On-Farm Profitability of Remote Sensing in Agriculture

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ABSTRACT

Remote sensing is used in agriculture to guide application of fertilizer, pesticides and other farm inputs. Its application in agriculture is well documented. However, evidence of profitability to farmers remains fuzzy. The objective of this study is to summarize publicly available information on the economic benefits of remote sensing in agriculture. Out of the hundreds of agricultural remote sensing documents reviewed only a few reported economic benefit estimates. Many of those documents do not provide details on how the economic benefit was estimated. Clues in the reports and the fact that the numbers are often much larger than those for detailed studies suggest that the studies not reporting details are often reporting gross benefits without deducting the associated cost. Standardizing budgeting methods and using the reported changes in yield and input application in 12 studies, remote sensing is estimated to have the potential to improve average farm profits by about $31.74/ha Most of the studies based profit estimates on a single crop season of data. Key improvements needed for studies of the economics of remote sensing for field crops include: detailed reporting of budget assumptions, multiple year data sets in the same fields, and replication of studies of the same technology in different states.

Keywords: farm profits, crop yields, statistics

INTRODUCTION

Remote sensing (RS) in agriculture refers to the art and science of observing and obtaining information on crop and soil characteristics using sensors attached to aircraft, satellite, and less commonly on ground-based platforms. RS can provide information that is useful for many crop management decisions, including the detection of nutrient deficiencies, excesses or deficiencies of soil water, damage caused by insects, weeds, or diseases, and the magnitude of these factors in various portions of fields. Based on these spatial differences, variable rate application (VRA) of inputs such as fertilizers or pesticides can be made. Remote sensing information can be used to establish sub-field management zones for VRA, providing a less expensive and finer resolution option than grid sampling. The technical potential for use of RS in agriculture is well known and documented in hundreds of articles and research reports. The potential for profitable use of RS by farmers is less frequently studied. The objective of this review was to summarize publicly available research on the farm level economics of RS. Gathering this information in one place and identifying common conclusions will be useful to farmers thinking about use of RS in their crop management, agribusinesses offering RS services and researchers developing projects that will fill gaps in knowledge of RS use.

HISTORY OF REMOTE SENSING IN AGRICULTURE

The first aerial imagery dates to 1858 when Gaspaed Felex Tournachon took photos from a balloon (Slonecker et al., 1999). Modern researchers refer to RS as a new technology in agriculture, but literature shows it has been used in agricultural activities at least since 1927 when aerial photography was used to differentiate healthy cotton plants from plants killed by cotton root rot disease (Neblette, 1927 and 1928). The use of satellites dates back to the 1960s but the use of satellite crop imagery, obtained from Landsat, began in 1978 (NASS, 2005). Between the mid 1960s and the early 2000s, about five percent of satellites launched were associated with agricultural applications. The use of satellite and aerial images by governments and industry for forecasting crop production, estimating damage from natural disasters and other aggregate information on crop growth is well established.

POTENTIAL BENEFITS OF REMOTE SENSING ADOPTION IN AGRICULTURE

United States farmers face an estimated loss of US$20 billion a year as a result of fertility, insect, disease, weed and water problems (Agrio, 1988). For instance, in 1998 cotton insects infested 2.4 million ha causing losses of over US$71 million (Williams, 1999). Farmers have relied on crop scouting to diagnose these problems, and then remedies were prescribed as blanket applications across whole fields. However, scouting is slow, labor intensive and expensive (Tillet et al., 2003). Blanket applications of fertilizers, pesticides, irrigation, and drainage do not consider the variability inherent in all natural environments. The benefits of RS were once thought to have been oversold (Johannsen and Ranson, unpublished). But with increasing concerns regarding agriculture's role in surface and groundwater quality, there is renewed interest in using RS to more efficiently manage fertilizers, pesticides, and water in fields. While RS application has been in existence for decades, its use on farms is still very low.

