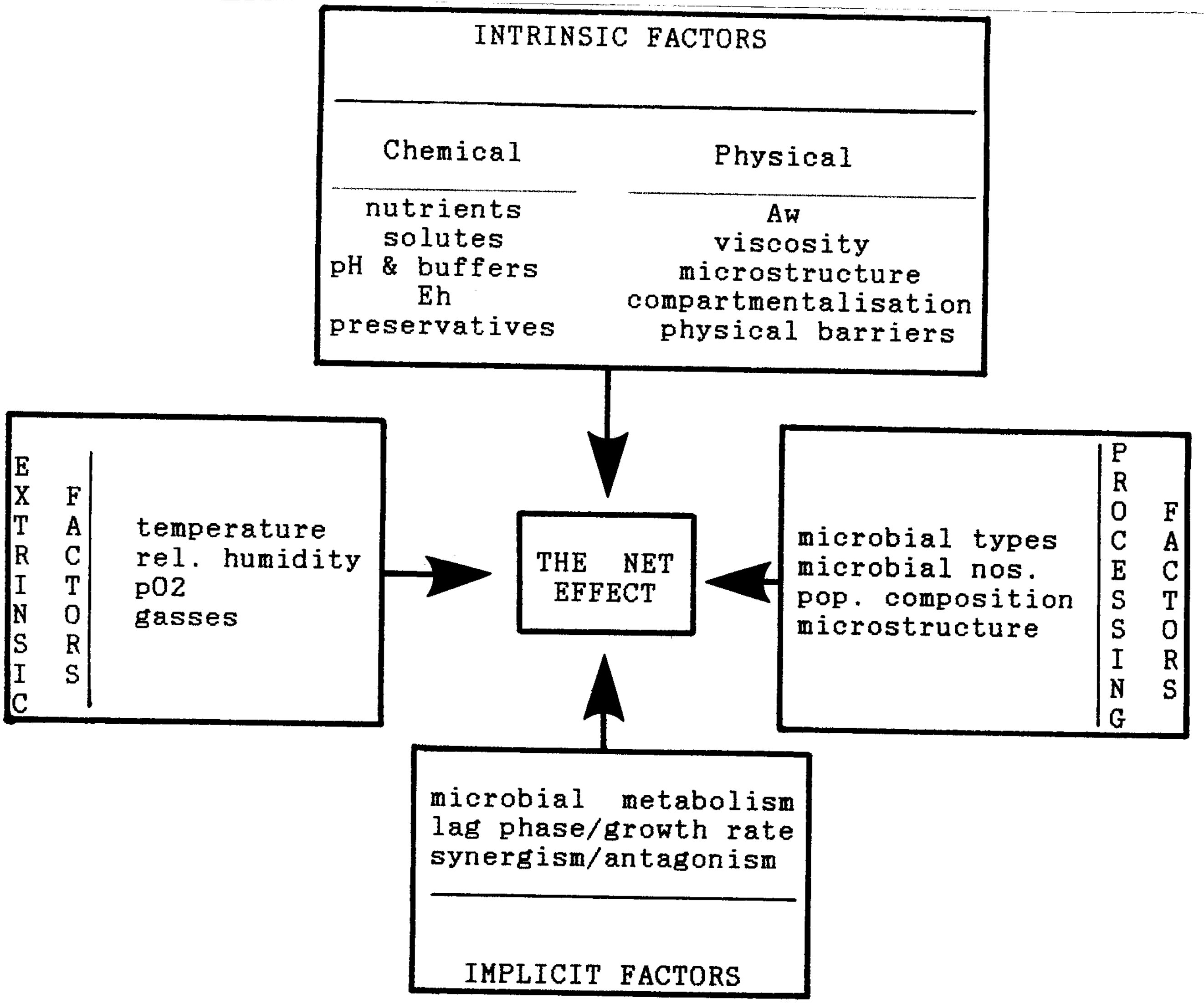


Fig. 6. The interactions of intrinsic, extrinsic, implicit and processing factors in determination of the net effect of microorganisms on the fate of a metabolic substrate.

diffusion, the oxygen levels in the wood reach levels which would provide an intrinsic pO2 optimal for microbial growth at a point which may lie somewhere in the danger zone, although low Eh may also develop as a hurdle against aerobes in the lower, anaerobic, zones of the soil profile,

iii) the macronutrient C is available throughout the wood, but, N is intrinsically limiting, and,

iv) resident microflora are intrinsically present and access by extrinsic soil fungi is unrestricted.

