POSTER SESSION 5D

PREDICTION, MONITORING AND PRECISION IN CROP MANAGEMENT

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Modelling the soil seed bank as an aid to crop management in Integrated Arable Farming Systems

A J Murdoch, S J Watson, J R Park
Department of Agriculture, The University of Reading, PO Box 237, Earley Gate, Reading RG6 6AR, UK
Email: a.j.murdoch@reading.ac.uk

ABSTRACT

A model of the dynamics of the weed seed bank in an integrated arable farming system (IAFS) is described. The model is used to predict the effects of crop rotations and herbicides on the soil seed bank of *Avena fatua* (spring wild oat) using data obtained from the literature and from studies of the soil seed bank within the Focus on Farming Project (FOFP) at Stoughton, Leicestershire. Interestingly, the dynamics of the seed bank in the FOFP IAFS effectively contained the broad-leaved weed infestation and neither *A. fatua* nor *Galium aparine* (cleavers) were capable of becoming problem weeds. Conversely, the two-year grass ley in the rotation probably helped to ensure that *Poa annua* (annual meadow grass) was present at economically significant levels. The use of the model as an aid to crop management in an IAFS by evaluating weed control sustainability as a strategy which would contain a weed infestation at or below a specified density will be described.

INTRODUCTION

Integrated arable farming systems (IAFS) employ a rationally selected mix of chemical, cultural and physical methods of weed control. IAFS appears to offer an attractive compromise between conventional high input and organic systems. Given public concerns, IAFS is attractive because pesticide and fertiliser inputs may be lower than with conventional husbandry. The purpose of IAFS may be stated as a sustainable farming system where pesticide and fertiliser use is optimised and integrated with other elements of the farming system in order to achieve the ill-defined objective of sustainability. Control of grass weeds has sometimes proved problematic (Watson, 2002) and the long-term sustainability of IAFS with respect to weed infestations is, therefore, unknown. Uncertainty about the consequences of IAFS may hinder its adoption by farmers. Unpredictability also makes it difficult for policy makers and implementers to appraise the extent to which IAFS may satisfy policy objectives with respect to reducing pesticide inputs and maintaining floral biodiversity.

These problems arise from a lack of knowledge of (1) the dynamics of weed populations in crop rotations and (2) the economic consequences of these population dynamics. This paper considers the former and provides a framework which may help farmers and policy makers to answer questions about the consequences of different integrated farming systems for (apparently) conflicting requirements.