Generally, technological change starts slowly, and increases gradually to a rapid growth (Rogers, 1995). According to Rogers (1995), the adoption process involves five stages. The first stage is getting to know about the technology (knowledge); second, persuasion of the value of the technology; third, decision to adopt; four, implementation; and five, confirmation (rejection or reaffirmation) of the technology. Individuals who start the process are said to be risk takers because in the early stages, little is known about the value of the technology. Factors that will enhance the adoption of the technology include 'trialability'- can it be tried out? 'Observability' – are results observable? 'Relative advantage' – is it better than present technology? 'Complexity' – is it easy to use? And 'Compatibility' – is it suitable for the circumstance? (Rogers,1995). While there is no question about the 'trialability', 'observability' and 'compatibility' of RS in farming, the other two factors are debatable. In regards to ‘complexity,’ RS provides large volume of data which frustrates many farmers, while its ‘relative advantage’ over manual scouting would be increased profit. Precision technology has been used in agriculture for many years but only a few of the applications (example yield monitoring) are used by farmers. RS application is one of the least used which could be attributed to the geography, the economics or the crop involved (Whipker and Akridge, 2005). Aerial imagery often produces distorted topography, especially when the land surface is unequal. Also, aerial imagery comes at a cost while its profitability is unclear. However, RS is believed to be popular on some high value crop farms and very large farms.

At the farm level the profitability of a new technology is increased revenue less additional costs that come with it (Lambert and Lowenberg-DeBoer, 2000). Revenue comes from increased yield and higher output price due to better marketing strategies and higher quality crops (Lowenberg-DeBoer, 2003). For instance in a Montana RS study, increased protein content in wheat due to VRA of N resulted in higher gross revenue (Long et al., 2002). The associated cost of RS comes from imagery acquisition and analysis, VRA input application fees, and training to develop RS interpretation skills. Added risk should also be taken into account because the information provided by imagery could be inaccurate or misinterpreted, and hence result in over or under application of inputs.

The objective of this study is to summarize the on-farm profitability of RS and put it in the context of the overall adoption of precision agriculture (PA). The overall adoption rate of RS is characterized using yield monitor and variable rate input application data as benchmarks of overall PA adoption. Adoption RS and other PA technologies are related because RS can provide some of the information needed for variable rate application, interpreting yield maps and other PA. The perception of RS service providers is included because in as much as RS should provide economic benefits to farmers, it should be profitable to the service providers as well to enable them stay in the business and provide the service. Their perception is key to the future of the technology. The key role of service providers is to transform RS data into information that farmers can easily use.

MATERIALS AND METHODS

This study focuses on the review of publicly available documents on RS. Documents of interest included those reporting yield and/or monetary values attributed to use of RS in management of field crops. In addition, documents containing cost of acquiring imagery and analysis, price of inputs such as fertilizer, and price of crop outputs were used. Publicly available material includes articles in scientific journals, papers in published conference proceedings, and articles in the farm press and websites. Although there are numerous documents containing information on the technical issues related to image acquisition and analysis, only few documents contain information on economic benefits.

First presented are RS and PA adoption rates, which are followed by the viewpoint of service providers. Finally, on-farm profitability of RS is discussed.

RESULTS AND DISCUSSION

ADOPTION OF PRECISION AGRICULTURE

While commercial use of remote sensing in agriculture has been discussed since the 1970s, use of the practice by farmers is quite modest. USDA data (USDA, 2005) shows that only about 3% to 4% of field crop acreage in the US is managed with the help of remote sensing images. On the service provider side, surveys by Whipker and Akridge (2003 and 2005) showed about 12% of US Ag retailers offered satellite RS images to their clients in 2003, and about 18% in 2005. The proportion of Ag retailers who find RS imagery business to be profitable has gone down from about 25% in 2002 to 20% in 2005. Consequently, the proportion of Ag retailers who think RS is not profitable has gone up from 13.5% in 2002 to 17.2% in 2005. Some anecdotal evidence suggests that the market for remotely sensed imagery is growing for use in managing high value vegetable and orchard crops, but no publicly available studies that document the adoption or value of RS for these horticultural crops were found.

Yield monitor adoption is often used as an index of the overall acceptance of PA (Lowenberg-DeBoer, 2003). United States accounts for about 90% of the world’s yield monitors (Griffin et al., 2004). Corn and soybean yield monitors have increased over the past years but the adoption rates are still relatively low (36.5% of planted corn acreage in 2001, and 28.7% for soybean in 2002, Daberkow et al., 2006). In 2000, there were about 335 yield monitors per million hectares of grains or oilseeds in U.S. (Griffin et al., 2004). Precision agriculture adoption rate is not similar in Europe. In 2003, Germany had the highest number of yield monitors with 500 per million hectares of grains or oilseeds. Denmark, Sweden and U.K had 250, 120, and 100 respectively in 2000 (Griffin et al., 2004).