If traces of available N are present on the wood surfaces, and this is often the case (King, Oxley and Long, 1974), commensals and soil fungi may then grow in the danger zone of the wood and cause some incipient decay by mineralising its C, but progressive decay is arrested by the limiting N status (Merrill and Cowling, 1966) of the wood. Nitrogen deficiency therefore remains as a single hurdle against the decay fungi (Fig. 7b). However, it is common knowledge that, with time, wood in soil will become totally mineralised. Therefore, since soil fungi can translocate N into wood (King and Waite, 1979) and thereby increase its N-content (King, Smith, Baecker and Bruce, 1981), it may well be the case that incipient decay progresses to failure in the danger zone of poles (Fig. 7c) primarily because the responsible fungi have unrestricted access across the wood-soil interface at such points in the soil profile. In these circumstances, it seems probable that at least one ecological function of fungal hyphae in the biofilms observed at wood-soil interfaces (Rogers and Baecker, 1987) may be to overcome the remaining hurdle of wood-nitrogen limitation by translocating soil nitrogen to the wood in order to mineralise the excess carbon available therein.

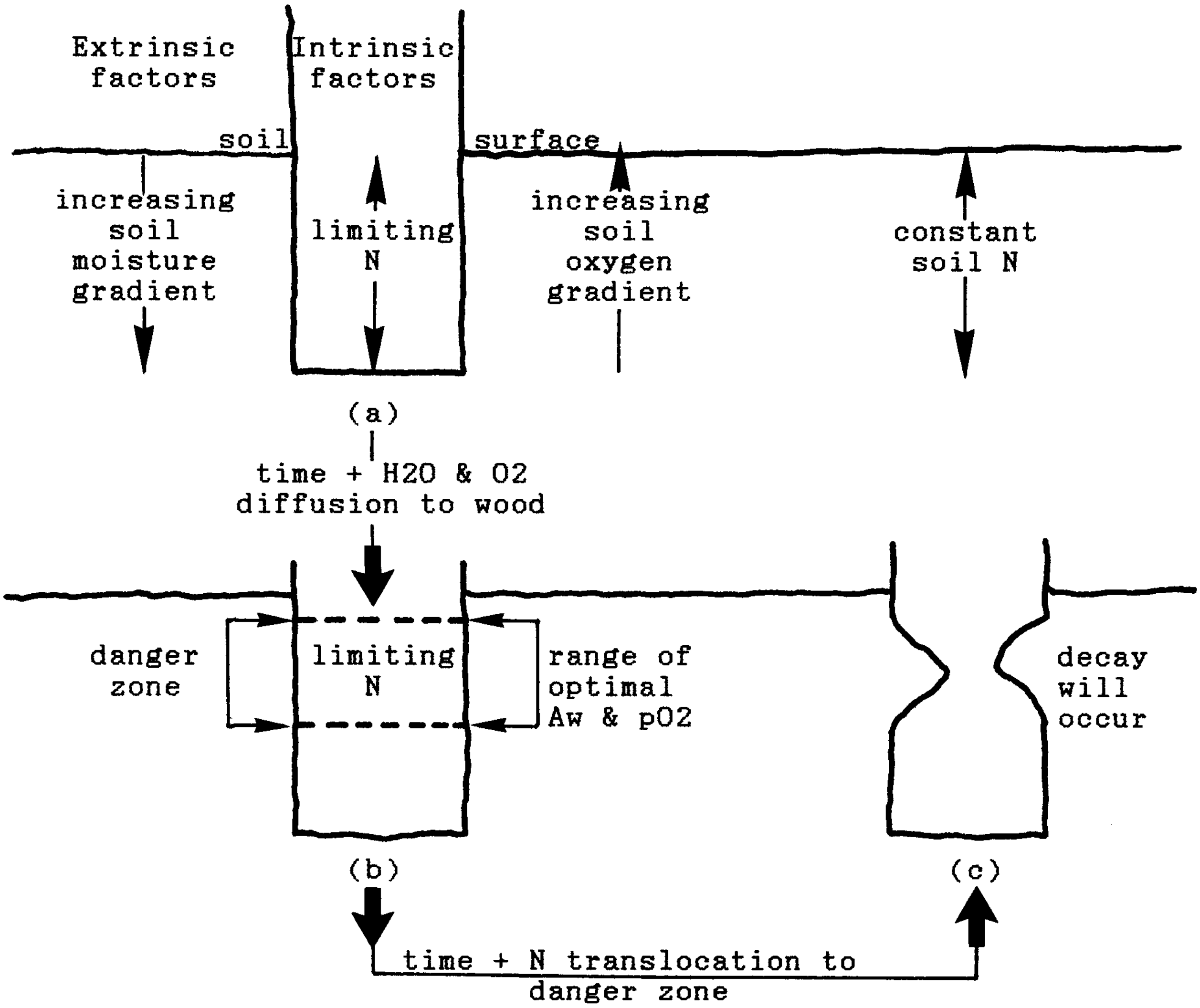


Fig. 7. Positive net effect of factors affecting the fate of an untreated pole in a domain of moist soil.

The nature of the failure of the untreated unsleeved poles in the present work (Fig 3) seemed consistent with the above argument and the biological events proposed to correspond with the progress of their decay are summarised schematically in Fig. 8 (a, b and c). In the counteraction of such failure, the traditional application of wood preservatives to unsleeved poles should now, in the present context, be regarded as the imposition of an additional hurdle against the progress of decay fungi.