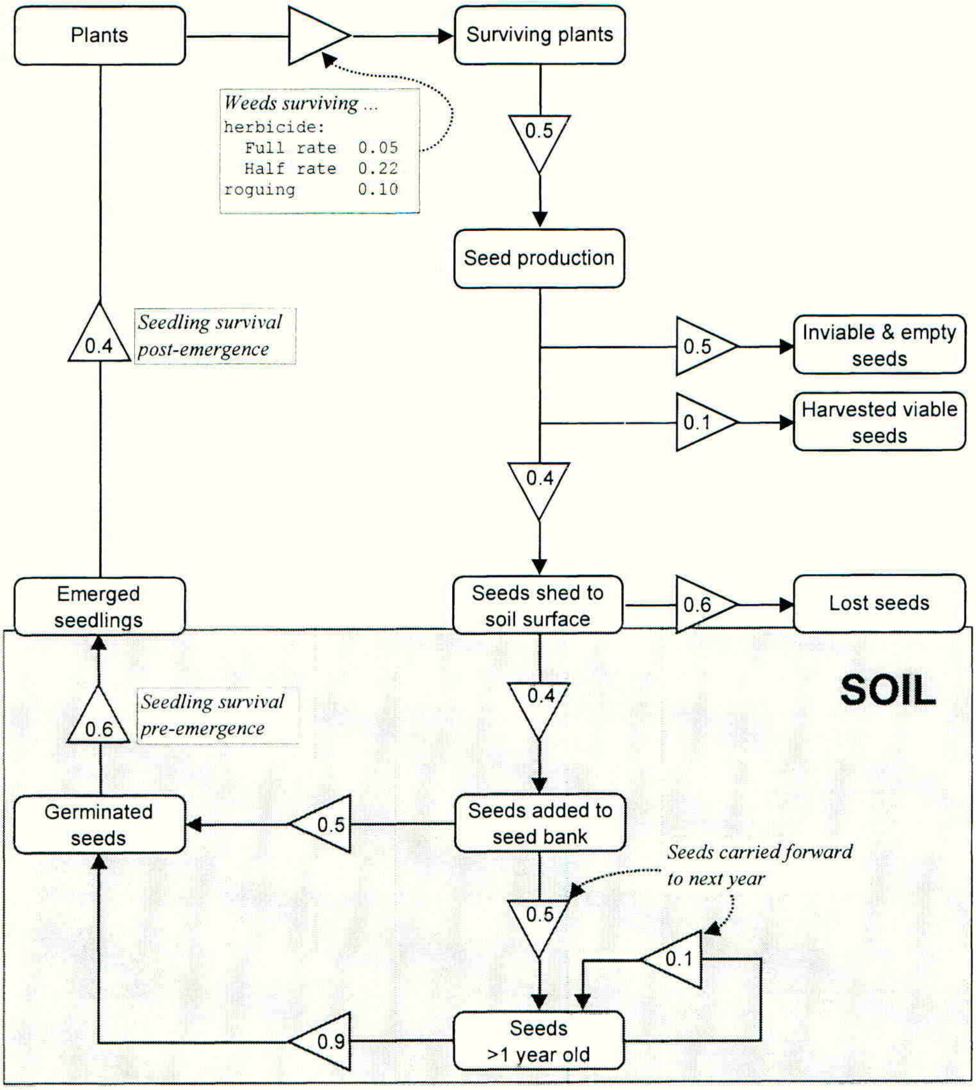

Figure 1. Principal stages of life cycle of *Avena fatua* (spring wild oat) showing parameter values for spring barley (modified from Murdoch, 1988). Parameter values were adjusted for different stages of the crop rotation as shown in Table 1.

In this paper, a sustainable, effective weed control strategy is simply defined as one which ***contains*** the infestation and the soil seed bank of annuals and seed-producing perennials, at or below some threshold level. Changes in the soil seed bank must be quantified within a rotation and predicted over several cycles of the rotation. Containment may not satisfy today's risk averse farmers and so these predictions of changes in the soil seed bank over several cycles of the rotation may need to show a net decline. Not surprisingly, in a previous BCPC Weeds Conference Coble (1996) stated,

> *A critical need exists for weed scientists to gain a more complete understanding of weed population ecology in the context of crop production systems. Without such an understanding, choices of control options cannot be made with an assurance that long-term management sustainability is being served.*

A further, and perhaps the crucial, element of sustainability for the farmer and the rural community is that an economic return must be maintained. The fact that the Long Ashton Less-Intensive Farming and Environmental Research Project showed lower yields and profitability than conventional systems was, therefore, cause for concern (Davies & Limb, 1996). The long-term economic optimum population density for containment of a weed in an IAFS is more complex than those calculated for cereal monocultures over fifteen years ago (Cousens *et al.*, 1986; Doyle *et al.*, 1986; Murdoch, 1988). In an IAFS diverse methods of weed control are adopted. It is suggested that the integration of these methods may only be optimised once the parameter values of weed population dynamics are known for the farming system.

Sustainability may also imply that biodiversity will be preserved. This objective is consistent with a long-term strategy of containing infestations since species diversity should, in theory, be preserved. But depending on the crop rotation selected for an IAFS, some species whose seeds have short persistence in the soil (e.g. grass weeds such as *Anisantha sterilis* (barren brome) and *Alopecurus myosuroides* (blackgrass)) may well be eliminated. Their eradication from arable fields may not be seen as a sad loss by most since these species are not seen as being endangered, they are often relatively new weeds to agriculture, their control is both expensive and requires a lot of chemicals and herbicide resistance has been found in some such as *A. myosuroides* and *Avena fatua* (spring wild oat). A quantitative understanding of the dynamics of soil seed banks will however provide a predictive framework to identify other species which may be eliminated unintentionally by an IAFS. The ability to assure the public that biodiversity is being conserved within the agro-ecosystems is one important element in satisfying public concerns regarding continued pesticide inputs to crops.