Because RS can provide some of the information needed to guide variable rate application, the adoption of RS and VRT are linked. In 2001 VRT was used to manage soil fertility of 10% of corn planted in the U.S., and in 2002 about 5.0% of soybeans planted. Pesticides are also managed with VRT (Griffin et al., 2004). About 3.8% of planted corn, (2001), 2.7% of cotton (2000) and 1.3% of soybeans (2002) were managed with VRT pesticide. A survey of PA service providers, in 2005, shows that 31% of service providers offered multi-nutrient and seeding VRT, and satellite imagery (Whipker and Akridge, 2005). The ability of RS to cover a larger area and hence provide whole field diagnosis at a lower cost may improve the adoption of PA technology in the near future. RS service providers could have a significant role to play in speeding up of the adoption process.

REMOTE SENSING – SERVICE PROVIDERS' POINT OF VIEW

A survey by Whipker and Akridge (2005) shows that about 40% of PA service providers claim they make profit. However, a break down of the precision package shows that only about 20% of providers of satellite and aerial imagery claim to make profit. High investment required for RS discourages some potential investors. Other problems include a lack of cost and return information to support the investment and difficulty in directly generating revenues from the use of remote imagery (Whipker and Akridge, 2002). The experiences of Johnny Williams of GPS, Inc., Inverness, MS (Hudson et al., 2001), are illustrative. Williams (Hudson et al., 2001) wanted to take advantage of the potential benefits of the RS service business using airplane. The high initial cost of about $185,000 (for cameras, global positioning system (GPS) receivers and airplane service) and potential competition from satellite imagery providers in the near future created a dilemma. If he ventured into the business and had a high adoption rate, the expected present value is high ($3.2 million). But with a lower adoption rate he could lose $250,000. If, satellite images replace aerial photographs sooner than expected, this could cut his 12 year planned investment period short.

According to John Ahlrichs, the director of agricultural markets for Digital Globe (personal communication), the key to selling imagery is making decisions "quicker, faster, better." "What they do with the extra time separates into two groups," Ahlrichs said, "The younger ones use the time to bring in more acres. The older ones often want to spend more time with their families." He said that their greatest success has been selling imagery to vegetable and orchard growers in the western US. In orchards, imagery has been used to identify irrigation problems and areas needing soil amendments (e.g. gypsum). For vineyards, irrigation and soil amendments are important, but identifying diseases and guiding flavor sampling are also important (Ahlrichs, personal communication). In addition, Ahlrichs said that imagery is the only practical way to guide VRA on cotton farms because of their large size, usually 2,834 to 6,073 ha. The use of VRA could lead to some yield increases, maybe a 140 kg/ha. He expects imagery sales to increase 8,097 ha in 2004 to 101,215 ha over a period of three years. Ahlrichs attributed the high expected growth to the availability of global positioning system (GPS) guidance in the Arizona and California, and also to aggressive marketing of images.

ON-FARM BENEFITS OF REMOTE SENSING

Close to a hundred RS studies were reviewed in detail, and majority of the studies focused on the technical aspects of the technology. That is, the use of RS to estimate crop acreage, identify or distinguish between crops, to detect crop stress and to predict crop yield. Only 12 reported economic benefit estimates or information about net benefit. Three of those documents (OSU, 2002; Reynolds and Shaw, 2002; and Seelan et al., 2003) do not provide details on how the economic benefit was estimated. Clues in the reports and the fact that the numbers are much larger than those for detailed studies suggest that those three are reporting gross benefits without deducting the associated cost of RS, that is, the cost of imagery, analysis, VRA and other expenses related to site-specific management. Based on these studies, skepticism is suggested when a study of remote sensing in field crop management reports very high benefits such as $222/ha reported by OSU (2002). Benefits over $100/ha are possible in higher value crops (e.g. sugar beets, cotton), but unlikely for grains and oilseeds. Four studies (Carr et al., 1991; Copenhaver, 2002; Long, 2002; and Long et al., 2002) reported returns of between $2.00/ha and $5.00/ha, which could easily be eroded by RS associated costs (about $5.00/ha) if these costs were not accounted for.