Wood preservatives are considered to toxify the metabolic pathways of microorganisms at the wood-soil interface, which, in the present terms of reference, should effectively prevent fungal growth and should thus preclude decay in soil (Fig. 8d), even if N was not limiting. However, with time, incipient decay of treated poles can occur, as shown in the present work (Fig. 4) and represented schematically in Fig. 8e. This symptom, which appeared within 6 months in the present trial, constitutes the forerunner of premature failure of treated poles at the danger zone (Fig. 8f), for reasons not yet fully explained, as mentioned above.

In the case of a sleeved untreated pole in soil (Fig. 8g), two interfaces are created by the sleeve, i.e.,

a) the wood-sleeve interface, where

  i) resident microflora are present, but direct access of soil fungi is excluded,

  ii) H2O is present, and it is proposed that the sleeved portion of the pole will contain a danger zone wherein Aw will not constitute a hurdle against decay fungi,

  iii) air is present and the pole may contain oxygen levels suitable for growth in the danger zone, in which circumstances pO2 would not constitute a hurdle in the danger zone, and,

  iv) C is present, but N remains a hurdle, therefore,

decay is limited (Fig. 8h) as before; however it is further proposed that decay remained limited in sleeved untreated poles in the present work (Fig. 3) because at

b) the sleeve-soil interface

  i) aerobic soil fungi were undoubtedly present as viable hyphae in the danger zone, and probably as spores at the top and bottom of the soil profile, but,

  ii) access of N-translocating soil fungi to the danger zone of the wood was indirect and restricted to via the top or bottom of the sleeve, and,