The Focus on Farming Practice (FOFP) project on the Farmcare estate at Stoughton, near Leicester was set up in 1993 by CWS Agriculture (now Farmcare), Hydro Agri and Profarma to evaluate integrated farming practices in a real farm situation. The 60 ha site is medium to heavy clay loam. A seven year rotation was in use during the period of study: grass/grass/wheat/set aside/wheat/beans/wheat. Grass weeds on the farm include *A. fatua*, *A. sterilis* and *Poa annua* (annual meadow grass). Seven fields are used so that all phases of the rotation are present each year. Each field is subdivided such that one part is managed conventionally with high inputs and the rest follows the IFS. Weed management includes the two years grass (silage) and set aside as cleaning crops in which no seeds are allowed to shed. Bastard fallows precede winter crops while reduced cultivation minimises bringing buried seeds to the surface. Crops are not sown early to reduce competition while herbicides are used to remove weeds prior to direct drilling.

During the period of study, small control plots within each field were excluded from fertiliser and/or herbicide inputs by overlaying the plots with polythene sheets at the time of application.

MODEL DESCRIPTION

The underlying model of the population dynamics essentially followed that for *A. fatua* in spring barley (Figure 1). The three principal parameters of weed seed dynamics (seed influx to the soil seed bank, the annual depletion of seed in the seed bank and germination and emergence) have however been adjusted to take account of the IAFS and values based on both the literature and derived from experimental data (Watson, 2002) as shown in Table 1. As a simplifying assumption, it is assumed that depletion of buried seeds is via germination (Murdoch, 1983) whereas 60 % predation or loss of viability is assumed for seeds on the soil surface (Figure 1). Tillage practises have a dramatic impact on the extent of this predation which are reflected here to some extent in the depletion rates (Table 1).

Only 24 % of germinated seeds are assumed to achieve maturity (Figure 1) and that only in wheat and beans. It is assumed that no seed production would take place in properly managed grass leys or in set aside. It is recognised that these parameter values need to be estimated more precisely in order to gain a predictively useful understanding of the dynamics of seed banks in the soil.

Table 1. Seed production per plant and annual percentage depletion of *Avena fatua* seeds in the seed bank.
Reported values from literature vary for seeds present for less than or greater than one year in the soil. Seed production values are from Chancellor & Peters (1970). Observed depletion values (Watson, 2002) are shown for conventional and integrated farming systems at FOFP, Leicester.

Parameter	Stage of rotation				
	Grass	Wheat ($1^{st}/2^{nd}$)	Wheat (3^{rd})	Set Aside	Winter Beans
Seed production, seeds per plant	0	39	39	0	238
Annual depletion, % Seeds >1 yr old	25	70	70	25	25
Observed depletion, %					
Conventional	76	87	78	87	89
Integrated	76	65	89	65	78

Notes on Table 1:
Low survival is predicted for new seed in first grass and set aside because it is assumed new seeds will be left on the soil surface and subject to predation. High survival of older seed (buried in the soil) will occur due to low nitrogen availability in the soil in the early spring (cf Murdoch & Roberts, 1982, 1996). Rapid depletion of older buried seed in wheat is expected on the assumption that nitrogenous fertiliser is applied in spring (*ibid.*). No first year seed will exist in the years where seed production is prevented.