Because the budgeting information provided varies widely in what is being managed and how the remote image is used, it is difficult to see any pattern in the published profitability estimates. In addition it is not clear how some researchers came up with their estimated returns. A standardized economic analysis could be done if detailed information had been provided. Most of the information reported in the studies is changes in yield and inputs managed.

Yield change and input change in the reviewed studies are ascribed to RS application. Monetary values of the yield and input changes were obtained by using 2005 national averages of yield, input cost, and output price from United States Department of Agriculture. For instance, in White and Gress (2002), corn yield decreased by 8.7% which is 851.90 kg/ha based on 2005 national average yield of 9,792 kg/ha. This yield decrease has a market value of $60.70 based on the national average corn price of $0.071/kg. The $60.70 is negative because of the yield decrease. Similarly, in the same study, the 42% N decline has a market value of $57.96 based on national average fertilizer cost of $138/ha. The sum of the values of the yield loss and input gain, $-2.74/ha, is the gross gain/ha in Table 1. Subtracting the cost of RS application, $4.42/ha, gives the estimated return of $-7.16/ha. The other estimated returns were obtained in a similar manner. The last column in Table 1 contains the reported returns to RS in the reviewed studies. It was assumed that RS application has replaced manual scouting, and that VRA is done under either method. Although many farms practice VRA of fertilizer and pesticides, fewer farms use RS (Whipker and Akridge, 2005). Hence most of VRA is guided by manual scouting/GPS. The assumption is that any estimated profit to be wholly attributed to RS. Hence only the cost of RS imagery acquisition was subtracted from the total gains. A better measure of RS profitability would be a comparison between RS profitability and manual scouting/GPS profitability. In 2005 the cost of RS image ranged from about zero to $14.83/ha with an average of $4.42/ha (Whipker and Akridge, 2005). The average cost of soil sampling (with GPS) and field mapping (with GIS) were $15.60/ha and $10.32/ha, respectively (Whipker and Akridge, 2005). These costs were used as cost of manual/GPS scouting for soil nutrient and zone mapping management. The cost of pest scouting, $24.70, was obtained from the Cooperative Extension Service, University of Arkansas (Hogan et al., 2007). This figure was deflated, using the consumer price index, to $22.30/ha for a 2005 estimate. USDA national averages of fertilizer cost per ha and chemicals cost per ha were used as proxy for N cost and pesticide costs, respectively, in the calculations.

Remote sensing application of nitrogen (N) and other inputs in crop production can result in significant amounts of input reduction (Table 1). Although some studies did not report the change in the quantity of input used, no study reported an increase. For N application under corn production, the N reduction ranges from 6% to 60% (N cost $138 per ha in 2005), while N reduction for wheat is between zero and 10% ($63 per ha in 2005). Other chemicals (herbicide and insecticide) had about 30% reduction in quantity. In 2005, pesticide cost about $21 per ha, $33.58 per ha, and $151 per ha for wheat, soybeans and cotton, respectively. The input cost information is based on 2005 USDA crop production estimates. There were only three studies reporting an increased yield (Koch et al, 2004, Seelan et al., 2003, and Long, 2002). Seelan et al. (2003) reported a yield increase of 20.5% while Long (2002) reported an increase of 17%. No change in yield was assumed for the studies that did not report yield change.

Table 1. Computed Net Gains for Reported Yield and Input Changes Due to Variable Application Based on Remote Sensing