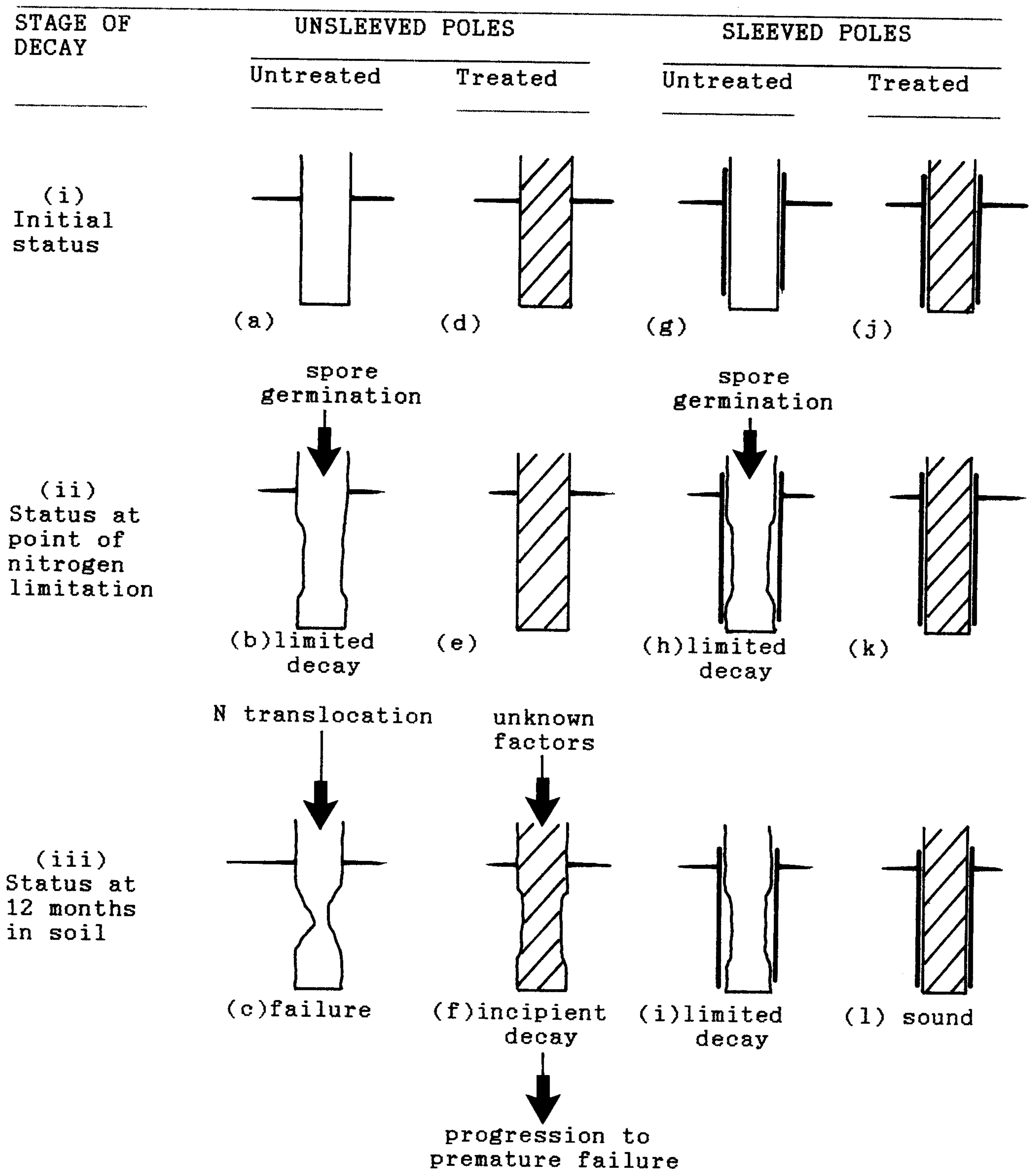


Fig. 8. Schematic representation of biological events leading to decay status of (a, b, c) untreated, unsleeved poles; (d, e, f) treated sleeved poles; (g, h, i) untreated sleeved poles, and; (j, k, l) treated sleeved poles at stages when (i)initially placed in soil, (ii) at the point of nitrogen limitation and(iii) after nitrogen translocation from soil to the poles.

iii) H_2O was available at the bottom of the sleeve but pO_2 and probably also Eh constituted hurdles at this point therefore dormant soil fungi could not germinate and grow there, nor could viable hyphae descend to this point from the danger zone of the soil, and,

iv) air was available at the top of the sleeve but at that point Aw constituted a hurdle therefore dormant soil fungi could not germinate and grow there, nor could viable hyphae ascend to this point from the danger zone, therefore,

access to the danger zone was effectively denied to soil fungi, therefore nitrogen translocation could not have been used to overcome the intrinsic N hurdle, and decay would consequently have remained limited to that produced by the resident microflora at the wood-sleeve interface (Fig. 8i).