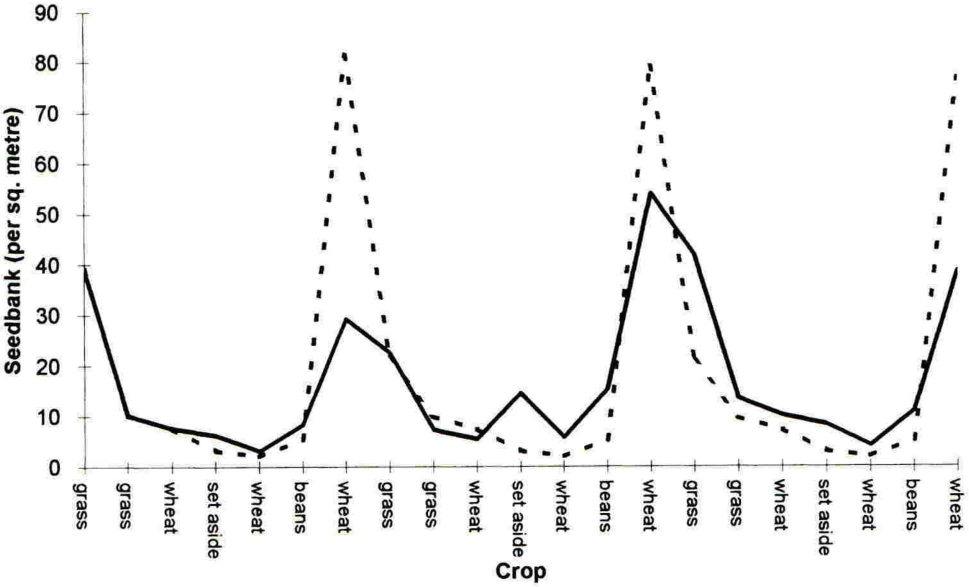

Figure 2. Predicted soil seed bank of *Avena fatua* at the Focus on Farming Practice site managed according to IAFS with full rate (dashed) or eight half rate (solid) herbicide applications achieving 95 or 78 % control of seed production, respectively.

Using a combination of parameter values from the literature and data given in Figure 1 and Table 1, the theoretical feasibility of containing *A. fatua* in the FOFP IAFS near Leicester is demonstrated (Figure 2). The model's outputs shown in Figure 2 are based on spraying for *A. fatua* whenever the infestation in wheat or beans exceeded one plant per square metre.

Containment of weed populations is clearly feasible but the ability to reduce herbicide inputs appears to reside largely in the selection of an appropriate rotation. Assuming the use of half rate herbicide, spraying would be required for 8 out of 21 crops over three rotational cycles. Six full rate sprays would be needed for containment. Given that 9 of the 21 crops would not receive herbicide (grass leys and set aside), the performance of the system – at least as predicted - may not be as efficient as desirable.

DISCUSSION

The dynamics of the *A. fatua* seed bank in the FOFP IAFS was predicted to need substantial herbicide inputs to achieve containment. In practice, *A. fatua* was not becoming a problem weed on the farm, and such infestations as did occur were being controlled effectively. Interestingly, and perhaps more significantly, the actual farming system was successfully containing the broad-leaved weed infestation including *Galium aparine* (cleavers; data not shown). Conversely, the two-year grass ley in the rotation was probably a major contributory factor which helped to ensure that *P. annua* was present at economically significant levels with very high levels of seeds being produced. Indeed it may be argued that the high levels of *P. annua* were suppressing the broad-leaved weeds in the system (data not shown, cf. Watson *et al.*, 1999; Watson, 2002).

Although the target containment and economic threshold levels within an IFS have never been predicted, it must be recognised that where this type of information has been published for intensive monocultures, the technology has never been effectively transferred to farmers. We, therefore, suggest that the predictions of models must not only be accurate, but that future work should include risk-benefit analyses in such a way that managers can make decisions based on the ***probability*** of achieving the aim of containment. Much greater use of participatory methods may also enhance adoption of such technology.

The benefits of being able to predict biological, environmental and economic outcomes of IAFS with respect to weeds together with an associated estimate of the uncertainty would constitute a major advance in the quality of information available to farm managers, advisors and policy makers. Further benefits accrue from the ability to provide more information to allay public fears regarding agricultural practices and especially the use of herbicides.

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Prediction of residues of crop protection products on crops

K Hyder, K Z Travis
Dietary Safety, Syngenta, Jealott's Hill International Research Centre, Bracknell, Berkshire RG42 6EY, *UK*
Email: kieran.hyder@syngenta.com

ABSTRACT

The ability to predict residues of crop protection products (CPPs) on crops at harvest has many potential applications including: (i) advocacy of CPPs to regulatory bodies and the food industry; (ii) reduction of CPP input by the optimisation of application rates; (iii) real-time decision support systems; and (iv) understanding variability in residues. Many factors affect the initial deposit and dissipation of residues. A model has been developed for non-systemic CPPs. The model assumes that the initial deposit is dependent on the application rate and the surface area of the edible crop part. Residue decline is due to the independent action of decay and growth dilution. Residues from field trials on apples (*Malus domestica*) were measured throughout the application period and used to investigate model predictions. The model explained significant variation ($R^2 = 0.678$), indicating that simple models can be fitted to data even in multiple application scenarios. However, variation amongst composite samples was large, which may influence the ability to predict accurately. Optimisation of the application rate to give residues that conform to the baby food directive (< 0.01 mg/kg) gave an application rate equivalent to one quarter of the label rate.