Study	Input Managed	Crop	Change in Yield (%)	Change in Input (%)	Yield Gain $/Ha	Input Savings $/Ha	Gross Gain $/Ha	Estimated Returns $/Ha	Reported Returns $/Ha
In-Season Management									
Watermeier (2003)	Nitrogen	Corn	0	- 30	0	41.40	41.40	36.98	32.11
White & Gress (2002)	Nitrogen	Corn	-8.7	- 42	-60.70	57.96	-2.74	-7.16	-2.63
Hendrickson & Han (2000)	Nitrogen	Corn	NP	- 48	0	66.24	66.24	61.82	4.82
			NP	- 60	0	82.80	82.80	78.38	28.00
White et al. (2002)	Nitrogen	Wheat	-1.6	- 10	-4.56	6.30	1.74	-2.68	-2.99
Zone Determination									
Long et al. (2002)	Nitrogen	Wheat	NP	NP	NA	NA	NA	NA	2.30
Carr et al. (1991)	Nitrogen	Wheat & barley	-1.8	NP	-5.13	0	-5.13	-9.55	2.15
Larson et al. (2004)	Nitrogen	Cotton*	37[a]	- 10	39.47	9.67	49.14	44.72	-5.71
			55[a]	- 20	58.67	19.34	78.01	73.59	-36.95
Koch et al. (2004)	Nitrogen	Corn	-9.2	- 6	-64.19	8.28	-55.91	-60.33	25.60
	Nitrogen	Corn	2.7	- 46	18.84	63.48	82.32	77.90	38.35
Insecticide/Herbicide/Fungicide Application									
Seelan et al. (2003)	Fungicide	Wheat	17	NP	48.48	0	48.48	44.06	397.00
Long (2002)	Pesticide	Wheat	20.5	NP	58.46	0	58.46	54.04	2.27
Copenhaver et al. (2002)	Herbicide	Soybeans	NP	- 30	0	10.074	10.07	5.65.	4.15
Seal et al. (2001)	Insecticide	Cotton*	NP	- 34	0	51.34	51.34	46.92	NA

NP – not provide: assumed to be zero
NA – not available
[a]Physical unit of yield increase given (kg/ha) because yield level of the control was not reported
Average Remote Sensing cost: $4.42/ha (source: Whipker and Akridge, 2005)

2005 Data: United States Department of Agriculture, ERS
Corn: yield - 9,792 kg/ha; price - $0.071/kg; fertilizer cost - $138/ha; chemicals cost - not applicable
Wheat: yield - 2,448 kg/ha; price - $0.117/kg; fertilizer cost - $63/ha; chemicals cost - $21/ha
Soybeans: yield - 3161 kg/ha; price - $0.21/kg; fertilizer cost - not applicable; chemicals cost - $33.58/ha
Cotton*: yield: - 0.89 Mg/ha; price - $1,066/Mg; fertilizer cost - $96.70/ha; chemicals cost: $151/ha

NET RETURNS TO REMOTE SENSING

Net returns were computed by deducting the cost of RS from gross gains. Estimated returns ranged from a benefit of $78.38 to a loss of $60.33/ha. The use of national average yield and input changes makes the net gains for the various studies more comparable than the reported gains which are based on disparate yield and input levels. The reported gains in the original articles due to RS range from $2.15/ha to $397/ha. Long et al. (2002) did not provide information to allow for returns computation, but the study reported a return of $2.30/ha.

On average, estimated return (ER) to RS application for the 12 studies was $31.74/ha. Without cotton, a high value crop, the average estimated return is only $25.37/ha. By type of management, pesticide management had the highest average ER of $37.67/ha (cotton included), and $34.59/ha without cotton. In-season fertilizer management had an average ER of $33.47/ha (without cotton). The studies do not include in-season fertilizer management of cotton. Zone management accounted for the lowest returns, $25.56/ha (with cotton) and a moderate $2.67/ha without cotton. These returns support Ahlrichs' assertion that RS is a practical way to guide VRA on large cotton farms.

Contrary to expectations, only a few studies (Carr et al., 2002; White and Gress, 2002; and Seelan et al. 2003) had estimated returns (ER) less than the reported returns (RR). Carr et al. (2002) and White and Gress (2002) are among studies with reported losses or very low returns (less than $3.00/ha). The Seelan et al. (2002) calculation shows a big difference between the reported and estimated returns, probably because the reported return fails to subtract some major costs. Among the studies with ER greater than RR, Watermeier (2003), White et al. (2002) and Copenhaver et al. (2002) have small differences between the two returns calculations. These differences could be due to varying reasons including i) low RS cost, such as $0.40/ha in White et al., (2002); ii) low yields; and iii) low input costs in the reviewed studies.

In Watermeier (2003) the difference cannot be attributed to the difference in yields between ER (9.8 Mg/ha) and RR (6.9Mg/ha) since no yield change was assumed in the calculation. The higher ER is due to the higher cost of N ($138/ha) compared to $107.26/ha used in RR calculation. Similarly, higher herbicide application rate could be the reason for the higher ER than RR in Copenhaver et al. (2002). Difference in yields, however, could explain the higher ER calculation in White et al. (2002) because of the 1.6% yield change. The ER calculation is based on 2.4 Mg/ha wheat yield, which is far less than the 6.2 Mg/ha reported in the study. Hence the value of the yield loss is greater in the ER calculation than in that of RR.