In the case of a sleeved preservative-treated pole (Fig. 8j) it is assumed that the toxins introduced as processing factors prevented germination and/or metabolism of the resident microflora (Fig. 8k) and in that result (Figs. 4 and 5) even incipient decay did not occur in the danger zone (Fig. 8l).

It is now considered appropriate to discuss an important reason for ensuring that the ends of the sleeves were not sealed over the lower transverse ends of the poles, which sealing would, at first sight, appear to constitute a simple procedure to increase the hurdle effect of the sleeves.

The open-ended configuration of the sleeves precluded their internal accumulation of rainwater via the wood-sleeve interfaces. Under such conditions water accumulated inside end-sealed sleeves would soon be rendered anaerobic owing to respiration of resident aerobes followed by fermentation by facultative anaerobes in that niche. The lowered Eh would then render conditions suitable in that microniche for sporulation and growth of recently-discovered (Rogers and Baecker, 1991) obligately anaerobic bacteria which can degrade wood (Rogers, Jackson, Shelver and Baecker, 1992). These bacteria produce xylanases in wood (Baecker and Rogers, 1991) and enhance the delignification of such wood at low Eh (Shelver, Matai, van Wyk and Baecker, 1991). Such events may have led to the extensive bacterial colonisation of CCA-treated vineyard poles which recently suffered premature failure in New Zealand (Singh and Butcher, 1989). In contrast, the open-ended nature of the sleeves probably permitted the upper sections of the poles to act as evaporative wicks (Levy, 1968) which drew water from the depths of the soil profile. Such water could contain traces of oxygen sufficient to maintain the Eh over the upper limit of obligately anaerobic growth, but below the level required for the strongly oxidative metabolism of basidiomycetes. Therefore, the advanced effects of these major agents of wood decay were considered to have been excuded from the wood niche because a low Eh hurdle was created when open-ended sleeves were applied.

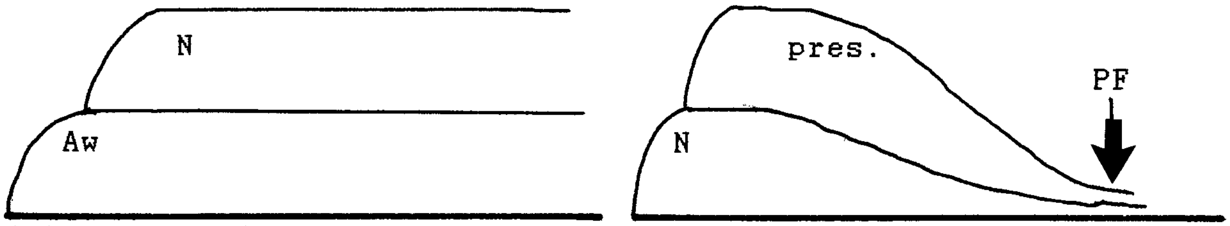
Some conclusions of the above hurdle analysis of sleeved poles in moist soil are summarised in Table 1, and from that summary it was possible to construct schematic representations of the proposed hurdles in Fig. 9. It should be noted that the sequence of hurdles in given substrates is not arbitrary, but it may indeed be fixed because, during the processing and storage of certain foods, such as raw hams, particular hurdles develop or fade out again. Since the existence of the hurdles proposed to have affected decay in the present work have neither been confirmed nor quantified by the writer, it was not considered appropriate to speculate on sequences when constructing Fig. 9.

Table 1. Hurdles proposed to have protected stability of wooden poles for 12 months in various domains which contained microorganisms.