INTRODUCTION

Many field trials are done each year to collect data on residues of crop protection products (CPPs) for regulatory submissions and monitoring. Models for the prediction of residues of CPPs could help to: (1) reduce the number of trials and indicate potential label expansions; (2) help to reduce CPP residues by optimising application rates (e.g. to comply with the EU Baby Food Directive); (3) reduce CPP inputs by incorporating residue prediction in real time decision support to advise farmers when to spray; (4) reduce response times to questions from the regulators and food chain; and (5) provide insight into residue variability.

The residue on the harvested crop is the result of two processes: initial deposit and residue decline. Application technique, canopy and growth stage have all been shown to affect variability in initial deposit amongst leaves (Cross *et al.*, 2001a, 2001b). The decline of residues is affected by weather (Bruhn & Fry, 1982) and growth dilution (Holland *et al.*, 1996). Models for the prediction of CPP residues have been developed for different systems based on these assumptions (e.g. Bruhn & Fry, 1982, Holland *et al.*, 1996, Patterson & Nokes, 2000), but do not provide confidence limits for their predictions. These models are rarely used despite massive potential benefits.

In this study, a model for the prediction of CPP residues on persimmon (Holland *et al.*, 1996) is extended to apples. The model is parameterised and validated using data collected for an insecticide applied to apples. The potential of models for optimisation of application rates that will give a certain residue is demonstrated.

METHODS

The model is based on Holland *et al.* (1996) and is targeted mainly at fruit. The model can handle multiple application times and rates (g/ha) and incorporates growth dilution and decay of the CPP. The model predicts the residue over time (mg/kg). This model is parameterised for apples as they drive many European dietary risk assessments.

The model makes a number of assumptions: (1) only direct deposits are considered; (2) initial deposit is proportional to application rate and surface area of the crop part; (3) residue decline is due to the independent actions of decay and growth dilution; (4) decay is first order; and (5) model parameters are time independent. A sigmoidal growth model was fitted to data for many different varieties of apple and a generic curve was derived. This model was scaled to a specific variety using the time between full bloom and harvest and maximum apple weight. Surface area was calculated from weight assuming spherical fruit with a density of one.

Replicate composite samples were collected throughout the application period for multiple applications of an insecticide on apples and used to test the model. Confidence limits were derived using the variation between model and field data (Draper & Smith, 1998). The model was tested using a ‘Lack of Fit’ ANOVA, where variation between model predictions and observed data is tested against variation amongst replicate samples. However, a probability cannot be assigned as F-ratios are not exact due to non-linearity of the model (Draper & Smith, 1998). This model was then used to calculate optimum application rates for the insecticide, so that an average apple (or a composite sample) met the residue criteria in the EU Baby Food Directive (< 0.01 mg/kg).

RESULTS

Most observed data is within the prediction limits, with the model explaining about 70 % of the observed variation ($R^2 = 0.678$) (Figure 1). The model was tested against the error in replicate samples to see if the model explained significant variation using a ‘Lack of Fit’ ANOVA. Here the variation between model predictions and observed data is tested against variation amongst replicate samples (Draper & Smith, 1998). The F-ratio for lack of fit is less than ‘Critical F’ indicating the model fits the data (Table 1). Predicted dissipation half-lives were similar to those observed in residue decline trials. The model was used to predict the application rate required to obtain a residue that satisfies the EU Baby Food Directive (< 0.01 mg/kg) (Figure 2). The use pattern for this insecticide applied to apples gave an application rate of 6 g/ha, equivalent to one quarter of label application rate.