Various reasons could also be attributed to the substantial difference between ER and RR in the remaining studies. The 20.5% increase in yield in Long (2002) transforms the 0.37 Mg/ha yield difference into the big difference between ER and RR calculations. Larson et al. (2004) assumed a consulting fee of $49.38/ha which drastically eroded returns to RS. Hendricks and Han (2002) would have been a perfect study for a good economic analysis. It provides the needed information but not the actual yields. The difference between ER and RR calculations could emanate from different levels of N application. The 48% to 60% reduction in N application could result in the substantial difference in the calculations if the difference between N applications is large.

SENSITIVITY ANALYSIS

Because of the wide range of remote sensing cost and the likely fluctuations in crop and input prices, sensitivity analysis was done to test the robustness of RS contribution to on-farm profitability. Assuming the highest cost of RS ($14.83/ha), the average ER of the study will fall by 18.87% ($31.73/ha to $25.73/ha). Also if the cost of VRT of fertilizer and pesticide ($11.38/ha) is deducted, then the highest RS cost will lead to a loss of $0.48/ha. An increase in crop price, however, will help to mitigate the loss. A 20% increase in crop price results in an average ER of $33.01/ha, an increase of 4.0% in ER However, the average ER will fall by $1.28/ha if crop price falls by 20%.Since input reduction contributes positively to returns, the impact of input price reduction is more interesting than its increase. Assuming the input prices used in the initial analysis were over estimated by 10% or 20%, then the average ER will be $28.8/ha or $25.78/ha, respectively. These are still substantial returns except if the cost VRT services are considered. From these analyses, it can be concluded that average ER is fairly robust to crop price changes. The main factor that reduces returns is the cost component (RS cost and input price).

Comparison of the returns between manual scouting and RS provides an in-depth analysis of returns to RS. The average ER of $31.74/ha does not account for the VRT services cost because of the assumption that these services are used with both RS and manual scouting. Using cost of manual/GPS scouting from the sources mentioned above, a similar analysis for manual scouting resulted in overall average ER of $20.09/ha. Therefore, RS has over 50% higher returns than manual scouting. The lower return of manual scouting is attributed to its high cost. The cost of manual scouting differs for the three management types. Pest scouting is the most expensive ($22.30/ha), and the return to pesticide management is $19.79/ha. Scouting soil test with GPS costs about $15.60/ha but in-season nutrient management has the highest return ($22.28/ha). Field mapping has the lowest cost ($10.32/ha) with ER of $19.36/ha. None of the management types will be profitable if VRT services are charged.

LIMITATIONS

Most of the studies appear to have data for only one year at any given site. The Tennessee report (Larson et al., 2004) was part of a multi year study, but it is not clear if more than one year of data was used for the profitability analysis. There are two years data in Carr et al. (1991), but none of it appears to be at the same site. Assessing the variability of returns to remote sensing will require multiple years of data at the same location. In addition to insufficient budgeting and data information, risk is a factor missing in all the studies. For example, it is implicitly assumed in Long (2002) that infested patches that are sprayed have the same yield as uninfested areas, but it is possible that treated areas might yield less because the herbicide was ineffective or the wild oats had already caused some yield loss before the herbicide.

CONCLUSIONS

The technical potential of remote sensing for agriculture is well documented, but only a few studies have made credible estimates of the farm level economic benefits. When budget assumptions are standardized the reviewed studies show that RS has the potential to improve average on-farm profit by about $31.74/ha. However, the adoption of remote sensing in field crop agriculture is still stuck in the first stage of the adoption curve in which a few innovators try the technology and most farmers watch. Although many farmers are aware of the technology, they are not convinced of its value to them. The slow adoption may be linked to the shortage of credible studies documenting the profitability of the technique. Key improvements needed for studies of the economics of RS for field crops include: detailed reporting of budget assumptions, multiple year data sets in the same fields, and replication of studies of the same technology in different states. Other useful information includes the pattern of RS profitability over time, and the factors influencing profitability.

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