Domain	Pole classification	Hurdle					Stability
		Aw	p02	Eh	N	pres.	
air	untreated	+			+		+ (Fig.9a)
surface soil	untreated	+			+		+
	treated	+			+	+	+
deep soil	untreated		+	+	+		+ (Fig.9b)
	treated		+	+	+	+	
danger zone of soil	untreated				+>		(Fig.9c)
	treated				+>	+>>	PF(Fig.9d)
	sleeved untreated				+		+ (Fig.9e)
	sleeved treated				+	+	+ (Fig.9f)

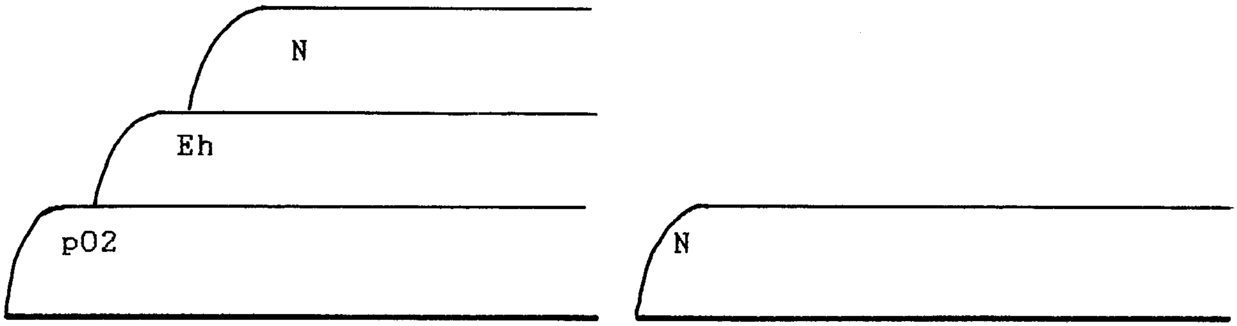
N :- limiting nitrogen
> :- diminishing by fungal translocation
>>:- diminishing for unknown reasons
PF:- premature failure possible consequence of incipient decay

On the basis of the theoretical argument presented above, the major hurdles which seemed to affect untreated wood in moist soil were considered to comprise Aw, p02, Eh and access. If this were the case, optimal adjustment of these factors could bring about a stable product, in spite of the close proximity of decay fungi. It is possible to construct a "magic square" (Leistner, 1987) of these parameters specifically for untreated sleeved poles in soil (Fig. 10a). If p02 and Eh are considered jointly, and if access is considered to represent N translocation, these, together with Aw and preservatives could be used to construct a "magic square" for treated wood in soil (Fig. 10b). As exercises with the present concepts have been used to develop practices such as the safe storage of sausages without refrigeration, it is here suggested that similar work could produce strategies to