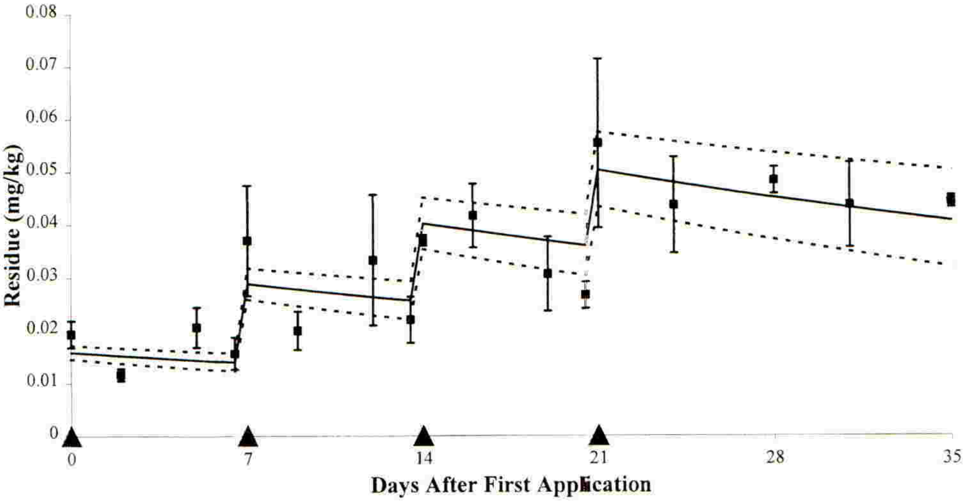

Figure 1. Apple model fitted to residues of a CPP ($R^2 = 0.678$).
The insecticide was applied 0, 7, 14, and 21 days (triangles). The model predicts the mean apple residue (solid line) and the 95 % confidence limits (dotted line) from parameters derived by fitting to data from field trials (solid squares are mean residue, error bars are standard deviation).

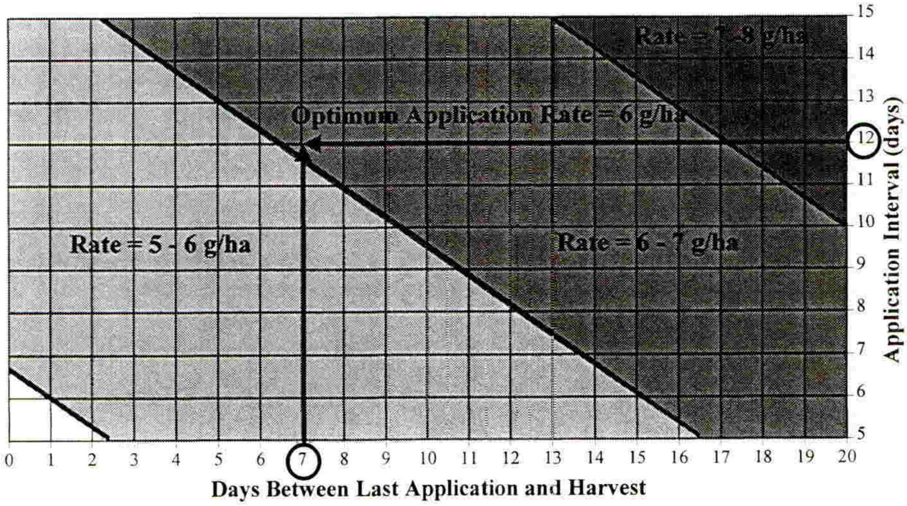

Figure 2. Application rate (g/ha) required to produce a residue of < 0.01 mg/kg. Predicted application rates required are in 1 g/ha bands from left to right from 4 to 5 g/ha (white) to 7 to 8 g/ha (dark grey). If the CPP was applied with an application interval of 12 days and 7 days between last application and harvest, an application rate of about 6 g/ha would give an average residue of < 0.01 mg/kg.

Table 1. ANOVA table for testing 'Lack of Fit' of model to data for apples. The F-ratio is less than the Critical F indicating that the model explains significant variation (MS = mean squares, df = degrees of freedom).

Source	MS	df	F-ratio	Critical F
Lack of Fit	9.40E-05	15	1.930	1.972
Pure Error	4.87E-05	34		

DISCUSSION

Models for the prediction of CPP residues can be used to optimise application rates to reduce inputs and residues, reduce response times and investigate variability. In this study a simple model has been created and validated for the use of an insecticide on apples. This model was fitted to data and explained significant variation even in multiple application scenarios. However, variation amongst composite samples was large, which may affect the ability to predict accurately. Optimisation of the application rate in order that the residue on an average apple conforms to the baby food directive indicated that one quarter of label rate is necessary for this insecticide. However, confirmation that the product is efficacious at these rates is lacking.

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