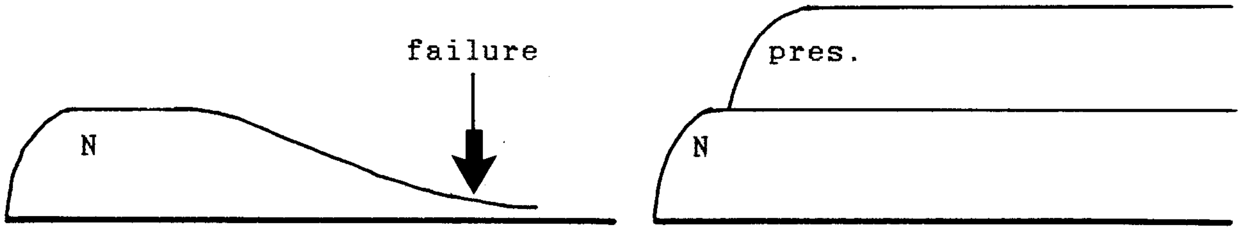
(a) untreated wood in air

(d) treated wood in danger zone



(b) untreated wood in deep soil

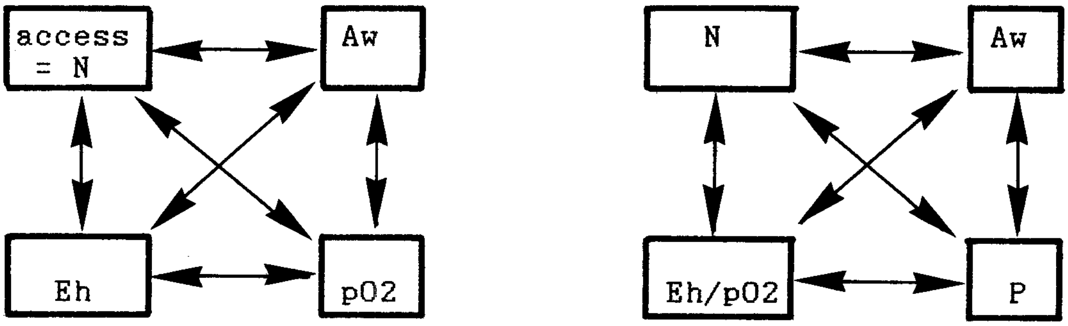
(e) sleeved untreated wood in danger zone



(c)untreated wood in danger zone

(f) sleeved treated wood in danger zone

Fig. 9. Illustration of the hurdle effects proposed to exist in wood exposed to microorganisms in (a-e) various domains (see Table 1).



(a)

(b)

Fig. 10. "Magic squares" (Liestner, 1987) proposed for possible interactions of the hurdles N, Aw, pO2, Eh and P (preservative) in (a) untreated wood and (b) treated wood in soil.

enhance stability of wood products. For example, the unknown factors which effected the decay of the above unsleeved treated poles clearly did not affect sleeved treated poles in the same way, which, although outwith the present terms of reference, may provide a clue in future attempts to explain premature pole failure. It is known that preservative levels decrease in wood as it decays in soil (King, Smith, Briscoe and Baecker, 1989), and in the sea (Shelver, McQuaid and Baecker, 1991), therefore it could have been the case in the present work that one of the important influences of the sleeve on the stability of a treated pole was a two-fold function of N-excusion and preservative retention.

In view of the significance of the primary conclusions of the present work, the method described appears to have real applications, and it is thought worthwhile to consider the possible advantages associated with its use. The direct financial benefits can be reckoned on the basis that, with labour, the replacement cost of a failed pole is 5 - 10 times the cost of the pole itself (Murira, 1992), excluding losses attributable to down-time in supply of service during replacement. The sales value of treated poles in South Africa alone was US$ 31m in 1991 (pers. comm., A. Currie, South African Wood Preservers' Association).

The environmental benefits may be less obvious, but this writer does not subscribe to arguments which put forward propositions that preventative solutions to premature pole failure centre on the application of increased retentions of biocidal chemicals in wood destined for service in the environment. The present findings suggest that sleeves may effect decreased contamination of soil and run-off if they inhibit preservative leaching. Therefore, in contrast to suggestions that standard retentions be increased, the use of sleeves may permit lower retentions of preservatives to be applied to wood specified for service in soil, and, if this is found to be true, it seems that we are morally obliged to determine the appropriate lower thresholds by standard methodology. Furthermore, in view of the ongoing search for alternative preservative formulations (Schnippenkoetter, Abraham and Baecker, 1988), it may also be possible that the application of sleeves would permit the use of environmentally preferable preservatives previously shown to lack permanence in unsleeved wood exposed to moist soil.

Since there seem to be many environmental features and financial benefits to be derived from the preventative, as opposed to remedial, method described here, due consideration should be given to its development. Primary aims of such work should identify and quantify factors neccessary to establish whether the theoretical argument presented above is correct. Field trials should investigate the other possibilities raised above, including the potential of sleeves to reduce preservative leach-rates in soil, the use of lowered preservative retentions and alternative preservatives, alternative sleeve formulations, and the inclusion of environmentally acceptable biocide pastes in matrices to seal and protect the wood-sleeve interfaces.

Acknowledgements

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